

# State of the Great Barrier Reef World Heritage Area Workshop

Proceedings of a technical workshop held in  
Townsville, Queensland, Australia, 27–29 November 1995

Edited by David Wachenfeld, Jamie Oliver and Kim Davis

An initiative of the Great Barrier Reef Marine Park Authority, with support from the CRC Reef Research Centre, the Queensland Department of Environment, the Queensland Department of Primary Industries, the Queensland Fisheries Management Authority and the Australian Institute of Marine Science



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ISSN 0156-5842  
ISBN 0 642 23026 9

Published May 1997 by the Great Barrier Reef Marine Park Authority

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**National Library of Australia Cataloguing-in-Publication data:**

State of the Great Barrier Reef World Heritage Area Workshop  
(1995 : Townsville, Qld.).

Proceedings of the State of the Great Barrier Reef World  
Heritage Area Workshop : proceedings of a technical workshop  
held in Townsville, Queensland, Australia, 27-29 November 1995.

ISBN 0 642 23026 9.

1. Environmental protection - Queensland - Great Barrier Reef - Congresses.
2. Conservation of natural resources - Queensland - Great Barrier Reef - Congresses.
3. Marine parks and reserves - Queensland - Great Barrier Reef - Congresses.
4. Environmental management - Queensland - Great Barrier Reef - Congresses.
5. Marine resources - Queensland - Great Barrier Reef - Congresses. 6. Great Barrier Reef (Qld.) - Congresses. I. Wachenfeld, D. R. (David Raymond), 1967 - .II. Oliver, Jamie, 1953 - . III. Davis, Kim, 1972 - .IV. Great Barrier Reef Marine Park Authority (Australia). V. Title. (Series : Workshop series (Great Barrier Reef Marine Park Authority (Australia)) ; no. 23).

551.42409943



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## Foreword

The Great Barrier Reef World Heritage Area is the largest in the world and one of just a few World Heritage areas which meets all four natural World Heritage criteria. It was inscribed on the World Heritage List in 1981. Although originally seen as a prize or badge of honour, World Heritage Status is now increasingly being seen as an international obligation to maintain an area of world importance in a condition which will enable future generations to appreciate its unique features. An important component of our responsibilities under the World Heritage Convention is to report at intervals on the status of the World Heritage Areas under our stewardship. Consequently, the Great Barrier Reef Marine Park Authority, in conjunction with other institutions with interests in research and management of the Great Barrier Reef, have undertaken to produce the first State of the Great Barrier Reef World Heritage Area Report in 1997. These workshop proceedings, which summarise our current technical knowledge on a wide range of topics, form a core part of this process of status reporting.

I would like to thank all of the authors of the papers in these proceedings for taking the time to summarise their knowledge and understanding of their specific areas and commend them on the quality of the final product. This document, together with the related summaries and reports associated with the State of the Reef program will, I am sure, be considered a valuable source of information on the status of the Great Barrier Reef and a guide to where we should be going in the future in order to ensure the Great Barrier Reef World Heritage Area keeps its status as the premier natural World Heritage Area.



Ian McPhail  
Chairperson  
Great Barrier Reef Marine Park Authority

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## Summary

State of the Environment Reporting is increasingly being seen as an important part of environmental management and is required at the national level as well as within several states. Although there are or have been, a number of long-standing and quite comprehensive monitoring and assessment programs on the Great Barrier Reef, the results of many of these programs have never been summarised in a management context and no overall summary of all of these programs has ever been attempted.

The Great Barrier Reef Marine Park Authority has decided to produce a report on the State of the Great Barrier Reef World Heritage Area (GBRWHA) in 1997. This report will be produced with assistance from the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef, the Queensland Department of Environment, the Queensland Department of Primary Industries, the Queensland Fisheries Management Authority and the Australian Institute of Marine Science. Emphasis will be placed on summarising long-term, large-scale data sets from existing monitoring programs. The report will include physical, chemical, biological and socioeconomic data as well as a section on the current management status of the area.

This first State of the GBRWHA Report will provide managers, policy makers and Reef users with an informative and readable summary of the status of the Reef, an indication of any long-term trends, and an analysis of possible management implications. The technical reports which form these workshop proceedings will provide a source for more detailed information and a pointer to other datasets and scientific studies which will underpin the report. The report will also fulfil the obligations of the Authority to report to stakeholders in the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area, and to UNESCO on our management of the World Heritage Area. The primary objectives of the report will be to: 1) summarise information on key attributes of the GBRWHA, and carry out a preliminary assessment of current status, trends and management implications; 2) report to the World Heritage Committee on the status of the World Heritage values of the GBRWHA; and 3) report to stakeholders in the 25 Year Strategic Plan for the GBRWHA on the status of the area.

As a first step, a technical workshop was held on November 27-29 1995. Researchers and managers responsible for specific data sets presented summaries of their data and commented on their management significance. Papers from this workshop are presented here, while the final status report will be published later in 1997.

The presentations at the workshop demonstrated that we have accumulated a wealth of knowledge about the status and trends for a variety of important attributes for the GBRWHA. The 40 papers and 3 abstracts in these proceedings are arranged in a loose thematic order, starting with overviews of the climatic and oceanographic characteristics of the area (Lough, Burrage et al.) then moving to reviews of water quality and terrestrial inputs (Furnas et al., Brodie). This is followed by status reviews for a variety of key groups of plants and animals (20 papers) and the last theme deals with a series of management and use issues (19 papers) such as fisheries, tourism, legislation, planning and day to day management.

In general the situation looks quite positive for plants and animals associated with reefs. Several papers indicate that while fish (Ayling, Sweatman et al., Williams) and corals (Ayling, Done, Lough and Barnes, Connell et al., Osborne et al., Wachenfeld) can fluctuate substantially from year to year, there are no indications of any large-scale degradation as a result of human activity. There are a number of important pressures on the reefs which will need to be monitored on an on-going basis. In particular, reef fish stocks as well as nutrients and sedimentation and their potential effects on corals and algae require continued vigilance.

Inter-reefal areas (especially some inner-lagoon areas) are subject to heavy pressure from trawling activities (Pitcher). It was agreed during the workshop that in areas where heavy trawling persists there is likely to be a continued decline in the plants and animals.

Of all the groups examined at the workshop, algae are probably the least studied (McCook and Price) and so it is difficult to make any firm comments on status or trends for this group. In general only fish and corals are being monitored in a comprehensive manner.

The status of some of the large animals associated with the GBRWHA, especially dugongs (Marsh and Corkeron) and some species of sea turtle (Limpus), is giving cause for concern. Dugong numbers in the southern Great Barrier Reef are declining, and although no trends have been demonstrated so far, several turtles species are subject to pressures which are considered to be unsustainable.

A number of fish, prawn and other crustacean stocks were examined (Higgs, Elmer, Healy, Gwynne, McPherson, Brown, Gribble). In most cases, fish stocks appeared to be in a stable condition, but in some cases there appears to be an indication of small declines in stocks. If these declines are a result of over-harvesting rather than natural fluctuations, then this could be rectified through modified management measures. It was stressed there were many challenges facing managers in the coming years (Robertson). In particular there is a need for effective coordination of management effort between the various agencies involved in fisheries within the GBRWHA.

We still know very little about long-term trends in the level and type of use of the GBRWHA (Benzaken and Aston, Benzaken). Generally, use is concentrated in the Cairns and Whitsunday region. For instance about 65% of all tourism use is located on only 15 reefs. Logbooks kept by tourism operators, and submitted with the Environmental Management Charge, will provide much of this information in the future. There is the potential for substantial increase in the level of use in the near future as a result of changes in transport technology and realisation of latent permitted use. Economically, tourism is by far the largest industry in the GBRWHA. Per annum, tourism is estimated to be worth four times that of commercial fisheries. Further work is urgently required on levels of recreational and indigenous use (Benzaken et al., Smyth).

While Australia is regarded as a world leader in the management of large marine protected areas, and has implemented innovative procedures and mechanisms, there is still a need to find more effective ways to monitor and manage this enormous region. The workshop identified problems arising from the size of the region together with the steady increase in its use. It is anticipated that a more integrated and consistent approach to zoning the entire marine park will be adopted in the future (McGinnity). Further progress on the development of management plans is required. Levels of day-to-day management activities such as surveillance and enforcement were reported to be declining as a result of a need to shift available resources towards coastal development issues and administrative matters (Day et al.). In future years, managers will clearly be facing major challenges to work more effectively and efficiently, and to find increased resources.

The purpose of the State of the Reef Report is to provide managers, policy makers and reef users with an informative, readable and integrated summary of the status of the GBRWHA. It will include an indication of any long-term trends and an analysis of possible management implications.

The formal State of the Reef Report will consist of a summary report which extracts the main findings, conclusions and recommendations of the workshop and presents this, together with

any other available and relevant information, in a compact and readable form. This first report will be published later in 1997.

It is not intended that the State of the Reef Report will include exhaustive statistics on the status of all attributes and issues relating to the GBRWHA. However, as part of the State of the Reef process, it is intended to produce a regularly updated Great Barrier Reef Almanac in which such statistics are presented. This almanac would be published in hard copy, on CD-ROM and on the World Wide Web. The Web version would be updated on a continuous basis, as new information becomes available, while the other forms will be published every five years, in the year following publication of the State of the Reef Report.

In the first State of the Reef Report, an attempt will be made to summarise information using the Pressure-State-Response approach adopted by the Commonwealth State of the Environment Report. During 1997, the reporting structure and format will be reviewed, and a list of standard indicators will be developed for use in future reports and the Great Barrier Reef Almanac.

It is anticipated the various products arising from the State of the Reef project will constitute a major output of the Research and Monitoring Section in future years and that the data and information base upon which this project draws will be a major responsibility of the newly formed Information Management and Coordination subsection.

Jamie Oliver  
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## **Acknowledgments**

These proceedings, and the workshop upon which they are based, have drawn on the assistance and advice of a number of people. Chris Crossland, Hugh Sweatman, Patrick Appleton, David Walter and Dan Currey served on the Coordinating Committee which assisted in identifying subject areas and potential contributors. Judy Anderson and Jon Ive both assisted in preparing for and running the workshop. Finally, Andrew Elliott and Brian Dare coordinated the production of the cover graphics and layout. We thank all of you, and all of the authors for making this publication possible.

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Jamie Oliver  
Kim Davis

**CONTRIBUTED  
PAPERS**



# Recent climate variation on the Great Barrier Reef

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## Abstract

Climate, the average expectation of weather, is not a static feature of the physical environment. It varies on all time and space scales. Global climate may also be changing at an unprecedented rate due to the enhanced greenhouse effect. The regional-level consequences of global climate change are, as yet, poorly understood.

Mean surface climate conditions and their seasonal variation are described for the Great Barrier Reef (GBR) over the period 1958 to 1992. Variables examined are sea-surface temperatures, sea-level pressure, surface winds, tropical cyclones and rainfall and river flow for adjacent land areas. The nature of recent climate variations on the GBR is illustrated in three ways: 1) the evolution of surface climate anomalies during the two extremes of El Niño-Southern Oscillation events - the major source of short-term climate variability in the region, 2) a comparison of average surface climate conditions of the 1970s (a period of vigorous summer monsoons) and the 1980s (when the summer monsoon was weak), and 3) examination of linear trends in surface climate conditions. Variations over the period 1958 to 1992 are placed in the context of climate variations of the past century using indices of rainfall and temperature over Queensland. Although there is no significant tendency to wetter or drier monsoons, average temperatures (especially night-time temperatures) have risen significantly.

## Introduction

Climate, the average expectation of weather at a particular time and place, is not a static feature of the physical environment. Climate varies on all time and space scales. It has varied in the past and will, exacerbated by the enhanced greenhouse effect, vary in the future. This report summarises average surface climate conditions in the vicinity of the Great Barrier Reef (GBR) over the period 1958 to 1992 and illustrates the nature of climate variations which have occurred. Variability of the physical environment needs to be considered both in terms of how components of the GBR ecosystem may respond to such variations and as a background of varying conditions when interpreting observations and measurements which may be isolated in space and time.

Extending for nearly 2000 km along the coast of Queensland between 8°S and 23°S, the GBR encompasses tropical to sub-tropical climates (see Gentilli 1971). The major seasonal variation is between the winter dry and summer wet seasons. The latter is due to the seasonal southward migration of the Southern Hemisphere summer monsoon (see McBride 1987). The strength of the summer monsoon is highly variable from year-to-year. The major known source of this variability is the global-scale El Niño-Southern Oscillation phenomenon (see Philander 1990).

Mean surface climate conditions and their seasonal variations are described for the GBR over the period 1958 to 1992. Variables considered include sea-surface temperatures, sea-level pressure, surface winds, tropical cyclones and rainfall and river flow for adjacent land areas. The nature of recent climate variations on the GBR is illustrated in three ways: 1) the evolution of surface climate anomalies during the two extremes of the El Niño Southern Oscillation (ENSO), 2) comparison of average surface climate conditions of the 1970s (a period of vigorous summer monsoons) and the 1980s (when the summer monsoons were weak) and 3)

examination of the evidence for trends in surface climate conditions. Variations over the period 1958 to 1992 are placed in the context of climate variations of the past century using indices of rainfall and temperature over Queensland (Lough, submitted).

## **Data**

### Climate data 1958 to 1992

There are relatively high quality climate records available for Queensland and the vicinity of the GBR. Monthly observations of sea-surface temperatures (SST), sea-level pressure (SLP) and the zonal (east-west) and meridional (north-south) wind components were obtained from the Comprehensive Ocean-Atmosphere Data Set (COADS; Woodruff et al. 1987). This data set is based on averages of observations made by all ships-of-opportunity for a particular month within 2° latitude-by-longitude areas for the world's oceans back to 1854. Monthly values for 1958 to 1992 were averaged for 10, 2° latitude boxes from 10-12°S to 28-30°S (see Fig. 1 in Lough 1994).

Monthly rainfall totals were obtained from the Australian Bureau of Meteorology. Four coastal rainfall indices were developed based on the average rainfall at a number of stations centred on 12°S (near Coen), 17°S (near Cairns), 20°S (near Townsville) and 24°S (near Rockhampton).

There are 35 drainage basins in Queensland whose rivers drain eastwards into the Coral Sea (Queensland Water Resources Commission 1980). The total catchment area of these basins represents 26% of the land area of the state of Queensland. Monthly river flows were obtained from the Water Resources Division of the Queensland Department of Primary Industries. Monthly river flows are presented for four of these rivers whose catchment area comprises 62% of the area draining into the Coral Sea. They are the Barron River at Myola (about 17°S), the Herbert River at Ingham (about 19°S), the Burdekin River at Clare (about 20°S) and the Fitzroy River at The Gap (about 23°S). The record for the Fitzroy River does not start till 1964.

Details of tropical cyclone activity near the GBR were obtained from Lourensz (1981) for the period up to 1980 and data since then from the Australian Meteorological Magazine (see Lough 1994 for a complete list of references). For each 2° latitude band and extending 220 km out from the coast, counts were made of the total number of tropical cyclone days per year. A tropical cyclone day is one with a tropical cyclone in a specified area. It is probably only with the introduction of routine weather satellites in the early 1960s that almost every tropical cyclone will have been observed so the first few years of observations examined may underestimate the totals.

### Climate data prior to 1958

The choice of the base period, 1958 to 1992, used in this study was based on the observational frequency of the oceanic data set. To examine longer term climate variations in the vicinity of the GBR a rainfall index (back to 1890) and a temperature index (back to 1910) were used. The rainfall index is based on 17 stations throughout Queensland and the temperature index on 6 stations (see Lough, submitted). The strength of the ENSO is now routinely monitored as the pressure difference between Tahiti and Darwin. This Southern Oscillation Index (SOI) was obtained back to 1876 (Rob Allan, CSIRO 1994).

## Results

### Average conditions

The average monthly variations of surface climate conditions along the length of the GBR are illustrated in Fig. 1 (see Lough 1994 for a more detailed description). The summer season is characterised by warm SSTs ( $> 28^{\circ}\text{C}$  north of  $20^{\circ}\text{S}$ ), lower pressure and north-westerly winds north of  $14^{\circ}\text{S}$ . Although the 'monsoon' circulation features extend only to about  $16^{\circ}\text{S}$ , the summer circulation introduces strong seasonality into rainfall and river flow regimes further south (see below). Winter is characterised by cooler SSTs ( $< 22^{\circ}\text{C}$  south of  $20^{\circ}\text{S}$ ), higher sea-level pressure as travelling anticyclones influence the more southerly part of the region and strong south-east trade winds.

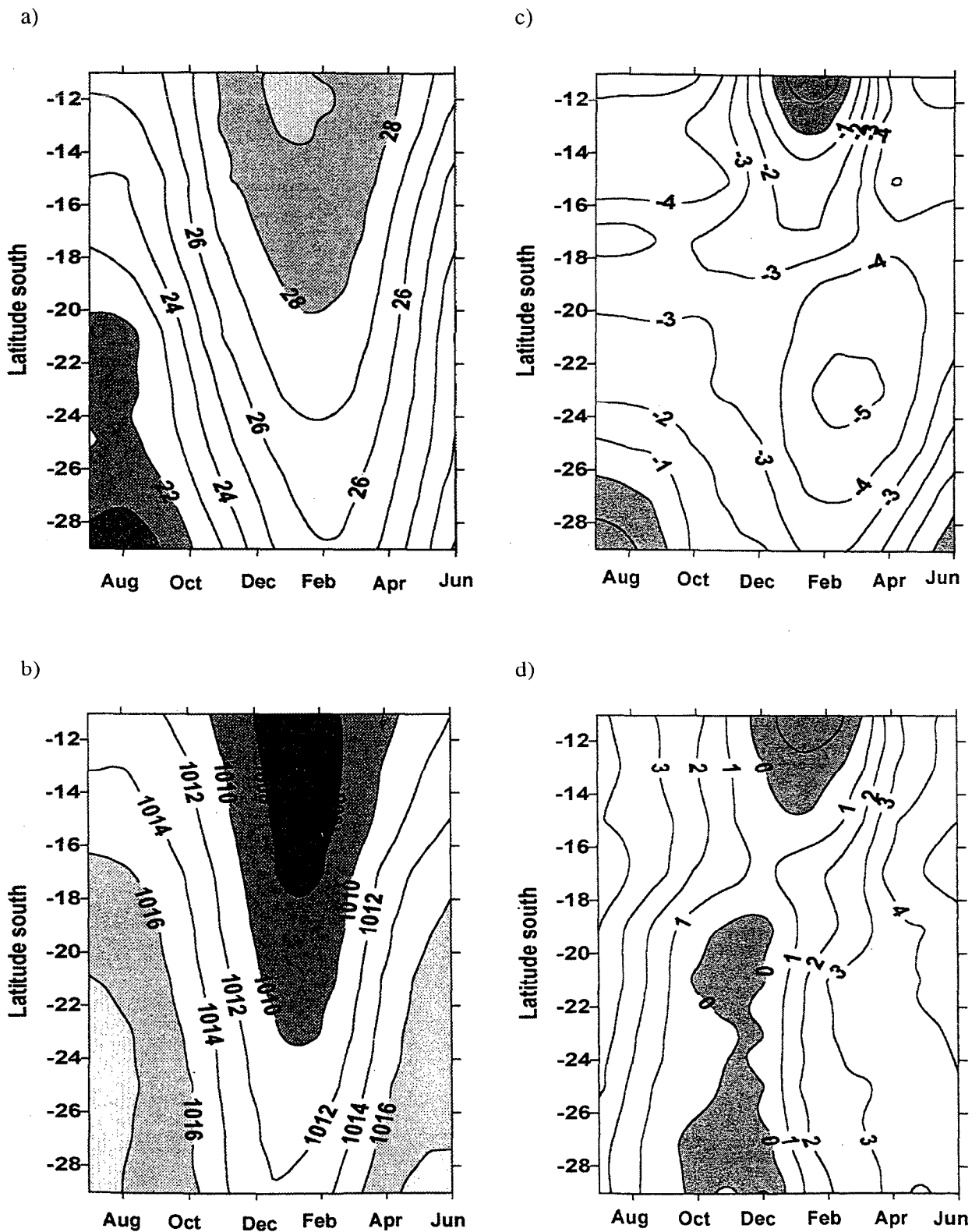
The strong seasonality of rainfall introduced by the seasonal migration of the summer monsoon circulation is illustrated in Fig. 2 for the four coastal rainfall indices. Peak rainfall occurs in January or February and minimum rainfall in August or September. On average,  $> 70\%$  of the annual total rainfall occurs during the summer months from October to March. This percentage is highest in the more northerly regions. The inter-annual variability of the summer rainfall is also high reaching a maximum of  $\sim 44\%$  around  $20^{\circ}\text{S}$  in the Townsville region adjacent to the central GBR.

The strong seasonality introduced by the summer monsoon circulation is also evident in river flow (Fig. 3). Peak river flow occurs slightly later than rainfall (Fig. 2) in February or March and minimum flows in September or October. River flows tend to be positively skewed with a few extremely high flow events elevating the mean. A more realistic perspective of 'average' flows is the median which for the two most southerly rivers is only about  $60\%$  of the average flow. (The rainfall series are also positively skewed though to a lesser extent than river flow, the median rainfall for the four regions shown in Fig. 2 is between  $95$  to  $98\%$  of the average). On average,  $> 70\%$  of the annual river flow occurs during the six months from October to March. The inter-annual variability of the summer river flow is extremely high, exceeding  $100\%$  in the two largest rivers, the Burdekin and Fitzroy.

### Variations associated with El Niño-Southern Oscillation

The average climate in the vicinity of the GBR described in the preceding section is just that - a statistical average picture which rarely prevails. The two extremes of the ENSO are the major source of year-to-year departures from 'average' in this region. To illustrate this, departures from the mean for individual extremes of ENSO are averaged together to give a composite picture of climatic conditions. These composites are presented for six ENSO years (negative SOI) and five anti-ENSO years (positive SOI) during the period 1958 to 1992 (see Fig. 4).

During ENSO events, SSTs tend to be cooler than average along the length of the GBR in the preceding winter and warmer than average in the late summer of the event (Fig. 5a). This is largely due to reduced monsoonal activity and cloud cover during ENSO events allowing increased radiative heating of the ocean. The reverse pattern characterises SSTs during anti-ENSO events (Fig. 5b). SSTs in the preceding winter tend to be warmer than average and then cool in late summer - as a result of enhanced monsoonal activity and reduced radiative receipt at the ocean surface.



**Figure 1.** Average monthly (July to June along x-axis) surface climate on the GBR, 1958 to 1992, for 2° latitude boxes (10-12°S to 28-30°S along y-axis) for a) sea-surface temperature (°C), b) sea-level pressure (mb), c) zonal wind ( $m.s^{-1}$ ; positive values are shaded and indicate winds with a westerly component), and d) meridional wind ( $m.s^{-1}$ ; negative values are shaded and indicate winds with a northerly component).

Recent climate variation on the Great Barrier Reef

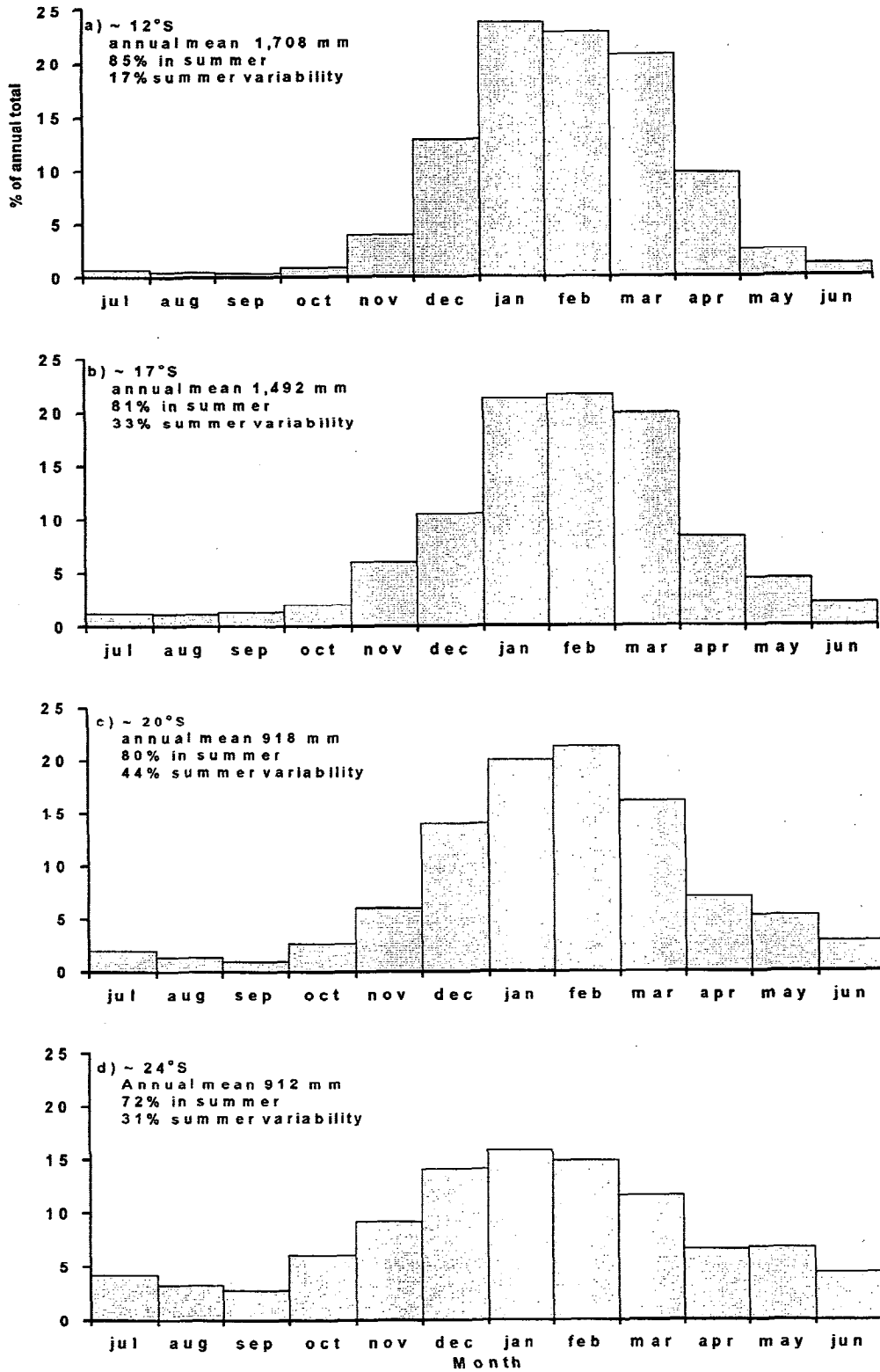
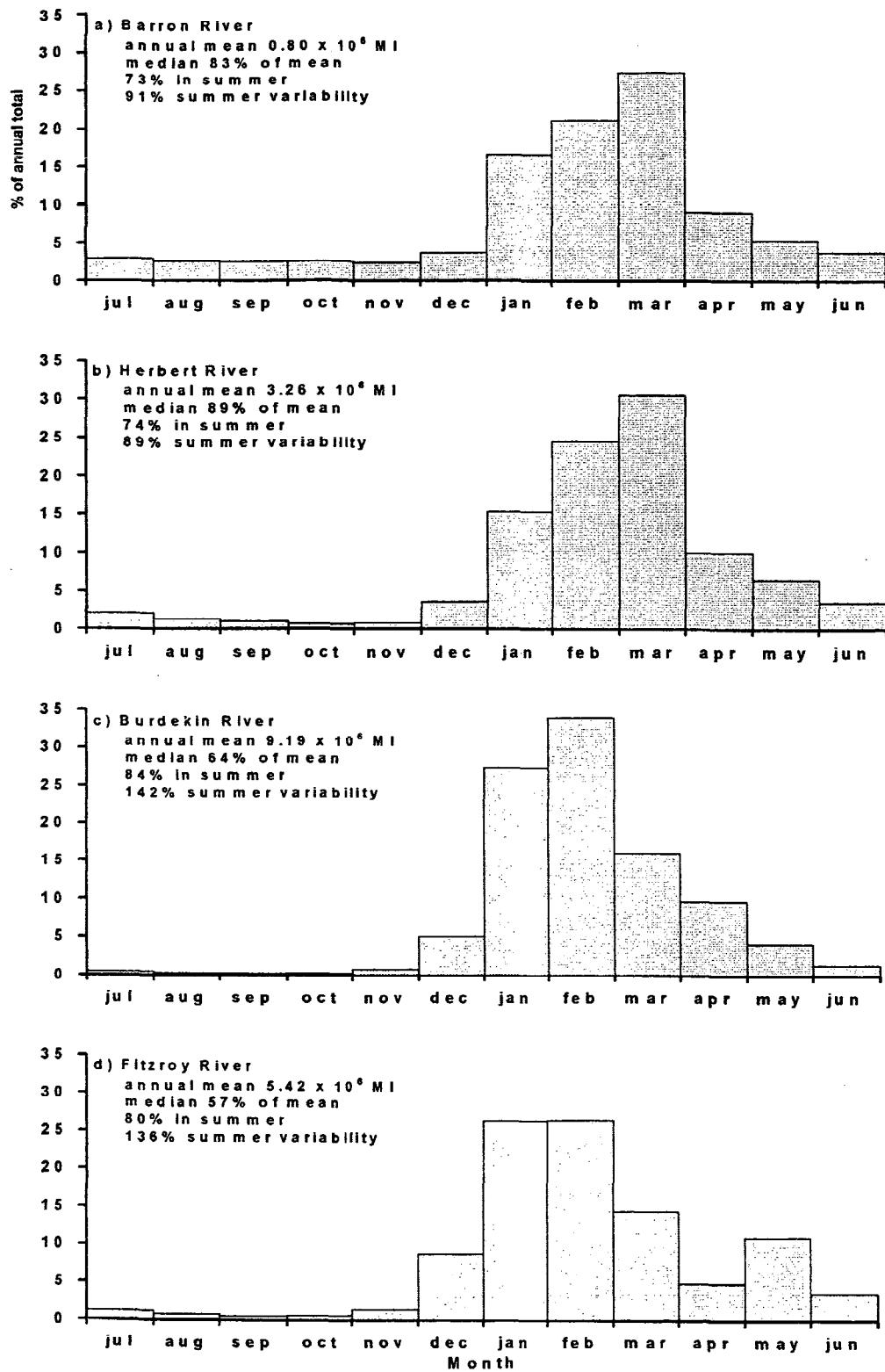
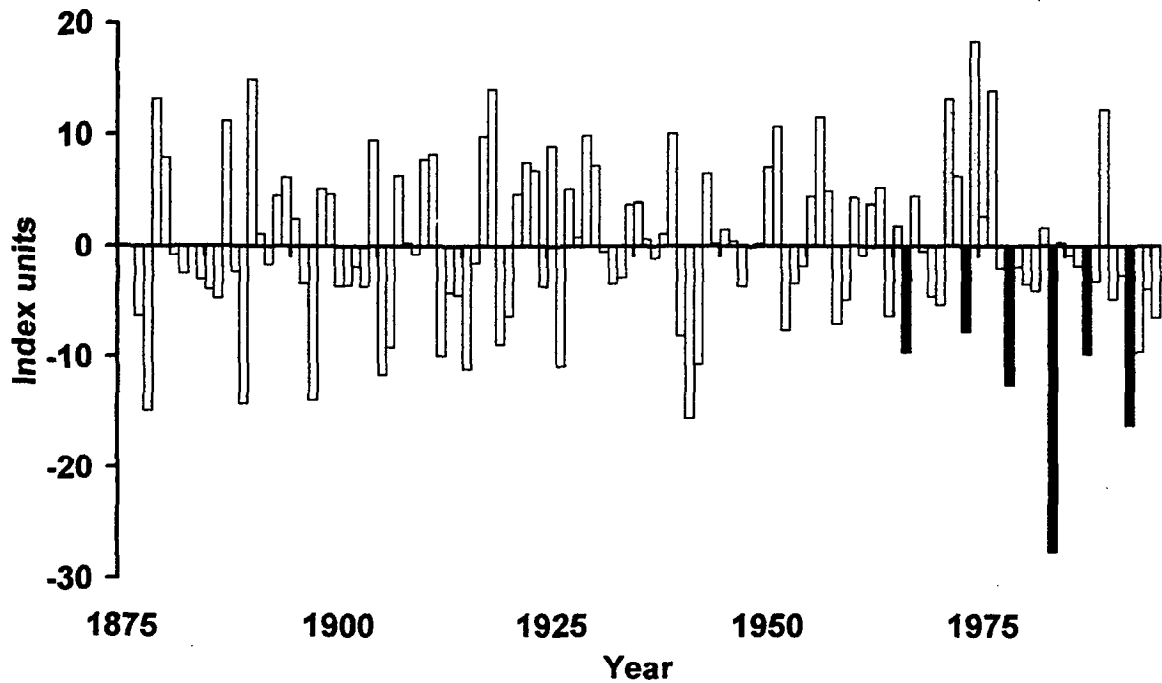


Figure 2. Average annual cycle of rainfall (monthly total as % of annual total) for four coastal regions adjacent to the GBR. Also given are average total annual rainfall for each district, the % of annual total occurring during the 6-month summer season (October to March) and the inter-annual variability of the summer rainfall total (s.d. as % of mean).



**Figure 3.** Average annual cycle of river flow (monthly total as % of annual total) for four rivers flowing into the Coral Sea. Also given are average total annual river flow, the median annual river flow as a percentage of the average, the % of annual total occurring during the 6-month summer season (October to March) and the inter-annual variability of the summer river flow (s.d. as % of mean).

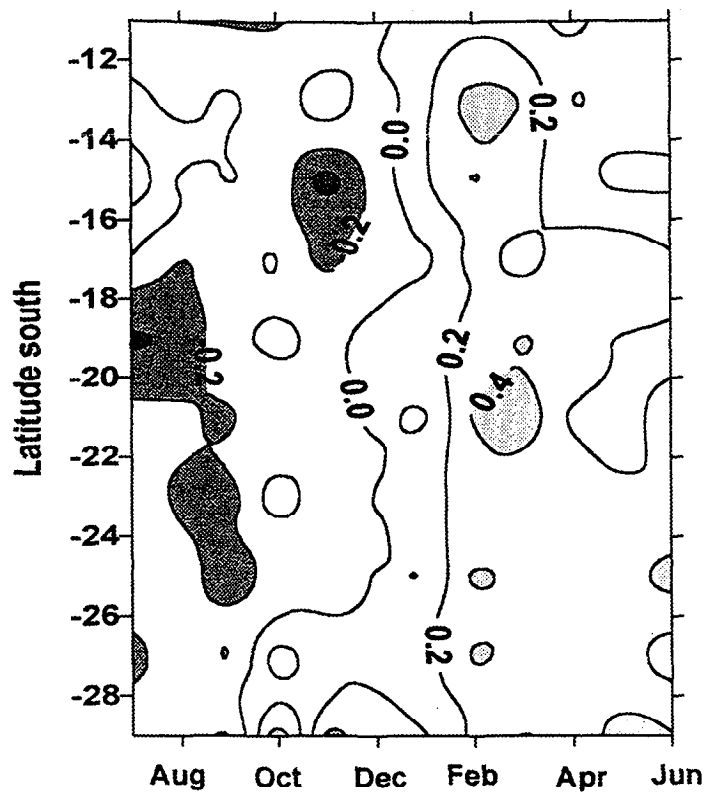


**Figure 4.** Summer (October-March) values of the Southern Oscillation Index, 1876 to 1995. Years of six ENSO events used in analyses (negative SOI) are indicated by dark shading and years of five anti-ENSO events by light shading.

The enhancement of the summer monsoon during anti-ENSO years is more evident than the suppression during ENSO years for the four coastal rainfall regions (Fig. 6). In the region near Townsville, adjacent to the central GBR over twice as much summer rain occurs, on average, during anti-ENSO years compared to ENSO years. These differences between ENSO and anti-ENSO years become more extreme when river flow is examined (not shown but see Fig. 15 in Lough 1994). Average summer river flow in anti-ENSO years as a percentage of that in ENSO years is 188% for the Barron River, 227% for the Herbert River, 688% for the Burdekin River and 681% for the Fitzroy River.

Tropical cyclones and decaying tropical cyclones (tropical depressions) can be a major contributor to rainfall during the summer wet season in Queensland (Lough 1991). The shift of the summer monsoon circulation away from north-eastern Australia during ENSO years also dramatically impacts tropical cyclone activity along the GBR (Fig. 7). In an 'average' year, about four tropical cyclones will occur in the region and about five tropical cyclone days. Maximum activity is usually in the belt 16-20°S (Fig. 7a). During an ENSO year, the number of tropical cyclones drops to two with about 2.5 tropical cyclone days (Fig. 7b). During anti-ENSO years the level of tropical cyclone activity increases with, on average, about 7.5 tropical cyclones and 8.5 tropical cyclone days in the region of the GBR (Fig. 7c).

a)



b)

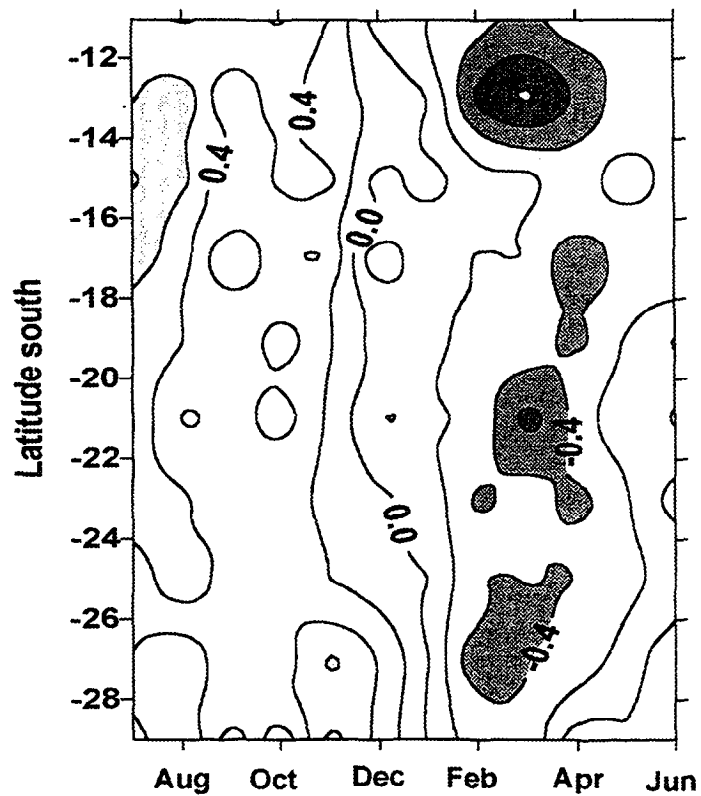
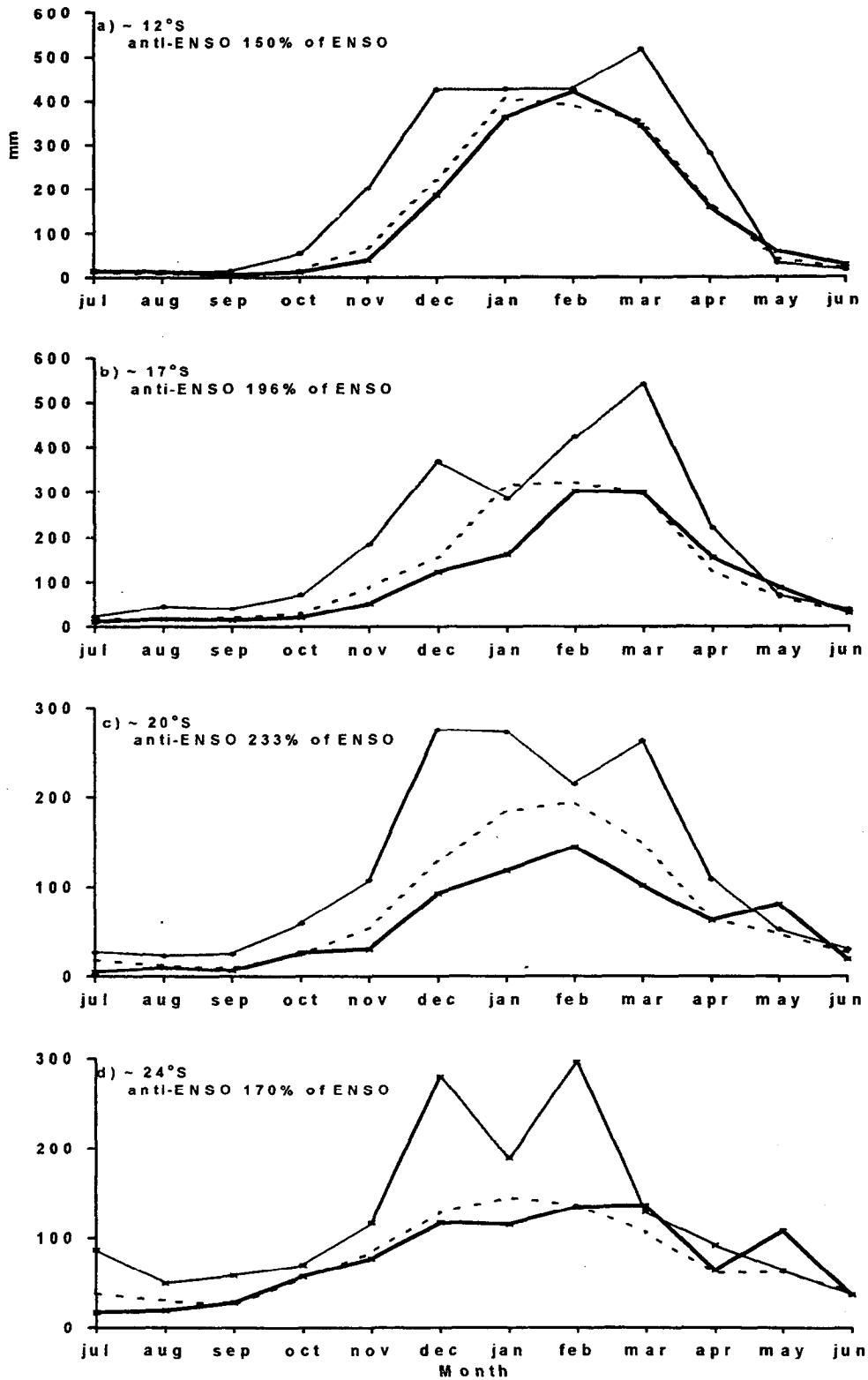


Figure 5. Average cycle of sea-surface temperature anomalies (from the 1958 to 1992 mean, °C) during a) six ENSO events and b) six anti-ENSO events.





**Figure 6.** Average monthly rainfall for six ENSO years (dark line), and five anti-ENSO years (grey line) for four coastal regions. Dashed line is 1958 to 1992 monthly mean. Also given is average summer rainfall for anti-ENSO years as a percentage of that for ENSO years.

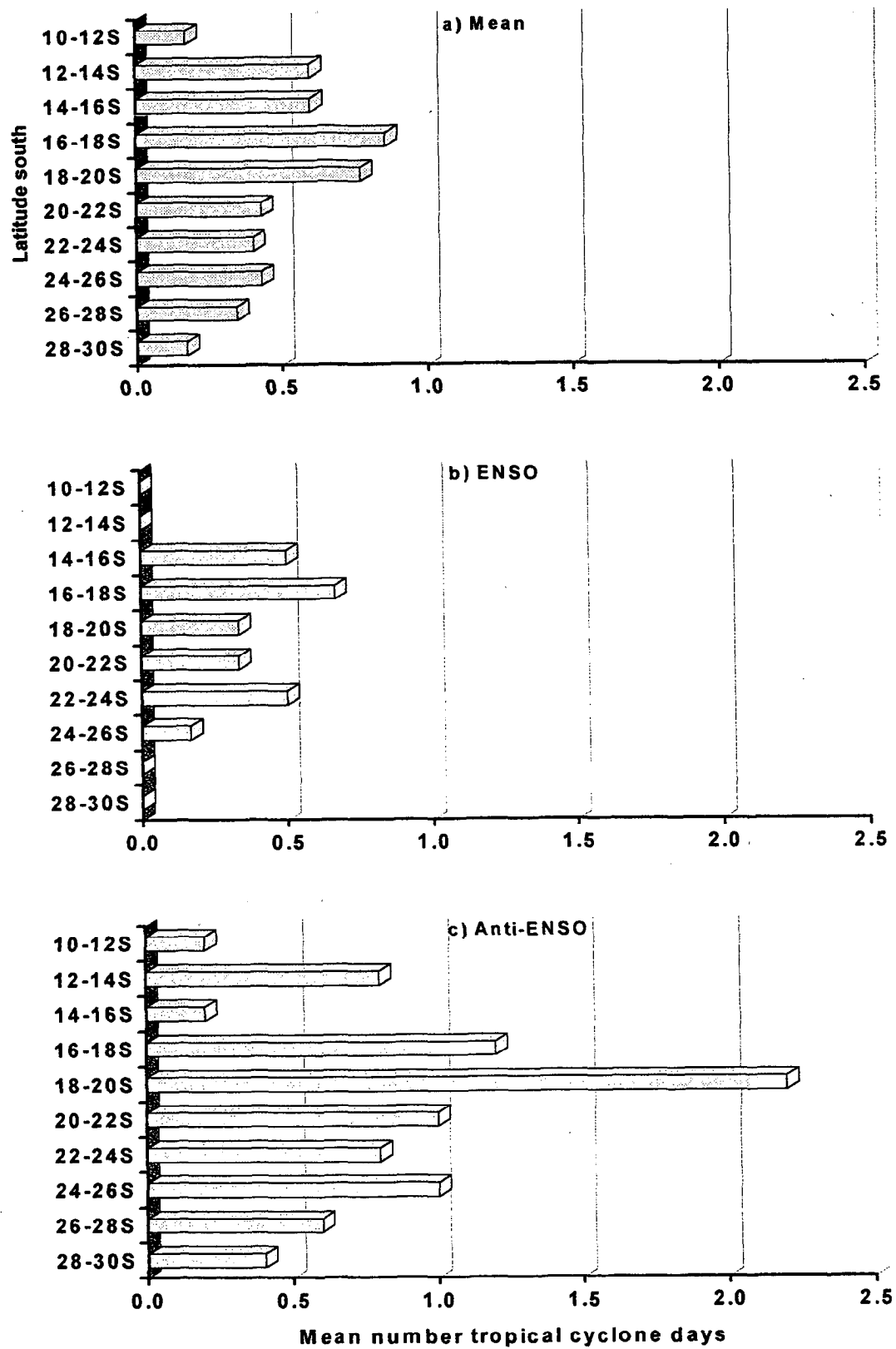
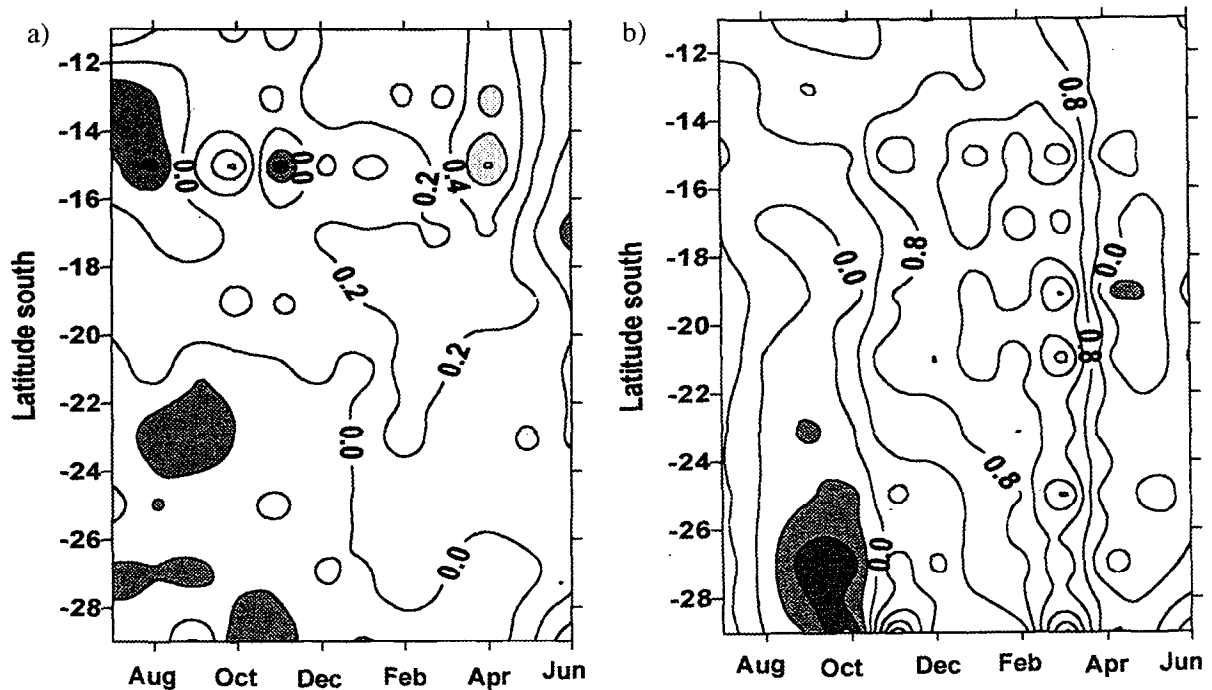


Figure 7. Number of tropical cyclone days for each 2° latitude band for a) 1958 to 1992 mean, b) average for six ENSO years and c) average for five anti-ENSO years.

## Difference between wet 1970s and dry 1980s

As observations of the biological status of the GBR start to accumulate over the past 20 to 30 years, there is a need to consider inter-decadal changes in the physical environment of the region. This is illustrated by subtracting the average surface climate conditions for the relatively wet 1970s from average surface climate conditions for the relatively dry 1980s. SSTs tended to be warmer in the 1980s compared to the 1970s along much of the GBR (Fig. 8a). This warming was greatest in late summer/early winter north of about 16°S. The difference in the average circulation between the two decades is illustrated by generally higher pressure in the 1980s compared to the 1970s (Fig. 8b). This is most evident during the months of the summer monsoon.



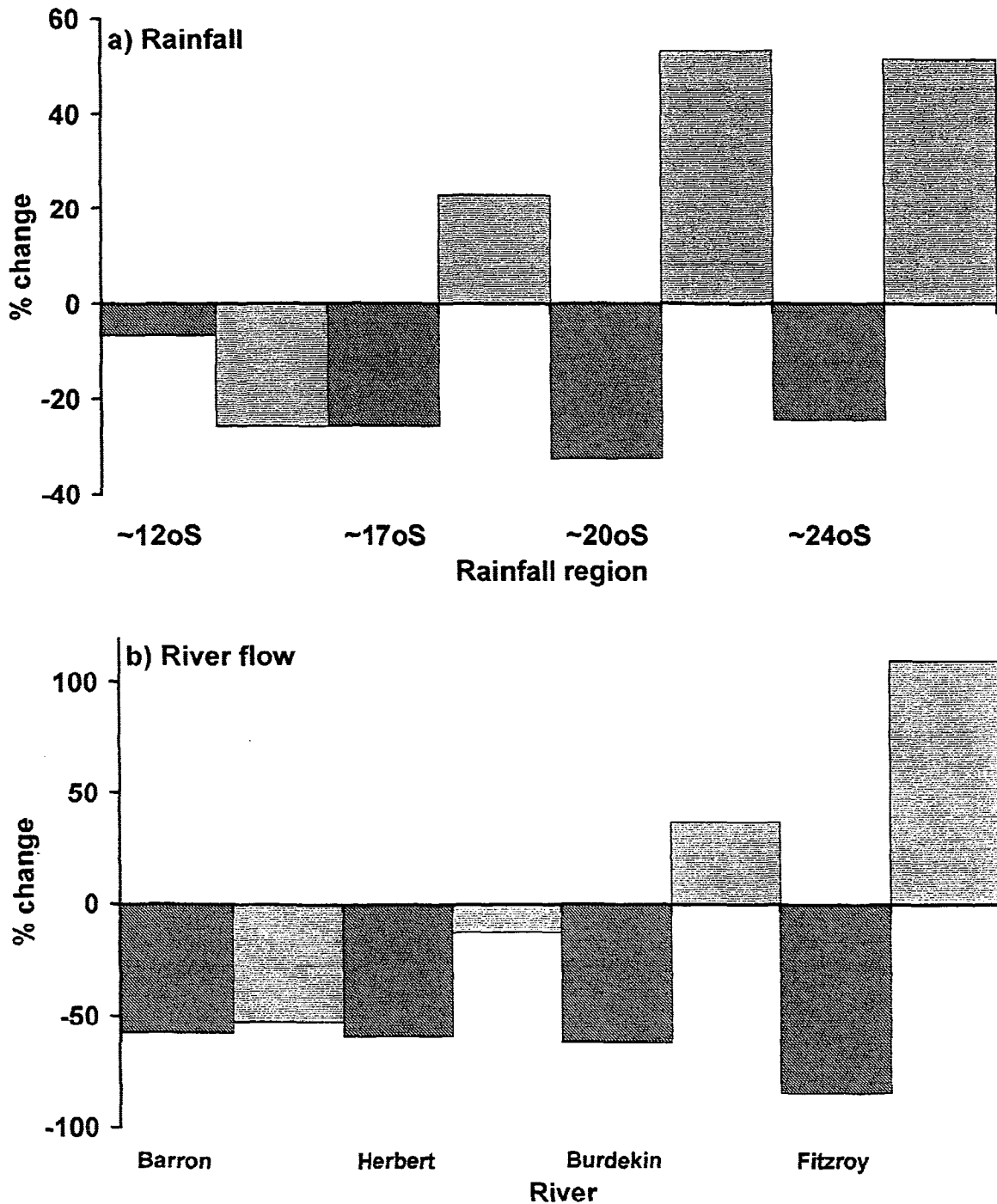
**Figure 8.** Difference between monthly average values for the decade, 1981-1990 and 1971-1980 for a) sea-surface temperatures (°C) and b) sea-level pressure (mb).

The weaker monsoon circulations of the 1980s compared to the 1970s resulted in much less summer rainfall particularly about 20°S (Fig. 9a) and up to 50% less flow in all four rivers (Fig. 9b). In the southern part of the region, winter rain and river flow tended to be higher in the 1980s compared to the 1970s.

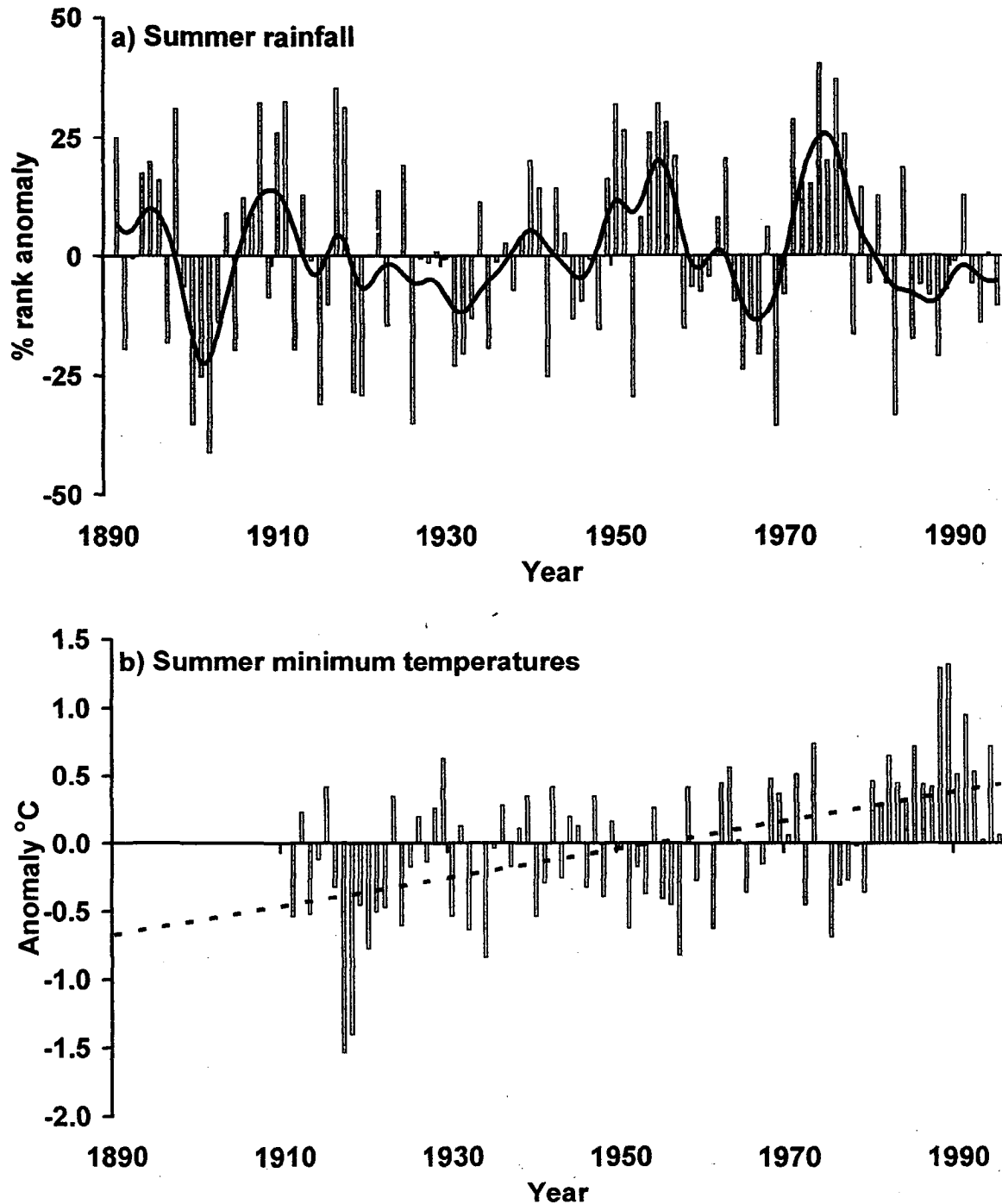
## Evidence for trends

Another mode of climate variability is sustained trends or changes in average conditions. Evidence for such trends in the vicinity of the GBR is illustrated using long-term record of rainfall in Queensland (Fig. 10a) and minimum (night-time) temperatures (Fig. 10b). Summer monsoon rainfall in Queensland has varied over the past century but there are no significant trends towards wetter or drier conditions (see Lough, submitted). The 1950s and 1970s were relatively wet and the dry conditions at the turn of the century culminated in 1902 with the worst drought in the state. In contrast, temperatures in Queensland appear to be following trends noted in many parts of the world (Karl et al. 1993). Average temperatures have increased

but most of this change is due to increases of minimum temperatures at night rather than maximum temperatures during the day. This results in an overall decrease in the average daily temperature range.



**Figure 9.** Percentage change in the median for the decade, 1981-1990 and 1971-1980 for a) summer and winter rainfall in four regions and b) summer and winter river flow. Summer values are hatched and winter values are stippled.



**Figure 10.** Index of summer a) rainfall in Queensland, 1891 to 1995 and b) summer minimum temperature anomalies, 1911 to 1995. Thick line in a) is 10-year gaussian filter to emphasise longer-term variations and dashed line in b) is linear trend line which accounts for 25% of variance.

**Summary**

Climate is a variable component of the physical environment of the GBR. There is a strong seasonal cycle of freshwater input (rainfall and river flow) between the summer wet monsoon and winter dry seasons. Superimposed on the average seasonal cycles are inter-annual and longer-time scale variations of surface climate. The major source of inter-annual climate

variability on the GBR is the ENSO. The level of 'disturbance' in the vicinity of the GBR is especially marked during anti-ENSO events when rainfall, river flow and the level of tropical cyclone activity increases. On inter-decadal time-scales, average climate on the GBR was markedly different between the 1970s (a period of vigorous summer monsoons) and the 1980s (when the summer monsoon was relatively weak). There are no long-term trends in rainfall in Queensland over the past century. In contrast average (particularly night-time, minimum) temperatures have significantly increased over the past century. The dynamic nature of the climatic environment of the GBR needs to be considered both in terms of its effects on the components of the ecosystem and when interpreting measurements and observations made at different times and in different locations.

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# Long-term current observations in the Great Barrier Reef

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## Abstract

Results of recent observations and model predictions of long-term currents in the central Great Barrier Reef (GBR) are presented. Key trends or patterns of likely significance to the status of ecological processes in the GBR are highlighted. Possible future developments of ocean models and data products, of possible value in managing the Great Barrier Reef World Heritage Area (GBRWHA), are also discussed.

## Introduction

The purpose of this paper is to address some key questions relevant to the analysis and modelling of physical processes and biological dispersal in the GBR region over daily to inter-annual time scales. The questions may be posed and answered generally as follows:

Why are currents and their variations important in the GBR?

Observations of ocean circulation are an essential component of a system for monitoring the status of the GBRWHA. Currents, which vary over a wide range of space and time scales, are responsible for transporting heat, salt, and mechanical energy for mixing, as well as a variety of chemical and biological constituents, to and within the GBR. The South Equatorial Current (SEC) provides a good example. It dominates the circulation of the Coral Sea giving rise to the East Australian Current (EAC) and the Hiri Current (HC), and imports warm clean nutrient-poor tropical surface waters into the outer GBR. Fluctuations in the EAC also induce upwelling of cooler, nutrient-rich waters into the subsurface on the continental shelf. Thus the boundary currents sweeping along the continental slope off the GBR strongly modulate the flows and nutrient levels in the GBR matrix on seasonal and inter-annual time scales.

What long-term current observations are available?

Long-term current observations or estimates are available from a number of strategic locations on the continental shelf and slope of the GBR. Those discussed in detail below include a cross shelf transect of five current meter mooring data obtained by the Australian Institute of Marine Science (AIMS) in 1985 (Morrow and Andrews 1986) and subsequent redeployments at two of these stations, one on the shelf and the other on the upper slope. The 1985 records which were of about seven months duration have been used to calibrate models which provide current estimates at these sites over a 30-year time span (beginning in 1966). An array comprising two upper slope current meter moorings (one at the upper slope location of the 1985 transect) and several tide gauges has also been maintained by AIMS, commencing late in 1986. The resulting current, temperature and sea level data can be used to identify long-term trends, to ground-truth satellite-derived ocean current maps, and for calibrating and validating numerical hydrodynamic models.

Can models be used to extend the record spatially and temporally?

Various kinds of mathematical models based on dynamical and/or statistical principles have been developed and applied in the GBR at spatial and temporal scales ranging up to approximately 1/3 of the length of the GBR and one year in duration. Efforts are now being made by modelling groups to extend the spatial and temporal scales of the model simulations to encompass interannual time scales and span the entire Western Coral Sea. Presently the most cost effective approach uses the numerical hydrodynamic model runs to generate verified simulations which are then used to calibrate simpler and more economical Linear Systems models which can be run over a 30-year time scale on a Personal Computer. However, as computing power is enhanced and as the numerical hydrodynamic models become more efficient decadal scale runs of the full models should become feasible.

What do data analyses and models tell us about physical influences on reef ecosystem status?

The data analyses and models can provide spatial maps and time series of physical parameters such as current speed and direction and temperature which are key parameters influencing the health and status of coral reef ecosystems. The current simulations can be used in constituent transport models (e.g. for water quality and larval dispersal) to predict the trajectories or concentrations of chemical and biological constituents. At this stage the transport model skill is limited by our understanding and knowledge of the underlying chemical and biological processes which govern non-conservative behaviour of the various constituents. Consequently the existing models are restricted in use to studies of passive advection of larvae from mass-spawning corals and crown-of-thorns starfish (COTS). Modelling of passive tracers has been used in larval fish dispersal studies, but incorporation of active migration behaviours is only at an early experimental stage.

This work is intended to provide some specific details and examples of research relevant to these questions. As a reflection of the extent of available data sets, and of the state of development of the relevant models, the discussion is confined primarily to applications of existing analyses and models to larval dispersal of mass-spawning corals and COTS. However, significant advances in fish larval dispersal modelling capabilities are anticipated over the next 3-5 years as new models and data become available.

The goals of the paper are thus: 1) to describe long-term current and sea-level observations in the GBR region; 2) to show how these can be integrated with hydrodynamic models and remote sensing data; 3) to highlight emerging long-term trends and patterns of variability; and 4) to identify implications for long-term monitoring of GBRWHA status.

### **Large-scale circulation and long-term current variability**

#### **In situ observations**

Available data on long-term currents in the GBR are derived from several direct and indirect sources. In 1985 J.C. Andrews, AIMS, deployed a current meter mooring transect for a period of seven months from Cape Cleveland, through Magnetic Passage in the central GBR off Townsville, terminating with a slope water mooring (site E, 18°9'S, 147°24'E) near Myrmidon Reef. A seaward extension of this transect was simultaneously deployed across the Queensland Trough between Myrmidon and Flinders Reef by J.A. Church, Division of Oceanography, Commonwealth Scientific and Industrial Research Organisation. The results of this Cross Shelf deployment were analysed in a dynamical study by Burrage et al. (1991). In October 1986 site E was re-occupied and has been continuously monitored by AIMS up to the present day. A second long-term mooring was deployed in slope water off Jewell Reef (14°S) by AIMS late in



1987, together with an array of tide gauges designed to span the continental shelf and slope. Several pressure gauges (initially three, later contracting to two) were also located on key off-shelf reefs. This array, which was deployed for a study called Transports of the East Australian Current System (TEACS), includes both temperature and current sensors. In addition to the mooring data, hydrographic transects comprising profiles of temperature and salinity have been acquired during the 20 or more mooring maintenance cruises executed to date. The TEACS dataset is an invaluable resource which is unique in Australia, and possibly globally in terms of continuous temporal coverage, dating from the late 80s.

The TEACS array (Table 1, Fig. 1), which spans the bifurcation region of the SEC in the central GBR, comprises two current moorings with Aanderaa RCM4 and RCM7 current meters measuring current and temperature at two or three levels. The current meter moorings are located on the upper continental slope offshore from Jewell and Myrmidon Reefs and lie just outside the northern and southern bounds of the Cairns Section of the GBR, respectively. In addition there are Aanderaa WLR4 sub-surface pressure gauges located on the inner shelf, at the shelf break, and on off-shelf reefs. Since most of these locations are paired with permanent State Government tide gauge installations at the coast, along-shelf geostrophic current fluctuations can be estimated from the across-shelf sea-level differences and compared with the slopewater current data.

Data from these instruments have been used to develop linear systems models of along-shelf currents for correlation with COTS outbreaks (Burrage et al. 1991, 1993; Black et al. 1995) and presently provide ground-truth data for AIMS radar altimeter studies of sea surface heights and currents using the ERS-1 and TOPEX/Poseidon satellites. The altimetry-derived sea levels are being used to determine long-term surface current variability in the Coral Sea (see below).

The TEACS array was designed to monitor seasonal and inter-annual changes in the EAC and the resulting current meter and tide gauge data have been processed to reveal decade scale variations in continental slope currents off the central and northern GBR (Fig. 2). The Jewell mooring reveals the seasonal and inter-annual fluctuations in the location of the bifurcation, which for near-surface waters (order 50 m depth) occurs, on average, close to the position of the mooring at latitude  $14^{\circ}$  S. Influences on shelf circulation in the Cairns Section remain speculative at the moment, although the influence is clearly evident further south where the Myrmidon Reef record shows a correlation with the linear systems model predictions of along-shelf current (compare Figs. 2b and c). This correlation is an indication of the extent to which the EAC (represented by the mooring data) is associated with current variations on the shelf (the predictions). Both the observations of slope currents and the along-shelf current predictions show that strong northward flows occurring prior to El Niño Southern Oscillation (ENSO) events are followed by a relatively rapid transition to strong southward flows in the late stages of such events. This pattern is, however, not uniquely related to ENSO, since it has occurred on a few occasions during non-ENSO years.

Burrage et al. (1994, henceforth BBS) studied the long-term sea-level variability in the GBR and found that much of the variability could be explained by fluctuations in the prevailing wind. They also found that sea level fluctuations were well correlated with prevailing along-shelf currents, as expected from the geostrophic relation used by oceanographers/meteorologists to infer the direction and strength of currents/winds from the horizontal sea level slope/pressure gradient. However, due to the effects of remotely forced (geostrophic) coastal trapped waves propagating into the area it was found that across-shelf sea level differences were a much more reliable and accurate predictor of alongshelf currents than was local wind. (Actually it is the difference in total pressure at two across-shelf sites which is used as a predictor, where the total is the sum of the pressure due to the sea surface elevation plus the overbearing atmosphere.)

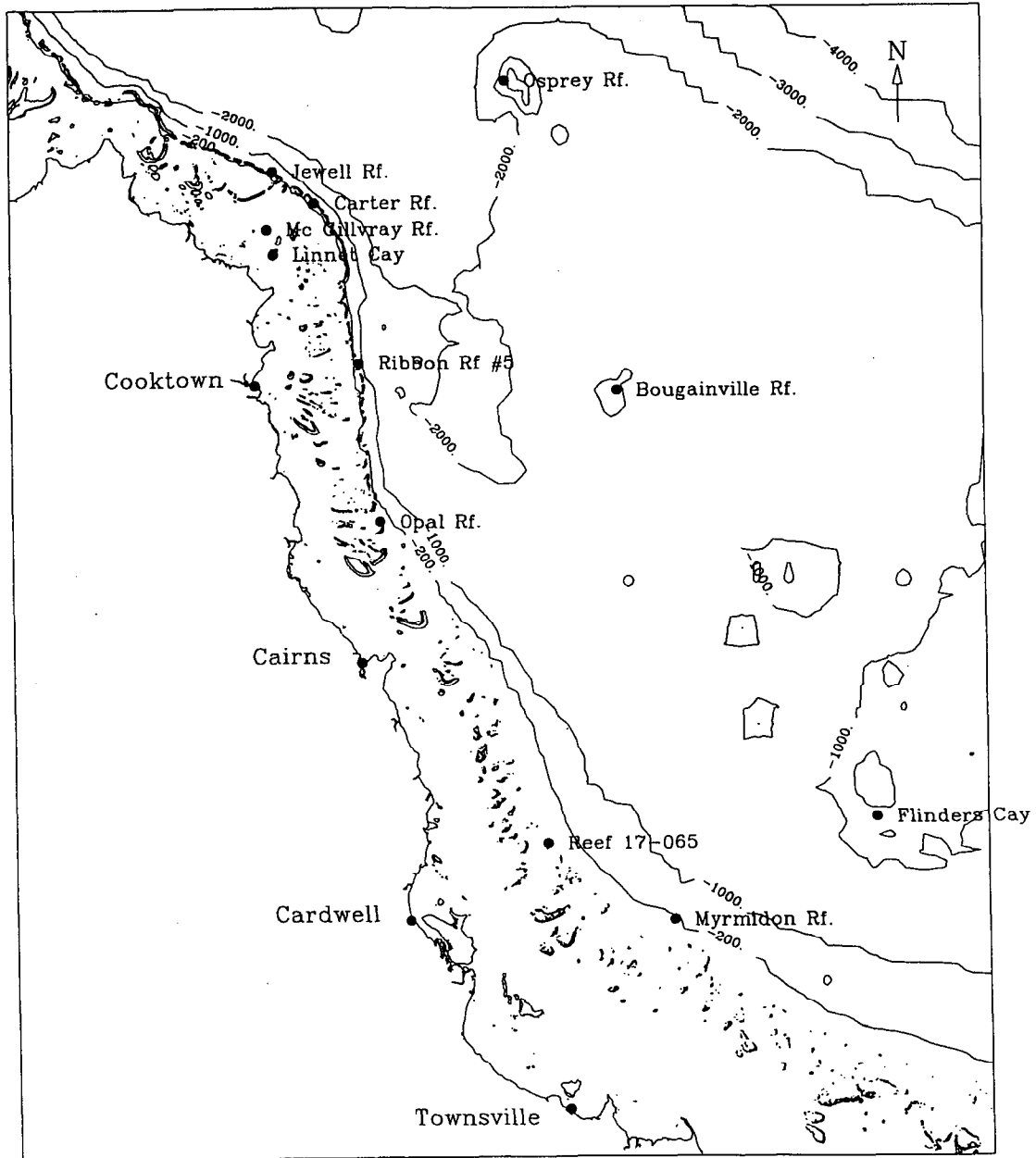
**Table 1.** TEACS current meter moorings and tide gauges. Depths are instrument depths (or water depth where under a line)

Location	Lat S	Start/ Finish Date	Time Intvl	Depth (m)	Parameters Recorded			
	Lon E				Curr Sp	Curr Dirn	Water Press	Water Temp
	ddd mm	mm/yy	min					
Current Meter Moorings								
Myrmidon Rf.	18 13	10/86	60	25	*	*	*	*
	147 21			50				
				75				
				<u>150</u>				
				200				
Jewel Rf.	14 21	8/87	60	30	*	*	*	*
	145 21			<u>80</u>				
				352				
Tide Gauges								
Myrmidon Rf.	18 16	10/88	60	12	-	-	*	*
	147 23							
Flinders Cay	17 44	10/88	60	9	-	-	*	*
	148 26							
Osprey Rf.	13 53	10/88	60	9	-	-	*	*
	146 33							
*Bougainville Rf.	15 30	10/88	60	4	-	-	*	*
	147 07							
*Mc Gillvray Rf.	14 39	10/88	60	6	-	-	*	*
	145 19							
Carter Rf.	14 31	10/88	60	9	-	-	*	*
	145 34							
Linnet Cay	14 47	10/88	60	6	-	-	*	*
	145 21							
Ribbon Rf. # 5	15 21	10/90	60	8	-	-	*	*
	145 47							
Opal Rf.	16 11	10/90	60	8	-	-	*	*
	145 53							
Reef 17-065	17 52	10/90	60	20	-	-	*	*
	146 44							

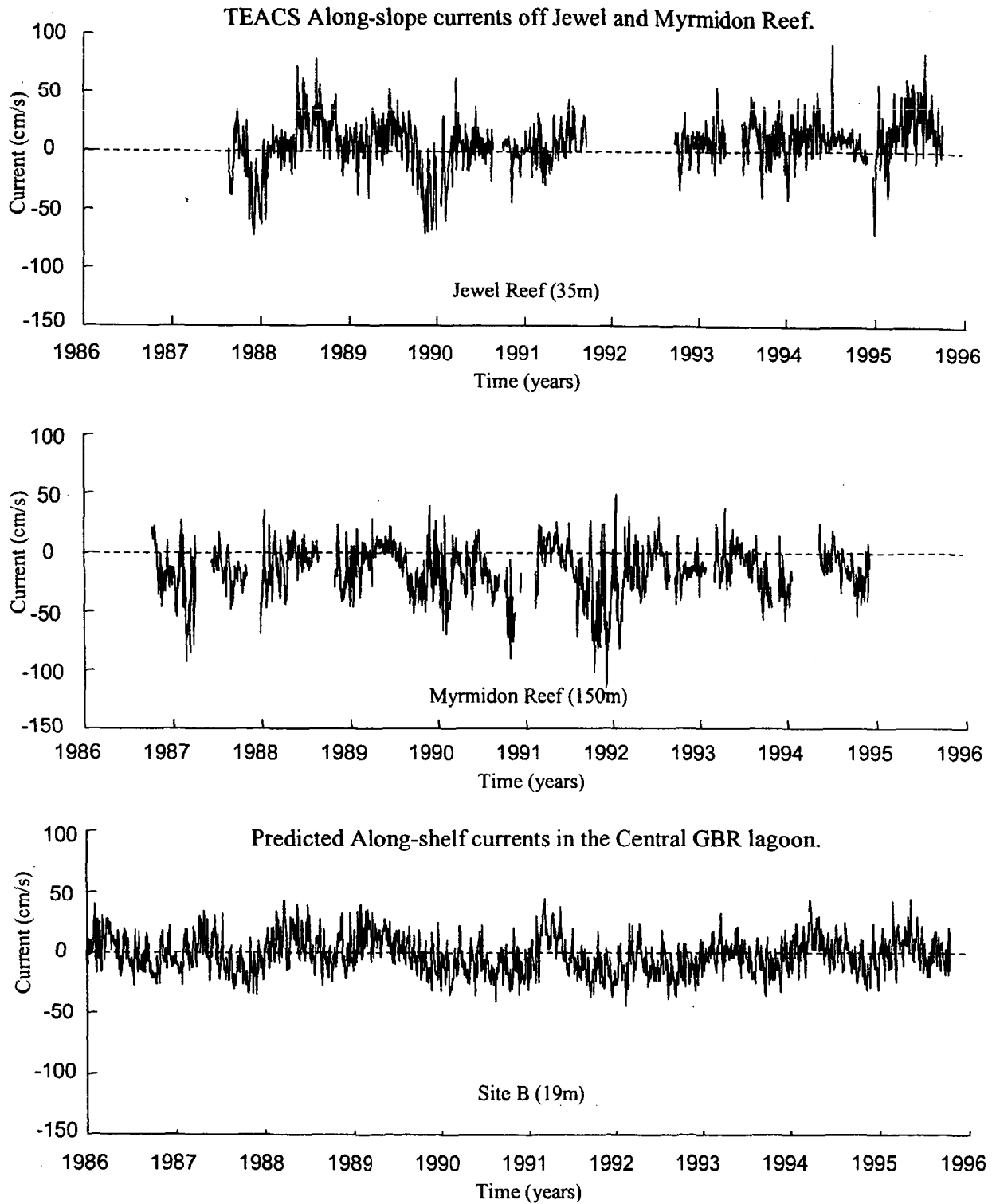
\* Record terminated at Finish Date shown

In addition to the TEACS array, a long term time series of Townsville (30 yr) and Noumea (20 yr) pressure-corrected sea level data has been analysed (not shown) to produce estimates of along-shelf currents. The sea level data set provides a unique view of the long-term seasonal and inter-annual sea level variability in the GBR. For example, ENSO related sea-level fluctuations are clearly evident in the record as are longer-term trends and interannual fluctuations (see BBS for details). More significantly, the data set has been used to calibrate linear systems models based on optimally-lagged regression techniques (Burrage et al. 1993a, henceforth BBN). These can accurately and precisely estimate low frequency (sub-tidal) geostrophic along-shelf currents on the GBR continental shelf. A 25-yr historical prediction has been correlated with the development of the primary and secondary outbreaks of the COTS recorded since 1966 (Black et al. 1995). Dispersal models based on the prediction show that periods of weak along-shelf flows during COTS spawning events are associated with primary outbreaks, and that the progress of secondary outbreaks is strongly influenced by along-shelf

currents during subsequent spawning events. The historical current predictions have recently been updated to include predictions for the 1991-1995 quinquennium. These new predictions are particularly relevant to the two most recent ENSO events and to the current surge in the numbers of COTS which has recently been reported in the Cairns Section of the GBR (Udo Engelhardt, pers. comm.).



**Figure 1.** Generalised Coral Sea bathymetry (depth contours in m) and locations of TEACS current meter moorings (Jewell and Myrmidon Reefs), offshore pressure gauges (Osprey Reef, Bougainville Reef and Flinders Cay) and outer shelf pressure gauges (Carter Reef to Reef 17-065).



**Figure 2.** TEACS along-slope currents 1986-1996, and predicted alongshelf currents in the GBR lagoon. The data have been smoothed with a 2.5 day cutoff low pass filter (a) upper panel: along-slope current off Jewell Reef, (b) centre: along-slope current off Myrmidon Reef, and (c) lower: the along-shelf current predictions at Site B. Tic marks indicate start of each labelled year.

## NOAA weather satellites

A particularly valuable source of sea surface temperature imagery and indirect source of surface current information comes from the Advanced Very High Resolution Radiometer (AVHRR) flown on the NOAA polar orbiting satellites. Observations of GBR currents and sea surface temperatures dating from April 1988 can be obtained from the satellite imagery archive of the Northeast Australian Satellite Imagery System (NASIS) consortium. This is received continuously and archived jointly by AIMS and James Cook University of North Queensland. Examples of the application of NOAA thermal imagery to oceanographic reconnaissance and to studies of mesoscale and sub-mesoscale circulation features such as upwelling, eddies and jets in the southern GBR are presented by Kleypas and Burrage (1993) and by Burrage et al. (1995, 1996).

## Radar altimeters

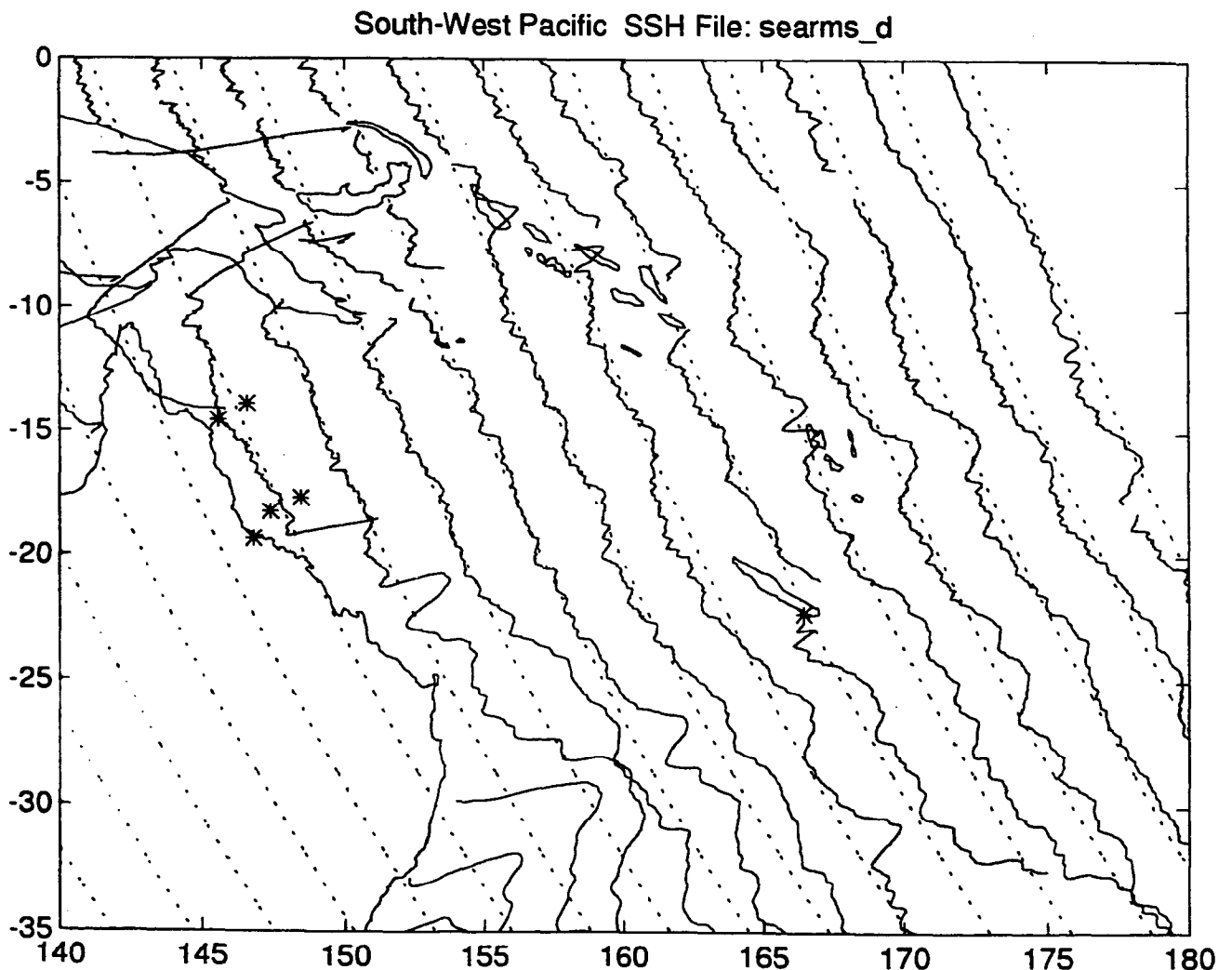
In October 1986 a new source of data for estimating geostrophic surface current variability became available, with the establishment of the GEOSAT radar altimeter Exact Repeat Mission. This was followed by the launching of the ERS1 satellite in 1990, of TOPEX/Poseidon in 1992, and of ERS2 in 1995. The resulting altimetry data sets provide low-frequency surface current and tidal estimates in the Coral Sea, and less completely in the GBR lagoon. They have an along-track spacing of order seven km, inter-track spacing of order 100 km, and a ground-track repeat cycle of 3-35 days (depending on mission and orbit phase). The level of accuracy (6 cm) and precision (2 cm) of the global TOPEX data set is unprecedented. Since a continuing commitment has been made by several National and International Space Agencies to such radar altimetry missions, a near-continuous source of altimeter data is assured over the next decade. The resulting datasets are revolutionising our understanding of ocean climate variability and of regional circulation patterns. For example, a recent analysis by Jacobs (NRL, Stennis Space Center, USA) has shown that a sub-tropical basin-scale Rossby wave generated by the 1987 ENSO impinged on the Coral Sea during the 1991-92 summer, with probable influence on the strength of the EAC. Preliminary tests of Coral Sea tidal models generated using TOPEX/Poseidon altimetry, global numerical hydrodynamic models and in situ data have been reported by Steinberg et al. (1993, 1995, 1996). Profiles of Root Mean Square (rms) low-frequency sea level variability for descending passes of the TOPEX radar altimeter over the period spanning the first two years of the mission are shown in Fig. 3. The rms height is plotted along the ground tracks with values greater than 10 cm plotted above the track line. This highlights regions of relatively high variability associated with, for example, the Gyre at the entrance to the Gulf of Papua and the SEC inflow area between the Solomon Islands and New Caledonia (Burrage 1993). It also shows the effects of much greater mesoscale eddy variability in the Tasman Sea, in comparison with the Coral Sea. This implies that the Coral Sea is in some respects more predictable and hence more amenable to study using the kinds of models discussed below. Elevated values along the southern GBR and PNG shelves could be caused by fluctuations in the EAC and HC. However, they might also be due to errors in the tidal corrections which are poorer near the coast. These shelf areas will be more accurately resolved when regional tidal models are introduced.

## **Long-term and large-scale modelling**

### Linear systems modelling

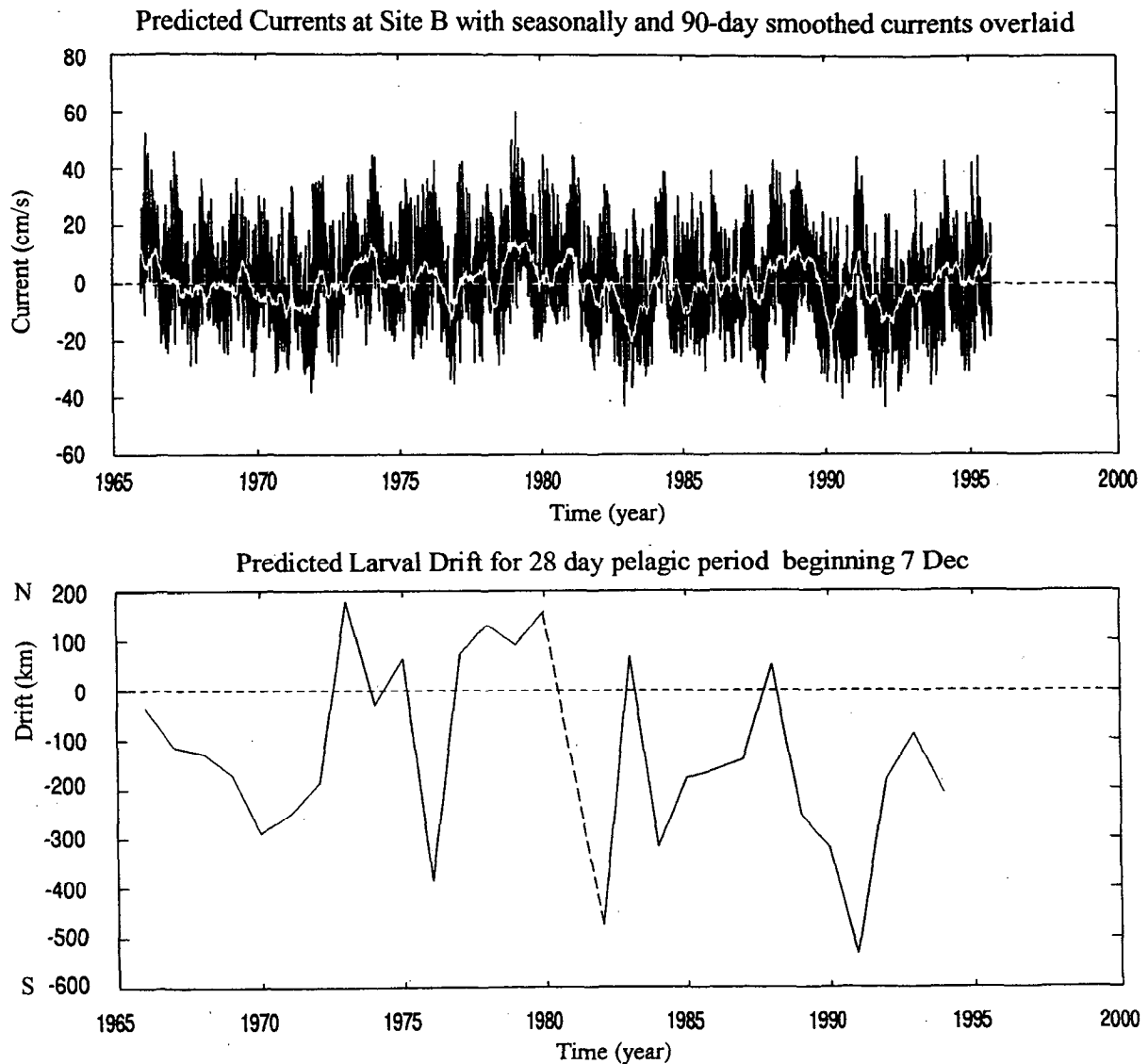
BBN developed a suite of linear systems models which allow low frequency along shelf currents to be predicted at selected locations based on readily available meteorological and oceanographic forcing data. The models which are essentially statistical, nevertheless reflect our understanding of regional hydrodynamics. Using optimally lagged multi-linear regression

they allow predictions to be made quickly and economically from input time series and a few specified parameters. The models were calibrated using current meter mooring data obtained from a transect across the central GBR in 1985 (Morrow and Andrews 1986) and validated using data from similar deployments in 1987 and 1990. The most useful models of this type are based on the geostrophic across-shelf momentum balance. Using as input coastal sea levels at Townsville (back to 1966) or, when available, offshore sea-level differences between Townsville and Noumea, New Caledonia (from 1976), they can be used to predict currents over time spans of up to 30 years. The Townsville-Noumea model has an estimated accuracy (bias) of  $< 5.0$  cm/s, a precision (standard error)  $< 10.0$  cm/s, and a forecasting skill (percentage of variance predicted)  $> 0.7$ , while the corresponding performance figures for the Townsville only model are an accuracy of 16 cm/s, precision  $< 9$  cm/s and skill  $> 0.75$ . The models thus respond accurately to fluctuations at weather time scales and, when offshore differences are used, at seasonal and inter-annual scales.



**Figure 3.** Root mean square (rms) sea level variability (solid line) from TOPEX radar Altimetry. Profiles of rms low-frequency sea level variability for descending passes (dotted) of the TOPEX radar altimeter during the first 80 cycles (800 days) of the mission. rms values exceeding 10 cm plot above the satellite tracks. Tide gauge data from TEACS locations and Townsville (\*) have been used for ground-truthing.

A time series of predicted currents for Site B (lat 18°48.8'S, lon 147°8.5'E in the central GBR lagoon) are shown in Fig. 4a. These predictions are based on the (atmospheric pressure-adjusted) Townsville minus Noumea sea level difference for the period 1976-1995, and on Townsville sea levels only for the period 1966-1975. The black lines correspond to predictions based on the sea-level differences which include seasonal and weather related variability (including events of 2.5 day period and longer). The white lines represent the same data, but with the mean seasonal signal removed and smoothed with a 90 day cutoff period boxcar filter, to emphasise the interannual variability to the exclusion of the seasonal and weather band signals. When drift predictions are made for particular spawning periods, only records smoothed over the 2.5 day time-scale are used and if desired, the daily tides are predicted separately and super-imposed.



**Figure 4.** a) upper panel: Predicted currents in the central GBR lagoon for the period 1966-1995. Smoothed with a 2.5 day low pass filter (solid black), and with seasonal average removed and a 90-day low pass filter applied (solid white). b) Predicted larval excursions after a 28 day drift period beginning on 7 December for each summer season (1966-67 through 1994-95). Tic marks indicate start of each labelled year.

The predicted currents were used directly by Black et al. (1995) to drive an elementary along-shelf larval dispersal model for the period 1966-1990. This showed that periods of relatively slow alongshelf currents were associated with the primary outbreaks of COTS which began in 1968 and 1979. The predicted alongshelf drift using the 2.5 day smoothed data for the summer spawning periods of 1966-67 to 1994-95 are shown in Fig. 4b (i.e. the seasonal and weather band signals are included). This confirms that relatively weak or northward drift prevailed during the late 70s as a precursor to the 1979 outbreak. The periods of weak or northward flow also experienced during 1988 and 1993 might have contributed to the present COTS population build up. Although the 1995-96 drift prediction is not available, due to filtering loss and a remedial technical problem at the Noumea sea level station, the predicted currents also show prevailing weak or northward flows late in 1995, as do the currents at the Jewell Reef mooring (Fig. 2a); suggesting that conditions favouring larval retention at source reefs may yet prevail.

New linear systems models have been developed for additional historical current meter sites in Bowling Green Bay and at Green Island in the central GBR (Burrage and Hall unpublished). These can be used to estimate alongshelf currents at the locations based on the historical sea-level record. They expand the range of available sites originally established by BBN. The various sites are now being incorporated into a Shelf Currents Simulation Program (SHELFLOW) written in Visual Basic by Doug Hall (AIMS) to provide marine scientists and managers with ready access to the Linear Systems Model predictions via a desktop computer and graphical user interface.

Model 3DD of Black et al.

The linear systems model predictions were also used by Black et al. (1996) to provide boundary conditions for a 4.5 km resolution numerical hydrodynamic simulation model of the central GBR. The assimilation of a 25-year historical current prediction into the model enabled it to accurately track the fluctuations in intensity of the shelf currents due to changes in the strength of the EAC. The results of the data assimilation model were input into a 2D water quality/larval dispersal model to simulate dispersal of COTS larvae for two particular outbreak years. The runs for the 1978 and 1982 COTS spawning periods showed a contrast between the effects of relatively weak flows and self-trapping by reefs of the 1978 primary outbreak year, and the relatively fast currents and secondary outbreak dispersal occurring in 1982. Further model runs to incorporate the new sea level difference data for the 1990-1995 quinquennium are planned. This will allow refinement of the relatively crude drift estimates illustrated in Fig. 4. Further runs of this hydrodynamic model at a resolution of 2.25 km are also planned, subject to availability of funds.

Gridded linear systems model

A MATLAB program called GRIDLSM for computing the linear transfer function of the above mentioned assimilation model has been developed and tested by Burrage et al. The purpose of the program is to provide a fast and efficient, though approximate simulation of GBR shelf currents which can easily be run on a Personal Computer. This is useful for applications not requiring the accuracy and sophistication of a computationally demanding numerical hydrodynamic model. The program has been used to analyse the data generated from the 2-D numerical hydrodynamic model of central GBR currents (Black et al. 1996) for the 1985 COTS spawning period. The program computes linear systems model parameters at each 4.5 km wide grid cell over the central GBR 3DD model domain. The parameters describe simple lagged regression relationships between boundary forcings (Mackay winds or Townsville-Noumea sea-level difference) and the simulated current velocities. This relationship is embodied in the numerical 2-D model dynamics. The program can produce 3-D surface views and 2-D vector



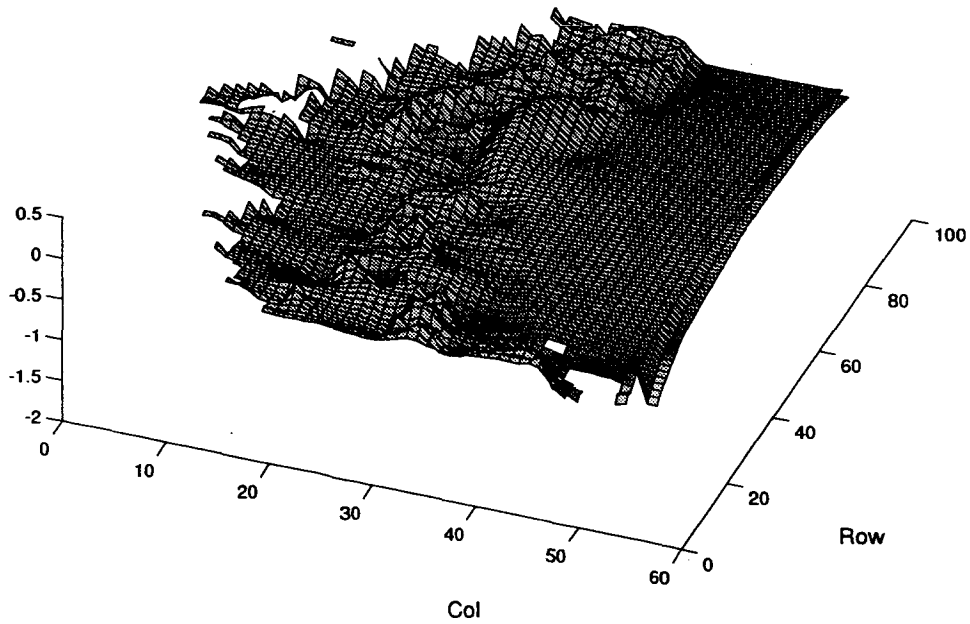
plots of various model parameters and current predictions over the grid. The program is presently being tested by using it to estimate currents throughout the central GBR for the period 1966-present (e.g. Figs. 5a and b) which can then be compared with the in situ data and with the results of a full 3DD model run. The surface view of instantaneous current speed (Fig. 5a) shows prevailing southward flows both on and off the shelf with weak near-zero currents (peaks) evident in the reef matrix. This illustrates the frictional effect of the reef matrix which slows the prevailing currents (Burrage et al. 1991). The broad peak in the outer central GBR domain (Fig. 5b, near Row 65, Col 30) corresponds to an anticyclonic eddy and central stagnation region seaward of Myrmidon Reef, a feature which was evident in the original 3DD hydrodynamic model run which was used to calibrate GRIDLSM. Future enhancements of GRIDLSM to account for the joint effects of wind and sea level fluctuations are also planned. The program is expected to produce acceptable approximations to the historical current record at all points throughout the hydrodynamic model domain, without the need to run the computationally more expensive hydrodynamic model over a full 30 year period.

#### Cox-Bryan ocean general circulation model (MOM 1.0)

The circulation of the Western Coral Sea is strongly dominated by the inflowing SEC which in turn drives the HC and EAC, northward and southward, respectively, along the slope and outer shelf of the GBR. Since the SEC comprises the northern limb of the South Pacific sub-tropical gyre, factors controlling long-term drift in the GBR act over a scale approximating that of the Pacific basin. It is thus essential that boundary conditions for regional hydrodynamic models adequately represent these large-scale influences. To ensure correct specification of these boundary conditions for his regional circulation study of the Coral Sea and Western Pacific, Hughes (1993, 1996) sacrificed fine resolution in a tradeoff for enhanced accuracy in boundary conditions, by modelling the entire global ocean in 3D at a lat/lon grid resolution of  $1^\circ \times 1^\circ$  with 17 vertical levels. This approach avoided the need to specify open ocean boundary conditions. The model was an implementation of the MOM1.0 version (Pacanowski et al. 1991) of the Cox-Bryan Ocean General Circulation Model (OGCM). This was carefully optimised for studies of the Coral Sea circulation and, in spite of the limited resolution, several important features of the Coral Sea Circulation were identified. Firstly, the HC (i.e. the northern branch of the SEC) was shown to be trapped and intensified against the north Queensland and south Papua New Guinea slope. It thus takes the form of a Western Boundary Current, similar in character to the Gulf Stream and EAC, but flowing equatorward, rather than poleward. Secondly, the northern arm of the bifurcation (HC) was found to transport a larger volume of water, of average 20 Sverdrup ( $1 \text{ Sv} = 10^6 \text{ m}^3 \text{ s}^{-1}$ ), in comparison with the southern arm (EAC,  $\sim 10 \text{ Sv}$ ). Thirdly, the relative proportion of the HC and EAC transport volumes varied seasonally; with the northward flow being larger in the southern hemisphere winter (25 Sv) than in summer (15 Sv). Fourthly, the latitude of the SEC bifurcation against the East Australian continental margin varied with depth; the surface bifurcation being near  $14^\circ \text{S}$  (close to Jewell Reef) and the depth-averaged bifurcation near  $18^\circ \text{S}$ . The model was forced by annual and seasonally averaged hydrographic and surface wind data and was run to a relatively stable 'steady' state in order to study the long-term mean and seasonal winter and summer-time regimes. Current predictions from this model were used by Bode et al. (1995) to simulate drift trajectories relevant to the dispersal of Raine Island Turtle hatchlings.

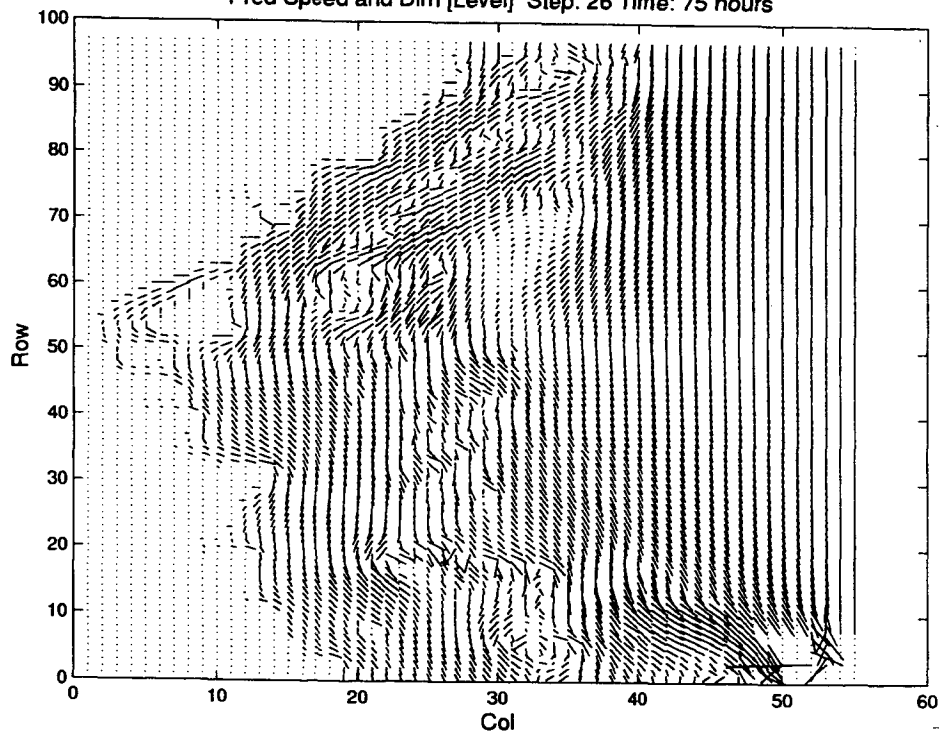
a)

Pred V-Cmpt [LEVEL] Step: 26 Time: 75 hours



b)

Pred Speed and Dirn [Level] Step: 26 Time: 75 hours



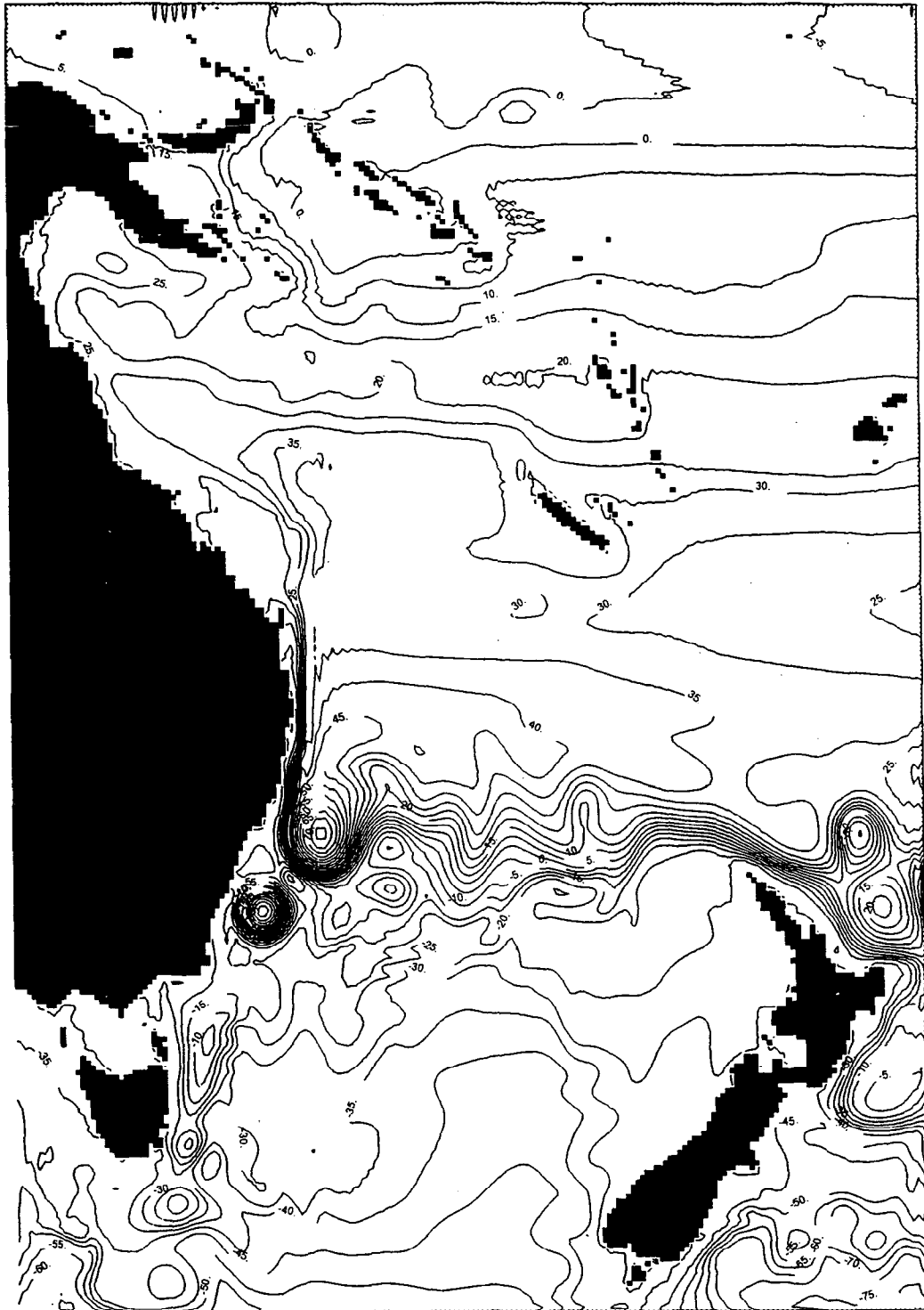
**Figure 5.** a) Surface view from SE of predicted instantaneous current speed (m/s) from GRIDLSM. All currents are near zero (peaks) or southward (troughs). The 'cutout' centred near col 3 represents the Palm Islands group. Ridged peaks near Cols 10-20 are currents slowed by reef-induced drag. Flat plane in Cols 30-50 corresponds to southward flowing slope water (model depth artificially limited to 350 m). The large smooth peak near grid centre represents an anti-cyclonic mesoscale eddy. b) Corresponding vector plot showing prevailing current directions with arrow length proportional to speed. Time series of 'snapshots' such as these can be animated to show the temporal changes in current.

### The Dietrich model (DieCAST)

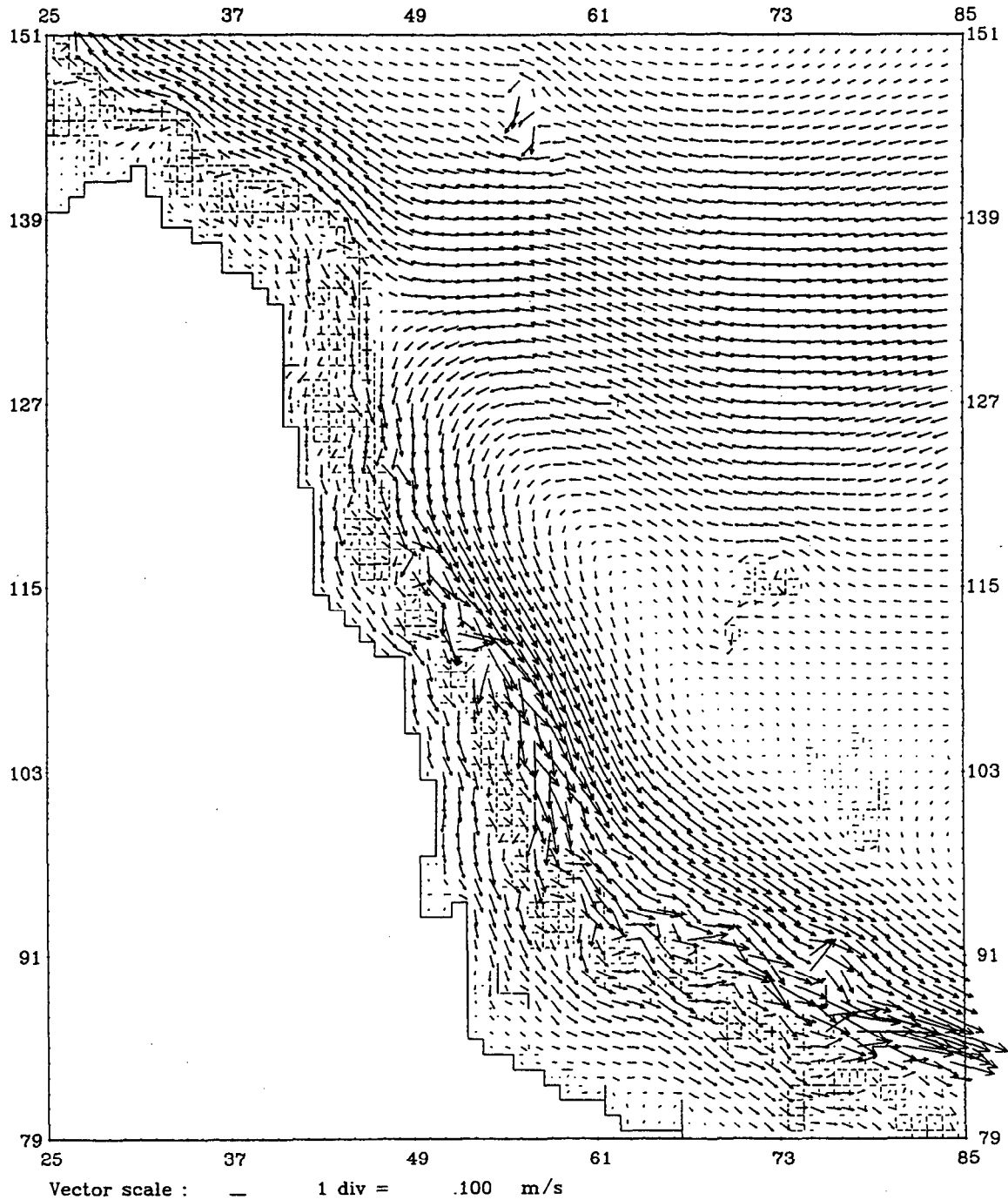
The OGCM DieCAST (Dietrich, et al. 1993; Dietrich and Lin 1994) has also been implemented at a global  $1^\circ \times 1^\circ$  grid resolution by Bode et al., 1996. The implementation is similar to that of the MOM1.0 model described above, but the model numerical techniques yield very low values of (artificial) numerical friction, which otherwise tends to smear out eddy features. This enables the model to run more efficiently, reproduce finer-scale features, and develop more realistic mesoscale eddies than is possible using MOM1.0 running at the same nominal resolution. For example, an animation of the surface pressure field (surface flow streamlines) of the DieCAST model shows the persistent Papuan Gyre, and suggests that Rossby waves propagating westward into the Solomon Sea strongly modulate flows in the northern Coral Sea (Mason 1996, pers. comm.). A high resolution  $1/5^\circ \times 1/5^\circ$  3-D nested model of the Western Coral Sea region is also being developed (Fig. 6). This model is currently being run with steady state (climatic mean) forcing at the boundaries, but is capable of resolving time-varying mesoscale eddies which arise naturally due to instabilities in the system being modelled. With the addition of observed time-varying forcing, this model should be capable of reproducing significant features of the ocean/shelf interaction, including the modulation of outer shelf current direction and strength.

### A depth-limited barotropic model of the EAC and GBR

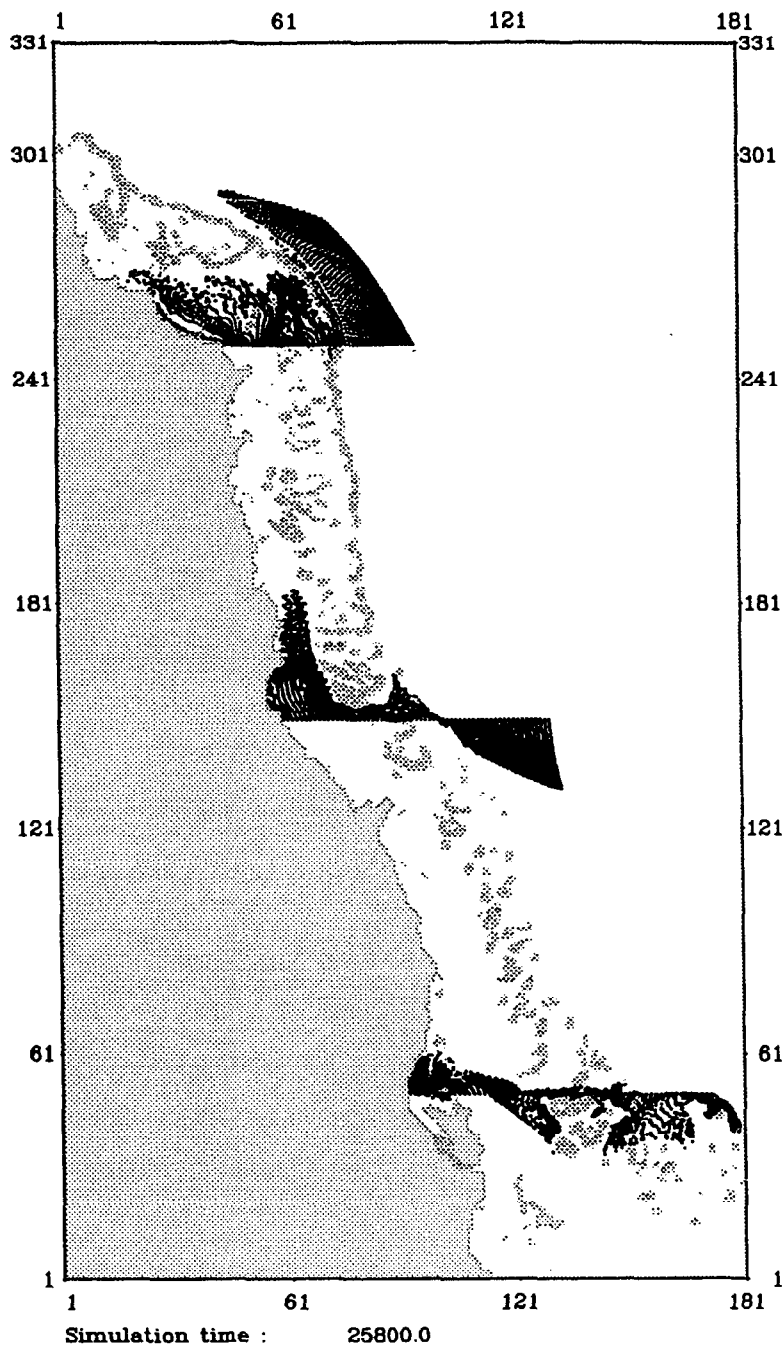
In addition to implementing DieCAST, Bode and Mason have developed a 2D Depth-limited, barotropic model of the Western Coral Sea. This appears to represent the upper layer flows of the SEC, EAC and HC sufficiently well to provide realistic boundary current forcings for simulating flows on the continental shelf. The open ocean boundary conditions for this model have been obtained experimentally from consideration of boundary values derived from the MOM1.0 model, and from in situ sea level stations at the coast and offshore. The model has shown that seasonal variations in the location and intensity of the SEC bifurcation strongly modulate the flows in the outer shelf of the GBR (Fig. 7). Furthermore, it simulates the strong across-shelf horizontal shear which can result in significant northward flows on the inner shelf, while flows are strongly southward on the outer shelf (Fig. 8). This shear provides an efficient dispersal mechanism (i.e. 'shear dispersion') such that small across-shelf excursions in the location of larval or water quality constituents can result in very large differences in the distance over which they are advected along shelf. There is some uncertainty in the extent to which inner shelf flows are influenced by the EAC in comparison with the effects of local winds acting over the shallower coastal waters, but the temporal variations in the strengths of the simulated currents suggest that northward inner shelf flows are regulated by the opposing southward flows on the outer shelf. This model has been developed to allow the shelf-scale flows to be economically computed for long-term larval dispersal studies, without repeatedly running the large-scale global OGCMs.



**Figure 6.** Surface pressure streamlines showing prevailing current directions from the regional DieCAST  $1/5^\circ \times 1/5^\circ$  Coral Sea model. While forced by the climatically-averaged steady state, the model shows time-varying eddy motions produced by inherent instabilities in the ocean current field. These eddy motions can be visualised by animation. The bifurcation of the E-W trending SEC off the north Queensland coast and recirculation (closed loops) of the Gulf of Papua Gyre and EAC are clearly evident. The Tasman front and enhanced mesoscale eddy variability are evident in the Tasman Sea.



**Figure 7.** Subgrid of the Depth-limited barotropic numerical hydrodynamic model of Bode and Mason showing the influence of the SEC bifurcation (near its average position) on the continental slope and shelf-scale circulation. The model which has a grid cell size of five nautical miles. The sub-domain shown extends approximately from north of Cape Melville (about 13.5°S) to Cairns (17°S). A sequence of such snapshots shows that seasonal variations in the location of the SEC bifurcation modulate the strength and direction of the continental shelf currents.



**Figure 8.** High resolution (1 nautical mile grid cell size) version of the Depth-limited model showing trajectories of drifting 'particles' released along three transects across the northern GBR. The sub-domain shown extends approximately from Cape Melville in the north to the Palm Islands (south of Hinchinbrook Island). The horizontal shear between slope, outer and inner shelf currents is clearly evident as is the effect of the SEC bifurcation which is located between the northward and central transects. Convergence within reef passages channels the flow while the larger reef platforms divert it.

### Patterns and trends

The major physical factors likely to influence large-scale dispersal of mass-spawning corals and the coral predator, the COTS are the direction and strength of prevailing low-frequency currents and sea-surface temperatures (Bode and Burrage 1996). Other physical factors which might play a significant role, at least in shallower areas and/or close to the coast are local wind,

salinity and turbidity. Relatively random weather, seasonal and inter-annual scale variations in these factors are superimposed on the more deterministic tidal signals. The latter oscillate periodically in time (in response to known astronomical forces), but range widely in intensity and character in geographical space. The tides contribute significantly to localised mixing in and around the reefs and coast and exert a retarding influence (dynamical drag) on the low-frequency currents.

Here we summarise the key results regarding variability of long-term current circulation, as deduced from the observations and models described previously. The main purpose of this summary is to highlight those fluctuations in currents which may be significant determinants of GBR ecological status, and to identify those which are worthy of further investigation. We restrict the discussion to aspects likely to affect interconnectedness among the reefs comprising the GBR matrix, and hence the ability of corals to recolonise damaged reefs or for starfish to infest them. We also confine the discussion mainly to consideration of COTS larval dispersal studies under the assumption that much of the knowledge gained, concepts and techniques of those studies is transferable to other marine organisms such as larval fish and mass-spawning corals. Such transfer is possible provided adequate account is taken of differences in spawning characteristics and larval behaviour and differences in the relevant temporal and spatial scales.

Dispersal of COTS larvae in the GBR occurs on a time scale of approximately one month in the summer (monsoon) season and, depending upon the prevailing currents during the pelagic phase, can attain dispersal distances of up to 500 km (i.e. roughly the distance between Cairns and Townsville, Figs. 1 and 4b). While dispersal occurs essentially in the along-shelf direction, random fluctuations (small scale eddies, surface wind-induced drift and turbulence) combined with the periodic excursions of the tides can result in limited across-shelf transport. Though small compared with the along-shelf transport these effects, when coupled with horizontal shear in the alongshelf currents (Fig. 8), can result in significant across-shelf variations in alongshelf transport due to shear dispersion. Unlike the mass-spawning corals the larvae are essentially neutrally buoyant during the entire pelagic phase, so that 2-D shelf-scale circulation models (e.g. Figs. 7 and 8) which do not explicitly account for boundary layer flows are valid and useful. However, global and regional scale 3-D hydrodynamic models (e.g. Fig. 6) and large-scale oceanographic satellite data sets (Fig. 3) are needed to account for the deep ocean forcing of the outer shelf by the intense western boundary current flows (EAC and HC). The evolving COTS outbreak which typically develops from a primary outbreak in the northern GBR and proceeds southward (and possibly northward) in a succession of annual secondary outbreaks can apparently span time scales of the order of a decade and spatial scales approximating the entire length of the GBR. This necessitates the use of long-term forcing data sets and models such as GRIDLSM (Fig. 5) to specify the drift characteristics of each successive spawning period with a spatial resolution sufficient to simulate the resulting larval dispersal trajectories. In this situation there is a place for both the relatively sophisticated numerical hydrodynamic models, which can predict inter-reefal circulation accurately and in considerable detail, but at greater computational expense (e.g. Fig. 7, and Black et al. 1996 in review), and the linear systems models which can be run on a PC repeatedly over interannual time scales to simulate long periods economically and allow repetitive tests of various scenarios.

Long-term data sets (e.g. TEACS, Table 1, Fig. 2; TV-NM, Fig. 4a and TOPEX Fig. 3) are obviously needed for setting boundary conditions for the various models or to provide independent verification data. They can also be assimilated directly into the models (e.g. Black et al. 1996 in review) to keep them 'on track' over prolonged time periods during which computational errors would otherwise result in significant departures from reality. However, they are also of interest in their own right as we emphasise below.

Shifts in the location and intensity of the SEC bifurcation (Fig. 6), which typically occur in surface waters at approximately latitude  $14^{\circ}\text{S}$ , could significantly influence the direction and intensity of prevailing flows on the shelf (as can be shown by applying time-varying forcing to the model of Fig. 7). The TEACS current meter mooring data (Fig. 2a) shows that at the latitude of Jewell Reef (near  $14^{\circ}\text{S}$ ) northward flows are at least as frequent as southward flows. In addition, strong southward flows tend to be correlated with southwards flow at Myrmidon Reef. Northward flows appear to be either less-well correlated or anti-correlated. The latter relationship is complicated by the northward propagation of free (as distinct from forced) continental shelf waves which, with length scales of order 1000 km or greater, and equatorward propagation (coast on the left in the southern hemisphere) would tend to produce a lag-correlated response in the weather band. In any case these characteristics confirm that the mooring is located close to the average surface bifurcation position. Some uncertainties in the relationship between Myrmidon and Jewell Reef arise because of the occurrence of significant data gaps and because at this stage the best available records from the two sites were obtained at different depths (350m at Jewell compared with 150m at Myrmidon). Hence, the strong southward flow associated with the 1992 ENSO event was not captured at Jewell Reef, while the strong northward flow off Jewell Reef during 1995 is not recorded in the Myrmidon data processed to date.

The along-shelf current predictions from the LSM (Fig. 2c) show a modest correlation with the Myrmidon Reef along-slope current data. However, some caution is required in the interpretation. Firstly, it is possible to predict the Myrmidon currents directly from the appropriate LSM (K2\_VE1) of BBN (calibrated at Site E using 1985 observations only). If the prediction is compared with the complete TEACS data record (Fig. 2b) the bias is small ( $< 1$  cm/s), but the standard error is relatively large ( $\sim 18$  cm/s) and only 28% of the variance is predicted by the model. This suggests that the TV-NM sea level difference is a good predictor of the lower frequency EAC variability, but a relatively poor predictor of the slope water weather band variability. Furthermore, two signals having significant seasonal variability will appear correlated, even if not causally related. The conclusion we draw from this situation is that the LSMs are effective predictors of the shelf currents and in particular, of the influence of the EAC on the shelf current flows, but are not adequate predictors of the slope water currents, per se. There are several possible reasons for this including, the baroclinic nature of the EAC, presence of shelfbreak eddies associated with shear instabilities, and coastal trapped waves which may be trapped over the slope, but lack energy on the shelf. This indicates the need to continue monitoring the EAC to provide boundary forcing and verification data for numerical hydrodynamic models which can account for the above effects.

The predicted currents over the full 1966-1995 time span at Site B, in the GBR lagoon (Fig. 4a) also show a number of interesting long-term trends and characteristics. Firstly, the low frequency (2.5 day and longer period) currents show extremes during the 30-year period of approximately 60 cm/s N and 40 cm/s S. Note that currents predicted by the LSMs for the inner (A) and outer shelf sites (C, D and E) show stronger southward tending mean currents further offshore (see BBN). These low frequency currents would be enhanced or diminished by superimposition of the diurnal and semi-diurnal tides. Secondly, there is an irregular long period fluctuation with a tendency for northward flows at the beginning, middle and near the end of the record, with perhaps a double peak in the later half. This suggests the presence of a 7-15 year time scale for long-term fluctuations, which approximates the time scale of evolving COTS outbreaks. Thirdly, there is also a strong seasonal signal superimposed on much less regular but significant inter-annual variations. The latter variations are best seen in the seasonally smoothed data which also excludes the weather band variability. Finally, the signatures of ENSO events (except the 1987 warming) are evident in this time series with a tendency for weak and/or northward flows followed by stronger southward flows during the 1972-73, 1976, 1982-83, 1990 and 1992 ENSO periods. These signatures are also present in the



drift predictions (Fig. 4b). There are thus significant links between ENSO and along-shelf current magnitude and direction. Note, however, that the COTS outbreak time scale spans several ENSO/anti-ENSO cycles, so that ENSO and COTS are not obviously causally related. The fairly rapid build up from prevailing southward to northward flows occurring during the early to mid-90s appears to have a precedent in the latter half of the 70s which was associated with the establishment of the previously recorded COTS outbreak. However, a similar event associated with the 1982-83 ENSO occurred when that outbreak was advanced well to the south (i.e. the event was associated with a secondary, but not a primary outbreak). Thus, a causal connection between the occurrence of weak or northward currents and the appearance of an incipient outbreak might require other coincident physical parameters (e.g. sea water temperature) or biological factors (e.g. available food supply, or predator populations) to be favourable, in order to give rise to a full blown outbreak. This highlights the need to carefully link physical and biological models to fully explain the origin and progress of COTS outbreaks.

### **Management considerations**

What are the implications for management of the GBR?

With the exception of the tides, the variability observed over particular temporal scales in most of the environmental variables considered as forcings for currents (water level, atmospheric pressure, wind stress, river flow) tends to increase in intensity as the scales get longer (i.e. most variables exhibit a 'red' variance or 'power' spectrum). This means that the magnitude of the longer-term variations (here the interannual signal) dominates that of the shorter-term fluctuations (seasonal and weather band). It also means that the longer you observe a variable, the larger the variations will appear to be. On the other hand, although the longer period fluctuations are the largest, they are also (usually, except in catastrophic situations) more gradual. This gives organisms more time to adapt to changing circumstances. The other consequence of such long-term variability is that the more dramatic events (e.g. ENSO events or COTS outbreaks) are harder to study statistically. This is because they are relatively infrequent and hence there are relatively few 'realisations' or samples of such events in a given time period. This makes the relevant parameter estimates less reliable because the number of 'degrees of freedom' is small.

While there is good historical and/or palaeontological evidence that ENSO and COTS outbreaks have recurred numerous times in the past, only a few recent events have been observed scientifically, so the reliability of the associated statistics is poor. Indeed, prior to the 1993 application of linear systems models to predict historical along shelf currents in the GBR, there was a complete dearth of information on currents with which to test any hypotheses concerning the effects of currents on dispersal of COTS. Having found evidence that the occurrence of the two historically recorded primary COTS outbreaks were correlated with periods of weak current in the central GBR, we are now in a position to assess whether the currently emerging COTS outbreak is associated with a similar current pattern. However, it may take several more cycles before much confidence can be placed on resulting model forecasts, and of course, there are numerous other possible models and competing hypotheses which also need to be tested and compared.

We have restricted the discussion to aspects likely to affect interconnectedness among the reefs comprising the GBR matrix. The basis for this is that the ability of corals to recolonise reefs destroyed by any means is strongly determined by the availability of upstream source of propagules and their availability for live settlement at the affected reef. Alternatively, the likelihood of destruction of reefs by the major coral predator (COTS) will depend on its ability to reach outbreak proportions and to reach target reefs. The critical time for dispersal for both mass-spawning corals and COTS is thus the pelagic drift period following spawning, during

which the larvae are available for dispersal within the water column and competent to settle. Because the duration and timing of these periods differ between the two types of organism and also differ somewhat from year to year, the prevailing wind, sea level and current conditions between the time of release and settlement will be crucial determinants of dispersal success in any one year. Furthermore, in developing statistical models of larval dispersal, which might be used to assess risks and uncertainties associated with particular scenarios, it is important to realise that the shorter the pelagic dispersal period the more short-term (weather band) variability will influence annual spawning success. This suggests that a more stochastic rather than a deterministic approach will be important for shorter dispersal periods (e.g. for mass-spawning corals compared with COTS). Furthermore, the timing of release relative to the seasonal cycle in the physical variables could significantly bias the long-term drift patterns towards more northward or southward tending dispersal directions (e.g. many mass-spawning corals tend to spawn earlier in the summer season than COTS with the result that the coral larvae would experience seasonally stronger southward drift, other factors being equal).

In order to model these processes it is thus important to have both a long-term view (long historical data sets and on-going monitoring) and the ability to resolve significant events in time (preferably down to 1-2 day sample interval). This requirement can be met by readily available historical records of certain meteorological and oceanographic parameters (wind, pressure, sea level) which are generally recorded at intervals of 0.5-3 hr. This means that diurnal variability (e.g. sea breeze and tides) can be identified without aliasing, and the records can be smoothed to reveal the low-frequency (weather-band) variability. This contrasts with the situation for chemical and biological data which can generally be obtained only at much longer sample intervals (weeks, months or longer).

The findings from monitoring and modelling physical processes in the GBR and the above discussion have general significance for the *zoning and protection of coral reefs*. Where reefs are identified as sources for recolonisation of other reefs by a particular type of organism (starfish, coral, clam etc.) the direction, proximity and degree of connectivity to adjoining reefs will strongly influence the availability of destination reefs. A simple example which views the COTS and mass-spawning corals as being in a predator-prey relationship illustrates the point. To the extent that the pelagic phase of mass-spawning corals is shorter (order 10 days) than that of COTS (28 days) preserving reefs within a complex that has an inter-reefal spacing too great to allow mass-spawning corals the opportunity to disperse to downstream reefs within a 10 day period would tend to favour the propagation of COTS at the expense of the corals. For similar reasons inter-reefal spacing within areas which generally experience stronger mean currents (e.g. the outer central GBR) could be larger than in regions experiencing weaker currents for a given probability of successful dispersal. Obviously the prevailing flow directions and speeds might influence the choice of location, shape, size or orientation of protected zones for similar reasons. Hence, it is important to model the inter-reefal flows sufficiently accurately to enable regions of strongly channelised flow to be identified. In addition regions of relatively slow currents (e.g. within reef complexes) and hence long retention times would tend to favour self-trapping and hence self-seeding of reefs. If this is an important consideration for successful spawning or growth of an organism then such areas need to be identified. While a number of 'guiding principles' could be developed based on the above concepts and examples, it is clearly difficult to apply these principles to specific organisms or areas without carefully assessing and modelling the particular life cycles, behavioural characteristics and habitats of the target organisms.

There are a number of possible applications of the models described above and their possible derivatives, apart from the quite specific problems of larval dispersal. For example the problem of coral bleaching is one that appears to be tied to available light and turbidity levels as well as to temperature. These are physical parameters which can be observed, and in principle

modelled, by employing fairly well-established thermodynamic, sedimentological and hydrodynamic principles and appropriate observation platforms (e.g. in situ gauges, thermal infra-red satellite imagery). To the extent that hydrodynamics is crucial to the issue at hand, a practical way to proceed is to link a water quality, thermodynamic or biological behaviour model to an existing hydrodynamic model in order to implement an integrated modelling system (e.g. Black et al.'s models 3DD and POL3DD). Process-oriented models designed to study particular mechanisms or processes, or to resolve modelling uncertainties would be a useful adjunct to such integrated modelling systems.

Problems which have inherently longer time scales or which involve the biota integrating identifiable effects over time or space (e.g. studies of gene flows) could also be addressed using the available modelling tools, with appropriate additions and modifications to account for stochastic variations and the mechanisms of genetic inheritance, selection and sampling or genetic drift.

Finally, the existing models could be run in a manner which generates long-term statistics of currents and other physical parameters such as connectivity matrices, in order to develop a basis for the assessment of risks and uncertainties associated with various manifestations of ecosystem change, and to facilitate the analysis of various scenarios or management approaches and their effects on coral reef populations.

What are the identifiable gaps in knowledge which require further attention?

Bode and Burrage (1996) in reviewing the physical oceanography of the Cairns Section of the GBR concluded that direct wind forcing is likely to play a more significant role in the dynamics in this section than in the region off Townsville, but left the question of the influence of the deep ocean western boundary current (EAC, HC) open. More current meter deployments are needed on the shelf in this section to resolve this issue. They also argued that the most effective approach is one which combines field observations at selected locations with a numerical hydrodynamic modelling to resolve slope, shelf and inter-reefal circulation. In this way models can be adequately verified and use of the available field instrumentation and computational resources can be optimised.

While the existing linear systems models based on the Townsville and Noumea Sea level records have been remarkably successful in predicting currents in the central GBR, their performance on the outer shelf and in the northern region is poorer and subject to greater uncertainties. In addition to current meter deployments, alternative forcing functions which utilise sea level stations from other locations on the Queensland coast, and in the Coral Sea and Western Pacific Region need to be explored to improve model skill, particularly in the northern and southern sections of the GBR.

Gaps in existing knowledge arise for a number of reasons. Firstly, as discussed above the technology (existing models) might be adequate, but data may be lacking. Secondly, new technology (new models, better instrumentation) might be needed. Thirdly new scientific research avenues might need to be explored. Lastly, the time and resources (people, funds) are required to undertake the work.

*Satellite altimetry:* In this case the technology is available to map sea levels and currents in the Coral Sea over time. This could be done on a monthly basis and the required data sets are already available. In addition there are sufficient data from existing and prior radar altimeter missions (GEOSAT, ERS1&2, TOPEX) to map seasonal patterns of variability of the SEC intensity and bifurcation position. This requires the adaptation of existing algorithms to the task of merging data sets from the disparate missions to allow compilation of multi-mission data

sets into (almost) decadal scale time series. This is technically feasible, but requires human resources and funding for its implementation.

To extend the altimetry data set onto the shelf requires a combination of numerical hydrodynamic tidal modelling and altimetry editing software, i.e. some technology development is required. Once this is achieved new avenues of physical oceanographic research which could be exploited in larval dispersal and other ecological applications will be opened up. For example, it might be possible to observe the structure of continental shelf waves in the GBR lagoon using altimetry observations coupled with a suitable hydrodynamic model. This would allow the energy levels associated with wind-driven shelf currents to be mapped spatially and would facilitate the development of long-term statistics for the purpose of ecological risk assessment.

*Real-time data and nowcasts:* In addition to a need for long-term current meter measurements on the shelf, current meter deployments are needed (and planned) for areas between Cairns and Cooktown to provide data relevant to the presently evolving COTS outbreak. It would also be a tremendous advantage for both predictive modelling and for logistical purposes to have a real-time telemetry capability for continental shelf currents. This would allow immediate establishment of a 'now-casting' capability for shelf currents, i.e. predicting currents based on contemporary forcing data, and would provide a basis for short to medium term forcing of prevailing shelf currents. The latter could have a number of practical applications in addition to the obvious implications for predicting COTS larval distribution. For a 'now-casting' capability the modelling technology is already available, all that is required is funding for telemetry equipment and the personnel to implement the hardware models.

*Long-term forecasts:* One open scientific question is whether long-term data sets and predictive models currently being used to assess large-scale changes in the Pacific Ocean could be used to forecast conditions on the shelf. These could be based on ENSO forecasts and local seasonal and interannual trends. Such a 'fore-casting' capability would require further technology development supported by scientific research. A research effort could be aimed initially at exploiting and, if appropriate, adapting long-term predictive models and data sets designed for forecasting ENSO conditions in the tropical Pacific (e.g. NOAA 1996) to predict fluctuations in the position and strength of the SEC, EAC and HC.

*Other parameters:* In addition to currents a number of other variables can be observed, analysed and 'in principle' modelled. These include *sea levels* which, while not discussed here in detail, have been well studied and are to some degree predictable using existing models. *Temperature* observations are also available in the form of NOAA satellite thermal imagery, in situ moorings and the AIMS weather stations as well as from numerous reef loggers (deployed by the Great Barrier Reef Marine Park Authority) and the AIMS radiometer system. Some technological developments are required to bring these observations into a scientifically useful form. For example, due to high atmospheric water vapour and cloudiness in the tropics improved algorithms are required for retrieving sea surface temperatures from NOAA imagery. Furthermore, scientific research is needed to model the relationship between the surface skin temperatures observed by radiometers and near (sub) surface temperatures observed by in situ instrumentation. Though long-term data of this nature are lacking there appears to be sufficient spatial coverage to provide inputs to thermodynamic models. Scientific research is needed, however, to identify and implement appropriate modelling approaches, and it is likely that numerical hydrodynamic models would need to be coupled to the thermodynamic models in order to account for the advective heat fluxes. These kinds of models could have immediate applications to the specification of ecological temperature optima or range limits for marine organisms, as well as to the study of physical stress factors contributing to coral bleaching.

*Salinity:* This is another variable for which long-term observational data are seriously lacking. With the exception of cruises conducted by AIMS during the 1979-80 floods (Wolanski and Jones 1981) and Burdekin plume modelling work carried out by Wolanski and van Senden 1983, BBS and more recently by Brian King for the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef, there has been little work conducted on freshwater inputs which is applicable to regional scale ecological problems. New observational technology is needed here also. The capability exists in the US to map sea surface salinity using a passive microwave radiometer (ESTAR, SLFMR) at a scale and accuracy sufficient to identify estuarine inputs and salinity distributions in the GBR (Burrage 1996). Routine observations of this nature would require the building of a new instrument for use in the Australian region and collaborative plans are being made to transfer the technology to Australia on an experimental basis over the next 3-5 years. A distinctly different technology developed in Australia for mapping soil salinity (SALTMAP) might also be adaptable to salinity profiling applications with the possibility of remotely sensing sub-surface salinities. This application is more speculative, but the technology and expertise to perform the required experiments are already available from a Western Australia-based company. Both temperature and salinity together determine the density of sea water, which is a vital parameter for estimating currents and for assessing eddy instabilities in numerical hydrodynamic models. Furthermore, the distribution of heat and salt in the outer GBR is strongly determined by fluctuations in the strength and direction of the prevailing western boundary currents. Hence the ability to observe and model heat and salt fluxes would, in turn, enhance the quality of numerical hydrodynamic modelling technology.

*Extreme value statistics:* A major gap in our knowledge lies in the determination of extreme value statistics. Because large and catastrophic events tend to be few and far between it is difficult to determine reliable statistics (as discussed above). This problem is most obviously addressed using long-term monitoring programs. However, this is also an area where modelling and observations can be used in a synergistic manner to investigate various scenarios associated with particular types of events and their impacts. Advances in this area can at least be made in the area of long-term sea levels and currents by utilising the 30 year historical time series developed for the linear system modelling work described above. An example of this approach is given by Burrage et al. (1993b).

What kinds of products would be useful for addressing future management questions?

In addition to the on-going observational and modelling studies and outputs described above there are a few examples of specific products or tools which are emerging or planned as a 'spin-off' from the research conducted to date. These include interactive simulation models, such as SHELFLOW, which could be greatly expanded beyond its present capabilities by adding features specifically requested by users. This kind of model could also be adapted for use on the internet to provide an experimental or educational tool useful in simulating GBR currents and other environmental parameters. The availability of radar data (altimetry, scatterometry and Synthetic Aperture Radar) and thermal imagery from oceanographic satellites raises the possibility of producing active atlases of such parameters as sea surface temperatures, winds, waves and surface currents on say a monthly basis in media such as CD ROM or the World Wide Web. These are areas where expressed user needs would be particularly helpful in identifying the kinds of tools and information which would be required.

## **Summary**

Observations and predictions of currents in the central GBR now span decadal time-scales, and these are being correlated with ecological processes. Some significant trends and patterns of variability relevant to GBR ecosystems have been identified. An appropriate balance between

field and satellite observations, and numerical hydrodynamic and systems models will maximise availability of current information. Data could be made available through interactive simulation models, active atlases and near real-time prediction to marine scientists and managers.

### **Acknowledgments**

Funding and material support provided by the Australian Institute of Marine Science, James Cook University of North Queensland, the University of Waikato and the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef is gratefully acknowledged. Jamie Oliver (Great Barrier Reef Marine Park Authority) is thanked for his efforts in organising the workshop and for his patient encouragement of this contribution. This is AIMS contribution no. 843.

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# River inputs of nutrients and sediment to the Great Barrier Reef

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## Introduction

The ecosystems of the Great Barrier Reef (hereafter GBR) receive the nutrient materials which sustain them from a variety of internal and external sources. External nutrient sources include Coral Sea upwelling (Furnas and Mitchell 1996), rainfall (Furnas et al. 1995), biological nitrogen fixation (Larkum et al. 1988); sewage discharges (Brodie 1991) and river runoff (e.g. Moss et al. 1992; Furnas et al. 1996). These external inputs augment nutrients recycled within the ecosystem through remineralization of organic matter by benthic and pelagic communities (Alongi 1989; Ikeda et al. 1982; Hopkinson et al. 1987) and disturbance of shelf sediments (e.g. Chongprasith 1992; Walker and O'Donnell 1981).

River runoff is the largest external nutrient source likely to be significantly affected by human activities and is both locally and regionally significant (Wolanski and van Senden 1983; Brodie and Furnas 1995; Brodie and Mitchell 1992; Furnas et al. 1995). At this time, however, neither the magnitude of terrestrial imports to the GBR or effects of terrestrially derived nutrients within GBR ecosystems are well resolved. Based upon land-use and catchment runoff models, Moss et al. (1992) calculated that runoff of sediments and nutrients from catchments draining into the GBR has increased several-fold following European settlement and the development of significant agricultural and pastoral industries. While the Moss et al. model and its implications remain to be rigorously tested, such calculations suggest that human activities on the land may be affecting the marine ecosystems of the GBR.

To date, several estimates of terrestrial nutrient and sediment inputs to the GBR have been made (Belperio 1983; Cosser 1989b; Moss et al. 1992; Furnas et al. 1995; Neil and Yu 1995). All of the above estimates are based on broad-scale extrapolations from studies carried out in a small number of catchments or sub-catchments. The extent to which export statistics derived from single rivers or sub-catchments can be reliably generalised over the diverse range of catchments and land uses in the GBR region is unresolved. In the absence of time series of nutrient data from a range of catchments, such extrapolations are the only means available for estimating nutrient fluxes.

Discharge records are available for most rivers flowing into the GBR, although the period of measurement varies, ranging from > 80 years in catchments with long-established sugar cane cultivation (e.g. the Johnstone River) to < 20 years in many of the smaller or more remote rivers. Histories of river discharge inferred from fluorescent banding patterns in coral cores (Isdale 1984) indicates that water (and presumably nutrient and sediment) exports from individual catchments can vary significantly over decadal time intervals.

Thirty-five drainage basins with an aggregate area close to 450 000 km<sup>2</sup> drain eastward into the GBR and Coral Sea (Queensland Water Resources Commission, 1982; Fig. 1). The Burnett River (25.13°S) is the most southerly river likely to directly affect the GBR ecosystem in any material way. The drainage basins between Cape York and Fraser Island have an aggregate area of 410 790 km<sup>2</sup>. Rivers in twelve of the drainage basins (Normanby, Daintree, Barron,



Mulgrave, Russell, North Johnstone, South Johnstone, Tully, Herbert, Burdekin, Fitzroy and Burnett Rivers; Table 1) with an aggregate watershed area of 315 000 km<sup>2</sup> account for 77 percent of the total watershed area north of Fraser Island. Collectively, these twelve rivers have a long-term mean annual freshwater discharge of 29.1 km<sup>3</sup> (1 cubic kilometre = 10<sup>9</sup> m<sup>3</sup> = 10<sup>6</sup> megalitres). For the purpose of making first-order estimates of terrestrial freshwater input to the GBR, we will assume that annual and monthly gauged runoff volumes from the twelve major drainage basins can be divided by 0.77 to estimate total terrestrial freshwater runoff (annual total = 38 km<sup>3</sup>) into the GBR. For a recent 35 year period (1958-1992) when regional climatological variability was examined by J. Lough (1992, 1993) the average of annual gauged discharges from these rivers was 31 km<sup>3</sup> (42 km<sup>3</sup>, adjusted for total watershed area). Since comprehensive river gauging began, the largest freshwater runoff volume was recorded in 1974 when 92 (gauged) km<sup>3</sup> of water flowed into the GBR from the twelve rivers in Table 1. If adjusted for total watershed area, the estimated total 1974 freshwater input to the GBR would have been on the order of 120 km<sup>3</sup>. The next highest discharge occurred in 1991 when 79 km<sup>3</sup> (gauged) or 103 km<sup>3</sup> (watershed area adjusted) of water flowed into the GBR. The lowest annual flow during the last 35 years was measured in 1987 when only 8.9 km<sup>3</sup> (11.7 km<sup>3</sup>, watershed area adjusted) was discharged to the GBR shelf.

**Table 1.** Major river systems draining into the Great Barrier Reef region. Catchment areas and flow statistics are taken from Lough (1992, pers. comm.)

River	Gauged Catchment Area (km)	Mean Annual Discharge (x 10 m)	Period	Maximum (x 10 m)	Minimum (x 10 m)
Normanby	2460	0.911	1968-1992	2.615	0.054
Daintree	830	1.011	1968-1992	2.252	0.351
Barron	1940	0.807	1958-1992	2.617	0.144
Mulgrave	365	0.567	1966-1992	1.045	0.187
Russell	231	0.851	1966-1992	1.344	0.488
North					
Johnstone	930	1.840	1967-1992	3.761	0.651
South					
Johnstone	390	0.813	1958-1992	1.384	0.291
Tully	1475	3.039	1972-1992	4.704	1.660
Herbert	8805	3.370	1958-1992	10.418	0.407
Burdekin	129 660	9.272	1958-1992	50.927	0.540
Fitzroy	135 895	5.574	1964-1992	22.126	0.172
Burnett	2455	1.050	1958-1992	6.237	1.050

The most conspicuous dynamic feature of discharge from north Queensland rivers is the dramatic inter-annual, seasonal and event-coupled variability of flow. This variability directly influences the process of estimating terrestrial sediment and nutrient inputs to the GBR. The north Queensland climate is monsoonal, with nominally 'wet' summer (November -April) and 'dry' winter (May-October) seasons. Over decadal time scales, total volumes of regional rainfall and resulting river flow are also modulated by fluctuations in the strength and duration of the summer monsoon which, in turn, is coupled to global ENSO climate variability (Lough 1992, 1993). In contrast to larger tropical river systems (e.g. the Amazon) which go through relatively smooth seasonal fluctuations in discharge, flows in all north Queensland rivers vary erratically. The largest variations are associated with tropical cyclones and monsoonal rain depressions, which cause significant changes in discharge on a day-to-day and often hourly basis (e.g. Mitchell et al. 1996). Significant proportions of annual river flow and considerable variation in nutrient concentrations (Mitchell and Furnas 1994; Furnas et al. 1995; Mitchell et al. 1996) can occur during these large events.

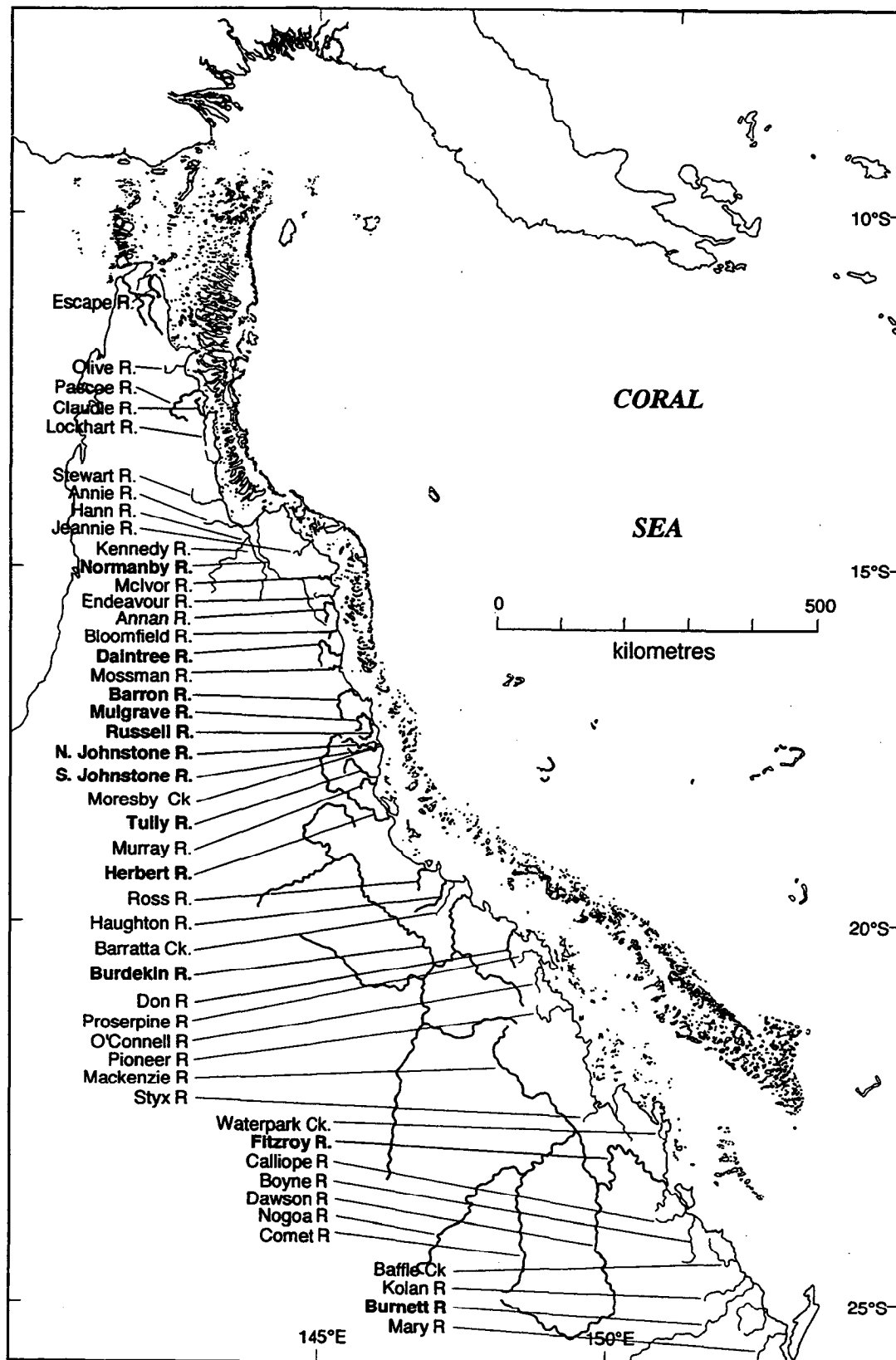


Figure 1. Queensland river systems draining into the Great Barrier Reef. Rivers used for flow extrapolations are identified by **bold** text. Rivers sampled by the Australian Institute of Marine Science are identified by **bold-italic** text.

Figure 2 shows representative daily flow rates between 1987 and 1995 in seven rivers of the wet-tropical zone between 16° and 19°S (Barron, Russell, Mulgrave, North Johnstone, South Johnstone, Tully, Murray, Herbert). Figures 3 and 4 present concurrent flows in the two largest rivers of the dry tropics (Burdekin and the Fitzroy). These plots collectively illustrate seasonal patterns of discharge from important north Queensland rivers and its variability, which in turn affects the process of accurately estimating nutrient and sediment delivery to the GBR.

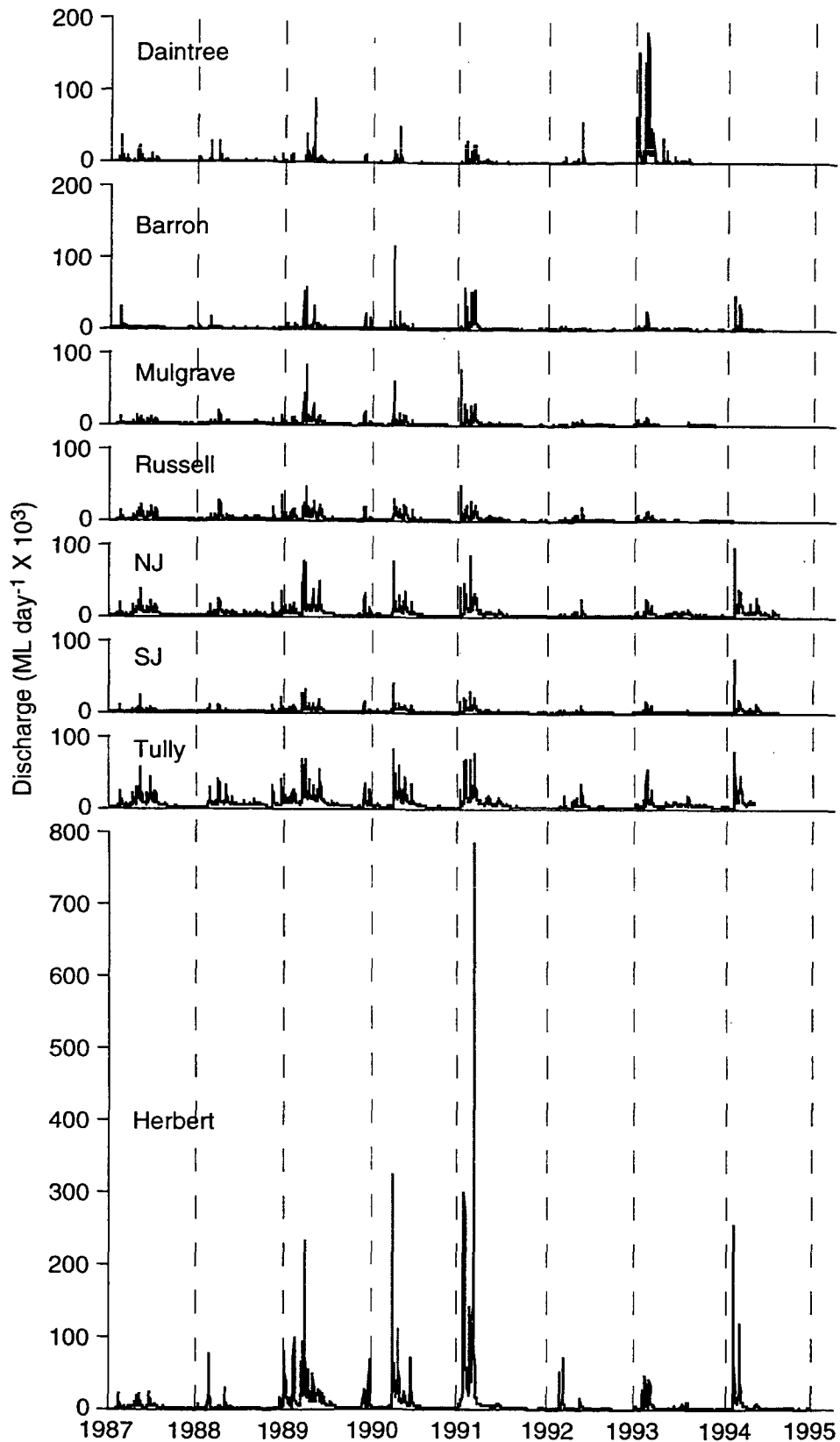
The first and most obvious feature of the discharge patterns is the huge difference between discharges from the large, dry-catchment rivers (Burdekin, Fitzroy: catchment areas  $10^5$  km<sup>2</sup>) during major floods and discharge coming from the smaller, wet-tropical rivers (catchment areas  $10^3$ - $10^4$  km<sup>2</sup>). In single flood events associated with tropical cyclones (Charlie [1989] in the Burdekin; Joy [1991] in the Burdekin and Fitzroy), discharge volumes from each of the dry catchment rivers dwarfed the combined discharge from all of the smaller catchments. To the extent that nutrient and sediment inputs are scaled to total water output during years or events, these very large flows obviously have a significant impact on nutrient and freshwater dynamics over large areas of the GBR shelf (e.g. Wolanski and van Senden 1984; Brodie and Furnas 1995). Based upon long-term discharge records, however, the average aggregate discharge (ca.  $12$  km<sup>3</sup> per year) from the wet-tropical rivers between 16 and 18°S (Daintree, Barron, Russell, Mulgrave, Johnstone, Tully, Herbert) contributes 32 percent of the total gauged river input to the GBR despite these rivers comprising only three percent of total watershed area.

In all catchments, regardless of size, most of the total annual discharge occurs between November and April, with little or no flow during the May- October 'dry' season. Within seasons, most flow occurs during discrete flood events. In the large rivers, these events can last for several weeks, while in the smaller catchments, flood events may only last several days. Hydrographs of individual flow events tend to be characterised by a sharp rise in water level, followed by a gradual decline with time.

On a year-to-year basis, freshwater discharge from the rivers of the wet tropics (Daintree, Mulgrave to Tully) is more consistent than discharge from the Barron, Herbert, Burdekin and Fitzroy rivers, which have significant areas of dry catchment. Hydrographs of the dry catchment rivers are characterised by large, discrete, flood events separated by extended periods with very little flow. All of the rivers in the central GBR, regardless of catchment type, were characterised by low annual flows during the 1992-1994 period while drought conditions prevailed over much of eastern Australia.

### **Nutrient concentrations in north Queensland river waters**

Prior to the mid-1980s, very little information was available on the magnitude and variability of nutrient concentrations in north Queensland rivers. Much of the early nutrient data was collected by state government agencies (e.g. Queensland Water Quality Council; Queensland Department of Environment) for the purpose of assessing compliance with water quality criteria downstream of point sources of sewage and industrial wastes. This data is generally not suitable for estimating fluxes of nutrients from river systems.



**Figure 2.** Measured discharge rates ( $10^6 \text{ m}^3 \text{ day}^{-1}$ ) from rivers in the wet tropics of north Queensland between 1987 and 1994. Flow data was obtained from the Queensland Department of Primary Industries.

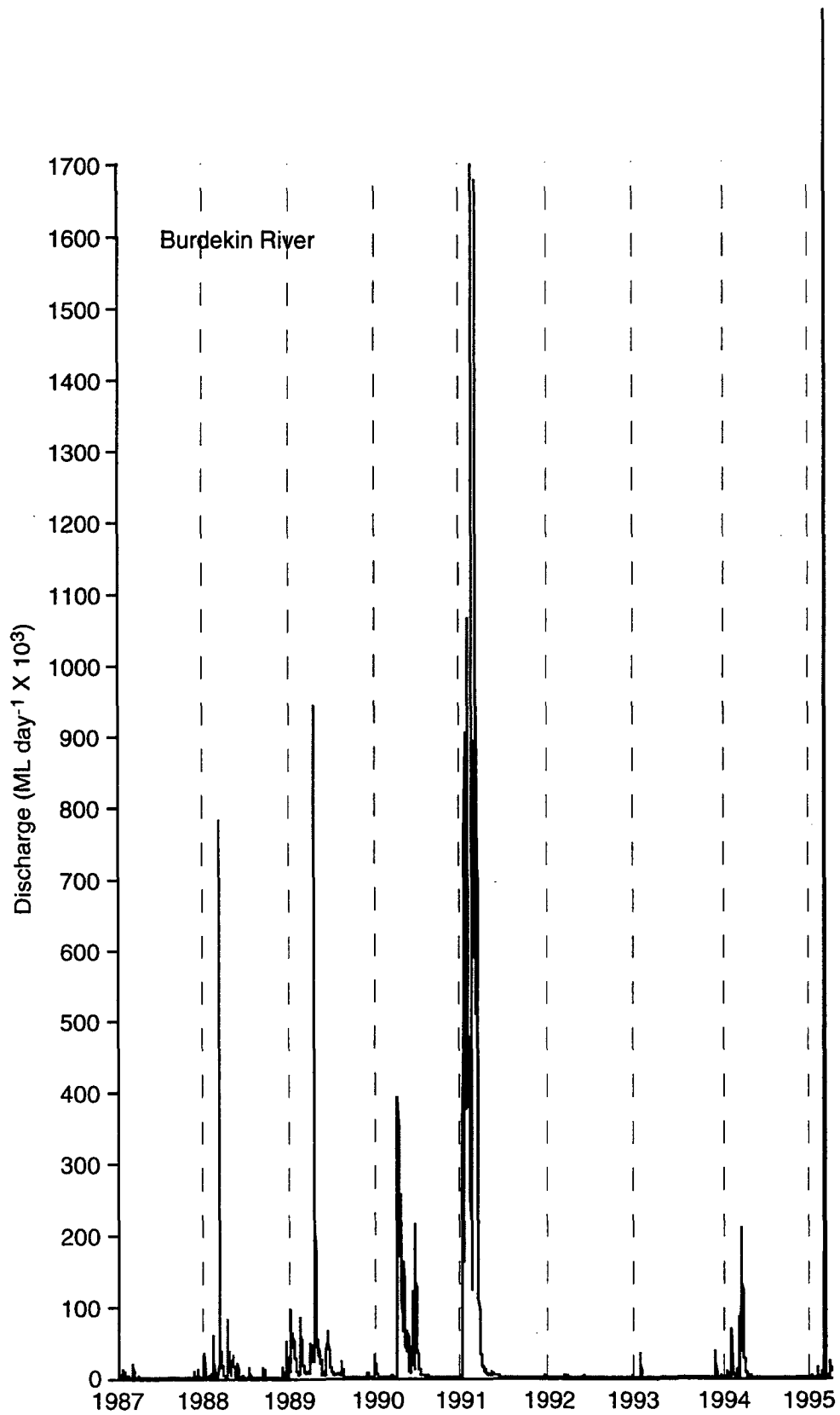
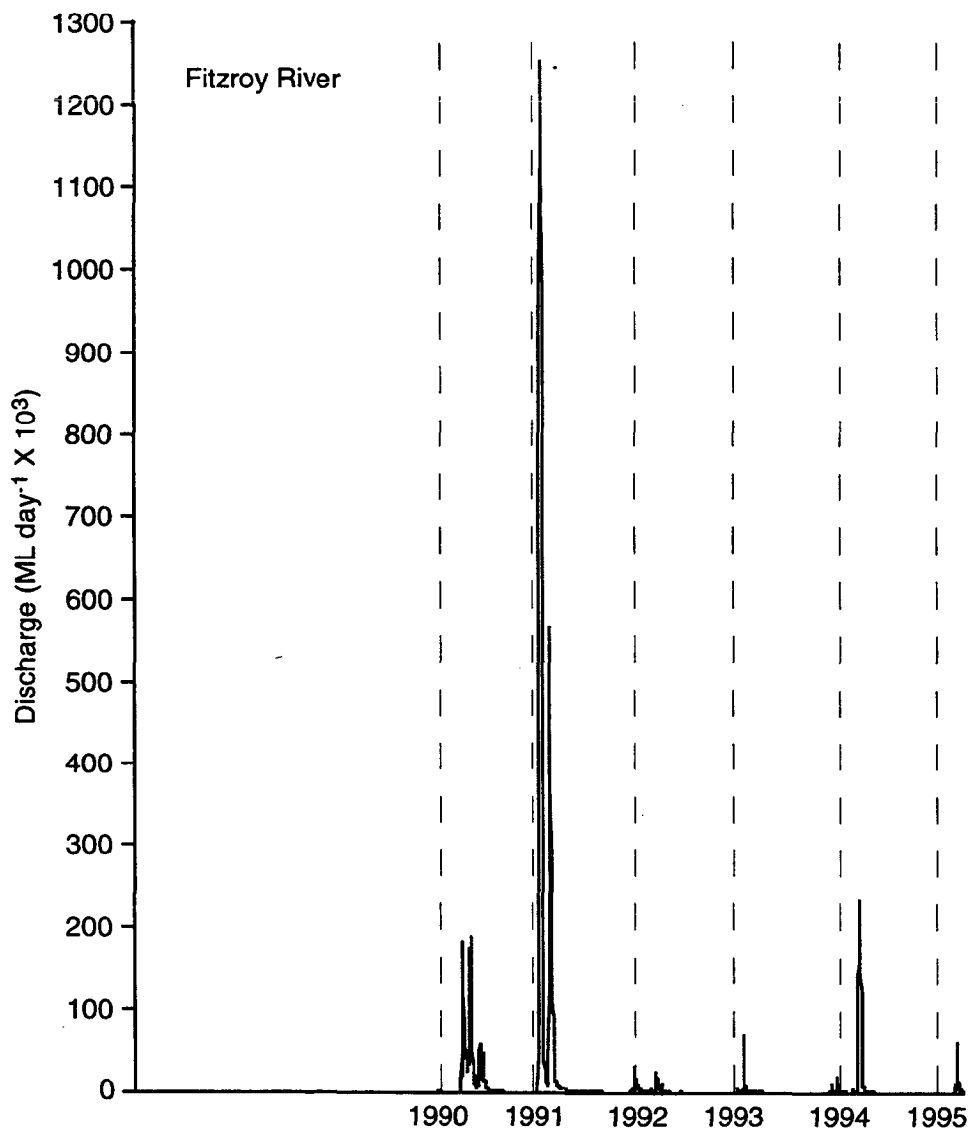


Figure 3. Measured discharge rates ( $10^6 \text{ m}^3 \text{ day}^{-1}$ ) in the Burdekin River between 1987 and 1994. Flow data was obtained from the Queensland Department of Primary Industries.

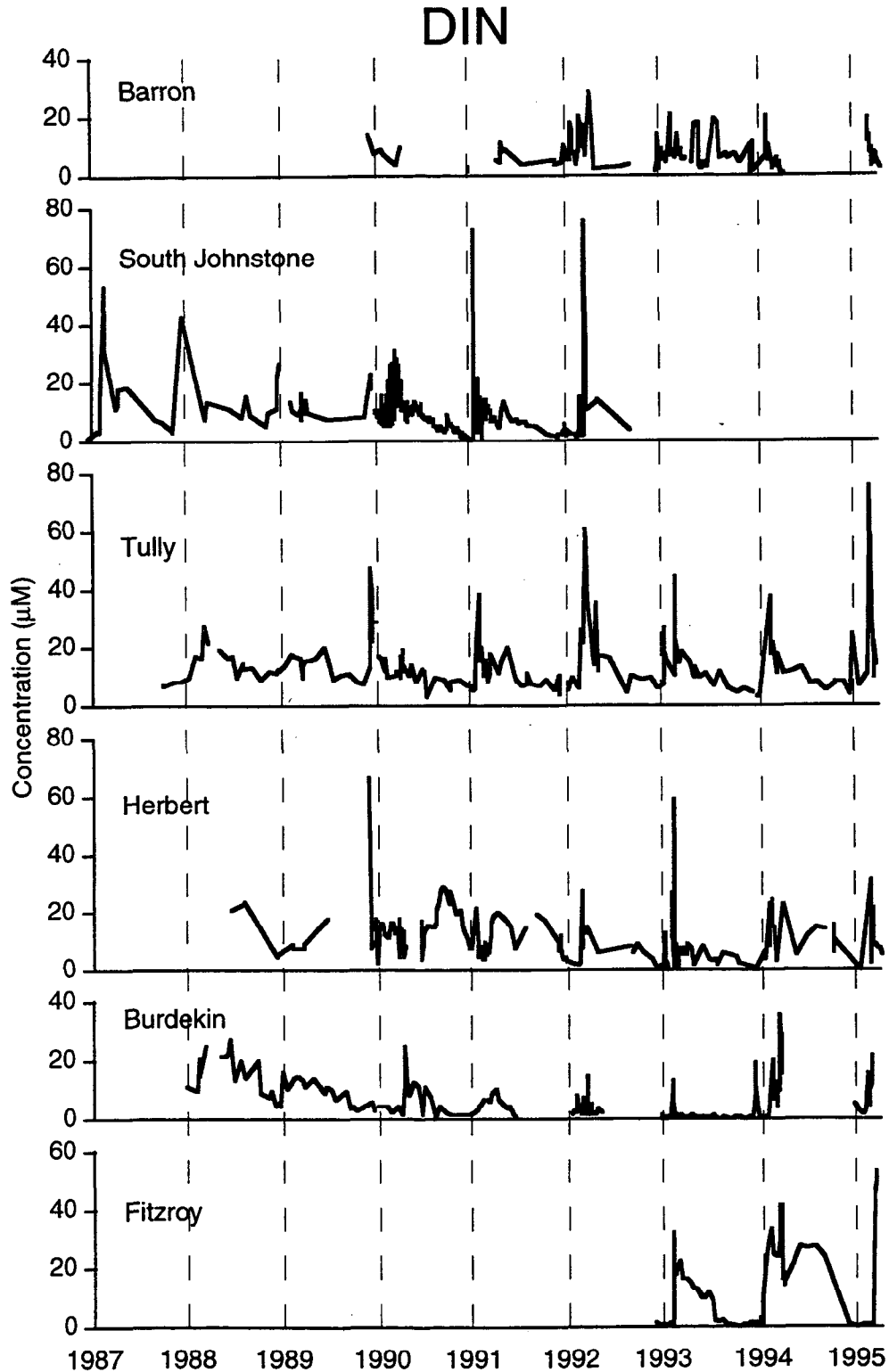


**Figure 4.** Measured discharge rates ( $10^6 \text{ m}^3 \text{ day}^{-1}$ ) in the Fitzroy River between 1990 and 1994. Flow data was obtained from the Queensland Department of Primary Industries.

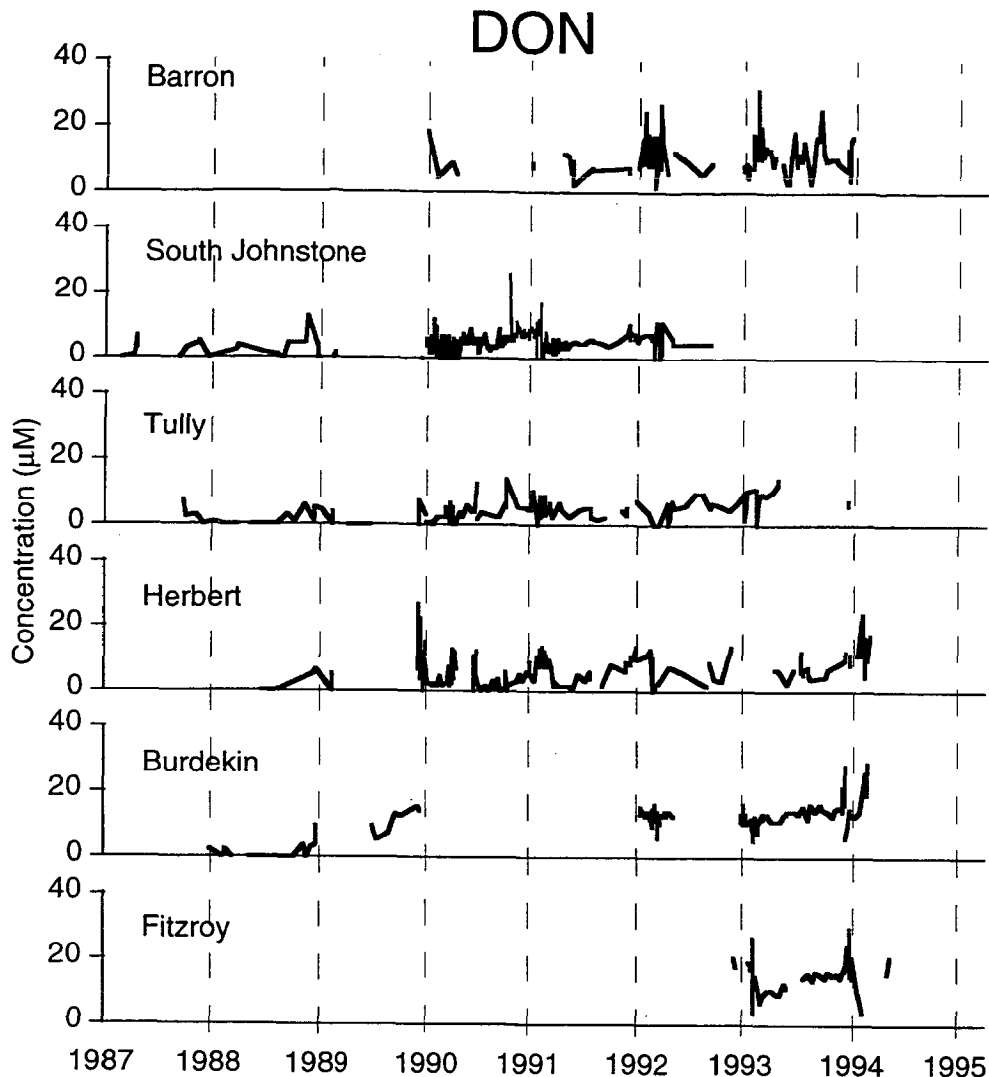
Figures 5 to 10 present concentrations of dissolved and particulate nutrient species measured to date in six major north and central Queensland rivers (Barron, South Johnstone, Tully, Herbert, Burdekin and Fitzroy) by the Australian Institute of Marine Science (AIMS) Biological Oceanography Group.

Seasonal peak concentrations of dissolved inorganic nitrogen (DIN) in river waters, chiefly in the form of nitrate ( $\text{NO}_3$ ) are consistently associated with the first significant flow event of each summer wet season, to some extent regardless of the size of the flow event. Maximum DIN concentrations exceeding  $40 \mu\text{M}$  ( $560 \mu\text{g l}^{-1}$ ) during first flush events are not uncommon. Ammonium ( $\text{NH}_4$ ) and nitrite ( $\text{NO}_2$ ) are relatively small components of total DIN pools in regional rivers. These 'first flush' peaks reflect the high solubility and mobility of oxidised nitrogen stocks built up in catchment soils during the dry season. Because the first flush event of the season may not be large, they are difficult to sample and it is presently unclear whether there is any relationship between the amount of DIN exported from watersheds during first

flush events and the volume of water discharged during these events. Following the first flush, baseline concentrations of DIN progressively decline over the course of the wet season, indicating a gradual exhaustion of leachable watershed DIN stocks. Concentrations of DIN appear to be diluted during very large flood events indicating that exports are not directly proportional to flood water volumes during such events.



**Figure 5.** Measured concentrations of dissolved inorganic nitrogen (DIN= $\text{NH}_4 + \text{NO}_2 + \text{NO}_3$ ) in north Queensland rivers between 1987 and 1994. Gaps in records = samples not collected or remaining to be analysed.



**Figure 6.** Measured concentrations of dissolved organic nitrogen (DON) in north Queensland rivers between 1987 and 1994. Gaps in records = samples not collected or remaining to be analysed.

Concentrations of dissolved organic nitrogen (DON) in north Queensland river waters are low and remain relatively constant throughout the year. Maximum concentrations were only infrequently greater than  $20 \mu\text{M}$  ( $280 \mu\text{g l}^{-1}$ ). DON levels increased in some rivers as flow declined over the course of the wet season, suggesting a relatively constant input from the watershed and dilution during major flood events.

In contrast to the dissolved nitrogen (N) species, concentrations of N in particulate form (PN) are generally proportional to river flow. Particle-associated N occurs in a variety of forms which include organic N compounds in detritus and ionic ammonium adsorbed to soil particles or bound within clay mineral lattices (Bremner 1965; Rosenfeld 1979). Although the PN data set is limited at this time, concentrations typically peak during flood events. This is not surprising as fine sediment concentrations in river waters and resulting export fluxes are also related to river flow, reflecting erosion of soils and associated organic matter within the watershed. Because of the close association between flow rate and PN concentrations during flood events (Mitchell et al. 1996), it is important that large flow events are sampled intensively, particularly during the rising limb of the hydrograph in order to develop accurate estimates of PN export from rivers.



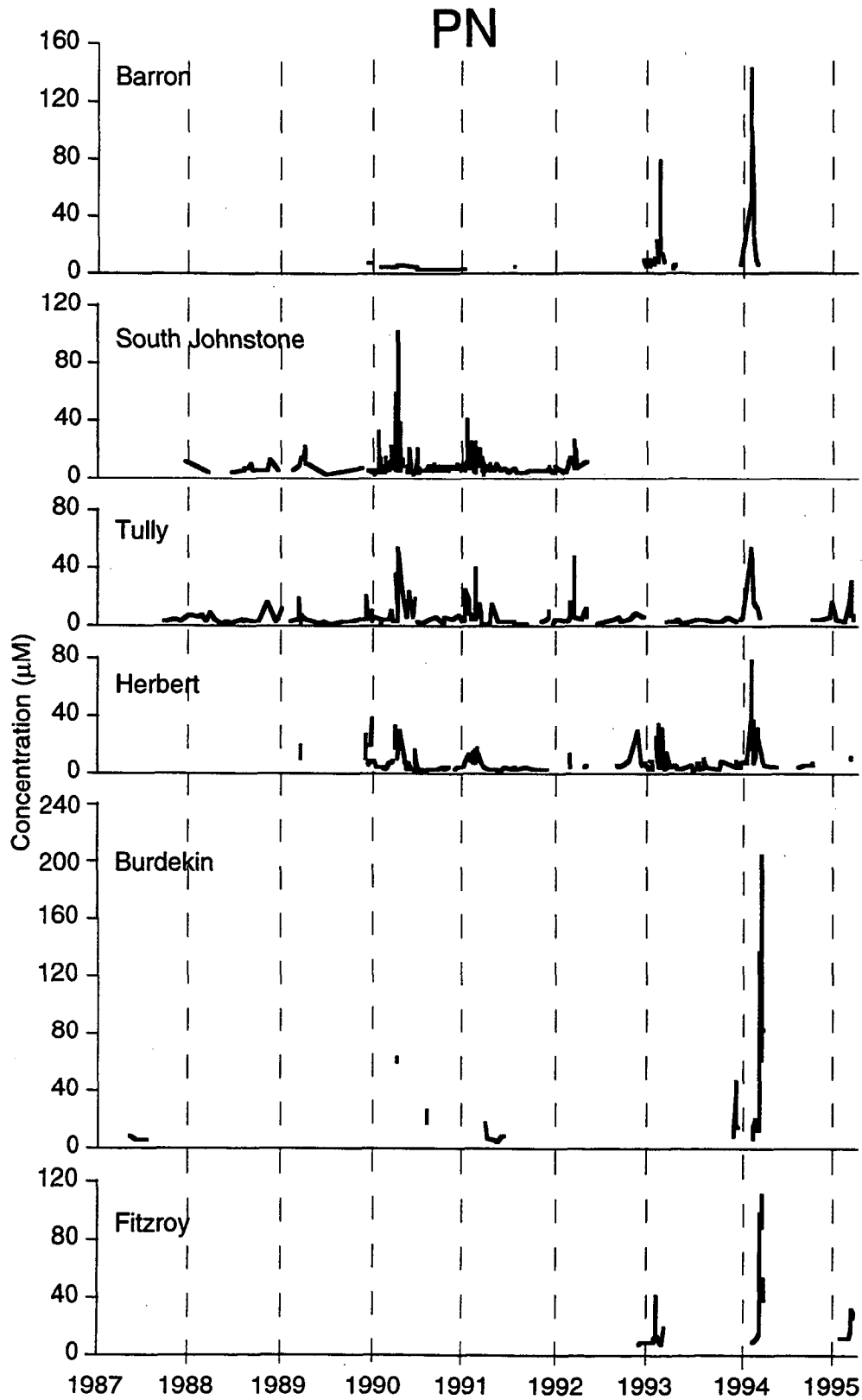
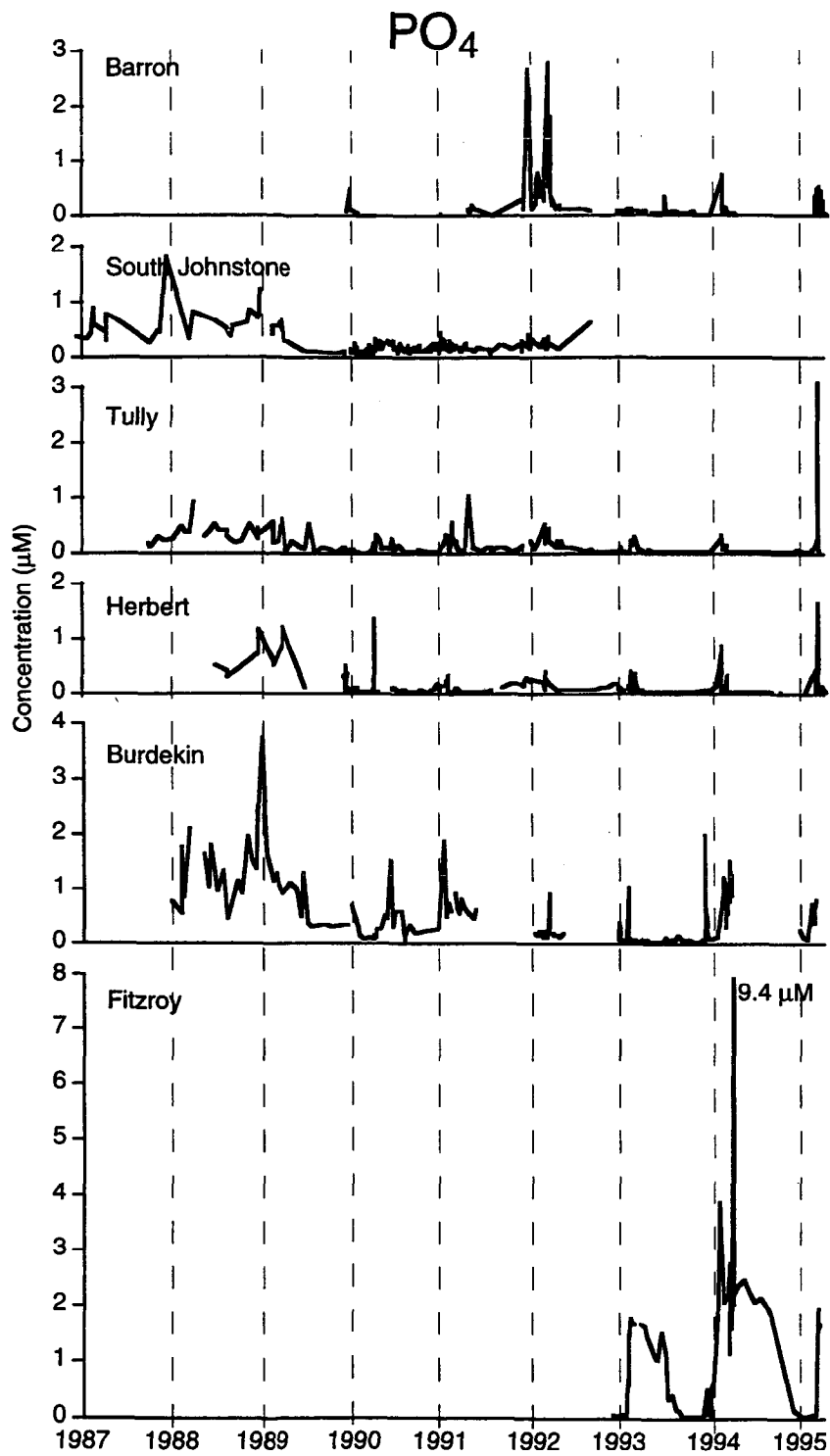
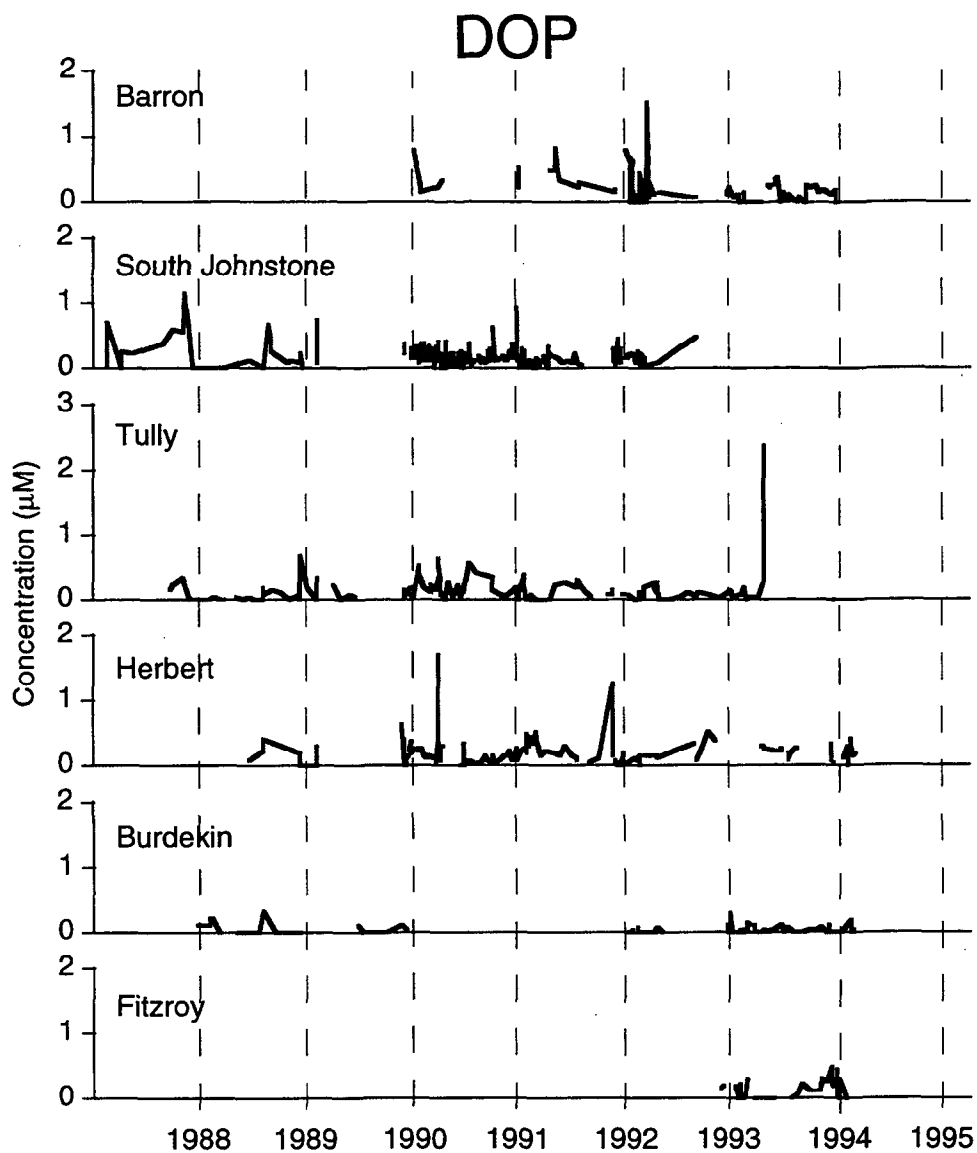


Figure 7. Measured concentrations of particulate nitrogen (PN) in north Queensland rivers between 1987 and 1994. Gaps in records = samples not collected or remaining to be analysed.



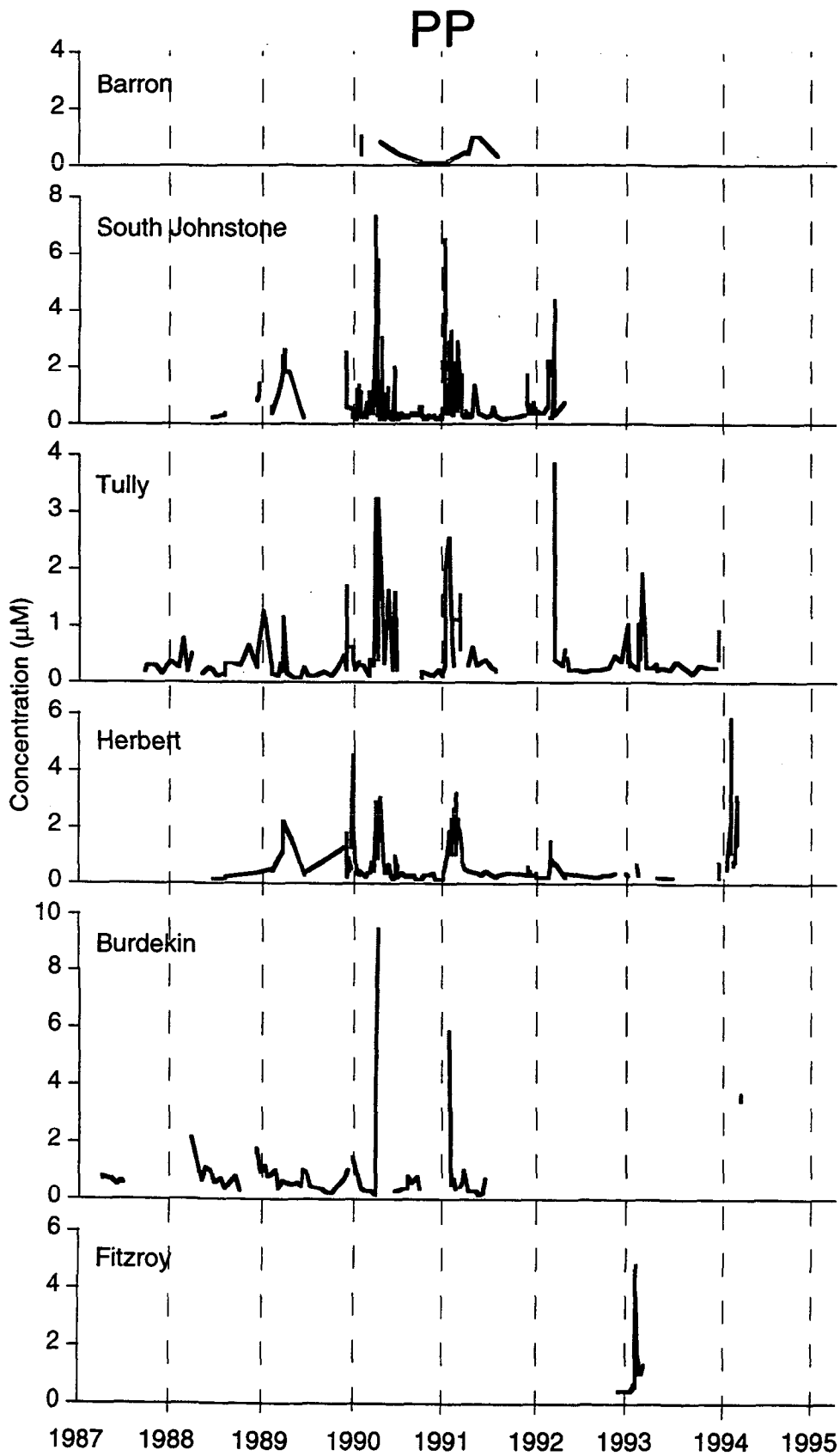
**Figure 8.** Measured concentrations of dissolved inorganic phosphorus (PO<sub>4</sub>) in north Queensland rivers between 1987 and 1994. Gaps in records = samples not collected or remaining to be analysed.



**Figure 9.** Measured concentrations of dissolved organic phosphorus (DOP) in north Queensland rivers between 1987 and 1994. Gaps in records = samples not collected or remaining to be analysed.

Seasonal fluctuations in concentrations of inorganic phosphorus (P) (chiefly  $\text{PO}_4$ ) in north Queensland rivers are not clearly related to fluctuations in river discharge or to major flood events. In particular,  $\text{PO}_4$  peaks were not consistently associated with 'first flush' events. Phosphate ions tend to be tightly bound to soil particles (Moody 1994) and are therefore not readily leached from soils or catchments in soluble form. Rather, soluble  $\text{PO}_4$  concentrations are determined by equilibria between the solid and particulate phases. With the exception of the Fitzroy river, concentrations of  $\text{PO}_4$  were generally less than  $1 \mu\text{M}$  ( $31 \mu\text{g l}^{-1}$ ) throughout the year. Reasons for this difference are unknown. It is also unclear whether the decline in  $\text{PO}_4$  concentrations measured in a number of rivers after 1990 reflects a genuine change in river  $\text{PO}_4$  levels, or is due to sampling and analytical procedures.

Dissolved organic P (DOP) concentrations in river waters are generally less than  $0.5 \mu\text{M}$  ( $< 15 \mu\text{g l}^{-1}$ ) throughout the year. No clear fluctuations in concentration with first flush or flood events are apparent at this time.



**Figure 10.** Measured concentrations of particulate phosphorus (PP) in north Queensland rivers between 1987 and 1994. Gaps in records = samples not collected or remaining to be analysed.

Particulate P (PP) concentrations measured in river waters varied in a manner similar to that observed for PN, with peak concentrations occurring during flood events when concentration of suspended sediment are also high. Maximum concentrations of PP during high flow periods ranged between 2 and 10  $\mu\text{M}$  (60-300  $\mu\text{g l}^{-1}$ ). During low-flow periods, PP concentrations in both wet and dry catchment rivers are on the order of 1  $\mu\text{M}$  (31  $\mu\text{g l}^{-1}$ ) or less. During low-flow periods between floods, considerable amounts of soil-bound P are accumulated within river sediments (Eyre 1993; Pailles et al. 1993).

The proportion of the total particulate P which is estimated to be 'biologically available' is strongly dependent upon the method used to extract P from the particles (e.g. Froelich 1988; Eyre 1993; Ruttenberg 1992). Phosphorus occurs in a variety of forms in and on the surfaces of soils, sediments and colloids, ranging from loosely bound phosphate ions to P directly incorporated into mineral lattices. The proportion of total P in river and marine sediments or particulate matter which is bio-available, and over what time frames, remains a subject of considerable research and discussion (e.g. Froelich 1988; Pailles and Moody 1992; Eyre 1993). At least some of the P attached to particles is subject to rapid desorption under conditions of increasing ionic strength as riverine particulate matter is transported through estuarine or river plume salinity gradients (e.g. Brodie and Mitchell 1992). The equilibrium kinetics of this process (Froelich 1988) are poorly resolved. Until better models of P solubility and particle-solute interactions are available for a variety of soil and sediment types, the bio-availability of the total P stock transported by rivers to the GBR remains uncertain. The acid/persulphate digestion procedure used to obtain the PP values shown herein is a 'mild' extractive procedure and would not include P strongly bound within mineral lattices (e.g. Ruttenberg 1992). Very little of this mineral P would likely be directly available for biological uptake.

To date, results from the detailed sampling necessary to integrate annual export fluxes of individual forms of N and P have only been published for one wet-tropical catchment (South Johnstone River, e.g. Hunter 1992; Furnas et al. 1995). These measurements indicate that the bulk of both N (40-50 percent) and P (77 percent) are exported in particulate form. Most of the remaining N exported from the South Johnstone River in soluble form is transported as DIN (30-40 percent). DON fluxes are relatively small (10-20 percent). In contrast to N, relatively little P is exported in soluble form ( $\text{PO}_4$  - 15 percent; DOP - 8 percent). The extent to which these proportions apply to other catchments, particularly the large dry catchments remains to be established. In the case of P, however, data from a medium sized southern catchment (South Pine River, Cosser 1989a) indicates that a similar high proportion of P (77 percent) is also exported in particulate form.

### **Estimates of river nutrient exports to the Great Barrier Reef lagoon**

Given the sparseness of the extant data on nutrient concentrations in regional rivers, only first-order estimates of total terrestrial nutrient and sediment inputs to the GBR lagoon can be made at this time. The available data on suspended solids concentrations, during floods in particular, is insufficient to support accurate estimates of fine sediment and associated nutrient (N, P) fluxes. This omission is currently being addressed by monitoring programs in a number of rivers (AIMS - Tully, Herbert, Burdekin, Fitzroy, Commonwealth Scientific Industrial Research Organisation (CSIRO) - Herbert, Queensland Department of Primary Industries (QDPI) - Johnstone, Fitzroy). With the available data, three approaches can be taken to estimate riverine nutrient fluxes. The reader is advised to accept these estimates with caution, given the still small number of samples and poor temporal resolution of most major flood events in individual rivers.

Our first approach is to use the discharge-weighted mean annual concentrations of N (27.3  $\text{mmol N m}^{-3}$ ) and P (1.22  $\text{mmol P m}^{-3}$ ) calculated for the South Johnstone River. These mean

concentrations are based upon intensive wet season sampling during 1990 and 1991 (Furnas et al. 1995). Precipitation from two cyclones (Ivor, Joy) affected the South Johnstone catchment during this period. The measured annual discharges for the 1990 and 1991 hydrological years (October-September:  $0.80$  and  $0.87 \times 10^9 \text{ m}^3$ ) are reasonably close to the long-term annual discharge ( $0.81 \times 10^9 \text{ m}^3$ ) of the South Johnstone River (72 years). This would indicate that significant flood events occur on a relatively frequent basis in the South Johnstone catchment. Multiplying the above discharge-weighted average N and P concentrations by the mean annual discharges of the twelve major river basins draining into the GBR gives mean annual export fluxes of 11 890 metric tons of N and 1175 metric tons of P. When adjusted for the proportion of gauged watershed area (0.77), this yields a mean total annual river input of approximately **15 440** metric tons of N and **1530** metric tons of P. Taking this approach, Table 2 presents estimates of total river N and P inputs to the GBR lagoon for the period between 1969 and 1992. Because the nutrient inputs are directly scaled to freshwater inputs, the maximum nutrient input to the lagoon would have occurred in 1974 (46 000 metric tons N, 4500 metric tons P) and 1991 (39 000 metric tons N, 3900 metric tons P).

**Table 2.** Estimated annual inputs of N and P to the GBR lagoon between 1969 and 1992 based upon total gauged flow from the twelve largest rivers flowing into the GBR and the volume-weighted mean annual concentration of total N and total P measured in the South Johnstone River during 1990-91. The total N and P estimates are calculated as the gauged N and P inputs divided by the proportion (0.77) of total watershed flowing into the GBR represented by the 12 major rivers.

Year	Gauged Flow Cubic km	Gauged N Mmoles	Gauged P Mmoles	Gauged N Metric Tons	Gauged P Metric Tons	Total N Metric Tons	Total P Metric Tons
1969	10.8	295	13	4133	408	5367	530
1970	18.1	494	22	6921	684	8988	888
1971	38.7	1058	47	14816	1464	19242	1901
1972	38.3	1045	47	14643	1447	19017	1879
1973	30.5	832	37	11656	1152	15138	1496
1974	92.4	2523	113	35344	3493	45902	4536
1975	34.8	950	42	13314	1316	17291	1709
1976	39.0	1065	48	14927	1475	19386	1916
1977	39.4	1075	48	15066	1489	19566	1934
1978	23.0	629	28	8806	870	11437	1130
1979	47.4	1293	58	18114	1790	23525	2325
1980	13.9	380	17	5327	526	6918	684
1981	42.6	1163	52	16295	1610	21163	2091
1982	15.7	429	19	6010	594	7805	771
1983	35.5	969	43	13573	1341	17628	1742
1984	17.2	470	21	6581	650	8546	845
1985	13.9	378	17	5298	524	6881	680
1986	15.9	434	19	6082	601	7898	780
1987	8.9	242	11	3394	335	4408	436
1988	19.4	530	24	7419	733	9636	952
1989	34.9	953	43	13345	1319	17332	1713
1990	29.1	794	36	11129	1100	14454	1428
1991	79.0	2157	96	30217	2986	39243	3878
1992	7.7	210	9	2948	291	3828	378
Mean		849	38	11890	1175	15442	1526
Median		813	36	11393	1126	14796	1462
Std. Dev.		564	25	7904	781	10264	1014
Max		2523	113	35344	3493	45902	4536
Min		210	9	2948	291	3828	378

This approach assumes that the discharge-export relationships derived for the wet-tropical South Johnstone River are broadly applicable to all rivers running into the GBR. This assumption is tenuous as seasonal rainfall-runoff dynamics, land cover patterns and types of land use vary widely across the various watersheds draining into the GBR. We consider the estimates of river nutrient fluxes derived by this method to be highly conservative and most likely form a lower bound for reasonable nutrient input estimates.

A second approach to estimating river nutrient inputs from the available data is to divide the river flow and nutrient concentration data into discrete (monthly) periods and multiply the mean monthly discharges of each of the twelve major rivers by monthly means of dissolved and particulate nutrient concentrations measured in, or extrapolated to, individual rivers. This approach applies an increased degree of seasonal and event weighting to both the flow and concentration data. As all of the twelve major rivers were not sampled, nutrient concentration data from nearby rivers with (hopefully) similar watershed characteristics (Barron= Daintree= Normanby; South Johnstone= North Johnstone= Mulgrave= Russell; Burdekin= Fitzroy= Burnett) have been extrapolated to fill the gaps. Where concentration data was not available for a particular river-month-nutrient combination, mean monthly nutrient concentrations were interpolated from adjoining months.

Annual inputs of N, P, and Silicon (Si) to the GBR lagoon calculated using the monthly flow and concentration means are presented in Table 3. Using this approach, we calculate annual river export fluxes of 25 500 metric tons N, 1820 metric tons P and 55 380 metric tons Si from the twelve major river basins draining into the GBR. When adjusted for total watershed area, this yields estimated input fluxes of 33 000 metric tons of N, 2400 metric tons of P and 72 000 metric tons of Si, respectively.

The second approach, based upon means of flows and concentrations within months, again conservatively weights a sparse data set. This approach yields estimated export fluxes of N and P which are nearly 60 and 20 percent greater, respectively, than the estimates based upon annual discharge-weighted mean nutrient concentrations in the South Johnstone River. The difference illustrates the importance of interactions between seasonal fluctuations in flow and concentration, and differences between concentrations in wet- and dry-catchment rivers. Because of the small overall size of the data sets available for individual rivers, we feel that the second approach still underestimates the significant contribution that large flood events make to nutrient concentration variability and nutrient exports.

Because a large proportion of the P (ca. 80 percent) and N (ca. 40 percent) transported by regional rivers is associated with fine sediments (Cosser 1989a; Furnas et al. 1995), a third approach to calculating total river nutrient fluxes is to work backward from estimates of total terrestrial sediment exports to the shelf. At present, there are three estimates of terrestrial sediment inputs to coastal waters bordering the GBR. Belperio (1983) used the discharge-sediment export relationship derived for the Burdekin River ( $3 \times 10^6$  tons per year: Belperio 1979) to calculate an average total sediment export to the GBR of  $25.4 \times 10^6$  tons per year. As noted above, > 80 percent of this sediment is in the fine fraction likely to strongly adsorb ionic N and P. Belperio's calculation assumes that all rivers discharging into the GBR have volume-specific sediment export characteristic similar to the Burdekin River. Such a coincidence is unlikely given the diversity of catchment characteristics. Recently, Neil and Yu (1995) have re-evaluated a variety of new and old data on suspended sediment levels in catchments of NE Queensland rivers during flood events. They calculated an average annual sediment input to the GBR of  $23 \times 10^6$  tons per year. In contrast to Belperio's estimate, however, the Neil and Yu model for sediment inputs indicates that most (ca. 2/3) of this sediment discharged into the GBR comes from the large dry catchments (Burdekin and Fitzroy Rivers). The recently observed 5 to 10-fold differences between suspended sediment loads during flood events in

wet- and dry-catchment rivers (Furnas and Mitchell, unpublished) would lend support to this weighting. Since major flood events in the large catchments occur infrequently, they must contribute huge amounts of sediments and associated nutrients to shelf waters when they do occur. Estimates of the amount of nutrients transported during these large flood events await appropriate sampling and the development of rating curves for sediment and nutrient discharge.

**Table 3.** Estimated annual inputs of N, P and Si from major rivers entering the GBR based upon weighted monthly flow rates and monthly mean nutrient concentrations.

		DIN	DON	PN	DIP	DOP	PP	Si	
Normanby	Mmoles	10.24	14.7	19.0	0.2	0.3	0.8	164	
	Metric tons	143.4	206	266	7.5	8.3	23.5	4615	
	Σ tons		N=	615		P=	39.2	Si= 4615	
Daintree	Mmoles	7.4	10.9	10.7	0.2	0.2	0.6	139	
	Metric tons	103	153	150	5.0	7.0	18.9	3888	
	Σ tons		N=	406		P=	30.9	Si= 4615	
Barron	Mmoles	6.1	9.1	10.7	0.1	0.2	0.5	66	
	Metric tons	85	127	150	4.4	4.9	14.0	1838	
	Σ tons		N=	362		P=	23.3	Si= 4615	
Mulgrave	Mmoles	6.4	2.3	5.8	0.1	0.1	0.5	207	
	Metric tons	90	33	82	3.6	2.4	14.1	5810	
	Σ tons		N=	204		P=	20.0	Si= 4615	
Russell	Mmoles	9.4	3.5	8.5	0.2	0.1	0.7	309	
	Metric tons	132	50	120	5.3	3.5	20.6	8676	
	Σ tons		N=	301		P=	29.5	Si= 4615	
No. Johnstone	Mmoles	20.8	7.7	18.8	0.4	0.2	1.5	674	
	Metric tons	292	108	263	11.6	7.7	45.5	18921	
	Σ tons		N=	663		P=	64.9	Si= 4615	
So. Johnstone	Mmoles	9.1	3.3	8.3	0.2	0.1	0.6	293	
	Metric tons	128	47	116	5.0	3.4	20.0	8229	
	Σ tons		N=	291		P=	28.4	Si= 4615	
Tully	Mmoles	43.4	10.8	22.7	0.5	0.4	1.7	646	
	Metric tons	608	152	318	16.7	13.3	51.9	18127	
	Σ tons		N=	1077		P=	81.9	Si= 4615	
Herbert	Mmoles	35.6	24.1	43.3	0.5	0.7	3.9	1266	
	Metric tons	499	338	606	15.8	22.6	122.0	35533	
	Σ tons		N=	1444		P=	160.4	Si= 4615	
Burdekin	Mmoles	71.9	115.5	251.0	4.6	0.2	11.3	2199	
	Metric tons	1007	1618	3516	142.6	5.5	351.3	61692	
	Σ tons		N=	6141		P=	499.4	Si= 4615	
Fitzroy	Mmoles	99.4	69.3	121.6	7.3	0.5	6.7	1282	
	Metric tons	1393	970	1703	226.1	15.3	208.4	35964	
	Σ tons		N=	4066		P=	449.8	Si= 4615	
Burnett	Mmoles	17.1	13.6	20.4	1.3	0.1	1.2	241	
	Metric tons	239	190	286	39.2	3.2	35.7	6769	
	Σ tons		N=	715		P=	78.2	Si= 4615	
Target River Inputs (Metric Tons)				N=	16285		P=	1506	Si= 55380
Total GBR River Inputs (Metric Tons)				N=	21150		P=	1956	Si= 71923

Through modelling of relationships between land use and soil runoff from (largely tropical) catchments, Moss et al. (1992) estimated sediment runoff to the GBR was on the order of 14 x



10<sup>6</sup> metric tons per year. From this, Moss et al. calculated total N and P inputs to the GBR of 77 000 and 11 000 metric tons per year, respectively (Table 4).

**Table 4.** N and P inputs (tons per year) to the GBR calculated from river sediment inputs. River sediments are assumed to have a flow-weighted N and P content of 0.165 and 0.115 (w/w). Sediment associated N and P inputs are assumed to be 43 and 77 percent of total inputs (Furnas et al. 1995).

Source	Tons Sediment x 10 tons	Sediment N x 10 tons	Sediment P x 10 tons	Total N x 10 tons	Total P x 10 tons
Belperio, 1983 (from Moss et al. 1992)	25.4	41.9	29.2	97.5	38.0
Moss et al. 1992 (calculated by Moss et al. 1992)	14.0	23.0	16.1	53.6 77.0	20.9 11.0
Neil and Yu (1995)	23.0	38.0	26.5	88.3	34.4

Using recent data on the composition of particulate matter collected in several north Queensland rivers (principally the Herbert River), we have re-calculated sediment-associated and total N and P inputs to the GBR shelf using the estimates of total sediment input given in Table 4. Using this approach, sediment-associated N inputs to the GBR would range between 23 and 42 x 10<sup>3</sup> metric tons per year, while sediment-associated P inputs fall between 16 and 29 x 10<sup>3</sup> metric tons. When adjusted for the ratio between total nutrient (N or P) and the sediment-bound nutrient fractions, estimates based on the third approach suggest that total river inputs of N to the GBR should fall between 54 and 96 x 10<sup>3</sup> metric tons per year. Total river P inputs estimated from sediment fluxes should fall between 20 and 38 x 10<sup>3</sup> tons per year.

The sediment-based N, and particularly P, inputs to the GBR shelf are considerably larger (1.5 to 3-fold for N, 8 to 16-fold for P) than the total inputs estimated from water sampling alone. The discrepancy is most likely due to under-sampling of water and sediment during very large floods, particularly in the two large dry-catchment rivers. The sediment-based nutrient input estimates have factored these large floods into the average sediment inputs to the shelf. The discrepancy will most likely be reduced as dissolved and particulate nutrient data from large floods are included in the calculations. At the least, the large discrepancies highlight the importance of data from large flood events, particularly those in the dry-catchment rivers, for making accurate estimates of fine sediment and sediment-associated nutrient inputs to the shelf.

## Discussion

Relative to both tropical and temperate zone rivers where catchments have been substantially altered by human activities (Meybeck 1982), nutrient concentrations in rivers draining into the GBR region are very low through much of the year. The highest nutrient loads, chiefly as particulate matter, occur during flood events (Mitchell et al. 1996). Accurate estimates of nutrient loads transported to the shelf by the large dry-catchment rivers (Burdekin, Fitzroy) remain to be established. The principal limitation of such estimates is the lack of appropriate historical data on nutrient levels during flood events and the infrequent (decadal) occurrence of the large events which dominate exports of water, sediment and nutrients from these rivers.

At the present time, it is difficult to put bounds on the accuracy of estimated river nutrient fluxes to the GBR. As an example, the estimated annual export of N from the South Johnstone River derived from the long-term means of flow rates and nutrient concentrations (430 metric tons) is in reasonable agreement with the annual export of N (340 metric tons) derived from an integration of flow rates and nutrient concentrations measured at daily intervals (Furnas et al. 1995). In contrast, the estimate of P exported calculated from the monthly flow and concentration means (13 metric tons) is significantly lower than the value derived from the

integration of daily flows and P concentrations (35 metric tons: Furnas et al. 1995). The discrepancy is most likely due to underweighting of particulate P exports occurring during flood events. The discrepancies clearly suggest that any effort at improving accuracy's of river nutrient export estimates will require increasing the frequency of sampling in all rivers and continuing the sampling program long enough to include a representative number of flood events and drought periods.

When normalised to catchment area (390 km<sup>2</sup>) and runoff volume (2050 mm per m<sup>2</sup>: 1958-1988 period), runoff-specific export coefficients for the AIMS South Johnstone river catchment data are calculated to be 0.044 kg P and 0.42 kg N mm<sup>-1</sup> km<sup>-2</sup>, respectively. The P export coefficient is approximately one order of magnitude smaller than values (0.46-0.54 kg P mm<sup>-1</sup> km<sup>-2</sup>) calculated by Cosser (1989a) for stormflows in the Pine River catchment (SE Queensland). Export coefficients for N and P summarised by Moss et al. (1992) for north Queensland rivers fall in the 0.47-0.8 and 0.07-0.3 kg mm<sup>-1</sup> km<sup>-2</sup> ranges, respectively. Nitrogen and phosphorus export coefficients for southern Queensland rivers, in contrast were on the order of 1 and 0.4 kg mm<sup>-1</sup> km<sup>-2</sup>, respectively. Why the export coefficients for southern rivers should be more than two times greater than the north Queensland rivers was not resolved. The difference may be narrowed when a number of large flood events have been sampled in wet and dry-catchment rivers. As a result, early calculations of river P inputs to the northern GBR (9357 ± 4679 metric tons per year: Cosser 1989b) are likely to be considerable over-estimates. The variability in runoff export coefficients, however, clearly points to a need to carefully account for the characteristics of individual catchments.

The considerable event-related variability in both dissolved nutrient and particulate matter concentrations measured in all north Queensland rivers makes it unlikely that secular trends in nutrient and particulate concentrations within river waters or export to the shelf can be unequivocally detected within short (< 10 year) time intervals. Discharge rates for individual rivers vary with the stochastic occurrence of cyclone-associated floods or monsoonal rain depressions and also vary significantly over longer decadal time scales due to regional climatic factors (Isdale 1984; Lough 1992). Dissolved and particulate nutrient concentrations within seasons are strongly dependent upon both instantaneous flow rates and the pre-occurring flow regime within a wet season. The highest concentrations of a number of species occur either during the first-flush event of the season (e.g. NO<sub>3</sub>) or upon the ascending limb of flood hydrographs (e.g. PN, PP). Peak concentrations of nutrients and sediments during subsequent flow peaks are generally lower. Because of the considerable inter-annual variability in total river discharge rates and strong intra-annual co-variability between nutrient concentrations and discharge rates, the only statistic which can be reliably compared between years and with time for a given river is the integrated annual export flux for a particular nutrient species.

The sediment-based export estimates in Table 4 are also constrained by the (unlikely) assumption of constant weight percentages of N (0.165) and P (0.115) for all terrestrial sediments entering the GBR and constant percentages of N (43) and P (77) assumed to be transported in particulate form. These factors were derived from samples collected in the Herbert and South Johnstone Rivers. At present, there is very little published data on the N and P content of fine suspended sediment in NE Queensland rivers, particularly during major flood events when a significant proportion of the total transport occurs. Eyre (1993) reported that wet season river sediments from pristine parts of the Moresby River catchment had a mean N and P content of 0.034 and 0.015 percent by weight, respectively. Sediments from farmed portions of the catchment had N and P contents of 0.123 and 0.047 percent by weight. On a global scale, Meybeck (1982) reported that riverine particulate matter contained N at levels between 0.1 and 1.3 percent of dry weight and had a mean P content of 0.011 percent of dry weight.

Where do riverine nutrients go? Direct observations of river flood plumes indicate that most turn northward near the river mouth and remain close to the coast (e.g. Wolanski and van Senden 1983; Brodie and Furnas 1995). Exceptions occur when offshore or northerly winds predominate, however (Brodie and Mitchell 1992). A variety of geological and geochemical evidence (Gagan et al. 1987; Johns 1988; Johnson and Carter 1988) clearly indicates that the bulk of particulate matter entering the GBR with rivers is constrained close to the coast, generally within 10-15 km of the coastline. Equivalent gradients of dissolved nutrient species do not exist (Brodie and Furnas 1995), indicating that once in dissolved form, terrestrial nutrients added to the shelf can be widely dispersed.

How does the magnitude of nutrient inputs from river runoff compare with existing stocks of nutrients in shelf waters and inputs from other sources? At present, this comparison can only be drawn in the central GBR (16°-18°S) where detailed inventories of shelf nutrient stocks and inputs have been constructed (Furnas et al. 1995). Terrestrial inputs of N and P (including relatively small sewage inputs) to shelf waters of this sector of the GBR were found to be equivalent to 16-20 percent of quantifiable N and 15-27 percent of P stocks in shelf waters, respectively. Because of uncertainty in the amount of atmospheric N fixed by the pelagic cyanobacterium *Trichodesmium*, the contribution of terrestrial N to total N inputs is still unresolved. Terrestrial N and P inputs, again including sewage, were equivalent to 35-46 percent of identified total external N and 52-59 percent of identified total external P inputs to central GBR shelf waters. As this sector of the GBR is characterised by a relatively narrow shelf and a disproportionate amount of freshwater inputs, it is likely that river runoff provides a smaller proportion of total external inputs to shelf waters to the north and south.

Most of the freshwater and nutrients added to shelf waters by rivers are initially constrained by oceanographic processes to the nearshore zone (depth < 20 m). This coastal band covers less than 10 percent of the GBR shelf area and contains considerably less than five percent of shelf water volume. As a result, the impact of nutrients from river sources will be magnified in the nearshore zone. The above terrestrial inputs are on the order of 100-500 percent of nutrient stocks present in inshore (< 20 m) waters. Until dissipated by cross-shelf mixing, concentrations of nutrients within the nearshore zone after flood events can be considerably elevated over those normally found in shelf waters (Brodie and Furnas 1995). Reef and seagrass communities within the nearshore zone likely experience episodically elevated nutrient concentrations several times during the summer wet season when rivers flow.

In summary, rivers are a major external source of nutrients to the Great Barrier Reef ecosystem. The magnitude of this input varies considerably between years and rivers depending upon rainfall, monsoonal and cyclonic activity, and within years due to local rainfall dynamics in catchments. Estimates of nitrogen and phosphorus inputs to the GBR remain subject to considerable uncertainty due to inadequate sampling of both dissolved and particulate nutrients in wet and dry catchments, particularly during flood events. At present, we estimate that terrestrial N inputs to the GBR shelf are between  $10^4$  and  $10^5$  metric tons per year. Terrestrial P inputs appear to fall between  $10^3$  and  $10^4$  metric tons per year. Detailed instrumental sampling of fine sediment fluxes in both wet and dry-catchment rivers and intense sampling of floods over the next few years will greatly constrain these estimates.

#### **Acknowledgments**

A number of people and organisations contributed greatly to the present and ongoing success of this project in large and small ways. We particularly wish to thank the people who collected samples for us at times we couldn't and maintained daily sampling regimes through one or more summers. John Wellington (deceased), Neil Johnson and Sue Windsor ran large numbers of samples through the autoanalysers. Margaret Wright and a number of volunteers assisted

with particulate N and P analyses from time to time. River flow and river basin data was kindly provided by the Queensland Water Resources Commission (QDPI). Financial support was provided by AIMS appropriation funding, the Great Barrier Reef Marine Park Authority and Cooperative Research Center Program through the Cooperative Research Center for Sustainable Development of the Great Barrier Reef. We particularly thank Don Kinsey, Wendy Craik, Jon Brodie, Terry Done and Professor Chris Crossland for their encouragement and support. This is AIMS contribution no. 805.

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# The water quality status of the Great Barrier Reef World Heritage Area

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## Abstract

Water quality monitoring programs in the Great Barrier Reef (GBR) region are primarily focussed on sediment and nutrient concentrations in the water column. Far fewer results are available from monitoring of persistent organic compounds, trace metals or hydrocarbons or from the sediment or biota compartments. Relatively comprehensive monitoring of the river discharge of sediment and nutrients has occurred over the last decade. Results show the extreme temporal variability in these inputs. Limited monitoring of nutrient upwelling at the shelf-break, nutrient content of rainfall and nitrogen fixation over the last few years has allowed first order estimates of a nutrient budget for the central GBR. Biological oceanographic research from the last 15 years has allowed a synthetic monitoring data set for nutrients to be constructed for a large part of the GBR lagoon. This shows the lack of temporal trends in nutrient concentrations over this period but does quantify some cross-shelf and latitudinal spatial trends. These trends are corroborated by results from the long-term chlorophyll monitoring program, now in its fourth year, and the Australian Institute of Marine Science (AIMS) long-term monitoring program for nutrients and chlorophyll. Results from long-term nutrient programs listed above are for 'ambient' conditions in the GBR lagoon and are supplemented by specific monitoring programs during river flood plume conditions. These highlight the extreme sediment and nutrient concentrations found in these plumes and the oceanographic/meteorological control of the dispersion of the plumes. Few monitoring surveys for chlorinated hydrocarbons, pesticide residues, trace metals and petroleum hydrocarbons have been carried out in the last decade. Low levels of these contaminants were generally found in surveys conducted between 1975 and 1985. The Torres Strait Baseline Study is the largest recent program examining any of these contaminants (trace metals).

## Introduction

Source of this review

This review draws extensively from a large body of work carried out in the last 70 years in the GBR region and reference is made to this work throughout the document. In addition, however, the review draws directly on a number of recent comprehensive papers and passages of these papers are directly reproduced in this review. The papers concerned are:

Furnas, M. and J. Brodie 1997. Current status of nutrient levels and other water quality parameters in the Great Barrier Reef, pp. 9-21. *In* H.M. Hunter, A.G. Eyles and G.E. Rayment (eds), *Downstream Effects of Land Use*, A National Conference on Downstream Effects of Land Use, held in Rockhampton, Queensland, Australia, 26-28 April, 1995.

Brodie, J. and M. Furnas 1997. Cyclones, river flood plumes and natural water quality extremes in the Central Great Barrier Reef, pp. 367-374. *In* H.M. Hunter, A.G. Eyles and G.E. Rayment (eds), *Downstream Effects of Land Use*, A National Conference on Downstream Effects of Land Use, held in Rockhampton, Queensland, Australia, 26-28 April, 1995.

## Background

The Great Barrier Reef system covers an area of about 350 000 sq km on the north-eastern Australian continental shelf. It is a long, narrow system stretching 2000 km along the coast from 10.5°S at Cape York to 24.5°S near Bundaberg ranging from 50 km wide in the north to 200 km in the south and bounded by the coast on the west and the Coral Sea on the east. Generally the range of habitats found in the GBR is relatively uniform from north to south but varies across the continental shelf in a regular way (Hopley 1982). The principal habitats of the system have only existed in their present form since sea level rose 9000 years ago flooding the shelf. Inshore the coastline is dominated by mangroves of total area 3900 sq km (Robertson and Lee Long 1991) interspersed with areas of low energy sandy beachline and limited rocky shorelines. Immediately offshore shallow seagrass beds are common with a total area of 4300 sq km (Lee Long et al. 1993) and in the north large areas of deepwater (> 10 m) seagrass are found further offshore. The GBR lagoon floor is dominated by soft-bottomed communities of algae, sponges, bryozoans and echinoderms interspersed with bare sand. In the north extensive *Halimeda* sp. algal beds occupy the deeper offshore waters, their growth stimulated by nutrient-rich water upwelling from the Coral Sea (Drew and Abel 1988). The coral reefs of the GBR consist of two main types, the fringing reefs (~ 760 reefs) which occur inshore around the continental islands, and those of the main reef (~ 2200 reefs) which occupy a band on the outer edge of the continental shelf. The latter group are often considered as either mid-shelf reefs on the inside of the band and adjacent to the GBR lagoon or outer-shelf reefs adjacent to the Coral Sea. The main reef does not form a continuous barrier but consists of individual reefs separated by inter-reefal waters. In some areas considerable passages exist breaking the maze of reefs and joining the lagoon to the Coral Sea.

Coral reefs are generally considered to do best in low nutrient conditions. Sources of nutrients to the GBR include Coral Sea surface water (nutrient poor), upwelling Coral Sea deep water (nutrient rich), terrestrial runoff and atmospheric inputs, including nitrogen fixation by cyanobacteria (Furnas et al. 1995). Flushing of the GBR lagoon is limited by the enclosure formed by the main reef. Residence times of water in the lagoon, while not precisely known, may be prolonged (Wolanski 1994). The major uses of the GBR are tourism, recreation, fishing and shipping. These are in addition to the primary natural environment values and the Aboriginal cultural values.

## Shipping inputs

Shipping is a major activity within the GBR with over 2000 ships per year passing through the area (Driml 1994). The potential for large oil spills from this traffic is well recognised and active management efforts are underway to minimise the risk. A number of substantial ports line the GBR coast. These include large bulk shipment ports for the export of coal, alumina and sugar. Ships entering these ports empty of cargo are ballasted with water collected in their last port of call. The ballast water is then discharged before the bulk cargo is loaded. This ballast water has been shown to contain organisms including bacteria, viruses, algal cells, plankton and the larval forms of many invertebrates and fish. Invertebrates regularly detected in ballast water include echinoderms, polychaete worms and molluscs (Jones 1991). Globally, ballast water introductions have caused serious ecological and economic problems but, as yet, no undesirable introductions have been detected in the GBR region.

## Sediment and nutrients

There is growing realisation that change in the water quality of terrestrial runoff is one of the most significant anthropogenic impacts on the GBR region (Baldwin 1990; Rasmussen and Cuff 1990; Yellowlees 1991; Bell 1991; Brodie 1994). The watersheds of rivers in north and



central Queensland have been extensively modified since European settlement by forestry, urbanisation and agriculture - particularly sugar cane cultivation and grazing. Recognition of the potential problems of land degradation and subsequent downstream effects of agriculture occurred some time ago (Douglas 1967; Dawson et al. 1983) as did recognition of the potential impacts on the GBR (Bennell 1979). Scientific evidence of effects on the nutrient and sediment loads of the rivers is sparse but research effort is increasing as the potential problems are recognised. Scientific debate continues as to the severity of the problem (Walker 1991; Bell and Gabric 1991; Kinsey 1991a) but there is general agreement as to the need for clarification of the scale of the problem and the principal sources.

Recent studies using catchment models and existing data have quantified the principal sources of sediment and nutrients to the coastal catchments of Queensland (Moss et al. 1992). The report estimates that 15 million tonnes of sediment, 77 000 tonnes of nitrogen and 11 000 tonnes of phosphorus are exported via river discharge to the coastal waters of the GBR. Other significant findings of the study are that grazing is a bigger contributor (~80%) of nutrients than sugarcane cultivation (~15%) and that sewage discharges are a minor component (~1%) to the overall flux. Sewage discharges can be significant at local scales due to their concentrated entry and chronic daily delivery mode. It is estimated that sediment and nutrient delivery to the GBR from terrestrial discharge has increased by four times since European settlement of the adjacent coast, i.e. the last 130 years.

Recent research (Furnas et al. 1995) has quantified all the sources of nutrient input to the central GBR showing that river discharges comprises about 40% of the total input of nitrogen (N) and 50% for phosphorus (P) with sewage discharges 2% for N and 8% for P. When combined with the information on increases in riverine inputs this suggests that total nutrient input to the GBR has risen by about 30% in the last 140 years. However the increase for the inshore part of the GBR lagoon (i.e. in depths less than 20 m and less than 20 km from the coast) will have been much greater as this section, being relatively shallow, holds only 5% of the volume of the lagoon but receives the full impact of the increased river and coastal inputs.

The principal nutrients lost from grazing lands are the nutrients naturally present in the soil as distinct from added fertiliser and the principal cause of this nutrient loss is forest removal (Beckman 1991) and overgrazing (Gardiner et al. 1988). In the case of sugarcane cultivation nutrients are lost as a combination of natural soil nutrients and added fertilisers with fertiliser addition and loss far more important than in the grazing situation (Prove and Hicks 1991).

Studies in the Johnstone River system show that while agricultural activity has had a noticeable influence on the nutrient content of riverine and estuarine sediments the effect is local and does not extend far across the GBR shelf (Pailles et al. 1993). Phosphorus present in the sediments examined is also apparently not readily desorbable into the water column (Pailles and Moody 1992).

Moss et al. (1992) also identified the principal sources of the increased sediment yield for each catchment. Grazing, with the huge areas involved, is the predominant source with cropping and urban significant, but smaller, sources. Even at low runoff levels grazing lands can lose large amounts of sediment in comparison with natural or plantation forest and woodlands.

Much of the four fold increase in sediment and nutrient export from the coast to the GBR has occurred in the last forty years. In this period fertiliser use has increased dramatically on all the major catchments. In addition deforestation has continued on a massive scale with land development programs such as the Brigalow scheme (Fitzroy and adjacent catchments) resulting in loss of three million hectares of Brigalow woodland in the period 1960 to 1975. Increased soil erosion on the resulting grazing lands exacerbated by droughts and seasonal

overgrazing has led to large increases in sediment, and nutrient delivery to the coastal zone. Sewage discharges, associated with a large population increase on the GBR coast, have also contributed to the overall accelerated rise in nutrient discharge in this period.

Large increases in the use of fertilisers in the last 30 years have occurred (Valentine 1988; Pulsford 1991, 1996) in coastal catchments and it has been postulated that significant amounts of runoff of this material has occurred. Studies in the Johnstone catchment have demonstrated that up to 50% of applied nitrogen fertiliser can be lost to drainage and runoff while another 30% may be lost through volatilisation. For phosphorus losses are smaller though significant (Prove and Moody 1994).

Prawn farming is an expanding industry along the GBR coast and prawn farm effluents may be a considerable source of nutrients. At present the amounts involved are small with only potential local risks but as acreages increase some of the eutrophication problems seen in overseas states with intensive prawn farming may begin to occur.

While sand and silt sized sediment fractions may be redeposited within catchments most of the fine clay fraction is transported to the river mouth (e.g. the Johnstone River, Arakel et al. 1989). Material redeposited within the catchment during low flow events may also be resuspended and transported to the coastal zone in the major flood events associated with cyclonic rains. These major events are responsible for almost all the transport of material from catchments to the coastal zone. This can be seen clearly from the work of Cosser (1989) on the South Pine River in SE Queensland where 77% of material flux occurred during stormflow and similar data from the Johnstone River in north Queensland (Furnas and Mitchell 1991; Hunter 1995, in press). In recent years intense rainfall associated with Cyclones Winifred (1987), Joy (1991), Sadie (1994) and Violet (1995) has caused massive river flows and river plumes which have intruded into the GBR lagoon (Fig. 1).

Opinions as to the spatial extent of terrestrial runoff across the continental shelf differ (Wolanski et al. 1986; Johns et al. 1988; Johnson and Carter 1988; Gagan et al. 1987, 1990). In the estuarine mixing process as salinity, Eh and pH change clay materials in the river plume flocculate and tend to settle out close to the coast. Most of the terrestrial sediment deposited on the floor of the GBR lagoon does so in a band within 15 km of the coast (Belperio 1983). Some studies suggest that terrigenous input reaches only halfway across the shelf while others have found terrigenous marker chemicals extending right to the edge of the shelf break. In general there does appear to be an inner reefal area dominated by terrestrial sediment and an outer area dominated by carbonate sediment (Johnson and Carter 1988; Wolanski and van Senden 1983). This effect can also be seen in studies which have examined the presence of terrestrial marker chemicals such as carbon isotopes or complex organic alcohols in sediments from transects stretching across the GBR lagoon. These chemicals, characteristic of a terrestrial source, are generally found in a zone less than 15 km from the coast. However nutrients such as phosphate associated with the sediment may travel much further offshore than the sediment itself. This occurs as the phosphate desorbs off the sediment particles in the estuarine mixing process and is then in a dissolved form able to move greater distances in the prevailing currents or is taken up by phytoplankton and travels in this form (Brodie and Mitchell 1992).

Shelf sediments may act to store large nutrient stocks and studies have shown this occurs on the GBR and that these stocks may be able to be re-released back into the water column (Ullman and Sandstrom 1987; Chongprasith 1992). It is known that nutrient pulses from resuspension of bottom sediments during moderate south-easterly winds can occur (Walker and O'Donnell 1981) and during cyclonic wind events the large pulses of nutrients released into the water have caused extensive phytoplankton blooms (Furnas 1989).

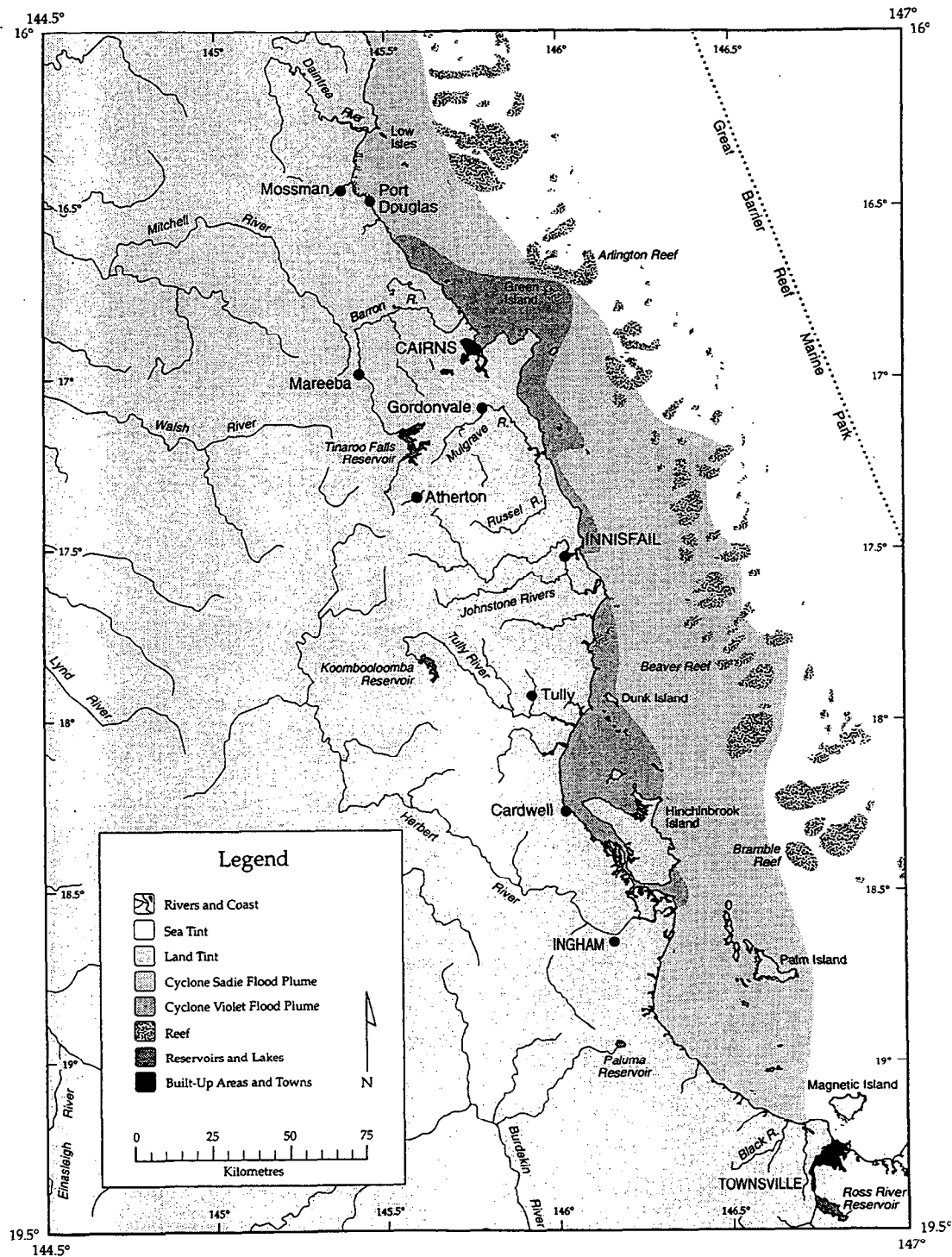


Figure 1. Areal extent of cyclone Sadie and Violet flood plumes

The effects of nutrient enhancement on coral reefs are now fairly well known (Kinsey 1991b) with the largest 'natural experiment' having occurred in Kaneohe Bay, Hawaii. In this large partially enclosed bay with an extensive barrier reef system primary and secondary treated sewage effluents were discharged from after World War II until 1977. Extensive reef degradation occurred with the areas nearest to the outfalls becoming dominated by filter-feeding organisms while in areas some distance away coral was replaced by algal communities

(Smith et al. 1981). Since the discharges were removed in 1978 the coral communities have made a slow recovery although this is by no means complete (Maragos et al. 1985).

Excess nutrients can have a number of affects on coral and reef systems (Kinsey 1991b). Nitrogen or phosphorus are often limiting nutrients for the growth of phytoplankton, especially in warm, clear tropical waters where light is unlikely to be limiting. Thus phytoplankton flourishes in nutrient enhanced conditions leading to decreased water clarity and reduced light for coral growth on the bottom. This effect was recorded in Barbados by Tomasic and Sanders (1985). The increased phytoplankton crop also encourages the growth of filter-feeding organisms such as sponges, tube worms and barnacles which compete for space with coral. As many of these organisms bore into the coral reef structure enhanced reef bioerosion may occur leading to the loss of reef structural integrity. These effects have been documented in the Cayman Islands as well as in Kaneohe Bay. Coral-boring urchins such as *Echinometra matheii* also proliferate on such reefs and have been documented in Tanzania, Fiji and the Ryukus. In addition nutrients enhance the growth of turf and macroalgae which overgrow the coral, both competing for space and shading the colonies. Macroalgal overgrowth of coral reefs in nutrient enhanced conditions has been studied in Bermuda and the Red Sea (Walker and Ormond 1982). Excessive phosphorus concentrations weaken the coral skeleton by making it grow with a less dense structure and making the colony more susceptible to damage from storm action (Rasmussen and Cuff 1990). A general reduction in calcification of the reef system also occurs (Kinsey and Davies 1979). Diseases in corals (black-band, white-band) also appear to increase in intensity in nutrient polluted waters.

A possible secondary effect of increased phytoplankton abundance is the postulated increase in crown-of-thorns larval survivorship arising from increased phytoplankton food availability. The increased survivorship is postulated to lead to subsequent increased recruitment and outbreaks of the starfish. The population of the crown-of-thorns starfish (*Acanthaster planci*) has exploded in waves of outbreaks on Indo-pacific coral reefs since the mid-1960s (Birkeland and Lucas 1990). This coral-eating echinoderm has devastated reefs in many parts of the western Pacific region and many anthropogenic causes have been invoked to explain the outbreaks. The two most enduring have been overfishing of predators (fish or the triton shell) (Lassig and Engelhardt 1994) and enhanced survivorship of the larval stage of the animal (Brodie 1992; Birkeland and Lucas 1990) due to phytoplankton blooms associated with enhanced nutrient runoff from coastal development (agriculture, sewage, soil erosion). Despite many years of substantial research effort a conclusive answer as to whether the outbreaks are caused or enhanced by human activity and if so what are the causes has not emerged.

In seagrass beds low to moderate nutrient enrichment has led to increased seagrass biomass and expansion of seagrass areas. With higher levels of enrichment epiphytes overgrow the seagrass (as seen in temperate waters) and the seagrass may be out-competed for space by benthic algae. Severe reductions in seagrass coverage may then occur. This has been the case in Florida Bay (USA) where recent large scale losses of seagrass have been associated with increased release of nutrient rich waters from agricultural areas in Florida. We have little information on changes in seagrass communities in the GBR as no wide-scale temporal monitoring has occurred.

Increased sediment loads lead to muddier systems with less light for bottom communities, disturbance to bottom fauna due to siltation and river-mouth aggradation. River aggradation in the lower reaches of the river may lead to increased flooding and boating problems due to lack of depth. In north Queensland both the Pioneer River (Goulay and Hacker 1986) and the Johnstone River (Arakel et al. 1989) have dramatically increased sedimentation and aggradation in recent years blamed in both cases on land use practices in their catchments. Other rivers can be expected to be in a similar condition but have not been studied.

Mangroves, which grow in muddy environments, may actually increase in area with increased sediment deposition and this appears to be the case in Cockle Bay, Magnetic Island where the area of mangrove has expanded at the expense of beach and seagrass areas (Alan Mitchell pers. comm.). However in areas with severely increased suspended sediments mangroves may also be damaged and lost (Hatcher et al. 1989).

Seagrasses are more susceptible to sedimentation damage than mangroves, suffering from both the lack of light caused by more turbid water and direct smothering from deposited mud (Hatcher et al. 1989; Robertson and Lee Long 1991). In recent times large areas of seagrass meadow has been lost in muddy flood events. Over 1000 square kilometres of seagrass were lost in Hervey Bay in February 1992 following two large floods in the Mary River (Preen 1993). As a result the population of dugongs in the area, dependent on the seagrass for food, crashed from an estimated 1466 animals in 1988 to 92 in November 1992. A similar loss of seagrass appears to have occurred around Townsville in the early 1970s (Pringle 1989), possible associated with cyclone Althea (1971), but this was not fully studied at the time and the sequence of events is not as clear as in the Hervey Bay case.

Coral reefs may be severely affected by even moderate increases in sedimentation and turbidity but paradoxically some corals thrive in the quite muddy conditions found on inshore reefs such as Virago Shoals and Middle Reef in Cleveland Bay and at Cape Tribulation. This depends on their tolerance for low light conditions and their sediment rejection and removal mechanisms (Stafford-Smith and Ormond 1992). There is considerable anecdotal evidence that many reefs, particularly inshore fringing reefs, are now muddier, have less coral but more algal cover. For example accounts suggest coral reef flats on Magnetic Island formerly had far higher coral abundance than at present. Similar stories can be documented from other inshore fringing reefs. The reef slope communities seem to be in better shape perhaps implicating sedimentation as the cause of coral loss on the flats.

Turbid water from sediment runoff also causes impacts to coral reefs by reducing light levels. Corals need light for their symbiotic algae (zooxanthellae) to function. A common response of corals to prolonged exposure to turbid water is expulsion of the zooxanthellae so that the coral appears white or bleached. In the long-term, depending on the level of stress, bleached corals may recover and reestablish their zooxanthellae or die. Bleaching followed by death was common in the Keppel Island reefs after the prolonged Fitzroy River flood of 1991 (Byron and O'Neill 1992) while bleaching followed by recovery appears to be occurring on Pandora Reef in Halifax Bay following the Cyclone Sadie floods of early 1994 (DeVantier et al. 1995, in press).

Many corals and coral reef systems seem to be able to exist successfully in relatively highly turbid environments. The reefs of the Cape Tribulation mainland shore north of the Daintree River exist in highly turbid water and large increases in turbidity associated with a poorly constructed coastal dirt road appear to have had minimal impact on the reefs (Craik and Dutton 1987; Ayling and Ayling 1991; Fisk and Harriot 1989).

As research and monitoring programs have progressed in recent years a confused picture of the scale and nature of eutrophication/sedimentation problems in the GBR have emerged. Anecdotal accounts from long-term residents or visitors to the GBR suggest that reef water is now more turbid and the reefs, particularly inshore fringing reefs, have more algae and less coral cover than in the period remembered before 1970. With a lack of good long-term monitoring records from these reefs to support this evidence the Great Barrier Reef Marine Park Authority has been collecting historical photographs of reefs (generally reef flats exposed at low tide) for comparison with current conditions. The comparisons appear to show less branching coral cover on some reef flats but relatively unchanged conditions on others.

Evidence of eutrophication in the phytoplankton record is unclear. No long-term records of phytoplankton biomass in the GBR lagoon exist which would allow us to definitively trace long-term trends. The existing records, particularly the data from the British Museum Great Barrier Reef Expedition in the Low Isles region of 1928-1930 (Orr 1933; Marshall 1933) and Revelante and Gilmartin's work (1982) in the late 1970s off Townsville, have been used as a comparative record by some researchers. Studies which have repeated measurements of phytoplankton composition and abundance first done in 1928-29 in a single area near Low Isles have found significant differences, e.g. for diatoms, and the claim has been made that the differences show the system to be in a higher nutrient condition than at that time (Bell and Elmetri 1993). Results from broad-scale phytoplankton surveys in the GBR on the other hand show biomass and species composition consistent with an unimpacted system (Furnas 1991; Liston et al. 1992).

Corals grow in annual increments and hence leave a record in their skeleton of their growth characteristics in the year of deposition. As coral growth is related to environmental conditions in the surrounding waters coral skeletons retain a record of these conditions. Corals may attain ages of several hundred years and thus interpretation of environmental conditions over this period is potentially available from cores taken from old coral colonies (Isdale 1984). Evidence from coral cores from near the Queensland coast suggest that coral growth conditions did change significantly in recent times and that this can be correlated with land use changes on the adjacent coast (Rasmussen et al. 1994). Some problems still remain in separating an anthropogenically sourced signal in the coral skeleton from natural variability in environmental conditions and the coral's response to these conditions but some evidence of deteriorating water quality conditions reflected in these cores has been reported (Rasmussen et al. 1994). Off Cairns studies of the 'void space', i.e. the proportion of holes in the coral, in coral growth rings suggest that significant changes in water quality occurred starting about fifty years ago. These changes adversely affected the growth of the coral and have been correlated with land use changes on the adjacent Barron River catchment (Rasmussen et al. 1994).

In some limited areas of the GBR region evidence of eutrophication is indisputable. Large increases in the area of seagrass beds around Green Island are associated with the prolonged discharge of untreated sewage from the island and the retention of the diluted discharge in the vicinity of the island (van Woessik 1989). Sediments in the vicinity of the actively expanding seagrass areas have high nutrient concentrations and the seagrass is growing in reefal environments where seagrass does not grow on other GBR midshelf reefs. Similarly Trinity Inlet, next to Cairns city, and subject to prolonged sewage discharge into confined waters is now known to be eutrophic with continuous and periodically intense phytoplankton blooms. A secondary treatment sewage discharge from the Hayman Island Resort in the Whitsundays caused localised effects on the adjacent coral reef (Steven and van Woessik 1990) including reduced species diversity, lower coral cover, suppressed coral recruitment and greater turnover of species. The outfall is now rarely used as effluent is used for resort gardens irrigation.

#### Pesticides

PCB, pesticide and herbicide levels in GBR waters and biota have been found to be low, and are not considered to pose a threat to the functioning or integrity of the reef (Olafsson 1978; Richardson 1985). Bioaccumulative pesticides such as organochlorins were phased out of most agricultural use in 1985 and from urban use for termite control in 1995. The current use of less persistent organophosphates, and the implementation of integrated pest management techniques has significantly reduced the threat of agricultural chemicals to the GBR. The presence of Atrazine, a persistent herbicide used extensively in the sugar industry, in a range of estuarine biota needs review.

## Heavy metals

Heavy metals are of local concern and are discharged in mining operations, industrial effluents, and sewage. Results from extensive baseline studies of metals in water and biota from the GBR in the 1970s revealed generally low concentrations comparable to other relatively pristine marine environments (Denton and Burdon-Jones 1986a, 1986b). One animal showing considerable concentrations of heavy metals in its liver and kidney was the dugong (Denton et al. 1980) a long lived species capable of accumulating metals in these tissues throughout its life. Presence of the cyanophyte *Trichodesmium* sp. has been identified as an important factor in the cycling of trace metals in the GBR lagoon (Jones et al. 1986; Jones and Thomas 1988).

At more local scales, trace metal studies associated with harbour and shipping channel dredging near Townsville, showed some potential for such activity to lead to the remobilisation of trace metals and movement to adjacent reefal areas (Reichelt and Jones 1994).

The Torres Strait Baseline Study (TSBS) was initiated in response to the concerns of Torres Strait Islanders, scientists and fishermen about the possible effects on the Torres Strait marine environment from mining operations in the Fly River catchment of Papua New Guinea. The study provided information on the trace metal content of sediments, indicator organisms, and some of the traditional seafoods of the Torres Strait and northern GBR. Major findings of the study (Gladstone 1996; Evans-Illidge 1996; Barry and Rayment 1992) are that:

- Trace metals derived from mainland Papua New Guinea include aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, lead and zinc. Levels of these metals are highest in fine-grained sediments in the northern Torres Strait near the mouth of the Fly River.
- Levels of aluminium, copper mercury nickel and zinc are higher in sediments coming from the Fly River, but these sediments penetrate only a small distance into the Torres Strait.
- Levels of cadmium, copper, lead, and zinc in the Torres Strait and mouth of the Fly River were similar to levels found in comparable, unpolluted locations in the tropics.
- Trace metal concentrations measured in the burrowing clam, *Tridacna crocea*, corresponded with trends occurring in the sediments, and are a product of environmental levels of these metals as well as a combination with other physical and chemical environmental variables.
- Trace metal content of a wide range of seafoods eaten by Torres Strait Islanders were generally low, compared to standards. The exception is cadmium which occurs in high concentrations in dugong, turtle and crayfish tissues. Similarly high levels also occur in dugong from other parts of Queensland.

## Hydrocarbons

Trace levels of hydrocarbons believed to be residues of human activity have been detected in water, sediments and biota, in areas of the GBR near tourism and boating facilities (Smith et al. 1984, 1985, 1987; Brodie et al. 1992; Coates et al. 1986), for example Green Island. It is not considered that, at the levels detected, the residues pose any threat to ecosystem integrity.

## **Sediment and nutrient monitoring**

Measurement of water quality parameters in the GBR region has a long history with significant data from as far back as the British Museum Great Barrier Reef Royal Society Expedition of 1929-1930 (Orr 1933). However continuous, reliable data sets really only started to be collected by the Commonwealth Scientific Industrial Research Organisation and then the AIMS in the last fifteen years. Large data sets of oceanographic parameters, nutrients and chlorophyll are available from the work of Andrews and coworkers in the early years of the 1980s (e.g. Andrews 1983; Revelante and Gilmartin 1982) and then the AIMS Biological Oceanography Group from the mid-1980s to the present (e.g. Furnas 1991; Furnas et al. 1992). Satellite remote-sensed monitoring of chlorophyll and turbidity using the Coastal Zone Colour Scanner has been attempted (Gabric et al. 1990) but considerable difficulties in the interpretation of the data and the loss of the platform in the mid-1980s have prevented continued use. Monitoring of benthic community condition started with broad scale surveys of crown-of-thorns numbers and gross coral cover in the mid-1980s and has progressed now (since 1991) to more detailed annual surveys of coral cover and composition on a large number of reefs (~150). Monitoring also encompasses long-term sea temperature monitoring and irregular surveys of pesticides and heavy metals in biota.

### **Inputs**

#### *Rivers*

The principal input of sediments and nutrients to the inshore waters of the GBR is river runoff. The scale and dynamics of this input is described in Furnas et al. in this volume.

#### *Upwelling*

The nutrient dynamics of outer-shelf waters are seasonally and episodically influenced by intrusive upwelling of Coral Sea thermocline water along the shelf-break. This intruded water, with elevated nitrate concentrations, moves into and through the reef matrix over extended areas of the shelf (Furnas and Mitchell 1986; Liston et al. 1992). The upwelled water is nutrient rich in comparison to water masses in the GBR lagoon and Coral Sea surface water and is an important input to the nutrient budget of the GBR (Furnas et al. 1995).

### **Lagoon status**

#### *Background*

Most of the ca. 2900 reefs forming the GBR are platform reefs located away (-100+ km) from the coastline in low-nutrient (Furnas 1991) shelf and oceanic waters. However, a significant number (ca. 750) of coral reefs and outcrops also exist throughout the GBR region in coastal and nearshore habitats. Reefs and corals near the coast are continually or episodically subject to varying degrees of stress from seasonal temperature fluctuations, freshwater runoff, coastal rainfall, sediment deposition and ongoing sediment resuspension. Sediments derived from eroded soils remain concentrated within the nearshore zone (Belperio 1983; Gagan et al. 1987; Johnson and Carter 1988, Pailles and Moody 1995) comprising a relatively small percentage (< 10 percent; Furnas et al. 1995) of total shelf area and water volume. Despite the apparent departure from the supposedly 'ideal' environmental conditions for coral reefs, nearshore and coastal reefs in the GBR are or have been both healthy and support coral assemblages as diverse as reefs in clear-water offshore habitats (Veron 1995). However, Kinsey (1987) has noted that while nearshore and fringing reefs are or may appear to be in a turbulent, but



'healthy' state, they are likely continually subject to frequent episodic and chronic stresses from salinity fluctuations, nutrient levels, organic inputs and sediment loading.

What information exists, therefore, about the current status of water quality and reefs, particularly nearshore reefs in the GBR and historical trends, if any, in reef status?

Surveys of mid- and outer-shelf reefs throughout the GBR indicate that most are in a nominally 'healthy', if perhaps naturally perturbed state. For these reefs, episodic crown-of-thorns starfish infestations are the major source of dramatic alteration, followed by cyclonic disturbance. However, major recent changes in coral cover in some areas (e.g. the Capricorn Bunker group) do not appear to be due to these causes.

Coastal and nearshore reefs exhibit a range of apparently healthy to clearly degraded states. While parts of many coastal reefs appear to be in a relatively 'normal' state and have recovered from disturbances, some shallow reef flat communities on nearshore reefs with significant coral assemblages have disappeared over the last 50-100 years.

### *Methods*

In order to determine the impact of human activities, particularly land use practices upon nutrient levels and water quality within coastal and reef waters of the GBR shelf, it is essential to first define, as best possible, naturally occurring nutrient concentrations in GBR waters and their variability. As part of oceanographic studies carried out by the AIMS within the greater GBR region over the last 15 years, a large body of nutrient and other water quality related information has been collected. While not collected explicitly to address water quality issues, it has the largest temporal and spatial coverage of any data set and the advantage of having been collected and analysed in a consistent manner by a small group.

In addition to this data set a long-term water quality monitoring program commenced in November 1992 to monitor the nutrient status of the GBR through chlorophyll measurements (Brodie and Furnas 1994). The objectives of this monitoring program were to detect long-term trends in nutrient status of the GBR lagoon; to detect and quantify regional differences in nutrient status and correlate these with nutrient input in those areas; to quantify cross shelf differences in nutrient status and correlate these to nutrient input information; and to monitor the effectiveness of programs to reduce the terrestrial input of nutrients on the nutrient status of Park waters.

The program was based around using chlorophyll measurements as a measure of phytoplankton abundance which is an integrating indicator of nutrient availability (Brodie and Furnas 1994). Thirty stations in six latitudinal transects are sampled on a monthly basis. A further hundred stations spread over the whole GBR are sampled once or twice a year.

Much of the raw data is summarised in data reports (Mitchell 1982; Bellamy et al. 1982; Furnas and Mitchell 1984a, b; Furnas et al. 1990, 1995). Details of sampling procedures and chemical analysis methods are given in the specific reports. With minor changes, sampling practices have been stable throughout the 15-year period. Sample handling and analytical methods have largely been similar throughout, changing in an evolutionary manner. The net effect of these changes has been to enable the reliable analysis of smaller in situ nutrient concentrations.

For the purpose of graphical presentation and statistical analysis, depth-weighted mean water column concentrations of all the nutrient species and water quality parameters measured at each station were calculated. If only surface samples were collected, this value was taken as the water column mean. Most surface samples were collected in the GBR lagoon where the water

column is well mixed. Comparisons between surface values and depth weighted means suggest that for most species, the two are similar. Where surface or near-bottom data were missing, values from the nearest sampling depth above and below were used.

### *Results*

#### Biological oceanography data

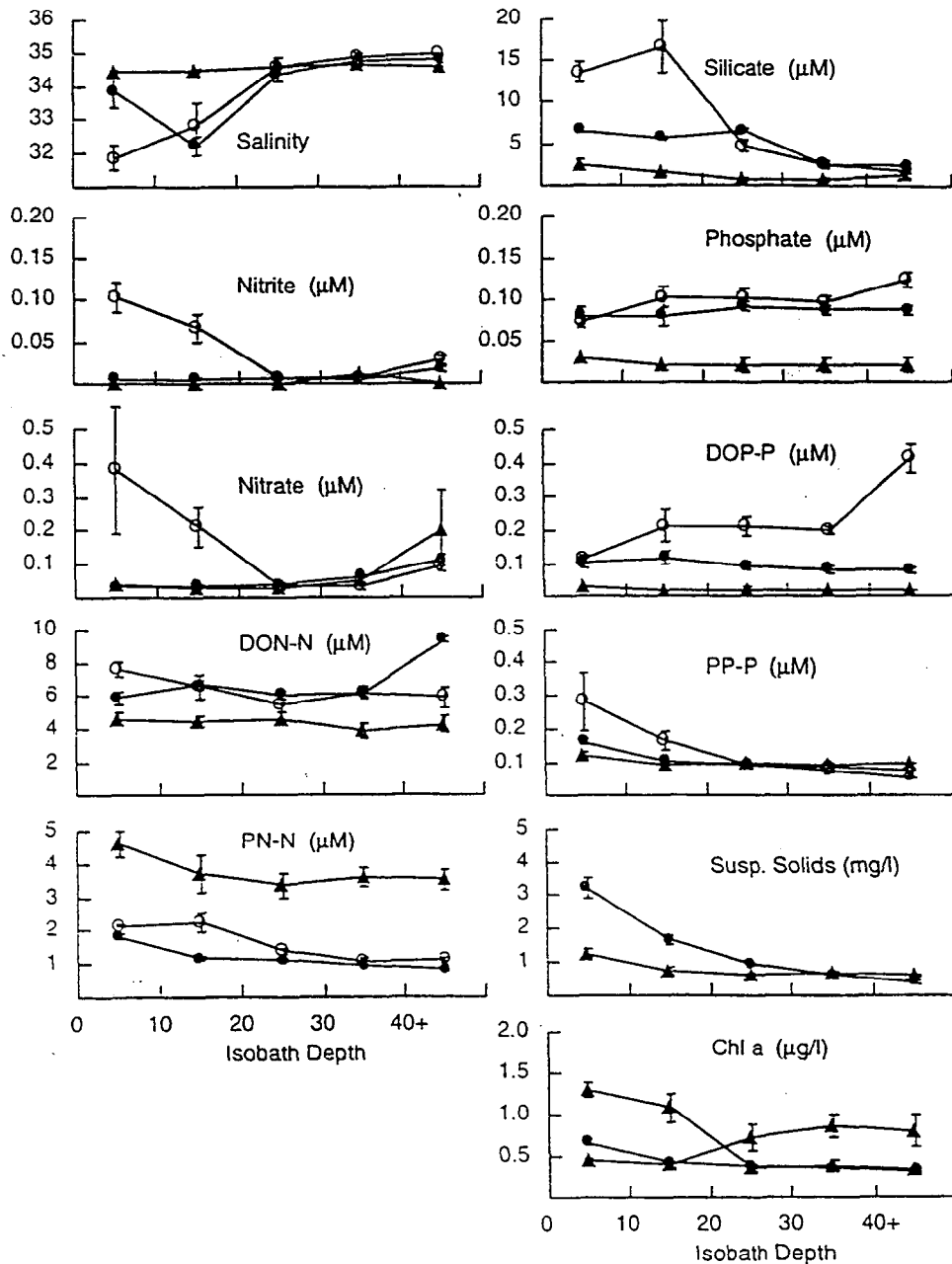
Water column nutrient, pigment and suspended sediment concentrations segregated into sectoral, seasonal and cross-shelf bins are summarised in Figs. 2-4. Despite the large number of stations considered overall (1500+), a small number of sectional/ season/depth combinations have not been sampled to date. Individual means shown are based upon data from 4 to 300 stations. Because of changing sampling objectives over the years (1979-1995) not all constituents shown were sampled at all stations. Of the constituents shown, fewer particulate nitrogen (PN) and suspended solids (SS) data are available. Ammonium (NH<sub>4</sub>) data is not shown because high quality data requires the analyses to be carried out on fresh samples, preferably at sea, which was not done in most cases. Where such procedures were carried out, chiefly in the Townsville, Innisfail and Cairns sectors, mean NH<sub>4</sub> concentrations were consistently on the order of < 0.1 μM. Most station data is from the central GBR region (Cooktown to Townsville).

Analyses of variances calculated with the station mean data (sector x cross-shelf x season) indicates that for all constituents save nitrite, chlorophyll and suspended solids, there were significant sectoral (latitudinal) variations. Minimum concentrations of almost all measured constituents were observed in the far northern GBR sectors (Shelbourne Bay - Cooktown). Maximum or near-maximum concentrations of a number of nutrient species exhibited a bimodal distribution, with elevated concentrations in the Torres Strait sector, the central GBR sectors (Cairns - Pompey Reefs), or both. While no sector adjoins completely pristine land, watershed areas on eastern Cape York used for agricultural (chiefly grazing) are generally smaller than to the south. In addition there has been minimal land clearing east of the continental divide on Cape York and inputs of fertilisers or sewage are negligible.

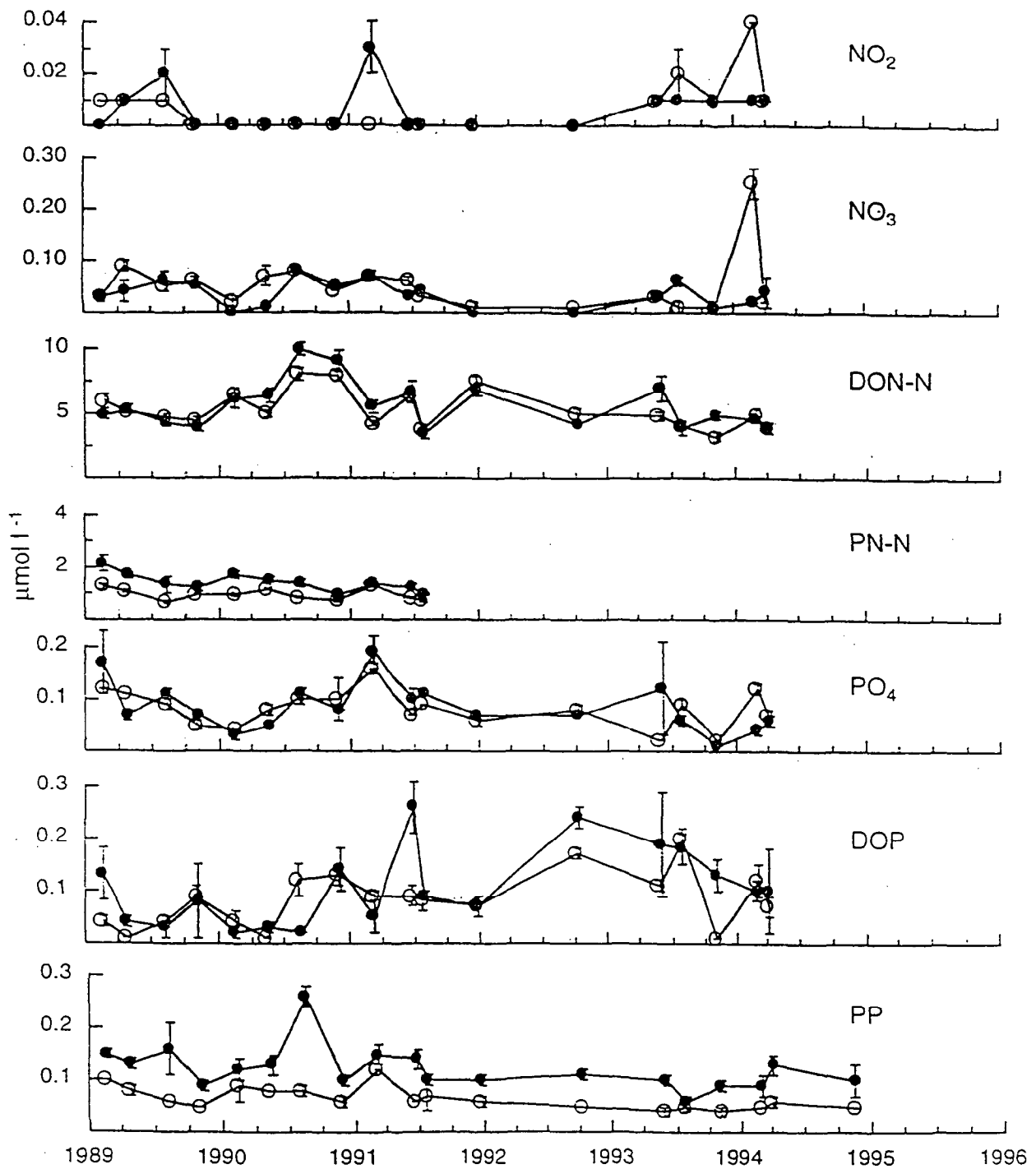
Over the full data set, only DON, phosphate and DOP did not exhibit statistically significant ( $p < 0.05$ ) cross-shelf gradients. However, in two sectors (Cairns and Innisfail) where relatively large numbers of stations were occupied across the full width of the shelf, local cross-shelf gradients in most water column characteristics are evident (Fig. 2). Not surprisingly, particulate species had higher mean concentrations at nearshore stations. Elevated concentrations of nitrite, nitrate and silicate were also measured in the river and mangrove-affected inshore waters of the Innisfail sector. Dissolved phosphorus species showed little or no cross-shelf variation off Cairns, and increased offshore in the Innisfail sector.

Within the full GBR data set, salinity, nitrite, particulate-N, dissolved organic-P and chlorophyll exhibited statistically significant seasonal differences in mean concentrations. In 2- and 3-way ANOVA designs, a considerable number of significant sectoral, cross-shelf and seasonal interactions were observed. These interactions exhibited no clear pattern and their ecological significance is difficult to judge given the long period over which the data were intermittently collected. Most of the observed seasonal and cross-shelf variability in nutrient and suspended matter concentrations is likely due to short-lived event processes (upwelling, winds, resuspension) which largely affect local or regional nutrient distributions. Time series of water quality parameters in the well-sampled Cairns sector between 1989 and 1994 (Figs. 3 and 4) are characterised by distinct between-cruise variability, but all lack an overall temporal trend. The absence of secular trends indicates that properly controlled data sets collected intermittently over several years can be aggregated to produce useful regional estimates of

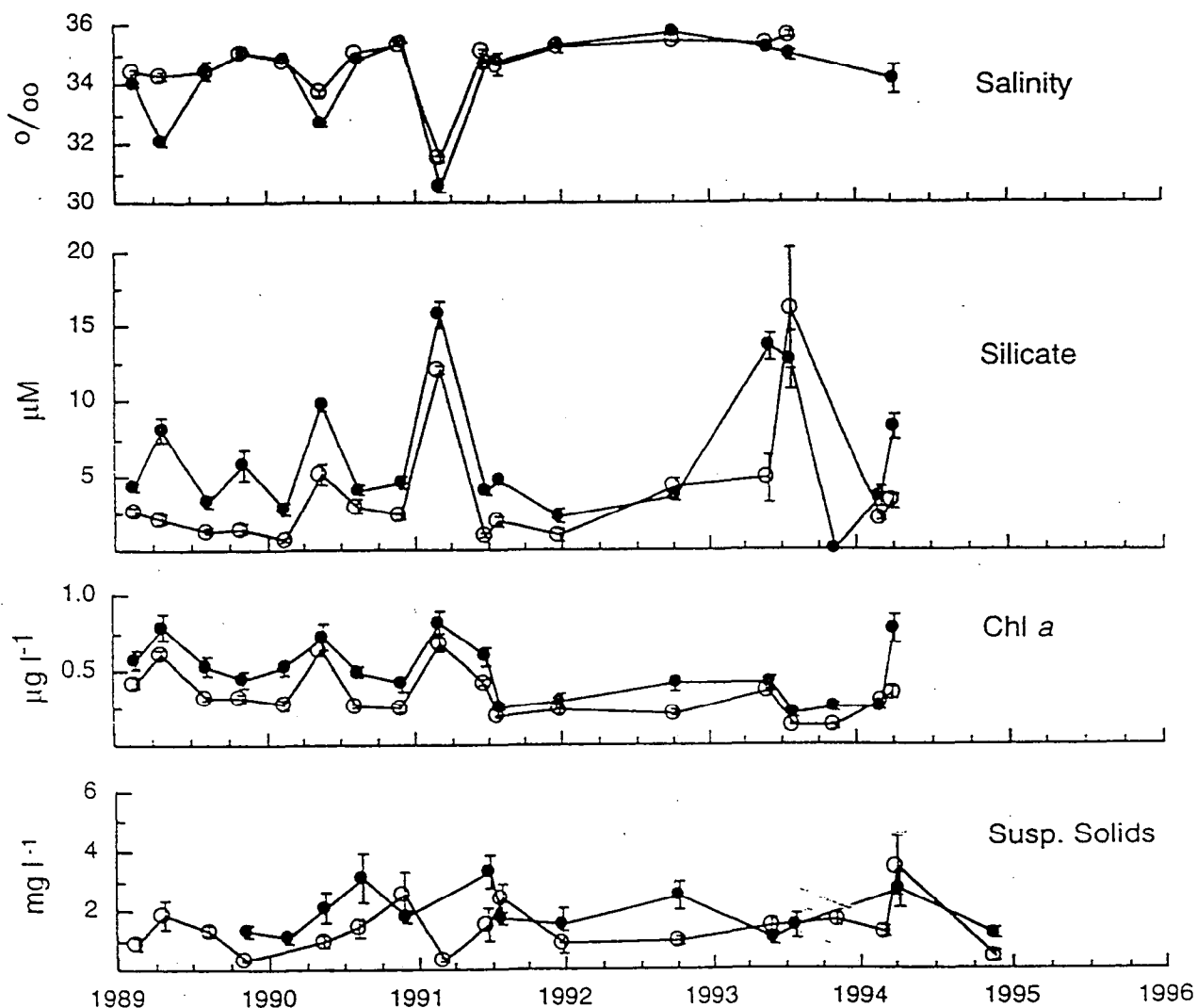
mean nutrient concentrations and variability. However, the inter-annual (medium term) variability observed in the Cairns data sets is sufficiently large to suggest that it may be unwise to estimate long-term trends in water quality from differences between temporally separated data sets derived from relatively short (1 year) sampling periods.



**Figure 2.** Mean cross shelf changes in water quality parameters for all stations within the Shelburne Bay (▲), Cairns (●) and Innisfail (○) sectors. Stations within each sector were grouped into 10 m depth bands for depths < 40 m. All stations deeper than 40 m were aggregated in the deepest band. Error bars indicate 1 standard error about the mean.



**Figure 3.** Temporal changes in mean concentrations of nitrogen and phosphorus species at coastal (< 20 m: ●) and offshore (> 20 m: ○) stations in the Cairns sector between 1989 and 1995. Error bars indicate 1 standard error about the mean.



**Figure 4.** Temporal changes in mean salinities and concentrations of silicate, chlorophyll a and suspended solids at coastal ( $< 20\text{ m}$ : ●) and offshore ( $> 20\text{ m}$ : ○) stations in the Cairns sector between 1989 and 1995. Error bars indicate 1 standard error about the mean.

#### Chlorophyll monitoring data

Results for chlorophyll for the first year of the monitoring program from the Lizard Island, Port Douglas, Cairns and Keppels transects are summarised in Table 1.

#### Plume monitoring

As discussed above, under normal circumstances dissolved nutrient and particulate matter concentrations in coastal and shelf waters of the GBR are low and do not exhibit dramatic latitudinal and cross-shelf gradients, or seasonal variability. When significant deviations from low nutrient levels occur over regional spatial scales, the increases are associated with tropical cyclones, or the river flood plumes which invariably follow cyclones and summer monsoonal rain depressions (Orr 1933; Revelante and Gilmartin 1982; Furnas 1989). In the absence of accidental or point-source pollution inputs, nutrient and suspended particulate concentrations associated with cyclones and floods are the highest that most GBR reef communities are likely to be exposed to.

**Table 1.** Chlorophyll trend summary

• Cross Shelf trends	gradient present - offshore range 0.2-1.0 mg/l - inshore range 0.4-1.8 mg/l - greater variability inshore
• Seasonal trends	- Dec.-April range -up to 1.8 mg/l - May-Oct. range-up to 0.5 mg/l
• Latitudinal trends	- not apparent
• Depth trends	- not strongly present but bottom generally greater than surface

A variety of observations made over the last 70 years can be distilled to identify natural extremes of nutrient and particulate concentrations in GBR waters. Most of these observations were made in shelf waters generally affected by terrestrial runoff, or directly by river discharge plumes. More recently, however, a growing body of sampling has been carried out in inner shelf waters following the major resuspension events caused by tropical cyclones. Post-cyclone nutrient and suspended particulate concentrations on the outer shelf are similar in a number of ways to those caused by river plumes. While the mechanisms which produce the high nutrient and particulate loads are different, the proximate cause (cyclones) is usually the same.

Australian rivers are known to have unusually erratic flow patterns (Harris 1995). The larger dry-catchment coastal Queensland rivers such as the Burdekin and Fitzroy are extreme in this sense with average intervals between major flows of several years. The 'wet tropics' rivers, on the other hand, although also displaying highly event driven discharge display a more even discharge pattern with one or more major flows almost every year. This is a consequence of their location in the relatively reliable monsoon rainfall 'wet tropics' coastal region. The Tully, Johnstone and Russell-Mulgrave Rivers have relatively even discharge patterns for Australian rivers (Anon. 1978).

Particulate and some, but not all, dissolved nutrient concentrations in NE Queensland river waters reach peak values during flood events. During floods, swollen rivers push normal estuarine mixing, biological and geochemical processes out over the middle and inner shelf in discharge plumes. Concentrations and forms of particulate matter and nutrients in flood plumes reflect the concentrations in the source waters, the extent of mixing with shelf waters and biological processes occurring over time in river plumes (e.g. Ryther et al. 1967). Since the largest proportion of the annual discharge of sediments and nutrients from rivers into the GBR occurs during large flood events it is important to understand if and how extreme water quality conditions associated with floods influence water quality and reefs in the GBR.

The Burdekin and Fitzroy Rivers (watershed areas 130 000 and 140 000 km<sup>2</sup>, respectively) are the two largest catchments draining into the GBR. Annual discharge from these rivers varies considerably from year to year, with major flood events separated by long, drier periods with little river flow. During major floods in the Burdekin and Fitzroy Rivers, high discharge rates may persist for several weeks, discernible plumes can extend for several hundreds of kilometres away from the river mouth (Wolanski and van Senden 1983) and low salinity water masses can be identified for several weeks. In the absence of strong wind forcing of surface currents, the buoyancy of low salinity water and geostrophic forces are the major factors controlling the movement of flood waters on the shelf (Wolanski and Jones 1981).

Following the major flood events of 1979-80 and 1980-81, low salinity anomalies derived from Burdekin River floodwaters were tracked along the central GBR shelf between the river mouth and Cairns, 350 km to the north, and as much as 40 km away from the coast (Wolanski and Jones 1981; Wolanski and van Senden 1983). For the most part, however, low salinity flood waters remained close to the coast, well away from outer shelf reefs. Significant interactions between plume water and offshore reefs only occurred north of Hinchinbrook Island (18°S), by which time, significant salinity alterations had occurred in the river water. High suspended sediment loads were restricted to the coast, with most particulate matter sedimenting at salinities < 10‰ (Wolanski and Jones 1981).

High dissolved nutrient concentrations have been measured off Townsville and in Bowling Green Bay, 20 to 50 km north of the Burdekin River mouth for periods of two or more weeks during the 1977-78 wet season (Revelante and Gilmartin 1982) and following cyclone Charlie in 1988 (Liston 1990), decreasing as local phytoplankton and zooplankton populations developed a pronounced bloom in response to the available nutrients.

Cyclone Joy (1990-91) produced significant floods in both the Burdekin and Fitzroy catchments which lasted for a number of weeks. Off Townsville, low-salinity water (22‰) was observed 25 km offshore. The frontal zone between low salinity plume water and low nutrient shelf waters was accompanied by enhanced phytoplankton concentrations and local increases in larval fish populations (McKinnon and Thorrold 1993).

Following major flooding in the lower Fitzroy River catchment (Brodie and Mitchell 1992; Preker 1992), low salinity plume water was observed in the Capricorn-Bunker group of reefs, more than 200 km from the mouth of the river. Salinities as low as 28‰ were recorded at the Capricorn Bunker reefs and some damage to corals was observed. Low salinity water (down to 8‰) persisted around the coral reefs of Keppel Bay for a period of three weeks (O'Neill et al. 1992) causing significant coral mortality (van Woosik 1991). Winds appeared to be a major factor influencing the movement of the Fitzroy River plume on the shelf. During the first two weeks of the flood, fresh southeasterly winds prevailed and the plume moved along the coast to the north. In the third and final week of the flood, the winds weakened and shifted to the north. During this period, part of the plume moved southeast toward the Capricorn-Bunker reefs.

Although smaller in discharged water volume, short-lived river plumes from the numerous small north Queensland rivers have been observed during and after cyclonic floods at a number of mid- and outer-shelf locations. Following cyclone Dominic (1981), Davies and Hughes (1983) observed abrupt changes in current and suspended particle loads at Boulder Reef, a mid-shelf reef near Cooktown arising from flooding in the nearby Endeavour River. Maximum suspended particulate loads impinging on the reef reached ca. 200 mg l<sup>-1</sup>. Aerial observations carried out immediately following cyclones Winifred (1986; M. Jones, pers. comm.), Sadie (1994) (Brodie and Baer 1995) and Violet (1995) have identified turbid river plumes in the GBR lagoon. During significant events such as cyclones Sadie and Violet (Fig. 1), discharges from a number of small rivers and streams (in particular the Herbert, Tully, Johnstone, Russell-Mulgrave, Barron, Mossman and Daintree) merged into a broad plume (Fig. 1) which covered substantial areas on the inner- and mid-shelf. In all cases, the short period of direct impingement upon outer-shelf reefs reflected the brief duration of high flow in these catchments.

Recognisable distributions of flood plumes in the central GBR appear to be directly related to winds over the shelf (Fig. 1). Under relatively calm conditions following cyclone Sadie, the merged plume extended seaward over much of the shelf. In contrast, the Violet plume was restricted to a shallow, nearshore band by stronger SE tradewinds following the cyclone.

The role of wind driven resuspension on the deposition of sediment on reefs and in stimulating phytoplankton blooms was first noted during the Great Barrier Reef Expedition (Marshall 1933; Marshall and Orr 1931). Increases in phytoplankton standing stocks were noted after a number of periods of strong wind. As most of the species of algae involved were wholly planktonic, the increases were likely caused by inputs of additional nutrients to the water column. Increases in terrigenous sedimentation on reefs was related to seasonal winds, but direct connections to wind events were not well resolved.

As cyclones pass over the GBR shelf, the strong winds and large waves surrounding the eye resuspend bottom sediments in a wide swath (Gagan 1990). Large amounts of dissolved and particulate nutrients within the sediments are dispersed throughout the water column (Chongprasith 1992). Following resuspension events, phytoplankton rapidly grow (Furnas 1989), utilising the added nutrients, while a range of biological processes which affect nutrient speciation, in particular, the mineralisation of organic N and P forms and bacterial nitrification are also stimulated (Chongprasith 1992). First order calculations based upon laboratory resuspension experiments (Chongprasith 1992) indicate that prompt and delayed inputs of N and P from resuspension are significant relative to concurrent inputs from rainfall and river plumes. The relative balance resuspension and other sources reflects the size of the shelf area affected, sediment type, duration of the storm and magnitude of local river influences. In contrast to river plumes, maximum concentrations of many nutrient species following resuspension events are highest in turbid near-bottom waters due to light limitation of phytoplankton uptake (Furnas 1989). At present, our principal source of information on nutrients and particulates derived from resuspension is derived from cyclones Winifred (1986) and Aivu (1989).

#### Nutrients in river plumes and post-cyclone shelf waters

Table 2 summarises minimum salinities and maximum concentrations of water column nutrients and particulate matter following recent summer rain depressions, tropical cyclones and the floods which followed. The lowest salinities (<10‰) were observed in Keppel Bay following cyclone Joy (Brodie and Mitchell 1992). Concentrations of nutrient species exhibited a range of relationships to salinity in water samples affected by river plumes. The scatter reflects variability in source concentrations (between rivers and with time in individual rivers) and subsequent biological/geochemical activity. Silicate and phosphate exhibited the strongest linear relationships to salinity which are indicative of conservative dilution in shelf waters over short (day-week) time scales. Nutrient species affected by biological and geochemical processes displayed more complicated relationships to salinity due to local production and consumption dynamics. Although minimum salinities were generally only a few parts per thousand lower than usual (ca. 35‰), dissolved and particulate nutrient concentrations were at least one order of magnitude (10-fold) greater than normally measured in shelf waters. In the case of silicate, concentrations in plume waters were as much as 100 times normal shelf concentrations. Because of the low density of fresh- and mixed plume waters, the highest nutrient concentrations were generally found at the surface. When dispersed over the shelf, plumes are often present as thin sheets (< 1 m thick) of fresher waters. In the case of nitrogen, elevated concentrations of nitrite, in particular, are indicative of organic N loading of shelf waters (McCarthy et al. 1984).



**Table 2.** Minimum salinities and maximum nutrient, chlorophyll and suspended particulate matter concentrations sampled in Great Barrier Reef waters following cyclonic events

Cyclone		Winifred	Jason	Charlie	Aivu	Joy	Sadie	Violet
Date		Feb-86	Feb-87	Mar-88	Apr-89	Jan-91	Feb-94	Mar-95
Shelf Region Sampled		Central Insh+ Offsh	Central Inshore	Central Inshore	Central Insh+ Offsh	Southern Inshore	Central Lagoon	Central Lagoon
Minimum Salinity	ppt	29.3	29.84	28.7	34.42	7.9	29.2	2.2
Maximum NH <sub>4</sub>	μM	5	1.25	2.81	11.15	4.06	0.44	1.3
NO <sub>2</sub>	μM	0.29	0.24	0.36	0.33	1.2	0.02	
NO <sub>3</sub>	μM	3.15	7.8	3.27	0.79	2.41	1.2	14
DON	μmol/l				8.7	25.2	17.8	11
PN	μmol/l				10.8	11.2		
PO <sub>4</sub>	μM	0.6	0.19	1.13	0.48	1.58	0.06	0.32
DOP	μmol/l				0.18	1.98	0.32	0.2
PP	μmol/l				0.43	0.85		
Si(OH) <sub>4</sub>	μM	48	76	56	29	174	25	110
Chlorophyll a	μg/l	17.9		2.96	0.93	20.1	1.33	1.9
Phaeophytin	μg/l	6.1		0.8	1.43	1.33		2.5
Suspended Solids	mg/l			56		36	3	26

#### Cross-shelf distributions of terrestrial materials

Concentrations of plume-borne materials change markedly with distance and time as freshwater plumes extend and disperse along and across the shelf. Most noticeably, clay minerals flocculate and settle rapidly as fresh and saline waters mix in the plume. Most terrestrial sediment is deposited within 15 km of the coast (Johnson and Carter 1988). Other materials may be more widely dispersed, though the bulk are again deposited near the coast. Carbon isotopic ratios in sediment organic matter show terrestrial ratios within 1-5 km of the coast, declining exponentially to marine ratios at 15 km from the coast (Gagan et al. 1987). Similar cross-shelf gradients are seen in specific plant-derived compounds (Currie and Johns 1989) and organic-rich sediments (Pailles and Moody 1995). In general, there appears to be an inner-shelf zone dominated by terrestrial sediments and a wider, outer-shelf zone dominated by marine carbonate sediments (Alongi 1989). Several important features of plume nutrient dynamics are unresolved at this time. First is the extent to which nutrient and other fine particulate materials move away from the coast and interact with inshore and offshore sediments. Second, the dynamics of soluble species (e.g. PO<sub>4</sub>) released from river-born materials are not well characterised. In the case of P, opinions differ as to the potential release of PO<sub>4</sub> from sediment particles in plumes (Froelich 1988; Pailles and Moody 1992, 1995). At least some sediment-bound P is desorbed upon mixing between fresh and salt waters, but for north Queensland rivers, the amount has not been accurately measured over short time periods (days). In laboratory experiments mimicking conditions during resuspension events, Chongprasith (1992)

found that total N and P releases from shelf sediments were proportional to the amount of sediment resuspended.

## **Discussion**

The ecology of corals and coral reefs is directly influenced by the 'quality' of the water in which they live. Waters washing over and around reefs deliver and remove dissolved and particulate nutrients, sediments, prey and propagules and generally protect reef organisms from extreme fluctuations in dissolved gasses, temperature and salinity. However, what 'quality' is for individual corals and reefs and how it is manifested remains to be definitively established.

Constantly clear 'oceanic' water is not, by itself, an obligate requirement for the growth and survival of healthy corals. Under natural conditions, a very wide range of GBR coral species live or once lived on nearshore and coastal reefs along the NE Queensland coast (Veron 1995). Pristine terrestrial influence is clearly not detrimental to corals over long periods. At the other end of the spectrum, however, there is unequivocal evidence that high, chronic inputs of terrestrial sediment, organic matter or inorganic nutrients to reef systems will lead to their destruction by burial, disruption of recruitment or deleterious community shifts (Smith et al. 1981). Where along these gradients do water quality and reef status in the GBR lie?

Tentative proposals have been made to define water quality standards for coral reefs in the GBR region (Hawker and Connell 1989, 1992). These standards are based upon observational and experimental studies carried out overseas, particularly in the Caribbean (Tomasick and Sander 1985). It is unclear to what extent the conditions used to construct cause and effect relationships coupled to water quality reflect conditions naturally occurring in the GBR, particularly at coastal and nearshore sites.

Herein, we have summarised salinities, nutrient and suspended matter concentrations determined at a large number of sites throughout the whole of the GBR. The emphasis is upon defining the mean values of these parameters and their central domains of variability: water quality conditions within which corals and reefs exist most of the time. We have not included temperature as few measurements of annual temperature cycles and variability have been made at coastal reef sites. The effect and importance of high, outlying concentrations is, for the moment, not considered. Some reported high concentrations may be due to sampling artefacts or analytical problems. However, away from discrete sources of nutrients and sediments such as river mouths and sewage outfalls and episodic, severe resuspension events patches of water with high concentrations of sediments, nutrients and chlorophyll appear to be rare and ephemeral (Liston et al. 1992). After major events such as cyclones and floods, elevated nutrient concentrations disappear within a relatively short period (Liston et al. 1992). As with coral (Veron 1995) and fish communities, latitudinal gradients in nutrient and suspended matter concentrations were slight. The largest relative gradients (> 5-fold) were observed in nutrient species ( $\text{NO}_2$ ,  $\text{NO}_3$ ,  $\text{PO}_4$ ) with small absolute concentrations. For other nutrient and particulate species (e.g. DON, PN, Chl a), latitudinal variations in mean values are on the order of 2 to 3-fold.

Cross-shelf distributions of the measured dissolved and particulate parameters in two well-sampled sectors (Cairns, Innisfail) exhibit a variety of patterns. Lower salinities in the nearshore zone of the Innisfail sector point to the influence of runoff from the Herbert River and adjoining wet tropical region. In the Cairns sector, elevated salinities near the coast are indicative of evaporation in shallow waters. Unsurprisingly, concentrations of PN, PP, chlorophyll a and suspended solids are highest in the shallow nearshore zone, where terrestrial inputs and resuspension are concentrated. Mean suspended sediment concentrations near the coast in the Cairns sector are nearly six times concentrations seaward of the 40 m isobath and

2-3 times concentrations around the 20 m isobath. Cross-shelf PN, PP and chlorophyll gradients are also on the order of 2- to 3-fold. In contrast, NO<sub>2</sub> (Cairns only), NO<sub>3</sub> (Cairns only), DON, PO<sub>4</sub> and DOP (Cairns only) exhibited relatively little cross-shelf variation. The high outer shelf DOP concentration off Innisfail is suspect. Elevated concentrations of NO<sub>2</sub>, NO<sub>3</sub> and silicate in the Innisfail sector are indicative of greater amounts of freshwater runoff in this sector.

Collectively, these cross-shelf patterns indicate that in the absence of local river runoff, the very low dissolved nutrient conditions which prevail in mid-shelf and lagoonal waters of the GBR are also characteristic of shallow nearshore waters. Particulate nutrient concentrations are consistently higher inshore, but cross-shelf concentration differences are on the order of 3-fold or less.

Phosphorus and nitrogen exhibit different speciation patterns in coastal and offshore waters of the GBR. Overall, most (60-70 percent) of the fixed nitrogen in the water column is in the form of DON, the composition and activity of which is largely unresolved. PN comprises much of the remaining water column nitrogen. In contrast, PP is the dominant form of phosphorus in nearshore waters. Offshore PO<sub>4</sub>, DOP and PP are present in roughly equal amounts. Slight nearshore declines in dissolved P concentrations in nearshore samples suggest that either nearshore sediments are a sink for P, or more likely, that soluble P is transformed to particulate form and exported away from the coast. Cross-shelf transects of sediment P in the pristine far-northern GBR (Furnas et al. 1990) are characterised by lower P levels near the coast due to dilution of carbonate sediments with low-P terrestrial sediments.

Shelf sediments may act to store large nutrient stocks and studies have shown this occurs on the GBR and that these stocks may be able to be re-released back into the water column (Ullman and Sandstrom 1987; Chongprasith 1992). It is known that nutrient pulses from resuspension of bottom sediments during moderate south-easterly winds can occur (Walker and O'Donnell 1981) and during cyclonic wind events the large pulses of nutrients released into the water have caused extensive phytoplankton blooms (Furnas 1989).

## **Conclusions**

From the available measured information water quality in GBR waters generally appears to be in good condition with no contaminants at long-term concentrations likely to adversely affect biota. However some evidence exists for pollution affecting ecosystems in very localised areas. There also exists widespread anecdotal accounts of inshore GBR waters being more turbid and inshore habitats being more muddy and algal dominated but there are no scientific measurements to support these accounts. It has been satisfactorily demonstrated that sediment and nutrient discharges from rivers to the GBR lagoon have increased markedly (about fourfold) since European settlement on the catchments but evidence of widespread adverse effects on GBR ecosystems from this increase are not available. This apparent lack of effect may reflect the ability of these habitats to adequately cope with such stress. It may also reflect our lack of knowledge of the state of these ecosystems in pre-European times and hence ability to detect adverse changes which may have occurred. Methods of assessing historical changes in ecosystem functioning using coral and sediment cores are now being pursued but conclusive results are not yet available.

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# Decadal changes in community structure in Great Barrier Reef coral reefs

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## Abstract

CRC-supported research within the Australian Institute of Marine Science's 'Sustaining Coral Reef Biodiversity' project is investigating current status and long-term change in communities of corals and associated benthos on Great Barrier Reef (GBR) coral reefs. Potential pressures on these assemblages are deterioration in water quality, reduction in beneficial impacts of fish and invertebrate predators and grazers brought about by fishing, outbreaks of predators such as crown-of-thorns starfish, and climatic conditions leading to mass coral bleaching. Several lines of research are in place to investigate states and changes in states of reef-building coral communities. A large database of 'snapshot' assessments is being accumulated and analysed for spatial pattern to map and to generate hypotheses about the spatial extent and distribution of 'near-shore' influence on coral reef benthic community structure. Experiments and field studies are focussing on macro-algae and soft coral, which are major non-reef-building groups that commonly dominate large areas. Time series studies are being undertaken to obtain information on rates of recovery and the importance of small scale demographic processes. Work to characterise the regime of natural disturbance by cyclone waves and by flood plumes is underway. For managers to make an appropriate response, they need, among other things, to be able to assess the ecological significance of anthropogenic disturbances and stresses added to natural disturbances and stresses.

## Introduction

The Great Barrier Reef's reef-building coral communities are fundamental to all the characteristics and superlatives which were recognised in its declaration as a World Heritage Area. In particular, they are the crucial biological basis for the ongoing maintenance and building the reef structures themselves, - 'formations... of exceptional natural beauty' and outstanding geological significance (Great Barrier Reef Marine Park Authority 1981). They are both part of, and habitat for, much of the remarkable biological diversity and complexity which represent 'a major stage in the earth's evolutionary history' (Great Barrier Reef Marine Park Authority 1981). One of the briefs for this paper was to comment on whether there may have been a decline in the status of reef-building coral communities which may be reflected in the much broader World Heritage values.

Reef-building coral communities monitored in the GBR since the Area's original listing in 1981 have certainly been in a state of flux (e.g. Connell 1978; Done 1992c, in press; Endean and Cameron 1990b, Fabricius 1995, in press; Moran et al. 1985; Tanner et al. 1994). However some degree of change is to be expected of any living assemblage. Both increases and decreases in localised cover and diversity of reef-building corals have been observed, and in most of the cases of decline, specific causes have been identified. Ideally, any response by Marine Park or reef resource managers should be based on a good understanding of the natural functioning and composition of coral reefs over a wide range of spatial and time scales.

This paper addresses some of these time/space issues in relation to reef-building coral communities and other assemblages which from time to time may displace them. We use the framework of the 'pressure, state and response' model (Johnson and Neil 1996) to indicate progress and approaches to the subject, mainly through CRC funded research at AIMS. The pressure-state-response model draws attention to pressures of human activity which may cause a change in the state of the ecosystem and elicit a response by the responsible management agencies. The model portrays a reactive mode of management. One hopes, of course, that with good forward planning and strong management, the need to respond to degradation of ecosystems will become increasingly rare.

Prior to any response, human impacts and activities affecting reef-building coral communities need to be evaluated in appropriate spatial and temporal contexts. Should the acceptability of damage caused by a ship grounding at some out of sight, out of mind region of the Great Barrier Reef be assessed any differently to a similar impact in the middle of a resort's snorkel trail, or in a frequently visited dive site? Even if long-term statistics suggest a cyclone wave would eventually have destroyed these corals, the question also needs to be asked as to the acceptability of that inevitable event having been brought forward, perhaps by some decades or centuries, by human action. Key information needs in addressing these issues are a quantitative understanding of the natural environment and dynamic processes of coral reef communities, and the frequency and intensity of natural disturbance and resulting ecological responses.

### **Pressure**

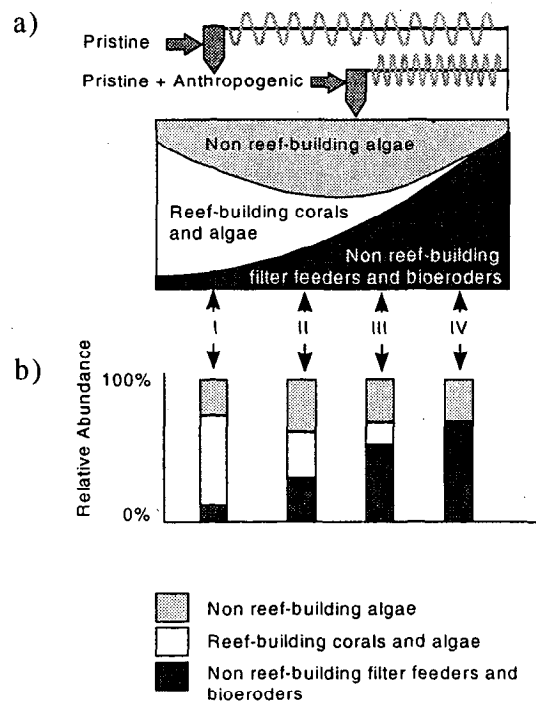
Potential pressures on the reefs of the GBR fall into three categories: anthropogenic (overfishing; physical damage from infrastructures, vessel groundings, oil-spills, anchors or divers; localised or wide-spread eutrophication, increased sedimentation and turbidity); natural (cyclones, floods); uncertain (the major broadscale impacts of coral predators and of coral bleaching). It has often been claimed or demonstrated that their individual or cumulative effects can, and have, degraded certain of the Great Barrier Reef's coral reefs and waters in various ways (e.g. Moran 1986; Endean and Cameron 1990a,b; Bell 1992; Brodie 1992,1995; Fisk and Done 1985). The strongest evidence for potential of overfishing to impact upon reef communities comes from countries other than Australia (e.g. Hughes 1994; McManus et al. 1993; McClanahan and Muthiga 1988). Within the Great Barrier Reef, potential impacts on benthic reef habitats include any direct effects of anchoring or the method of fishing, and/or any indirect effects which removal of target species and by catch may have on levels of predation on species which graze or prey upon elements of reef benthos (e.g. Ormond et al. 1990).

Natural disturbances which have occurred throughout the development of reefs on the GBR include floods, cyclonic waves, and wind-driven re-suspension of coastal sediments (Hopley 1982; Larcombe et al. in press). The addition of an anthropogenic component to these and other natural background disturbance and stress regimes (Furnas and Brodie in press) might on the one hand be so large and widespread (e.g. covering the entire GBR lagoon) as to favour significant transformations of benthic assemblages on and between reefs (see Bell (1992), Bell and Elmetri (1995) in relation to eutrophication). On the other hand, the anthropogenic component may be so small and localised that it is considered acceptable for the sake of some other economic or social advantage it offers. To date, the spatial dimensions and locations of none of the perceived pressures, nor of the states of coral reef communities, are particularly well defined.

**State**

CRC-supported research within AIMS is investigating current status and long-term change in communities of corals and associated benthos on GBR coral reefs. We are undertaking a range of studies which are a) providing snapshots of the composition and relative abundances of major benthic biota (especially hard corals, soft corals and algae) on reef slopes, reef flats and reef lagoons; b) using experimental and other process-oriented studies intended to help explain the spatial variability, and c); using time series studies to learn about the nature of changes in states which can occur over years to decades.

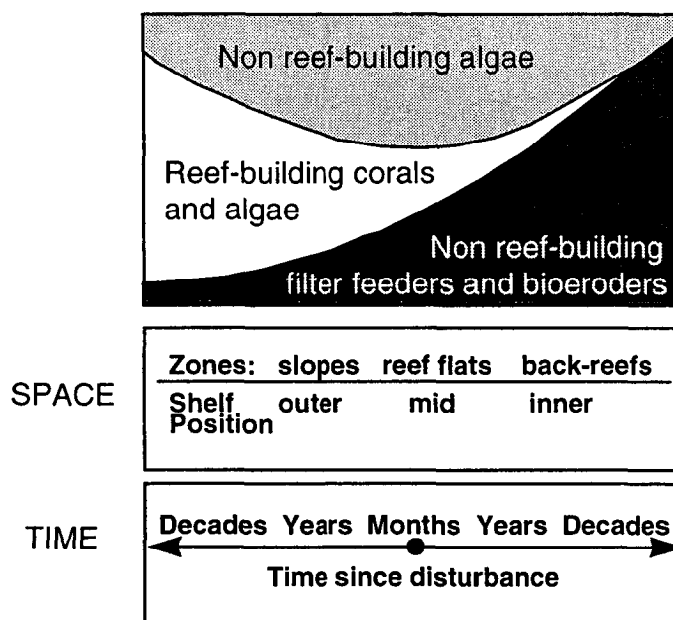
Figure 1 uses a conceptual model of Birkeland (1987) to illustrate how the 'pressure-state-response' model could be applied in relation to reef building coral communities and alternative non-reef-building assemblages. The coral reef benthos is portrayed (Fig. 1a) as a box in which the proportions of three all inclusive functional groups - reef-building algae and corals; non-reef-building algae; non-reef-building filter feeders and bioeroders - vary from left to right. The reef's state is indicated by a pointer attached to a spring, representing the reef's resistance against disturbance and stress. The spring is compressed a short distance by 'pristine' pressures, and a great distance by 'pristine + anthropogenic' pressure, and the pointer indicates the relative abundance of the three functional groups. For a given location, the pressure may be applied in pulses (e.g. periodic flood plumes; periodic re-suspension of bottom sediments; periodic depletion of key grazing species), and its influence on benthic communities will be a function of the duration and strength of these pulses. States I to IV represent a gradient from strong reef-building capacity and autotrophy through to no reef building capacity, major bio-erosion, and heterotrophy.



**Figure 1.** a) The pressure-state model in a nutritional and functional context. States I to IV represent a gradient from strong reef-building capacity and autotrophy through to no reef building capacity, major bio-erosion, and heterotrophy. The reef's state is indicated by a pointer attached to a spring, representing the reef's resistance against disturbance and stress. The spring is compressed a short distance by 'pristine' pressures, and a great distance by 'pristine + anthropogenic' pressure, and the pointer indicates the relative abundance of the three functional groups.

Interpreting the state of a particular reef or part of a reef can be contentious. It is necessary to decide whether that state is 'normal' for that place and time, or has been caused to shift to that state by human activities. A scenario which is potentially manageable is where the move to the right is caused by elevated losses from land-holdings of nutrients, sediments, and/or organic matter into the marine environment. Here, it is in the interest of both the land user and the reefs to change land use and overall catchment management to ameliorate the losses to the sea.

However some of the differences among states I to IV are believed to be a manifestation of normal spatial variability (Fig. 2) reflecting normal environmental and biological gradients - notably turbidity, wave energy and grazing pressure - across the GBR and within individual reefs (Wilkinson and Cheshire 1989). Alternatively, they may represent a transitional stage returning to a net reef building state (left of centre in Fig. 2), or non-reef-building state (right of centre), following disturbance (say a catastrophic crown-of-thorns impact, mass bleaching, cyclone impact or flood plume impact). A worthy goal for researchers is to come up with ways of distinguishing among these various scenarios, and to recognise any synergies and cumulative effects among them.



**Figure 2.** Spatial and temporal correlates of gross community structure. The differences among states I to IV (Fig. 1b) may have nothing to do with anthropogenic pressure. They may represent normal environmental and biological gradients associated with location. e.g. position of reef on continental shelf or position of community within reef (Wilkinson and Cheshire 1989). In addition, they may represent a transitional stage, as the composition of the assemblage changes through years to decades towards a net reef building state (I) or non-reef-building state (III or IV).

### Snapshots

In the context of perceived pressures of runoff from rivers and of re-suspension of nearshore sediments, we are currently building a large database of the status and distribution of reef-building and associated benthic communities. We are documenting the composition and relative abundance of hard corals, soft corals and algae among reef habitats and across and along the GBR between Cooktown and the Whitsunday Islands. In about 30-60 minutes diving at each site, we compile ranked species lists and make subjective bottom cover estimates within

discrete bathymetric, geomorphological and biotic zones of the reef (after Done 1982). In 1995, DeVantier and Turak (1996) surveyed 80 sites in the Whitsunday area, and the authors of this report surveyed ~ 200 sites in the Cairns to Cooktown sector (Fig. 3). These studies show that similar strong cross-shelf biotic patterns to those described for the central GBR by AIMS scientists in the early 1980s (summarised by Wilkinson and Cheshire 1989) exist at other latitudes. Surveys at a large number of inshore reefs from the Whitsunday Island to the Keppel Islands by R. van Woesik showed marked variation in composition and sizes of corals which had strong spatial concurrence with degree of sedimentation stress (van Woesik and Done in press).

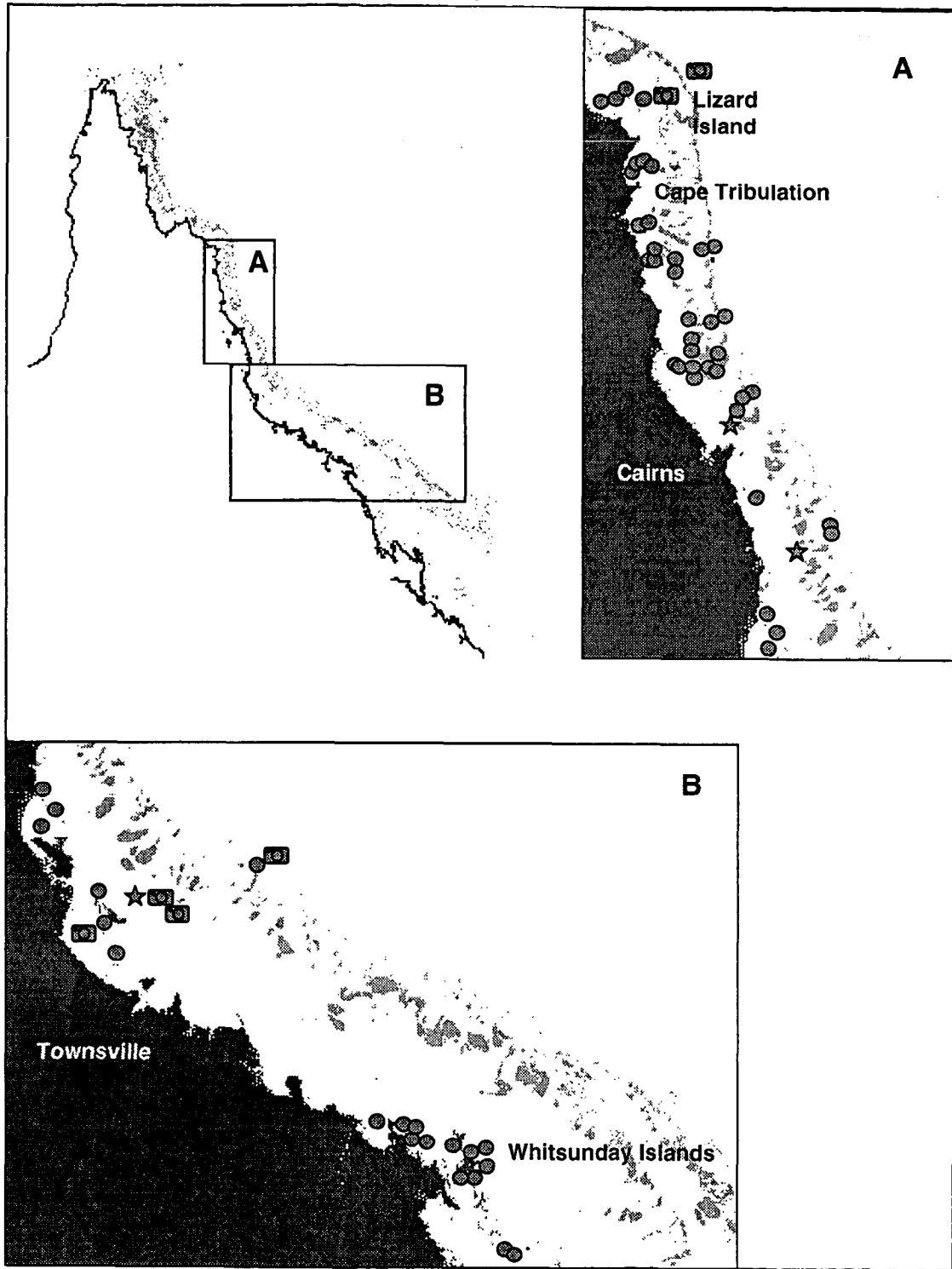
These snapshot surveys have also documented reef zones having high abundances of non-reef building biota, notably macro-algae and soft corals (Fig. 4). Macro-algae are especially abundant on reef flats and slopes of nearshore reefs (McCook 1996; McCook et al. in press; McCook and Burns 1995), whereas soft corals are locally dominant (10s to 1000s of m<sup>2</sup>) on reef flats, slopes and lagoons of both nearshore and offshore reefs (Fabricius and De'ath in press and Fabricius unpubl.). Of particular interest are the numerous sites where macro algae or soft corals (rarely both together) covered large areas recently occupied primarily by hard corals (as evidenced by abundant standing or recently fallen dead skeletons of hard corals). Dominance by either of the other two groups may or may not be a cause for concern. On the one hand, it may simply represent a temporary reduction or interruption to reef-building capacity which is of no consequence or significance in the contexts of the reef's geological development, or even its normal dynamics over decades to centuries. On the other, it may be stark evidence that the pressures associated with current use of GBR waters, resources, reefs and adjacent catchments are indeed causing deleterious changes in reef composition and reef-building capacity. For that reason, and recognising that ecological and physiological research on hard corals has been well supported for a long time, new studies focused on macro-algae and soft corals were initiated by the CRC.

#### Process studies

Three main hypotheses underlie current research aimed at understanding the significance of displacement of hard corals by soft corals or macro-algae:

1. The abundance of macro-algae or soft-corals may represent an opportunistic invasion of areas following the death of hard corals caused by a natural disturbance;
2. Abundance of algae may be the result of increased production resulting from nutrient runoff from land, of decreased grazing caused by low abundance of herbivorous fishes, or both;
3. Abundance of soft corals may be caused by increased availability of water-column organic matter.

Transplant and caging experiments (McCook 1996) suggest that some macro-algal distributions are probably only weakly or indirectly influenced by terrestrial sediment and nutrient inputs, but strongly influenced by the abundance of herbivorous fishes. This finding is important because it suggests that the presence of abundant macro-algae in coral zones is not *prima facie* evidence of eutrophication. Rather, it may reflect simply the algae's capacity to rapidly invade areas denuded by some other factor such as wave damage, flood damage, or predator damage (McCook 1996).

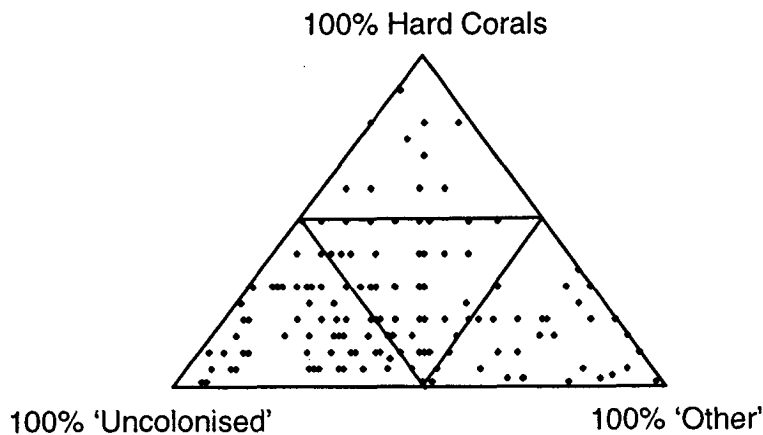


**Figure 3.** Location of AIMS-CRC study reefs - circle - 'snapshot' surveys, 1995; - camera - photographic study areas, 1980 - 1995; star - 'recovery' surveys, 1989 - 1994. (Each symbol usually signifies anything from 2 - 10 individual sites).

Some soft corals which lack zooxanthellae (*Dendronephthya* spp.) have been shown to consume phytoplankton as an energy source (Fabricius et al. 1995). These non-reef- building filter feeders could potentially benefit from increased phytoplankton blooms, one of the manifestations of eutrophication of coral reef waters. However there is no evidence that a proliferation of these particular species has taken place. Presently, studies are focusing on those



non-reef-building soft coral families which are very abundant on GBR reefs. Experiments, detailed characterisation of micro-environments (Fabricius and De'ath in press) and measurements of depletion of water-column organic matter (Fabricius in prep.) are completed or in progress. They are part of a broad study to assess the relative importance of nutrition compared to other environmental and demographic factors in determining the composition, distribution and abundance of soft-corals.



**Figure 4.** Ternary diagram showing benthic composition of ~200 survey sites between Cairns and Cooktown, in terms of proportions of three end-points: hard coral, 'uncolonised', and 'other'

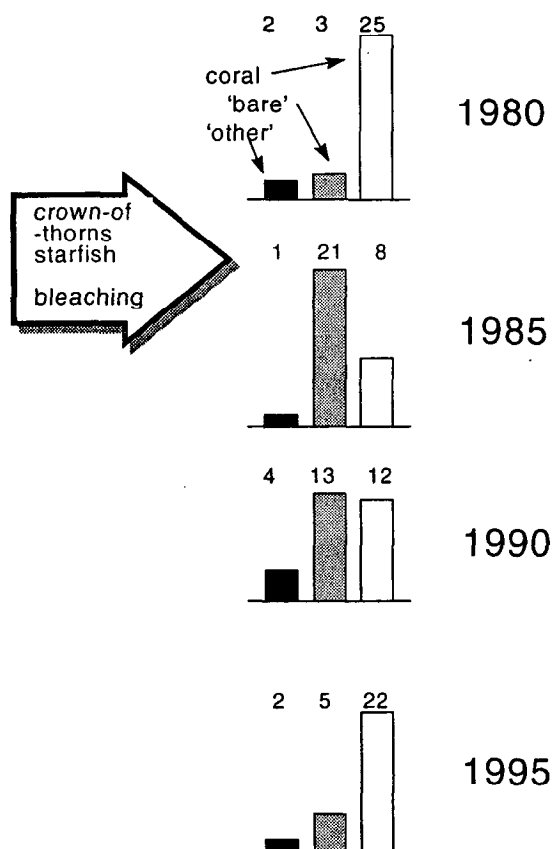
#### Time series studies

AIMS Long Term Monitoring Project (Oliver et al. 1995) has established a series of strategically placed study areas over a ~ 1000 km section of the GBR for monitoring a range of indicators of reef condition. One such indicator is the benthic (coral/algal/ soft-coral) community on reef slopes. Osborne et al. (this volume) document spatial patterns in the sites' baseline communities. As data from repeat sampling of the same sites become available, the emphasis will switch to documenting trends and inter-annual changes in the components of reef bottom cover at scales from individual sample unit (50 m transect) upwards. The null hypothesis is that there will be no change or a slight increase in hard coral cover over these scales, with any mortality and injury within a single sample unit (be it transect, site or reef) being fully compensated or exceeded by recruitment, growth and repair. When there is a net decrease in hard coral cover of > 5% over a 50 m transect (the measurement error of the video transecting technique used - Davidson in prep), this finding is to be drawn to the attention of the Great Barrier Reef Marine Park Authority and, if possible, an interpretation of the causes given (e.g. Doherty et al. in press).

Two long established Australian studies of fixed photo plots provide important underpinning for interpreting the significance of change in long term monitoring projects. The first is the landmark study of JH Connell established in 1962 at Heron Island and continued with colleagues from James Cook University of North Queensland and the Museum of Tropical Queensland (e.g. Connell 1978; Tanner et al. 1994; Connell et al. this volume). This study tracks the fates of individual corals and habitat patches in a range of reef-flat environments. The second study tracks individuals and patches, on both reef flats and shallow and deep slopes and on a range of reef types (Done 1992c - established in 1980 at six reefs off Townsville and Lizard Island). In both studies, there are two observations relevant to the larger scale monitoring study: First, they demonstrate that even over periods of relative stability in gross measures such as total hard coral cover, there is frequently a great deal of internal flux, as recruitment, growth and repair compensate for localised death and injury (Tanner et al. 1994).

The implication of this finding is that the significance of death or injury to individual corals needs to be assessed in a population context. Second, changes in cover, composition and species successions initiated by catastrophic disturbances can remain visible within coral communities for periods of years to decades. This suggests that even a snapshot survey, done cleverly, can be used to infer something of the site's recent past.

There are important issues still to be resolved in scaling up from these studies (1 - 10 m) to the scale of the Long Term Monitoring Program (50 m - 1 km). For example, a categorical assessment of the status of 30 permanent study areas on six widely separated reefs and at five year intervals (Done in press) suggested that there was no difference between 1980 and 1995 in the proportion of the areas dominated by corals, by other organisms, and by 'bare' reef. In the fifteen years, there had been great change at many sites which approximately compensated for one another at year 15 (Fig. 5). However, for some individual reefs, there were marked and persistent reductions in coral cover over all sites, and in others, a consistent increase. Some declines were caused by severe predation by crown-of-thorns starfish in 1984-85 (Moran et al. 1985). Others followed a severe bleaching event in 1982 (Fisk and Done 1985).



**Figure 5.** Categorisation of 30 photographic study areas (Done in press) according to its dominant bottom type: hard coral, 'bare' (=uncolonised), or 'other'. Most sites were established in areas with high coral cover. By 1985, many had suffered coral mortality resulting mainly from crown-of-thorns starfish or bleaching. By 1995, the overall relative abundance of sites in each category had returned to close to the 1980 situation, but many individual sites were markedly different to their 1980 state.

We are currently analysing data from another study which will provide an improved understanding of recovery rates following disturbance. A five-year (1989-1994) study was conducted on shallow slopes (1-7 m depth) of three 'mid-shelf' reefs: Green Island Reef, Feather Reef and Rib Reef (Done et al. 1992). These reefs were chosen because each had been

seriously damaged by the crown-of-thorns starfish: Green in 1980; Feather in 1982-83 and Rib in 1984-85. It is typical of severe predation events to inflict almost 100% mortality on corals over large sections (100s of metres) of shallow reef slopes (1-10 m) within a space of a few weeks to months (Moran 1986). Our samples, although completed within five years, encompassed reefs which had elapsed periods since the predation event ranging from 5 to 14 years. Overall there appears to be a fairly ordered and predictable recovery taking place, but recovery on slopes > 3 m deep is much slower than that on shallow slopes ( $\leq 3$  m deep). Over much of the most advanced shallow slopes (Green Island and Feather Reef), space had become limited by 1994 due to the prolific growth of a few species of fast growing table *Acropora*, as described by Pearson (1981) for an earlier outbreak of the starfish. However the outlook for slow growing massive corals, key reef builders, is uncertain (Endean and Cameron 1990b). When a simple model was used to estimate the sustainability of the 1980s intensity of impact, it suggested that an interval of 10-15 years between recurrent outbreaks, as is currently being seen, would probably result in a decline in the abundance of very large *Porites* heads (Done 1987; 1988).

### **Response**

The response options available to GBRMPA, the lead manager of the Great Barrier Reef World Heritage Area (GBRWHA) (Kelleher 1994) are both direct (through planning and management of levels of access, extraction and impact at specific locations within the GBRWHA) and indirect (through their influence on policy and practice in other jurisdictions, such as management of catchments). A form of interim response, in the case where information on pressures, states and their inter-relationships are incomplete, is the commissioning of assessments of reefs in specific geographic locations.

In reactive mode, once degradation has been confirmed, the appropriate responses are directed towards those pressures which are clearly anthropogenic, and those of uncertain origin for which there is reasonable, if not conclusive, evidence of being anthropogenic. In principle, it is relatively easy to recognise one class of change in reef community structure which does not require a response, i.e. those clearly caused by broad scale catastrophic natural disturbances such as cyclone wave impact (van Woelk et al. 1991) or flood impact (van Woelk et al. 1995). In both these studies, there were before and after data which put beyond question the cause of the substantial coral death and reef damage. Even without 'before' data, field data collected by experienced assessors soon after a discrete and well documented event such as a cyclone can also provide a reliable record of the geographic spread and pattern of an impact (Done et al. 1991b; Done 1992b).

However the first indication of a perceived problem is often the discovery of a degraded reef. For example, extensive areas of reef slopes in the Bunker Capricorn group were denuded some time between 1988 and 1990 (Osborne et al., this volume; Doherty et al. in press). A forensic approach is needed to reconstruct the cause of such degradation and the tools of 'retrospective risk assessment' (Suter 1993) offer great potential. This process provides an assessment, with the implied elements of judgement and uncertainty, e.g. there is a high (or a low) probability that reef X was impacted by severe cyclone generated waves in 1993; there is little chance that reef Y has been reached by the Burdekin River flood plume at any time in the last 25 years. A manager is thus provided with a considered judgement about the likelihood that a major natural disturbance could have been responsible for a reef's current state of disrepair. This advice is then factored into the manager's decision making process, with due regard for the implications that advice has for the precautionary principle.

CRC-supported work is being undertaken by a team of collaborating researchers at AIMS and James Cook University of North Queensland to develop such a forensic capability. A goal is to

be able to reconstruct, for all sections of the GBRWHA, the timing and likely geographic distribution of impacts of floods and cyclone waves over the last 25 years. This goal draws on work in individual research tasks which collectively use, or are developing, the tools of risk assessment, geographic information systems, climatology, hydrology, hydrodynamic modelling and databases, and ecological and physiological modelling and databases. Given the complexity and size of both this assignment and the geographic area involved, the potential for cumulative errors, and the use to which the advice will be put, there is a great deal of careful consideration and consultation with end-users on the form of the output, on the caveats and on the supporting documentation.

### **Acknowledgments**

We are grateful to the Australian Institute of Marine Science, the CRC Reef Research Centre, and the Commonwealth of Australia's Cooperative Research Centre Program for the support of our work. This is Australian Institute of Marine Science Publication No. 846.

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# The biological status of fringing reefs in the Great Barrier Reef World Heritage Area

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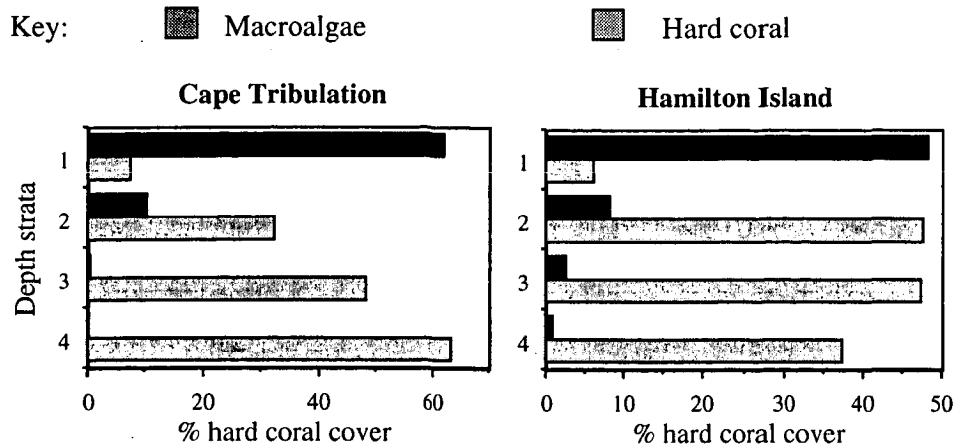
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Fringing coral reefs occur along the coast and around inshore islands throughout most of the Great Barrier Reef (GBR) region. If terrestrial human activities are degrading reefs in the GBR region then this effect is most likely to be felt on these fringing reefs. Impacts of most concern are nutrient enrichment from fertiliser and sewage run-off, increased siltation and increased turbidity from disturbed river catchments, but anchor damage is increasingly seen as a threat to fringing reefs in heavily used areas. Some fringing reef areas are close to large centres of population and are likely to be subjected to general industrial pollution in addition to those more widespread impacts mentioned above. Over the past 15 years surveys of the state of fringing reefs have been made over much of the GBR region, in areas ranging from Cape Flattery (14.9°S) to the Keppel Islands (23.2°S). Most of these studies have presented quantitative data on the percentage cover of benthic organisms, and also made some attempt to measure biodiversity (Ayling and Ayling 1991a, 1995a, 1995b, 1996 and unpublished data; Kaly et al. 1993; Mapstone et al. 1989; van Woessik 1992). Some studies have looked at changes in community structure on fringing reefs over time periods of from 4-10 years (Ayling and Ayling 1995b, 1995c; Kaly et al. 1993). This paper presents a summary of the results from these surveys and discusses the current state of these fringing reef areas in the light of the information currently available.

These studies used replicate 20 m transects to measure benthic cover, either line intersect transects (see Ayling and Ayling 1996 for full description), 20 m video belt transects (Kaly et al. 1993), or a combination of line intersect transects and belt transects (van Woessik 1992).

The majority of fringing reefs in the GBR region (> 95%) are algal dominated on the reef flat and the upper few metres of the reef slope (Fig. 1), with extensive stands of *Sargassum* spp. and a dense turf of smaller algal species covering over 50% of the substratum (Ayling and Ayling 1991a, 1991b). Hard corals generally cover only around 5% of the substratum on the reef flat. Hard coral cover increases rapidly down the reef slope, and at a depth of five m below Australian Height Datum (AHD: approximately the level of the lowest spring tides) cover of living corals is usually between 40 and 80% (Fig. 1). On some fringing reefs in the area of big tides between Mackay and Port Clinton, where maximum tide range is more than 5 m, macroalgae often cover more than 50% of the substratum to depths well below the normal 2-4 m below AHD, sometimes down to 8 m or more (Ayling and Ayling 1996; van Woessik 1992).

Coral cover is usually very high on the reef slope of fringing reefs, with the exception of reefs within the big tide area mentioned below (Table 1). Grand mean coral cover from over 100 sites between Cape Flattery and Keppel Islands was almost 62%. In comparison grand mean cover from the 110 sites within the big tide area was only 25%, although individual sites from this area had over 60% cover (Ayling and Ayling 1996). The reasons for the lower coral cover in the big tide area are unclear, but probably relate to turbidity and siltation caused by strong tidal currents, rather than to lower temperatures (Ayling and Ayling 1996; van Woessik 1992).



**Figure 1.** Depth stratification in fringing reef communities. Two typical examples are shown. For Cape Tribulation (Ayling and Ayling 1991a) depth strata are: 1 - reef flat; 2 - reef crest 0-1 m below AHD; 3 - reef slope 2-4 m; 4 - slope 4-6 m. Hamilton Island (Ayling and Ayling 1991b): 1 - flat; 2 - crest 0-1 m; 3 - slope 4-6 m; 4 - slope 10-12 m.

**Table 1.** Summary of hard coral cover on GBR fringing reef slopes. Figures show grand mean percentage cover from groups of 20 m line transects. <sup>1</sup>Ayling and Ayling unpublished data; <sup>2</sup>Ayling and Ayling 1991a; <sup>3</sup>Ayling and Ayling 1995a; <sup>4</sup>Kaly et al. 1993; <sup>5</sup>Ayling and Ayling 1995b; <sup>6</sup>Ayling and Ayling 1996; <sup>7</sup>van Woosik 1992. na = not available.

Region	Date	Latitude °S	No. sites	Hard coral cover	
				mean	sd
Cape Flattery <sup>1</sup>	Feb 1996	14.9	5	46.2	12.2
Cape Tribulation <sup>2</sup>	Nov 1995	16.0	12	60.0	12.5
Cairns Section Nth <sup>3</sup>	Jan 1995	16.5	34	81.0	7.5
Magnetic Island <sup>4</sup>	Aug 1993	19.2	36	48.4	18.8
Middle Reef <sup>4</sup>	Aug 1993	19.2	5	74.6	3.9
Hamilton Island <sup>5</sup>	Mar 1995	20.3	6	54.4	5.7
Sir James Smith Gp. <sup>7</sup>	1991	20.7	56	22.0	na
Northumberland Is. <sup>7</sup>	1991	21.5	20	11.7	na
Shoalwater Bay <sup>6</sup>	Dec 1995	22.3	34	37.8	16.2
Keppel Islands <sup>7</sup>	1991	23.2	8	54.3	na

Coral cover on fringing reefs is usually dominated by acroporids on the upper slope (60-80% of total coral cover). Explanate *Montipora* spp. are usually more important than *Acropora* spp., accounting for between 50-90% of acroporid cover. In deeper water (more than 5 m below AHD), or in particularly silty sites, faviids and *Turbinaria* spp. may also be abundant, sometimes covering up to 20% of the substratum (e.g. Blind Rock in Shoalwater Bay; see Ayling and Ayling 1996). Poritid corals usually only cover 1-2% of the substratum on fringing reefs, but occasionally a site will be encountered that supports large areas of these corals, usually *Porites* massive or *Porites* rus colonies. Examples of high poritid cover fringing reefs are the south side of Snapper Island and Normanby Island in the Frankland Island Group south of Cairns (Ayling and Ayling 1995a).

A comparison of fringing reef coral cover measurements with those recorded on offshore reefs is interesting (Table 2). Grand mean coral cover from 330 sites recorded throughout the GBR region over the past 5 years is only around 30%. This is half of that from fringing reefs outside



the strong tide area, and only marginally higher than that from fringing reefs in the strong tide area.

**Table 2.** Comparative coral cover on offshore reefs. Grand mean coral covers from: <sup>1</sup>data from AIMS long term monitoring program (personal communication from W. Oxley); <sup>2</sup>data from Bramble Reef replenishment area survey (Ayling and Ayling 1996b); <sup>3</sup>data from CRC Effects of Fishing survey (Ayling and Ayling unpublished data)

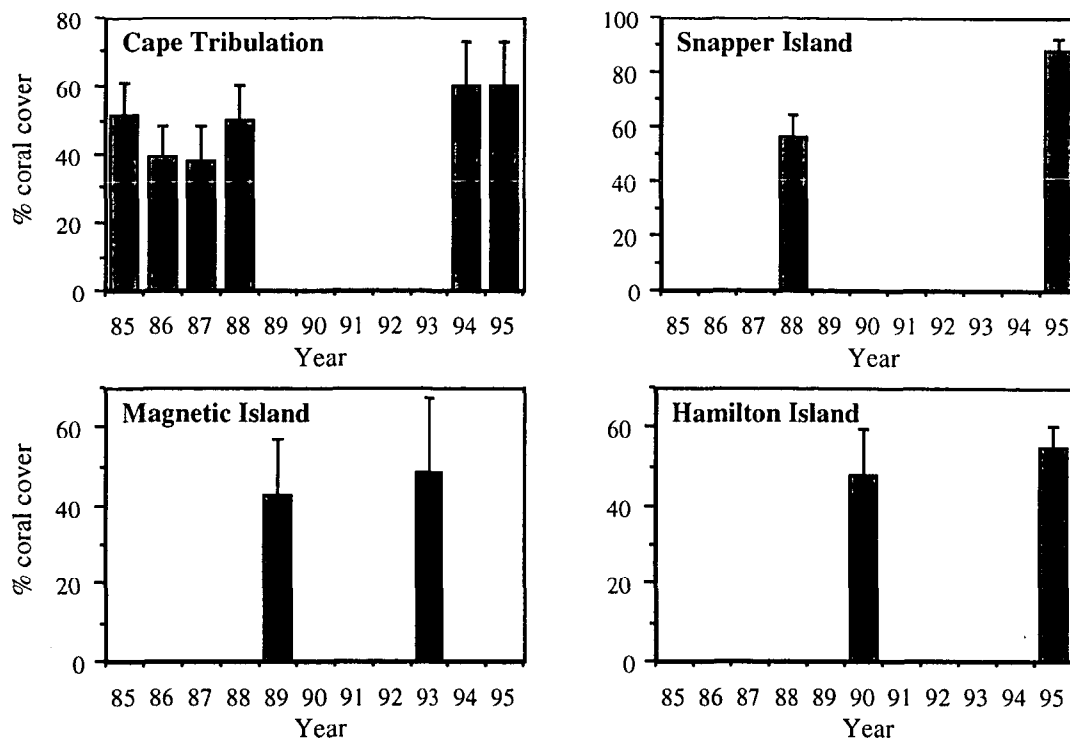
Region	Date	No. survey reefs	Total no. sites	Hard coral cover
				mean
GBR (AIMS reefs) <sup>1</sup>	1993-94	34	102	23
Offshore Townsville <sup>2</sup>	Aug 1995	7	84	29
Lizard Is. to Swains <sup>3</sup>	late 1995	24	144	37

Fringing reefs are also diverse. Over 140 species of hard corals were recorded from the Cape Tribulation fringing reefs (Veron 1987), while between 50 and 100 species were recorded on each of 15 Cairns Section fringing reefs in only an hour search (Ayling and Ayling 1995a). A 2 hour search of one site on Dent Island in the Whitsunday Group recently recorded over 130 species of hard corals (Ayling and Ayling 1995b).

Another feature of fringing reefs is that there are many large coral colonies in reef slope communities (Ayling and Ayling 1991b, 1995a, 1996). Notable examples include *Acropora* staghorn colonies 30-50 m across, tabulate *Acropora* colonies 3-5 m across, massive *Porites* heads over 10 m diameter, *Goniopora* colonies 20-30 m across, a *Pavona minuta* colony 15 m across and over 5 m high and *Turbinaria* colonies over 5 m in diameter. Although large colonies are sometimes seen on offshore reefs they occur more frequently on fringing reefs.

Over the past decade there has been no evidence of any decrease in hard coral cover, or change in coral composition, on fringing reefs that have been subject to more than one survey (Fig. 2). Changes recorded have been from 51% (1985) to 60% (1995) on 12 reefs in the Cape Tribulation area (Ayling and Ayling 1995c); from 56% (1988) to 88% (1995) from two sites on the north side of Snapper Island (Ayling and Ayling 1995a); from 43% (1989) to 44% (1993) from 12 sites around Magnetic Island (Kaly et al. 1993); and from 47% (1990) to 57% (1995) on nine sites around Hamilton Island (Ayling and Ayling 1991b, 1995b). There have also been no significant increases in algal cover on the reef slopes in these locations over the same period (Ayling and Ayling 1995c). Although there are no historical data from the reef slopes of fringing reefs with which to compare these data over a longer time period, i.e. > 15 yrs, there is to date no evidence of continuing degradation in coral communities on fringing reefs.

The available evidence suggests that the recovery of coral cover on fringing reefs after major disturbance is very rapid. During the monitoring program established on Cape Tribulation fringing reefs to look at the effects of sediment run-off from road construction, cyclonic waves and a bleaching event caused a major reduction in coral cover over two successive years (Fig. 2, Cape Tribulation 1985-1988). In the following 12 months, in the absence of any disturbance, coral cover increased by 33%, from 37.5 to 49.8% (Ayling and Ayling 1991a).



**Figure 2.** Changes in coral cover on fringing reefs: 1985-1995. Data summarised from: Cape Tribulation - Ayling and Ayling 1995c; Snapper Is. - unpublished data and Ayling and Ayling 1995a; Magnetic Is. - Kaly et al. 1993; Hamilton Is. - Ayling and Ayling 1991b, 1995b. Error bars are standard deviations.

In summary, fringing reef slopes support high cover of hard corals, are relatively diverse in terms of number of coral species present, have many large, old coral colonies, and recover quickly from major disturbance episodes. There is no evidence to date, either that coral cover is decreasing in any fringing reef area, or that algal cover is increasing. All this suggests that fringing reefs are not presently being degraded by the terrestrial derived impacts mentioned previously. However, it is important to continue long-term monitoring of fringing reef areas, as these communities will undoubtedly be affected by nutrient enrichment, or increased siltation before offshore reefs. Management response, if degradation of fringing reefs is shown to be occurring in the future, is complicated by the fact that the major impacts are terrestrially derived. Control of practices that lead to nutrient run-off or catchment disturbance would have to be implemented along large areas of the Queensland coast, and well inland to the south where rivers such as the Fitzroy and Burdekin drain huge catchments.

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# Long-term dynamics of reef crest corals on Heron Island: 1960s to 1990s

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## **Abstract**

Over a 30-year period, the abundance and recruitment of reef-building corals varied drastically, at several scales of space and time, at Heron Island, Great Barrier Reef, Australia. Observations were made at six study areas at spatial scales ranging from one to 1850 m apart, in depth from zero to 14 m, and at temporal scales ranging from one year to three decades.

The abundance of corals declined nearly to zero at some time during the study period at five of the six study areas. Recurrent cyclones (hurricanes, typhoons) were a major cause of coral mortality. In 11 of the 30 years of our study, 17 cyclones passed within 200 km, and in five of these years, at least 40% of the coral cover was killed in one or more study areas. Damage varied considerably among cyclones; the most likely reason for the variability in their effects was a difference in maximum wind speeds at Heron Island. Damage also varied considerably among the different study areas. Cyclones damaged and killed corals and other organisms, and also removed sections of hard substrate and shifted sediments, sometimes altering the pattern of water movement and drainage at low tide. Both the degree of damage caused at different sites, and the rate and extent of recovery thereafter, were influenced by the history of previous damage and recovery.

Recruitment of corals also varied at different spatial and temporal scales. Recruitment rate differed seven-fold among study areas. Years of high input were not consistent among the different study areas. Recruitment rates at two sites declined over the past decade as substrate conditions worsened with increased exposure to air at low tide.

Human impacts at these study sites were relatively small compared to natural changes. Management decisions should be based on a sound knowledge of the mechanisms underlying the dynamics of coral reefs. While long-term monitoring studies are invaluable tools for generating hypotheses, future research will require a much greater focus on experimental manipulations to answer basic and applied questions.

## **Introduction**

A principal goal of ecology is to understand patterns of variation of populations and communities, and the mechanisms that determine them. The present study represents a rare long-term examination of the extent of variation in abundance and recruitment of tropical corals, on a reef that is relatively free of human impacts. In recent years, the effects of human activities on ecosystems has been widely recognised. For example, several reviews (e.g. Rogers 1985; Brown 1987; Grigg and Dollar 1990; Ginsburg 1993; Hughes 1994) have concluded that many coral reefs are endangered by destructive human activities (such as overfishing, dredging, mining, logging, and urban and agricultural pollution). Since anthropogenic effects are superimposed upon natural patterns, an understanding of natural variation in abundances, and

of the mechanisms underlying them, is essential for making rational decisions as to how to manage ecological assemblages.

Studies on coral reef assemblages have been done at several spatial and temporal scales, but few of these extend beyond a single site or last for more than three years (i.e. the approximate duration of a PhD study or research grant). Notable exceptions include studies by Davis (1982), Done (Done 1992) and Hughes (1994). Connell (1996) provides a review of numerous other reef studies that have quantified variations in coral assemblages, and the mechanisms underlying them, over both small and large temporal and spatial scales.

Numerous physical and biotic processes may influence patterns of abundance of corals and associated species on reefs. Reductions in abundance are usually associated with mortality events, which vary hugely in spatial and temporal scale (e.g. from an instantaneous fishbite affecting a portion of a single coral colony to global extinctions of species in geological time). Increasingly, on many reefs significant declines in coral assemblages are being caused by both immediate and cumulative impacts of human activities (e.g. Lessios et al. 1988; Rogers 1985; Brown 1987; Salvat 1987; Grigg and Dollar 1990; d'Elia et al. 1991; Ginsburg 1993; Hughes 1994). Increases in abundance of corals are the results of recruitment and growth. Recruitment in corals has been extensively studied, usually within the first weeks or months after initial settlement from the plankton (reviewed by Harrison and Wallace 1990).

### **Objectives**

The major objective of our studies at Heron Island is to understand the mechanisms of change in assemblages of reef-building corals (rather than simply describing an increase or decline in abundance). This goal is difficult to achieve in species with long life spans and episodic recruitment, such as forest trees and corals, where disturbances may be sudden but recovery is often slow (Connell 1973, 1978; Colgan 1987; Hughes 1994). On the other hand, like most other sessile organisms, corals have the advantage of being relatively open to direct observations of recruitment, growth, and mortality. Therefore, by making frequent censuses of permanently-marked sites, it is possible to identify important mechanisms (such as mortality from cyclones and pulses of recruitment) that cause changes in abundance. By repeating censuses over long time periods, one can document variation in the effects of both relatively rare extreme events, such as violent cyclones, and of very gradual trends and slow changes, undetectable in a short-term study.

Specifically, we have addressed two general questions based on long-term studies at Heron Island, Australia from 1962 to 1992:

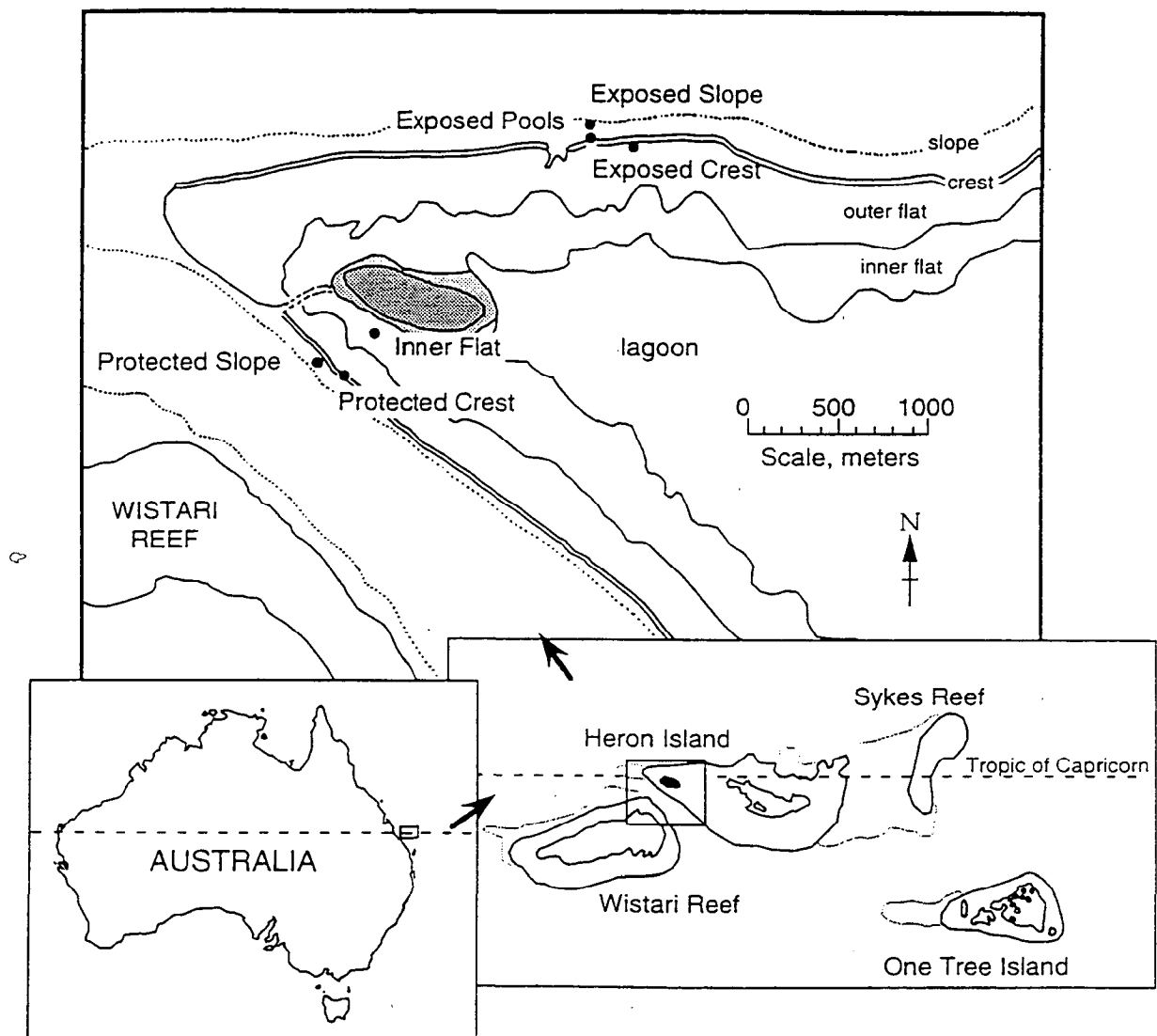
1. What were the patterns of variation in abundance and recruitment of corals, and
2. What were the principal mechanisms underlying these patterns

To address these issues, observations were made over both small and large spatial scales (from cm to km), and over short and long time periods (from annual to multi-decadal). Over the 30-y period of this study, the mean percentage cover of corals in four of six study areas ranged from >50% to <0.1%, revealing the considerable extent of natural variation at several temporal and spatial scales.

This report presents only a brief summary of our findings. Further details are found in Connell et al. 1997.

## Methods

To measure changes in distribution and abundance of corals under different environmental conditions, we established permanent study areas in different habitats arrayed across Heron Reef, from the inner reef flat close to the cay, to the reef crest, and beyond to shallow pools isolated from the open water at low tide, and finally to the outer slopes (Fig. 1). There was one or more sites within each study area, each with samples in the form of square meter quadrats, line intercept transects, or belt transects. Detailed site descriptions and methods are provided in Connell et al. (1997).



**Figure 1.** Study sites on Heron Island Reef: 1 = Inner Flat, 2 = Protected Crest, 3 = Exposed Crest, 4 = Exposed Pools, 5 = Protected Slope, 6 = Exposed Slope. Dashed lines to the SW of the island indicate a boat channel first dredged in 1966.

Within each of the study areas, we sampled the abundance and recruitment of corals and macroalgae. The data presented in this report are based on the quadrats only (see Connell et al., 1997 for additional results). The replicate 1 quadrats were established using stakes (reinforcing bars of mild steel, 9 mm diameter) driven in at the four corners. These quadrats were placed in one or more study sites within each study area. At low tide, a colour slide photograph was

taken of each side of these 1 m<sup>2</sup> quadrats from vertically above, using a 35 mm SLR camera which was mounted on a tripod attached to a 1 m<sup>2</sup> frame that fitted over the steel stakes; the pair of photographs of a single quadrat overlapped in the middle. Thirty-seven visits to Heron Island were made in 23 different years between 1962 and 1992.

Each colour slide photograph was projected and the boundaries of all coral colonies and clumps of macroalgae were traced to make a map at a scale of one-half the original size. The area of each individual was measured with a digitizer at each census to yield data on cover, population structure, diversity, growth, survival, etc.

## **Results**

In this section we discuss two of the major processes that influence abundance: mortality and recruitment. The principle agents of mortality were storm damage (which caused sudden crashes) and the effects of exposure to air at low tide (which caused gradual declines). Recruitment was significantly influenced by changes in characteristics of the substrate, both physical and biotic.

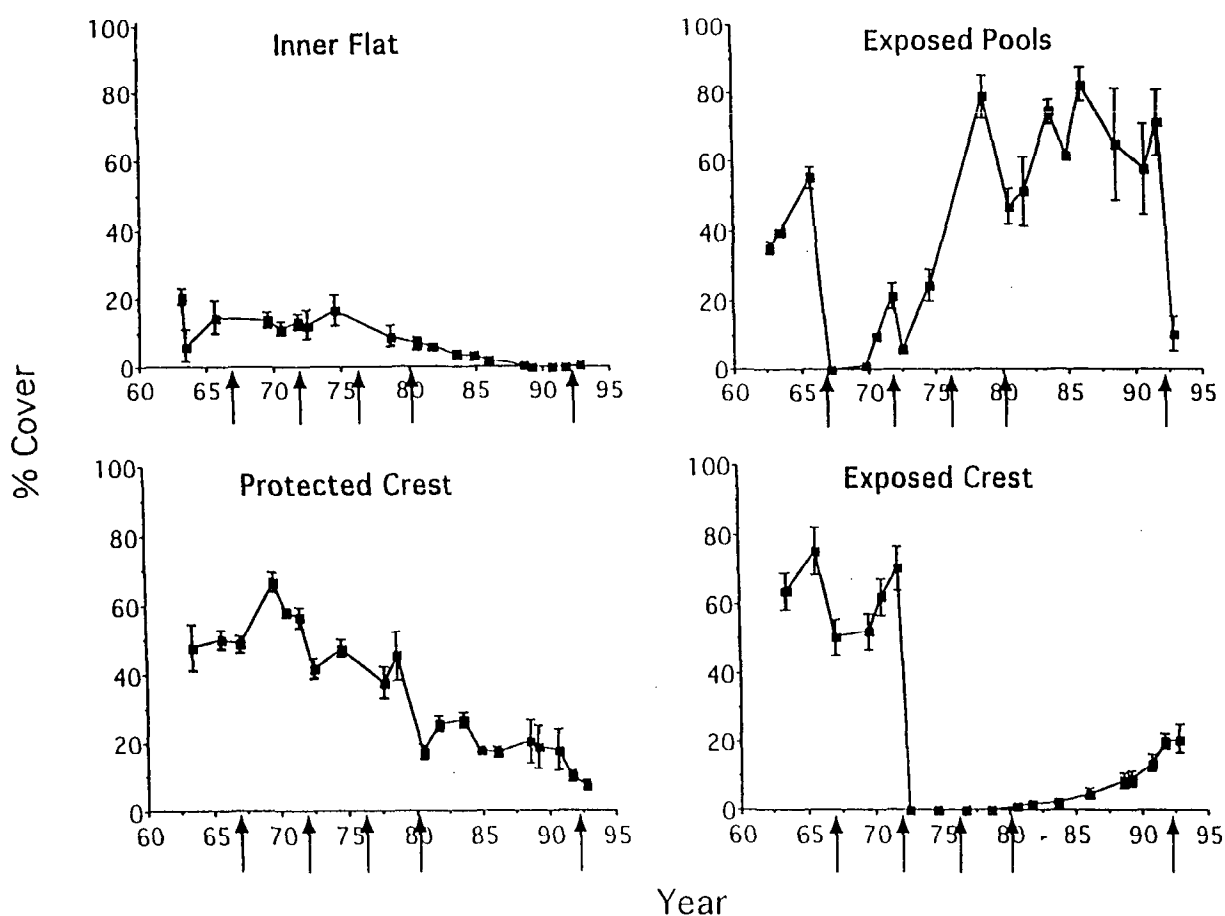
### Patterns of abundance

#### *Sudden declines: mortality in violent storms*

Corals exhibited a range of patterns of decline in different areas, showing sudden extreme crashes in cover in some places, and gradual long-term downward trends in others (Fig. 2). Each study area had a characteristic pattern of variation, due to different mechanisms operating (see below).

On the exposed (northern) edge of the reef, declines were abrupt, due to violent tropical cyclones passing close to Heron Island. Photographs of the permanent quadrats in the census after cyclones revealed extensive whole- and partial-mortality of corals: many branches were smashed or sheared off, abraided fragments were common, and many colonies had disappeared entirely. Significant damage to corals occurred in five years (1967, 1972, 1976, 1980 and 1992), and sometimes the physical environment was altered (e.g. sections of hard substrate were broken away, sediments shifted, and the pattern of water movement and drainage at low tide changed).

In contrast, on the protected side of the reef, the only pronounced cyclone damage was at the Protected Crest in 1980 (62% loss of cover), and at the Inner Flat in 1976 (46% loss). Clearly, the effects of each cyclone differed among the study areas. The 1967 cyclone was very damaging to corals at the Exposed Pools, but caused only minor or no damage to the other areas (Fig. 2). Similarly, although the 1972 cyclones killed almost all corals on the Exposed Crest, and caused relatively large reductions in cover at the Exposed Pools, they caused only minor damage to other study areas. The 1976 cyclone caused moderate reductions in cover and density at the Inner Flat, and minor loss of cover at the Protected Crest. The 1980 cyclone caused moderate reductions in cover and density at the Exposed Pools, to cover at the Protected Crest, and to density at the Inner Flat. Finally, the 1992 cyclone caused heavy damage to cover and moderate reduction in density at the Exposed Pools but had little effect at the other areas (Fig. 2). This cyclone removed most of the macroalgae from the Inner Flat; beforehand, in 1991, algae had covered almost all of the hard substrate there that was not occupied by corals; afterwards, algae remained at a low level in annual censuses up to 1995 (unpublished data).



**Figure 2.** Percentage cover of corals (mean  $\pm$  1 s.e.) on the four shallow sites with permanently marked quadrats. Arrows indicate cyclones.

*Gradual declines: mortality from exposure to air at low tide*

In contrast to the population crashes at the Exposed Crest and Pools, the long-term patterns of abundance at the Protected Crest and Inner Flats were remarkably different, being characterised by an early period of relative constancy, followed by very gradual declines. At the Protected Crest, coral cover peaked in 1969 (Fig. 2) and thereafter declined irregularly, with little damage (<27% loss of cover) in four of the cyclone years and greater damage (62% loss of cover) in 1980. Some of the decline in cover since 1981 was probably due to the effects of increasing exposure to air as the corals slowly grew upward. The photographic records show extensive in situ mortality of branch tips and tops of massive colonies, which slowly eroded. Basal parts of the colonies survived, but growth was gradually redirected sideways instead of vertically. This process may have been exacerbated when a 13 m launch ran aground on the reef crest in June 1982, eroding a shallow channel across the crest about 50 m east of the Protected Crest study area. As a result, some of the receding tide has continued to flow out this channel, increasing the exposure to air at low tide at this site.

The Inner Reef Flat usually had the lowest abundance of corals of any study area, except when cyclones killed most corals at other sites (Fig. 2). From 1963 to 1981, cover in the permanent quadrats fluctuated between 8% and 18%, then between 1981 and 1989, it declined gradually to nearly zero. This decline occurred over a large region of the inner flat (Connell et al. 1997).



This low average level of abundance on the inner flat in recent years is due to several factors. First, colonies died, partially or completely, from exposure to air as they grew above the low tide level. Second, the area had the lowest rate of recruitment, as described below. Last, some changes were related to the incidence of cyclones; coral cover fell, declining by 46%, in only one cyclone year (1976), and genet density declined between 22% and 32% in the cyclones of 1972, 1976, and 1980. During these cyclones, few colonies were broken, although some were tilted up above the low tide level and died from exposure to air. Cyclones also caused sediments to shift temporarily into groups of colonies, partially burying the larger ones, and completely burying and killing small colonies.

#### *Recoveries in abundance*

The rate of recovery of corals differed among study areas and among cyclones. At the Exposed Pools after the 1967 cyclone, which few corals survived, the rates of recovery of coral cover was slow (Fig. 2), because of limited recruitment by larvae and fragments (Fig. 3). In contrast, after the 1972 cyclones, cover recovered rapidly due to regrowth of survivors. In the 1980 cyclone, only a moderate reduction in cover and density occurred at this study area, and both recovered rapidly thereafter.

At the Exposed Crest the rate of recovery after the 1972 cyclone was extremely slow, because storms had caused most of the substrate to dry out at each low tide. Over the 20 years since then, much of the surface has been slowly eroded away in pockets which have vertical or overhanging shaded sides, providing moist spots in which coral recruits are able to survive. By 1992 erosion had removed about 60% of the uninhabitable dry surface and the maximum degree of recovery had reached about 63% of the original number of genets and 29% of the original cover.

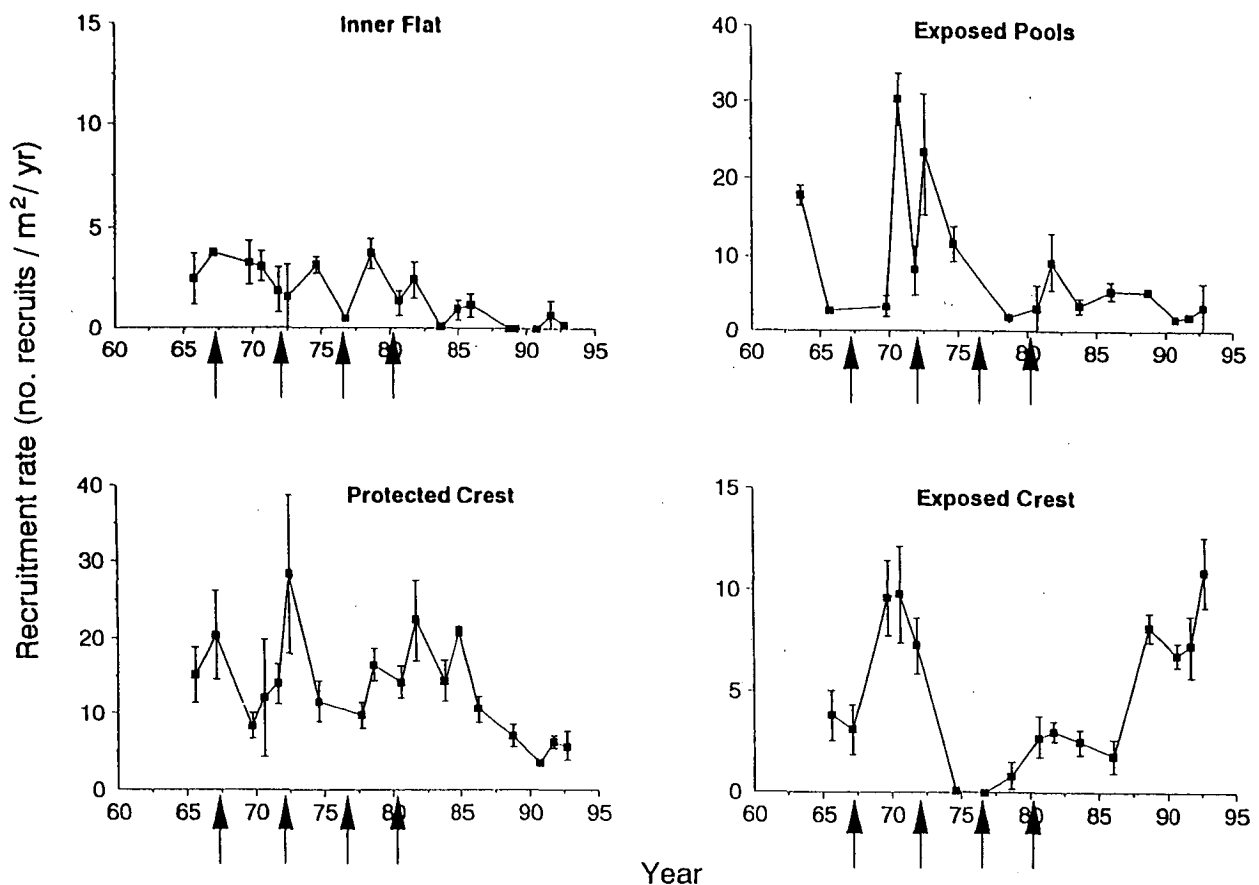
On the protected side of the reef, recovery from limited cyclone damage ranged from moderate to nil. At the Protected Crest, the recovery rate of coral cover after the 1980 cyclone, which caused the most damage, was slower than that after other cyclones. At the Inner Reef Flat, the rates of recovery were rapid after the minor damage from the 1972 cyclones, but were nil after the next two cyclones. In both areas, the overall long term trend was a gradual decline (Fig. 2).

#### *Recruitment of corals*

Recruitment rates showed considerable temporal variation within each study area. Moreover, the coefficient of variation ranged 7-fold among the study areas; the Protected Crest had the least variation, the Inner Flat the most, with the two other study areas being intermediate (Fig. 3). Recruitment rates also differed significantly among the study areas, the mean values for each area ranging from 1.7 to 12.7 recruits/sq m/year. The Protected Crest was highest, the Inner Flat the least, while the Exposed Pools and Exposed Crest were intermediate. Recruitment rates varied among study areas but not among years, with a significant interaction term (see Connell et al. 1997). This result suggests that years of good (or poor) recruitment were not consistent across all sites.

We tested the hypothesis that recruitment rate could depend on variation in free space, since coral larvae cannot attach to living coral. The recruitment rate increased with the amount of free space available at three of the four study areas (Connell et al. 1997). The exception was the Protected Crest, where free space never fell below 25%, so that the power of the test was low. Free space was preempted mainly by the presence of corals at the two crest sites and the Exposed Pools, since macroalgae never occupied more than 5% of the surface at the crests, or 15% at the Exposed Pools (unpublished data). In contrast, macroalgae were often the main occupiers of space at the Inner Flat site; here coral cover never rose above 35%, whereas

macroalgal cover ranged up to 90%. Therefore we hypothesised that reduction in coral recruitment at the Inner Flat was due mainly to preemption of space by macroalgae rather than by corals. To test this hypothesis we regressed recruitment rate against cover of either algae or corals at the Inner Flat. Recruitment rate fell as algal cover rose ( $r^2 = 0.21$ ,  $p < 0.001$ ,  $N = 50$ ), but showed no significant correlation with coral cover at this study area.



**Figure 3.** Coral recruitment (no./m<sup>2</sup>/year, mean  $\pm$  1 s.e.) over time on the four shallow sites with permanently-marked quadrats. Arrows indicate cyclones.

## Discussion

### Mechanisms affecting the abundance of corals

The two principal mechanisms associated with significant mortality in this study were natural rather than anthropogenic: cyclones and exposure to air. Recurrent cyclones produced sharp declines at most study areas at least once, but their effects were extremely patchy and they never impacted on all sites simultaneously. For example, although the Protected Crest study area is usually sheltered by nearby Wistari reef, it was the only location which suffered heavy damage in the 1980 cyclone. Similarly, the Exposed Pools and Exposed Crest, within 20 m of each other, suffered > 60% mortality in 1972, while other intertidal study areas were virtually unaffected. Therefore, we conclude that the spatial scale of cyclone damage was relatively small, usually affecting adjacent areas differently at a scale of a few 10s of metres or larger. Similar patchiness in damage from cyclones has been described elsewhere from subtidal sites, especially in relation to attenuation of wave damage in deeper water (e.g. Woodley et al. 1981; Porter et al. 1981; Blythell 1993; Hughes 1994).

Exposure to air as corals grew above the low tide levels was associated with more gradual declines in abundance. In larger colonies, damage from aerial exposure often began as partial loss of tissue, gradually increasing over several years as the colony grew upward. While this slow process occurred to some extent at all of the intertidal areas, its effects were strongest at the Protected Crest and Inner Flat, where coral cover gradually declined during the last 20 years of the study period. This slow decline in abundance occurred concordantly in both these study areas, and in study sites up to 350 m apart within each habitat. We conclude that mortality from exposure to air on Heron Island operates at a relatively large spatial scale of 100s of metres. Elsewhere, widespread mortality of corals from desiccation has been reported following unusually low tides (e.g. Loya 1990) and tectonic uplifting (e.g. Cortez 1993).

#### Mechanisms affecting recruitment of corals

Recruitment in marine organisms is notoriously variable in space and time (e.g. Coe 1957; Caffey 1985; Milicich and Doherty 1994). The causes of spatial variation in recruitment rates could include differences among study areas in: 1) supply of larvae from the plankton, 2) suitability of the substratum for settlement, and 3) mortality during the period between settlement and the time they were first censused.

Spatial variations in water circulation are probably more likely to supply similar numbers of larvae to adjacent quadrats than to widely separated sites in different habitats, which could produce the observed spatial pattern of variation in recruitment (see also Steele 1978, 1989; Caffey 1985; Babcock 1988; Harrison and Wallace 1990; Milicich and Doherty 1994). The swift currents channelled between Wistari and Heron reefs could explain, in part, the significantly faster rates of recruitment at the Protected Crest than at other areas. Similarly, sluggish water movement at the Inner Flats may have contributed to the very low rates of recruitment there (Fig. 3).

We documented evidence for two mechanisms which are likely to have affected the rates of settlement; inhibition by the established benthos and harsh physical conditions on the substrate. Firstly, recruitment rate per year was positively correlated with the amount of free space available at Heron Island, indicating that resident corals and/or algae preempt space sought by settling larvae (or subsequently smother newly settled juveniles). This relationship has been confirmed experimentally at Rio Bueno, Jamaica (Hughes 1986), where annual recruitment over six years was much higher on plots cleared of all corals than on undisturbed plots. Secondly, spatial and temporal patterns of recruitment may have reflected variation in the suitability of the substrate. For example, settlement is likely to have been inhibited by desiccation at the Exposed Crest after the 1972 cyclone up to 1986, and at the Protected Crest since 1985. Rates of recruitment at other periods at these two study areas were much higher (Fig. 3).

#### Conclusions

We measured a very wide range of community dynamics on Heron Reef, in part because we studied these assemblages for a relatively long period compared to most ecological investigations, and because the spatial scale of the study was sufficiently large to include a variety of habitats. The present study emphasises that there is considerable spatial and temporal variation in the effects of rare events such as cyclones. The dramatic differences in damage to corals at different sites and times at Heron Island caused by five different cyclones (Fig. 2), emphasises the difficulty in drawing general inferences from observations of a single event in isolation. Long-term studies are required to fully understand the full range of dynamic responses of coral reefs.

Anthropogenic changes had only minor impacts at our sites. However, we stress that this study was not designed to examine human impacts (e.g. with quadrats established close to areas of impact together with comparable controls further removed from human influence). To detect the effects of dredging, anchor damage, fishing, reef walking and nutrient additions on Heron Reef would require appropriate sampling designs and experimental tests.

### **Acknowledgments**

Many persons have helped us over the past 30 years. We would like to thank particularly R. Black, D.C. Potts, J.F. Grassle, M. Boyle, M. Pratchett, M. Fawcett, G. Goeden, M. Hunt, S. Schroeter, L. Smith, R. Standish, J. Wolstenholme, and J. Tanner. Taxonomic identifications were generously provided by C. Catterell, M. Pichon, I. Price, J. Tanner, J. Veron, and J. Wolstenholme. This research has been supported by the USA National Science Foundation. T.P.H. has been funded by the Australian Research Council and James Cook University. C.C.W. has also been supported by the ARC and the Queensland Museum.

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# The current status of sessile benthic organisms on the Great Barrier Reef

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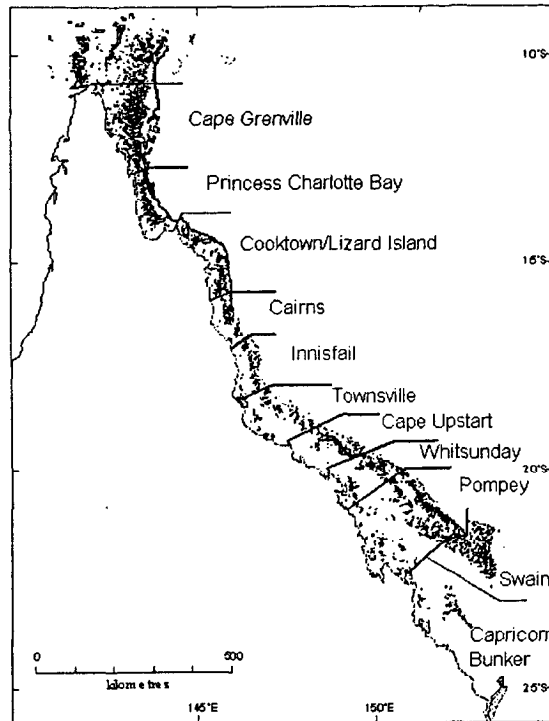
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## Introduction

Sustaining a healthy environment requires an understanding of the processes and extent of temporal change in sessile benthic assemblages. Case histories of reef degradation have clearly indicated the need for a systematic approach to understanding change (Hughes 1994; Maragos et al. 1985). For an area as large as the Great Barrier Reef (GBR) predictive and hypothesis generating models are the only option for such a systematic approach. However obtaining data of sufficient scope and detail is a difficult task. The area encompassed by the Great Barrier Reef World Heritage Area contains a large number of reefal and coastal marine communities. In order to assess status, information on distribution is required over a broad area so as to identify ecological communities that can form the basis for management plans. Most spatial studies have focussed either on a limited number of localities (e.g. van Woesik 1992) or the changes in community composition from inshore to offshore habitats (Done 1982; Oliver et al. 1995; Wilkinson and Cheshire 1988; Dinesen 1982). These studies demonstrated that the strength of the physical and biological gradients from inshore to offshore means that reefs that are widely separated in latitude, but are in equivalent positions on the continental shelf are more similar to each other than reefs in other cross-shelf positions at the same latitude.

In this document we present existing spatial information in a context which emphasises the relationship between physical and biological variables. This has been a successful strategy in the reef environment (Massel and Done 1993; Van der Laan 1994). We describe the distributional patterns of major components of the benthos at the same spatial scale as functionally connected hydrodynamic patterns. As the hydrodynamic regime is stable over decades, describing spatial patterns on this scale provides a stable framework in which to assess the response of benthic communities to changes in the biological, physical or anthropogenic pressures. Existing temporal information is discussed, but insufficient data are available at present to allow a meaningful analysis of temporal trends at the large spatial scales relevant to managing and conserving World Heritage values. More work is also needed to be confident of understanding how population dynamics manifest in small scale experimental and monitoring studies relate to larger spatial scales.

The data presented here were collected as part of the Australian Institute of Marine Science's (AIMS) Long Term Monitoring Program (LTMP). For the purposes of the LTMP the GBR is subdivided into 11 sectors, six of which contain reefs that are surveyed (Fig. 1). Sites on the north east flank of 52 reefs at 6-9 m depth are visited on an annual basis. Therefore, comparisons of benthic communities in this document refer only to a small subset of the habitats that may be encountered at any one reef. The advantage of this sampling regime is that a large spatial area is surveyed each year and relevant comparisons between reefs in different locations can be made. At each reef data are collected on water quality, reef fish and sessile benthos. A broadscale survey using the manta tow method (English et al. 1994) of the entire reef perimeter is also conducted at each reef, and the number of crown-of-thorns starfish (COTS) and an estimate of hard coral cover are recorded. A SONY hi-8 underwater video is used to film benthic cover on each transect. The resulting footage is a belt transect from which percent cover can be calculated.



**Figure 1.** Location of AIMS LTMP monitoring sectors in relation to the Queensland coast. Benthic surveys are conducted on inner, mid and outer shelf reefs in the following sectors; Cooktown-Lizard, Cairns, Townsville, Whitsundays, and the Swains. Outer reefs only in the Capricorn Bunkers.

The percentage cover data can be examined at various levels: broad groups, lifeforms, families, genera or species. Group level data summarise the components of the community into the following categories: abiotic, hard corals, soft corals, macro-algae, sponges and other. Lifeform data are concerned with hard coral growth forms. Generic and species level data group each hard coral according to its taxonomic affiliation. At generic level the results described here are confined to 30 of the most abundant hard coral genera found on the GBR. Genera were excluded from discussion if they were present on less than 50% of reefs within any one shelf position. In general the methods used in this study are biased against organisms with cryptic habitat association. This applies to some coral genera and also macro-algae and sponges. Detailed descriptions of the project design and relevant sampling protocols of the LTMP can be found in Oliver et al. (1995) and Christie et al. (1996).

#### Spatial trends in sessile reef benthos

##### Cross-shelf patterns

Most monitoring sites have a cover of living benthos approaching 100%, being composed predominantly of hard coral, soft coral and turf algae. The less abundant lifeforms, sponges and macro-algae, average  $1.2 \pm 0.3\%$  and  $2.6 \pm 0.8\%$  respectively. Shelf position (inner, mid or outer) refers to the location of a reef on the continental shelf and its relative proximity to the coast. Cross-shelf variation in the benthic community is well documented for the GBR (Done 1982; Oliver et al. 1995). The physical and biological gradients that characterise the cross-shelf environment create benthic communities with fundamentally different values for factors relevant to temporal change, such as disturbance regimes, recruitment, and growth and survival of hard coral. Cross-shelf patterns in the benthos are clearly related to exposure and water quality and are temporally consistent. At the levels of group, lifeform and genus, cross-shelf

trends account for 30-50% of the variation in the benthos (Oliver et al. 1995). Although most genera have broad cross-shelf distributions only a few account for most of the hard coral cover. *Acropora* is the most abundant genus in all shelf positions and increases from a mean of  $21 \pm 3\%$  on inner shelf reefs to  $35 \pm 3\%$  of the hard coral community on the outer shelf. *Porites* is the second most abundant genus, comprising on average 10% of the hard coral community in all shelf positions (Fig. 2).

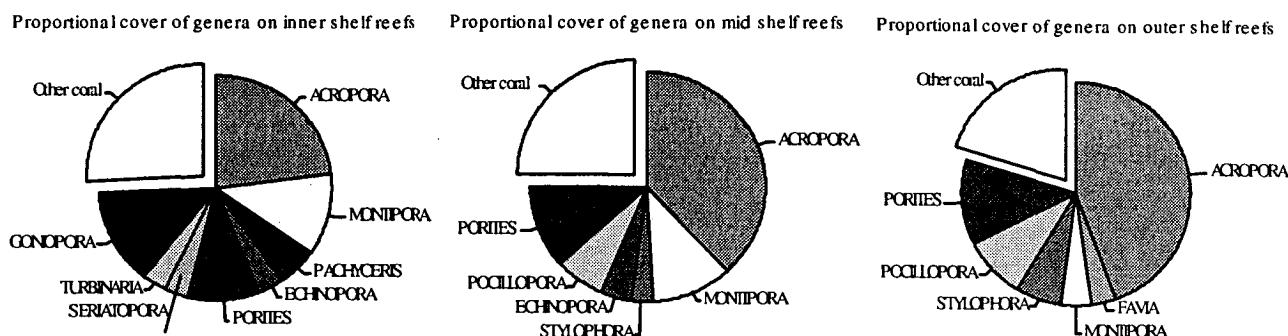


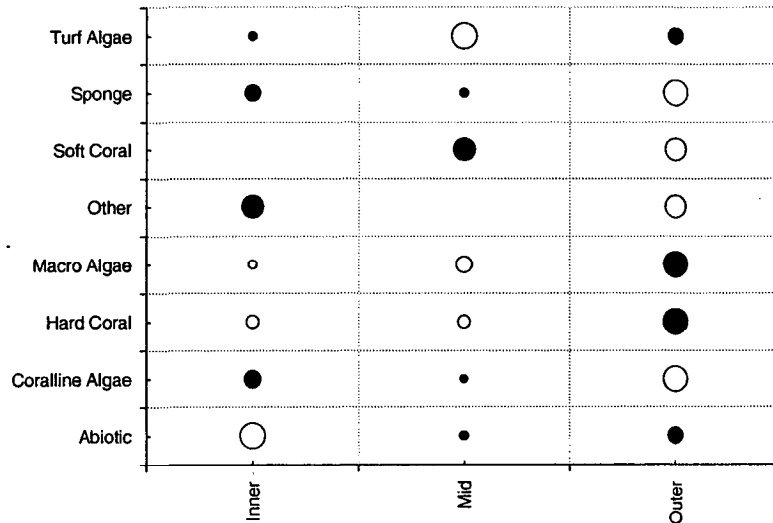
Figure 2. Proportional abundance of hard coral genera by shelf position

The outer reef environment is characterised by exposure to swell and water bodies dominated by oceanic conditions. Latitudinal changes in the effectiveness of the barrier formed by outer reefs lead to variable exposure regimes as well as geomorphology and productivity potentials in the mid-shelf environment. The benthic community is also more variable in response to the variety of habitats available in this shelf position. Inner reef communities are less affected by latitudinal changes in circulation than mid- and outer reefs and vary more in response to local variation in habitat availability and runoff. The inner shelf environment is characterised by low exposure to swell and water quality influenced by terrigenous factors. Suspended solids are consistently higher than on mid and outer shelf reefs which show similar values (Oliver et al. 1995). Some water quality parameters associated with runoff (e.g. salinity, nitrates, phosphates) are also very variable, with inner reefs experiencing extreme values during high rainfall events. Historically, inner reefs have been more influenced by sea level change resulting in variation in structure which influences benthic habitat availability.

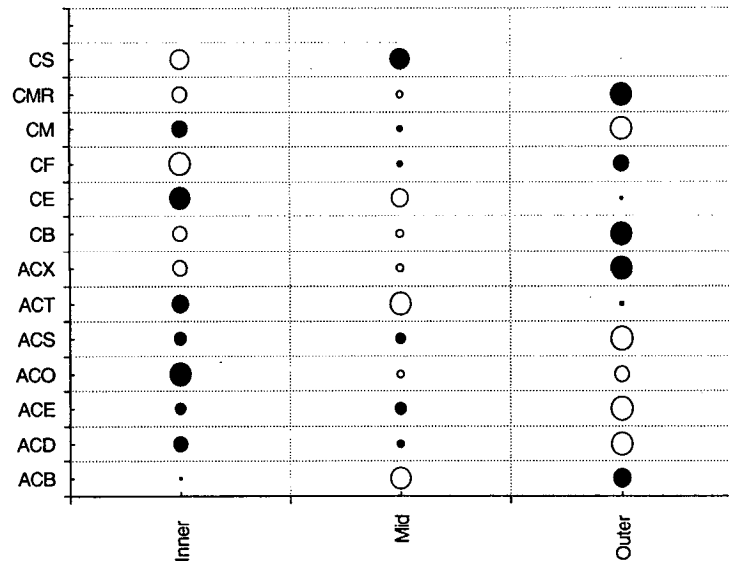
Inner reefs typically have non-contiguous reef structure which means that a higher percentage cover of silt, sand and rubble (abiotic) is found in these sites than on reefs in other shelf positions (Fig. 3). Rubble and consolidated substrate are colonised by turf algae, soft corals and hard corals. Large stands of coral (e.g. *Goniopora*, *Turbinaria* and *Pachyceris*) are found at some sites resulting in high overall percentage cover of hard coral.

Outer reefs have a greater proportion of coralline algae (Fig. 3). Foliose corals are more abundant on the inner shelf. Branching coral and bottlebrush growth forms of *Acropora* are more common on inner reefs while digitate, encrusting and submassive growth forms are more common on outer reefs (Fig. 3). The latter two growth forms are mainly represented by two species: *Acropora palifera* and *A. cuneata*. Corymbose *Acropora* spp. are relatively abundant on both mid- and outer shelf reefs. Tabulate *Acropora* are more abundant on mid-shelf reefs (Fig. 3). In general the more abundant hard coral growth forms are correlated with substrate type: those most abundant in environments with high sedimentation and low energy have smaller areas of basal attachment; those from high energy environments with consolidated substrates have lower profiles and larger basal attachments.





Abbreviation	Hard coral lifeform
CS	Coral submassive
CMR	Solitary corals
CM	Coral massive
CF	Coral foliose
CE	Coral encrusting
CB	Coral branching
ACX	A. bottlebrush
ACO	A. corymbose
ACT	A. tabulate
ACS	A. submassive
ACE	A. encrusting
ACD	A. digitate
ACB	Acropora branching



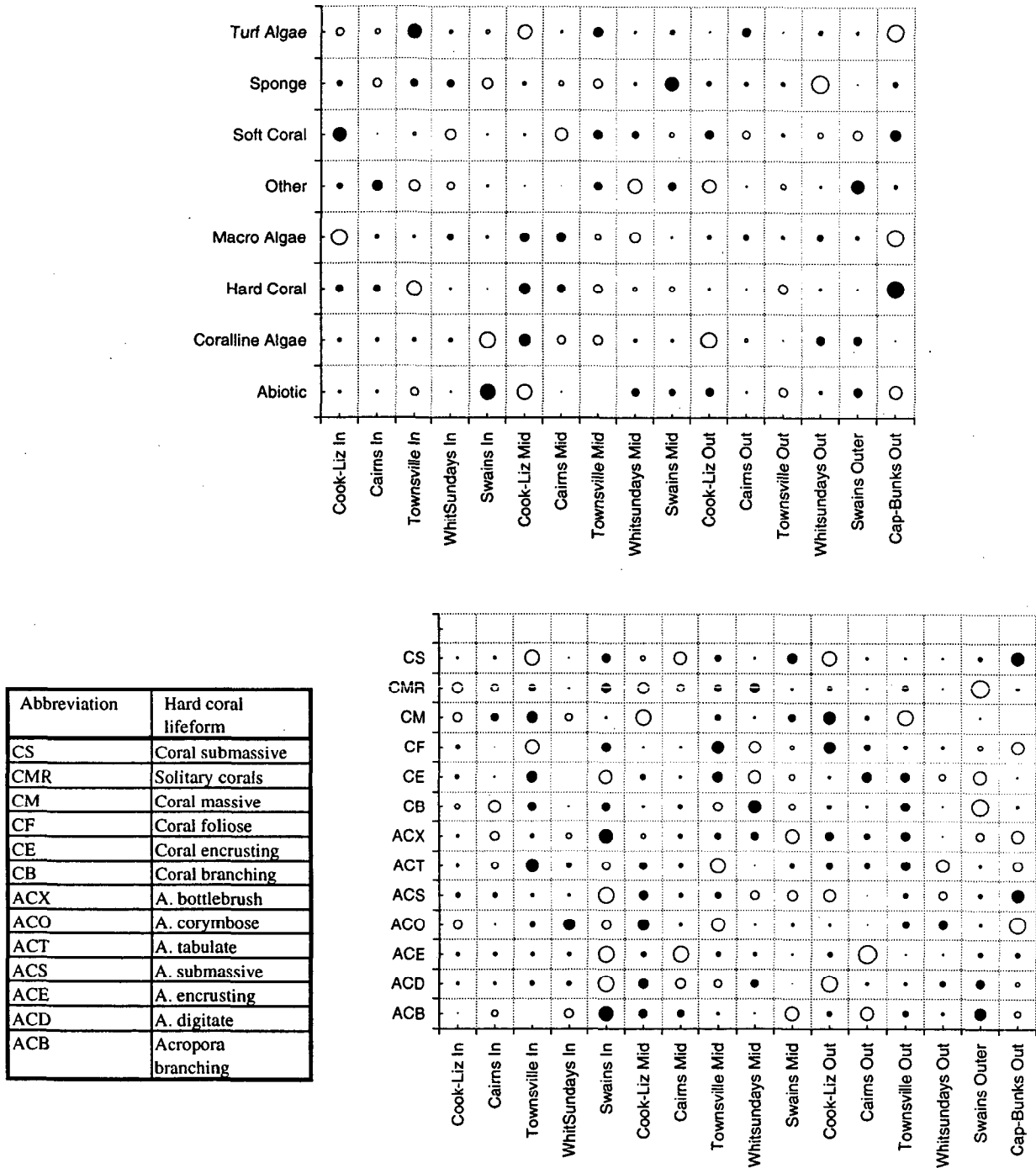
**Figure 3.** Relative abundance of benthos across the continental shelf of the GBR. Inner reefs are closest to the coast. The size of each dot indicates abundance relative to the overall reef mean. Clear dots indicate values above the mean and black dots indicate values below the mean. Blanks mean the value is equal to the reef mean. Values for lifeform are proportional to total coral cover.

#### Variations with latitude

Although small in comparison to cross-shelf gradients, regional patterns (Fig. 4) of benthic communities also provide a meaningful basis for management and assessment of status.

In the Cooktown-Lizard sector the shelf drops steeply into deep water. This has been favourable for reef growth and there are reefs situated on the shelf edge that have steep slopes and form a continuous barrier. They are structurally similar and have a high component of coralline algae, *Millepora* spp. and digitate Acroporid corals (Fig. 4). Corals of the genera *Pocillopora* and *Stylophora* are relatively more abundant than in other regions. The continuous outer barrier and small tidal variation means wave energy is low on mid-shelf reefs and

circulation is restricted. In the context of the GBR, mid-shelf reefs in the Cooktown - Lizard region form a distinct group, being more like inner reefs than mid-shelf reefs in other regions. They have higher relative abundance of sand and turf algae. In the coral community, massive corals and the genera *Porites*, *Diploastrea*, *Lobophyllia*, *Echinopora* and *Goniastrea* are relatively abundant. Solitary corals are also more common than on other mid-shelf reefs.



**Figure 4.** Relative abundance of benthos by sector and shelf position. Sectors are shown in latitudinal order from north to south. The size of each dot indicates abundance relative to the within shelf mean. Clear dots indicate values above the mean and black dots indicate values below the mean. Blanks mean the value is equal to the within shelf mean. Values for hard coral lifeforms are proportional to total coral cover.

To the south the continental shelf gets wider and the outer slope is more gradual. In the Cairns sector both outer and mid-shelf reefs are exposed to oceanic swells and circulation. In both Cairns and Townsville sectors, reef development is sparse in comparison with the Whitsundays and Swains regions which experience high tidal and current regimes as well as exposure to ocean swells. In the Cairns and Townsville sectors, reefs are scattered across the exposed outer slope and are variable in their structure, slope and aspect and have variable benthic communities. Mid-shelf reefs in the Cairns sector have a high incidence of digitate and submassive *Acropora* (Fig. 4). Mid- and outer reefs in the Cairns sector are similar to outer reefs in the Swains and Whitsundays in having relatively high abundance of soft corals (Fig. 4). High abundance of soft corals is correlated with low angle of the reef slope on exposed reefs. Sponges are also more abundant on outer reefs in the Whitsundays and Swains regions than in other regions.

The Swains region is unique in terms of the cross-shelf distribution of benthic communities. Inner-shelf reefs are unlike those in other regions, firstly because they have minimal influence from terrestrial factors due to the distance from the mainland and secondly because the broad inner channel allows more fetch and makes them more exposed than the midshelf reefs nearby, sheltered as these are behind the relatively dense outer reefs. In the low exposure mid-shelf communities, a contiguous reef slope commonly grades into a sediment-based slope with high coral cover and a diversity of coral growth forms and species. The benthic community on inner Swains reefs is similar to that on outer reefs in other regions.

Reefs in the Capricorn-Bunker region are isolated and influenced by a regime of current and water masses that is different from reefs in other sectors. They experience exposed conditions and typically have shallow reef slopes. Reefs in the Capricorn-Bunkers have a high component of turf algae (mean  $65\% \pm 6.9$  compared to a mean for all reefs of  $38\% \pm 2$ ). Corymbose *Acropora* corals and massive favid corals are relatively abundant.

#### The role of disturbance

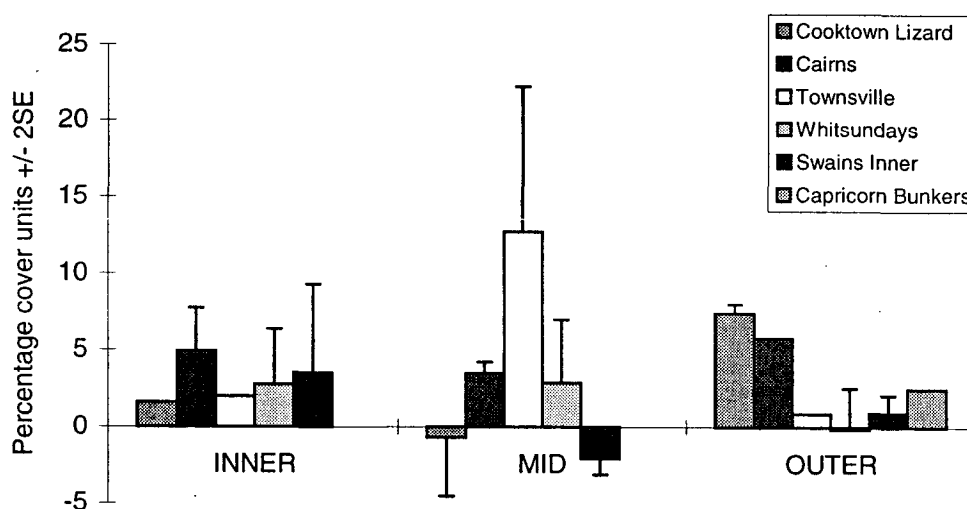
The relative stability of the spatial pattern of benthic communities created by hydrodynamic and structural constraints is overlaid by processes such as disturbance and recruitment variability operating at shorter time scales. Results of monitoring suggest that disturbance is a formative factor for many of the benthic communities of the GBR. The incidence of disturbance is unpredictable within a management time frame. Understanding the temporal response of communities is therefore crucial and long term temporal data are required to assess the present status and likelihood of persistence of benthic communities. In some cases historical information and monitoring data are available which support the findings of the benthic component of the LTMP. Factors that have caused large shifts in community structure on mid and outer shelf reefs are cyclones and COTS predation.

Communities dominated by *Acropora* appear to be characteristic of reefs with high disturbance regimes. Monitoring studies in the Capricorn-Bunkers region prior to 1990 indicated the benthic community was dominated by tabulate *Acropora*. Coral cover in 1987-88 was 40-50% (Bass et al. 1989) but dropped to 20-30% after 1990. No cyclonic storms were recorded and the disturbance event that produced the present algal-dominated community is unknown. Where recruitment and growth have occurred following the depletion of hard coral in 1989, the benthic community is once again dominated by tabulate *Acropora* (100% of regrowth was due to an increase in the percentage cover of *Acropora* at One Tree Island). Outer reefs in the Cooktown-Lizard and, to a lesser extent, the Cairns region are also presently recovering from damage to the reef slope community by cyclone 'Ivor' (van Woessik et al. 1991). The greater change in coral cover in Cairns and Cooktown-Lizard sectors (Fig. 5) compared to other outer reefs is primarily a result of *Acropora* recruitment and growth. In the Cooktown-Lizard sector,

59% of regrowth on outer reefs was due to an increase in the percentage cover of *Acropora*. The scale of patchiness both between reefs and within reefs as a result of disturbance and recovery varies in both the Cooktown-Lizard region and in the Capricorn-Bunkers (Doherty et al. in press). In both sectors however, there is evidence that a significant recruitment of *Acropora* occurred within a few years of disturbance and that pre- and post-disturbance coral communities were dominated by *Acropora* spp. There is also evidence for the persistence of *Acropora*-dominated communities following COTS outbreaks. Coral cover on mid-shelf reefs in the Townsville sector was greatly reduced by COTS activity in the 1980s but has been increasing rapidly over the last three years. In 1994-95 average coral cover was  $44.8 \pm 10.6\%$  compared to a mean for all reefs of  $22.2 \pm 2.3\%$  in the same period. This high value is a reflection of the dominance of tabulate and corymbose *Acropora*. As was the case in the Capricorn-Bunkers this community was also dominant prior to the most recent disturbance (Williams pers. comm.).

Biological disturbance events in the form of predation of coral communities by COTS have affected many of the survey reefs. Coral cover at Gannet Cay in the Swains sector decreased between 1993-94 and 1994-95 as a result of predation on coral within the monitoring sites. In these years the Swains was the only sector between Cooktown-Lizard and the Capricorn-Bunkers to have COTS outbreaks. So far COTS outbreaks have affected few reefs in the southern sectors (Whitsundays to Capricorn-Bunkers) compared to the north.

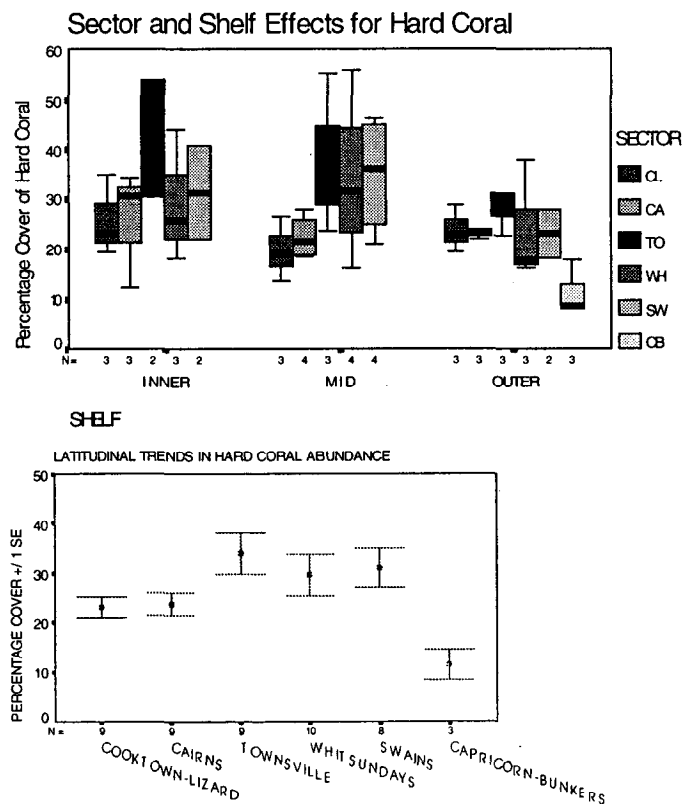
#### Change in Hard Coral Cover Between years 1993-94 and 1994-95



**Figure 5.** Percentage change hard coral  $\pm 2$  standard error by sector and shelf position. Percentage units are absolute.

In the Townsville, Cairns and Cooktown-Lizard sectors 17 of 25 reefs where benthic surveys are conducted annually have outbreak histories (Fernandes 1991). The benthic communities in these regions are clearly influenced by impact of and recovery from COTS predation. Recovery of reefs in Cooktown-Lizard and Cairns sectors differs from that observed on mid-shelf reefs in the Townsville region. In 1994-95 hard coral cover was lower on inner and mid-shelf reefs in Cairns and Cooktown-Lizard than the southern sectors (ANOVA  $p < .01$ ) (Fig. 6). The Cooktown-Lizard region is presently experiencing COTS outbreaks on three of twenty two reefs surveyed during 1995-96 and has an average decrease in coral cover on mid-shelf reefs (Fig. 5). Cairns sector reefs on the other hand are increasing in coral cover at a proportional rate of 35% which is above the overall mean of  $14.6\% \pm 3.2$  for all survey reefs. This suggests that recovery is now under way in the Cairns sector.

Further investigation is required to determine if inner and mid-shelf reefs in Cooktown-Lizard and Cairns sectors should be considered to have a higher risk of degradation than other sectors, as recovery has been slower. The probability of coral mortality due to flood plumes is higher due to the narrow width of the continental shelf compared with more southern regions. The Cairns area also has extensive human use of the hinterland, high rainfall and high human usage of reefs. Reduced mixing and circulation may affect recruitment and growth potential for coral in the Cooktown-Lizard region. There is increasing evidence for the location of a centre of recruitment for COTS in the northern region. Available evidence suggests that the occurrence of large numbers of starfish at a reef is predictable at large spatial scales as the manifestation of high recruitment south of areas with already large adult populations (Moran et al. 1992). Numbers of COTS are presently increasing on the northern GBR (Engelhardt et al. this volume) so further decreases in coral cover are expected in the future. Reefs from the Whitsundays south may experience a different dynamic of COTS dispersal and population dynamics. Continued research on this issue is important to determine management strategies for reef benthos on the GBR. In summary, the type, frequency and intensity of disturbance and probable recovery rate and trajectory that any reef experiences are also related to hydrodynamic and structural factors (see Burrage et al. this volume). Developing models to adequately integrate physical and biological variables is necessary to manage an appropriate response to the changing status of reef communities.



**Figure 6.** Boxplots of percent cover of hard coral in 1994-95 at each sector and shelf position and sector means (+/- 1 standard error).

The concept of assigning value for indices of reef health at a variety of spatial scales is used in conservation management and is relevant to management of the GBR World Heritage Area. For example, hard coral cover is commonly used by ASEAN countries as a measure of 'value'. While this has some relevance within defined boundaries it has little significance in comparing regions. In 1994-95 the mean percentage cover for hard coral was  $27.2 \pm 1.64\%$  with 50% of

reefs having values for coral cover between 8 and 30%. A great range of values is found within each shelf position (Fig. 6). The average coral cover on the GBR is lower than on many other reef systems in the Indo-Pacific. No evidence exists to suggest this is a result of degradation. How value is assigned needs to be relevant to the scale at which management is implemented and the relative importance of the processes which structure benthic communities within this area.

For the GBR some natural management structures suggest themselves on the basis of historical evidence and current status. The uniqueness and conservation status of inshore reefs should be assessed in relation to regional land use and circulation patterns and runoff regimes in addition to coral species diversity which is high on some inshore reefs (Veron 1995). Impacts on coral due to elevated water temperatures are more likely in inshore areas as are phase changes to communities dominated by macro-algae (Done 1995). For mid and outer reefs three management regions are suggested. In the regional context the Capricorn-Bunkers are unique in that reefs are isolated from other reef communities on the GBR by physical distance and by periodic changes in the prevailing hydrodynamic conditions. Species compositions of fish and coral are also distinctly different from other regions in the GBR (Veron 1995; Sweatman et al. this volume). Veron (1995) postulates that the lower number of coral species in this region is due to a lack of habitat diversity with all reefs having limited topographical relief. A second region is formed by the Swains and Whitsundays where hydrodynamics and structural factors are a primary influence on the community, and a third from Townsville to Cooktown-Lizard where a history of high biological and physical disturbance is a primary factor.

Insufficient observations currently exist on disturbance and recovery rates of non-*Acropora* community types. Current monitoring methods need to be modified to ensure that communities with 'high value' as assessed by parameters of demography and productivity are adequately documented, as suggested by Done (1995). Both these tasks require additional information and compilation of existing data resources.

The contribution of monitoring data to managing the reef as a healthy and sustainable environment is two-fold. Risk assessment models such as those suggested by Done (1995) require large scale spatial information on the distribution of community types and process information of how each community functions. Exposure, water quality and circulation interact with disturbance by affecting recruitment supply, growth rates and by defining the kind of habitat that is available for colonisation. A meaningful assessment of status, however, does require a dedicated inter-disciplinary project. Compiling information on demographic population structure is the next priority for the benthic component of the LTMP to ensure that models for management and conservation can be successfully implemented.

### **Acknowledgments**

We would like to thank the team member of the AIMS Long Term Monitoring Project for comments and Dave Williams and Dave Wachenfeld for supply of unpublished material.

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# Long-term trends in the status of coral reef-flat benthos - The use of historical photographs

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## Summary

Recently, there has been wide-spread concern that the coral reefs of the Great Barrier Reef (GBR) have suffered severe degradation from anthropogenic influences since European settlement in Australia. This concern has developed particularly in more recent times, as the human population has increased. Part of the evidence used to support this contention has come from comparisons between old photographs of reef-flats exposed at low tide and the same reef-flats as they are today. This technique is clearly relatively crude and can only be expected to detect gross shifts in benthic community structure. However, it is exactly this kind of change (for example from hard coral dominated to soft coral or algae dominated) that is of interest in the context of 'severe degradation'. Where such photographic comparisons have been used, typically only a small number of old photographs from one or two sites within the GBR have been employed.

The Historical Photographs Project of the Great Barrier Reef Marine Park Authority (GBRMPA) represents the only concerted attempt to use as many old photographs as possible from as many different locations as possible in order to fully assess the information that can be derived from such photographs.

There were two main aims of the project: firstly, to create as comprehensive as possible a collection of historical photographs of the GBR, using only photographs that show below-water substratum and to which an exact geographic location can be ascribed, and secondly, to return to the sites of as many of the original photographs as possible and take new photographs of the same areas of substratum.

In total, comparisons between historical photographs and modern observations can be made for 14 locations. Of the 14 locations for which comparisons can be made, six show no evidence of change in reef-flat benthic communities between the historical photographs and modern observations. These locations are Daydream Island, Magnetic Island, Great Palm Island, Orpheus Island, Fantome Island and Pickersgill Reef. Communities at these locations range from being dominated by *Acropora* spp. to being dominated by a mixture of massive hard corals (mostly faviids and *Porites* spp.) and soft corals. At four locations (Stone Island, Bramston Reef, Fitzroy Island and Michaelmas Cay) evidence of significant change in reef-flat communities has been found. At all four locations there is markedly less living hard coral on the reef-flat today than can be seen in the historical photographs. At least two of these locations have been badly affected by cyclones. At the four remaining locations (Hayman Island, Green Island, Double Island and Low Isles) some areas show evidence of change in the reef-flat community and others appear unchanged from the historical photographs.

Comparisons between historical and modern photographs can provide information that is useful in the management of the Great Barrier Reef World Heritage Area (GBRWHA). Such comparisons can be used to distinguish between reef-flats that should be of concern to managers and others that may require less attention. However, using comparisons between modern and historical photographs as a measure of reef-flat health is a coarse tool with several important limitations (such as only reef-flats near a recognisable landmark can be studied, non-



randomness of original 'sampling', absence of quantitative data and incompleteness of the temporal record). These limitations must be considered when considering photographic comparisons.

Given the limitations of this technique, comparisons between historical photographs and modern reef-flats can never provide definitive, stand-alone proof one way or the other in the debate over whether or not the GBR is undergoing a steady decline. Clearly, some of the reef-flats studied have suffered heavy mortality of hard corals. However, from the results of the project so far, the large number of locations that do not appear to have changed since the historical photographs were taken throws doubt on the proposition that the GBR is subject to broad scale decline.

## **Introduction**

For over a century, people have been taking photographs of the GBR. The first extensive collection of high quality photographs of coral reefs was produced by William Saville-Kent (1893). The book contains many photographs of the GBR taken at spring low tide. One of Saville-Kent's ambitions in publishing these photographs was that they should be used to monitor the growth of corals in the future. To this end, he made detailed notes about the locations of each photograph, and, in one case, even made a schematic diagram of the corals shown in the photograph with measurements of their sizes. In addition, many of the photographs have distinctive landmarks on the horizon, a further aid in relocation. Despite the existence of this impressive collection of photographs and the explicitly stated intention that they be used to examine coral growth, there exists no published record of an attempt to revisit the sites of Saville-Kent's photographs and take modern photographs for comparison. However, a site near Bowen where Saville-Kent had taken photographs of extensive hard coral formations was revisited in 1925 by Charles Hedley (Hedley 1925). Unfortunately, Hedley did not take further photographs, but his description of the site is very graphic: '... this famous, wonderful, and immense structure has now completely vanished. Not only has the coral all died, but every vestige of it, except the foundation, has been swept away.' This account clearly begs the question 'What would a modern photograph of the area show?'

Since Saville-Kent's book, 100 years have passed and tens of thousands more photographs of the GBR have probably been taken. In most of these the tide is too high to see the reef-flat substratum. In those where substratum is visible, only a few offer the opportunity to relocate accurately the site of the photograph. However, a certain number of photographs exist where reef-flat substratum is visible and the site of the photograph can be relocated. These photographs offer an unrivalled opportunity to compare reef-flats as they are today with reefs as they were many years ago.

Comparisons between historical photographs of coral reef-flats and modern observations have been used before (e.g. Endean 1976; Bell and Elmetri 1995). These comparisons have come from sites including Stone Island (near Bowen), Magnetic Island and Low Isles. In all cases, these comparisons have shown decreases in cover of hard coral and increases in cover of soft coral and/or macroalgae. Typically, these changes in reef-flat benthos are described as reef 'decline'. In some cases the proposition that reefs are declining or dying is extended to the entire GBR. However, these assertions typically are made on the basis of only one or two historical photographs from only one or two sites. The environmental pressure considered most likely to be causing such decline is eutrophication and/or increased sediment load.

No intensive and comprehensive study of historical photographs has yet been carried out. The Historical Photographs Project of the GBRMPA was instigated in order to fill this gap.

The project had two main aims:

1. To create as comprehensive as possible a collection of historical photographs of the GBR, using only photographs that show below-water substratum and to which an exact geographic location can be ascribed.
2. To return to the sites of as many as possible of the original photographs and take new photographs of the same areas of substratum.

## **Materials and methods**

### Collection of historical photographs

The libraries of GBRMPA, the Australian Institute of Marine Science and James Cook University of North Queensland were exhaustively searched for published material containing historical photographs. Various other sources were also investigated, for example, private collections of individuals who have worked on the GBR for many years and museum collections. However these sources were not investigated as thoroughly as the libraries.

In order to be acceptable for use in the project, each photograph had to fulfil the following criteria:

- each photograph had to depict coral reef substrate exposed above water; and
- each photograph had to contain a distinctive landmark that would allow relocation of the site of the photograph. Some photographs without landmarks were included, but only if they were part of a set of photographs, at least some of which did contain landmarks.

Photographs were used irrespective of the year in which they were taken in the hope of developing a collection that contained relatively recent photographs as well as very old ones.

All suitable photographs that were discovered were copied using three formats: colour slide, colour print and black and white print. In addition, two large (approximately A4: 297 mm x 210 mm) prints of each historical photograph were made for use in the field.

### Relocation of sites

Historical photographs were found associated with widely varying amounts of geographical information. The process of relocating the site of a photograph depended entirely on the quantity and quality of this information. Typically, text found with the photograph gave a rough indication of the location. Usually, this location was then narrowed down by consultation with people familiar with the area (usually staff of the Queensland Department of Environment, the Queensland Boating and Fisheries Patrol, the Queensland Department of Primary Industries and the GBRMPA). Final decisions as to the exact site of a photograph were taken on site at spring low tide. Field work was carried out in 1994 and 1995, during the winter, when the lowest tides occur during the day. Tides used for site visits and photography ranged from 0.02 m to 0.31 m above Lowest Astronomical Tide (LAT).

## **Results**

### Collection of historical photographs

In total 121 suitable historical photographs were found. These ranged from Thursday Island in the north to Heron Island in the south and dated from as far back as 1890. Of these 121 photographs, 96 have been copied and added to the image collection of the GBRMPA. The 25

photographs that were not copied were all from the Torres Strait. All locations for which photographs were found are listed in Table 1, together with the numbers of photographs for each location. The positions of each of these locations are shown in Fig. 1.

#### Relocation of sites

For most of the historical photographs, it was not possible to determine exact sites on the reef-flat. Most of the landmarks in the historical photographs are sufficiently far away from the site of the photograph that movement in the order of 500 m on the reef-flat has little effect on the appearance of the landmarks. The problem with distance between site of photograph and useful landmarks also affected the taking of bearings for relocation of the modern photographs. Thus, in most cases, the modern photographs are representative photographs of the same reef-flat as in the historical photograph, not exact replicas of the site of the historical photograph.

#### Interpretation of photographs

The following accounts of individual locations only cover those locations which have been revisited and for which modern information is available. Locations for which historical photographs have been found, but which have not been revisited (see Table 1) are not considered. In addition, no account is given for Border Island. When this location was visited, it was realised that the historical photograph had been taken when the tide was not at its lowest and a large part of the reef-flat was underwater. The accounts of individual locations are general in nature. For specific details of times and dates of photography, tidal heights etc. see Wachenfeld (in press).

#### Daydream Island

The single historical photograph from Daydream Island depicts a substratum of arborescent and caespitose *Acropora*. The exact year in which this photograph was taken is uncertain but the photograph was taken from a book published in 1950, so was certainly taken before that year. This area of the reef-flat still has similar corals to those shown in the historical photograph, with a band of *Acropora* approximately 100 m long and up to 10 m wide along the seaward edge of the reef-flat (Fig. 2).

#### Hayman Island

The three historical photographs from this location were taken in 1946 and depict the same area of the reef-flat. The benthos is dominated by extensive cover of branching hard corals, although the photographs are of insufficient quality to determine any detail. This is the only location at which the exact site of the historical photographs was relocated. Distinctive rocks in the middle distance of the historical photographs were found and thus the modern photographs are of exactly the same area of reef. The living coral in the foreground and middle distance of the historical photographs is no longer present. These areas are now covered predominantly in coral rubble. However, large areas of branching hard corals (caespitose *Acropora* spp.) are present nearer to the seaward edge of the reef-flat. Thus, the area of branching hard coral on the modern reef-flat appears to be less than that in 1946, although extensive areas of the reef-flat are still covered in such corals. It should be noted that a nearby area of the seaward edge of the reef-flat has a different benthic community comprised of a mixture of corymbose *Acropora* spp., massive corals (mostly faviids) and soft corals (mostly *Sinularia* sp.).

**Table 1.** Numbers of historical photographs found, copied and relocated and re-photographed for each location. Where possible, names of locations are followed by the relevant GBRMPA identification numbers.

<b>Location</b>	<b>Number of Historical Photographs Found</b>	<b>Number of Historical Photographs Copied</b>	<b>Number of Historical Photographs Re-photographed</b>
Heron Island 23-052	4	4	0
Wistari Reef 23-053	5	5	0
Daydream Island 20-035	1	1	1
Hayman Island 20-014	3	3	3
Border Island 20-067	1	1	1
Lindeman Island 20-090	1	1	0
Saddleback Island 20-015	3	3	0
Bramston Reef 20-005	5	5	5
Stone Island 20-004	9	9	9
Magnetic Island 19-009	6	6	6
Great Palm Island 18-054	8	8	8
Orpheus Island 18-049	8	8	8
Fantome Island 18-053	1	1	0
Palm Islands (unknown)	2	2	0
Fitzroy Island 16-054	1	1	1
Green Island 16-049	12	12	10
Double Island 16-047	2	2	2
Michaelmas Reef 16-060	3	3	3
Alexandra Reefs 16-039	1	1	0
Low Isles 16-028	12	12	3
Pickersgill Reef 15-093	3	3	3
Watson Island 14-068	1	1	0
Thursday Island	25	2	0
Warrior Island	2	0	0
Unknown	2	2	0
<b>Total</b>	<b>121</b>	<b>96</b>	<b>63</b>

### Bramston Reef

Five historical photographs from Bramston Reef (a mainland fringing reef, just south of Bowen) were found. All five were taken by William Saville-Kent circa 1890. Because the landmarks in these photographs are poor, the modern versions of all five historical photographs must be considered as general comparisons, rather than specific ones. Despite the inability to relocate the sites of the historical photographs exactly, comparisons are still valid because the modern reef-flat is fairly homogeneous.

All five of the historical photographs show many large colonies of massive corals such as *Porites* and faviids and tabular/corymbose colonies of *Acropora* spp. No such *Acropora* spp. are present currently and although large numbers of faviid colonies are still present, the vast majority are dead and those that are alive are comparatively small (< 15 cm diameter). The dead faviid colonies are typically covered in algae and/or mud. Some living large colonies and micro-atolls of *Porites* are present. The *Porites* micro-atolls present are alive around the sides, with mud and algae on top of them. Some areas of the reef-flat are covered in large amounts of rubble from branching corals and several dead colonies of *Acropora* were found cemented to the reef-flat, apparently where they had grown.

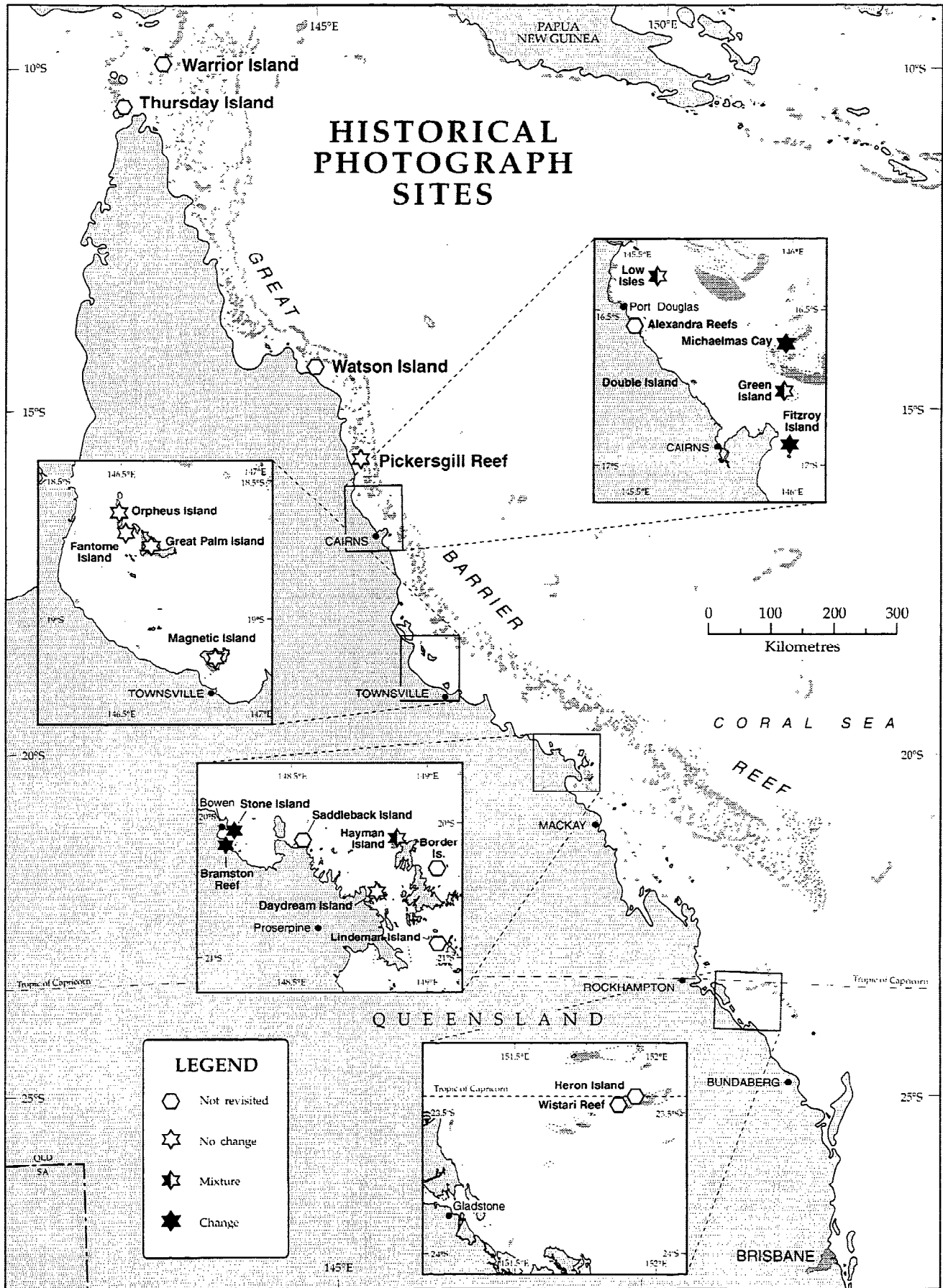
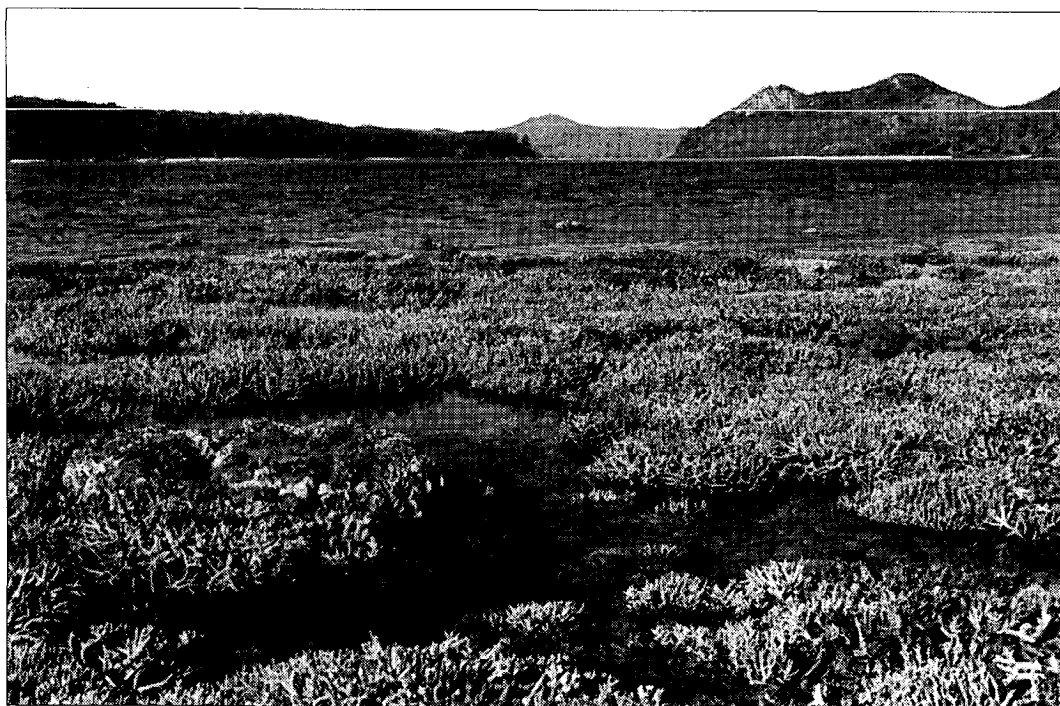
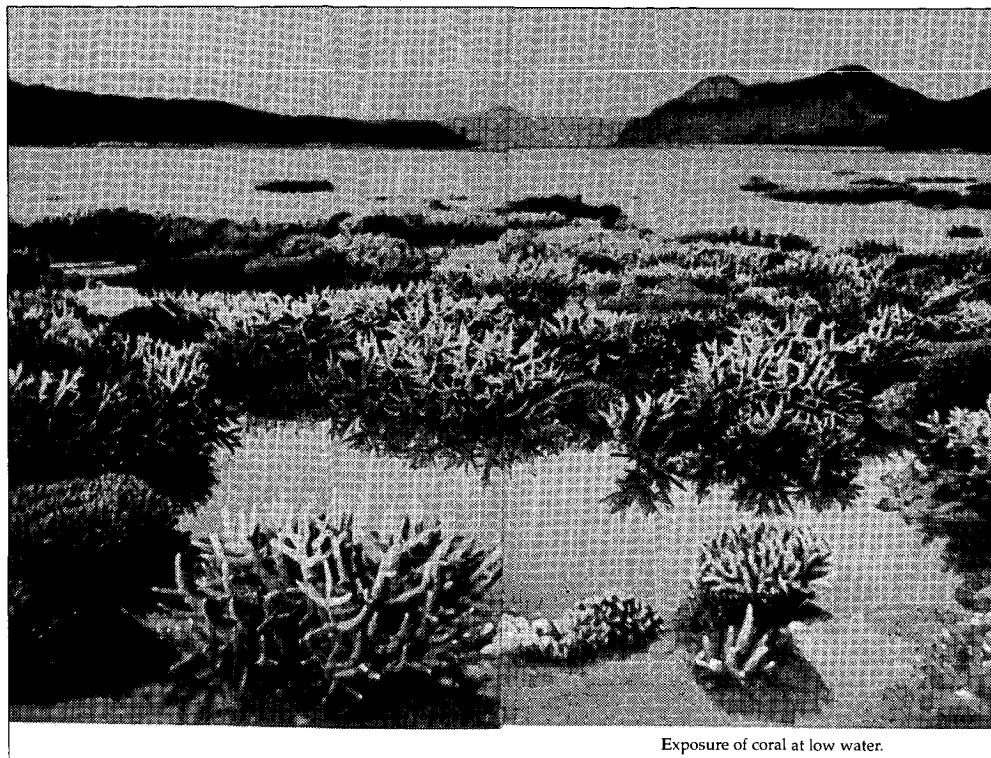


Figure 1. Map showing positions of locations for which historical photographs were found



**Figure 2.** Reef-flat at Daydream Island pre-1950 (top; photographer unknown) and 1995 (bottom; Andrew Elliott)

### Stone Island

Nine historical photographs from Stone Island were found. Six of these photographs have distinctive landmarks on the horizon, the landmarks are too distant to allow exact relocation of the original sites. Thus, the modern versions of these historical photographs must be considered as general comparisons, rather than specific ones. The other three historical photographs do not show any landmarks on the horizon, therefore, only general comparisons with the modern reef-flat are possible. Despite the inability to relocate the sites of the historical photographs exactly, comparisons are still valid because the modern reef-flat is very homogeneous, with movements of several hundred metres making little difference to the appearance of the reef-flat. All nine of the historical photographs were taken prior to 1915 and show extensive hard coral cover including many colonies of plating, corymbose and caespitose *Acropora* and many massive coral colonies. Today, the reef-flat has no colonies of *Acropora* exposed at spring low tide and few massive coral colonies. The surface of the reef-flat is now covered in a mixture of coral rubble and algae. Fig. 3 shows one of the typical historical photographs and its modern equivalent.

A cyclone in 1918 destroyed the Stone Island reef entirely (Hedley 1925; Rainford 1925). However, although no photographic evidence has yet been discovered, local residents say that between 20 and 30 years ago, there was a healthy reef-flat at Stone Island.

### Magnetic Island

Endean (1976) presented a photograph of the reef-flat at Geoffrey Bay taken in 1952. The photograph shows high cover of branching hard coral, although the quality of the photograph is too poor to distinguish any detail. Endean also presented another photograph, supposedly of the same area, taken in 1971 that shows no living coral at all. Endean used the two photographs to illustrate the 'destruction of the bulk of coral colonies that formerly flourished on the island's fringing reefs'. However, examination of the photographs indicates that the 1971 photograph was taken much further from the seaward edge of the reef-flat than the 1952 photograph.

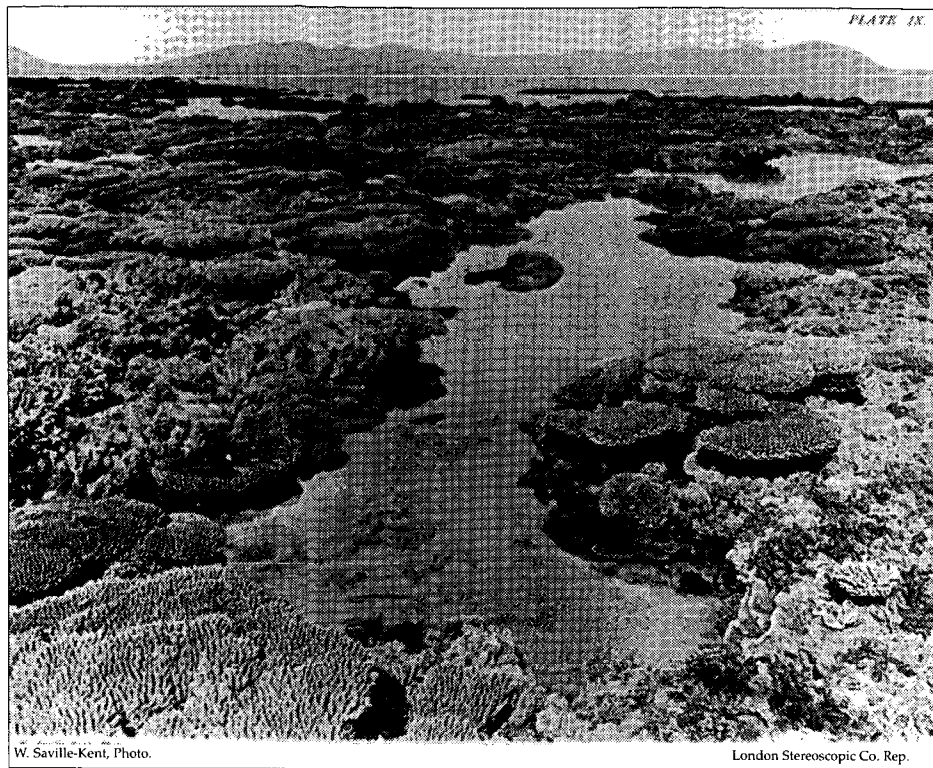
Geoffrey Bay was visited in 1995 in order to document the current benthos of the reef-flat. A variety of different benthic communities in different areas of the Bay were found.

Near the southern end of the Bay, two large areas of caespitose *Acropora* (30-50 m long and approximately 10 m wide) were found near the seaward edge of the reef-flat. Photographs of these areas closely resemble the 1952 photograph presented by Endean. Thus comparison of the modern reef with this historical photograph provides no evidence of change. However, these areas of *Acropora* represent a very small percentage of the total area of the Geoffrey Bay reef-flat. It is not possible to tell from the historical photograph whether or not this was also the case in 1952.

The majority of the seaward edge of the reef-flat of Geoffrey Bay was dominated by coral rubble covered in a variety of algae. Most of the reef-flat away from the seaward edge was of a similar substratum and closely resembled the benthos of the 1971 photograph presented by Endean (1976).

In the centre of the Bay, within approximately 15 m of the beach, there was an extensive area where the benthos was comprised of *Montipora digitata* and *Halimeda* sp.





**Figure 3.** Reef-flat at Stone Island circa 1890 (top; William Saville-Kent) and 1994 (bottom; Andrew Elliott)



In addition to the two photographs from Edean (1976) four other historical photographs of Magnetic Island were found, all taken in 1952. However, it is uncertain whether these were taken in Geoffrey Bay or Nelly Bay and all four photographs show only reef-flat substratum, with no landmarks, therefore it is not possible to relocate them. However, it is worth noting that all benthic organisms depicted in these photographs (including foliaceous *Montipora*, *Lobophyton* soft coral and branching *Acropora*) can still be found on the Geoffrey Bay reef-flat.

Thus, overall, comparison of the modern Geoffrey Bay reef-flat with available historical photographs provides no evidence of change.

#### Great Palm Island

Eight historical photographs of Coolgaree Bay, Great Palm Island were found. All eight were taken by William Saville-Kent circa 1890. In all eight historical photographs, the landmarks are relatively close to the site of the photograph, allowing accurate relocation. These sites, together with those at Orpheus Island, are probably the most accurately relocated sites in the project, with the exception of Hayman Island. The relatively large number of historical photographs from this location and the relatively high accuracy with which they were relocated make this one of the best studied locations in the project.

The historical photographs show a reef-flat consisting mainly of colonies of massive corals (*Goniastrea*, other faviids, *Porites*) and soft corals (probably *Sinularia* spp.). The modern photographs show a similar reef-flat.

#### Orpheus Island

Eight historical photographs of this location were found. All eight were taken by William Saville-Kent in Little Pioneer Bay circa 1890. As with Great Palm Island, the proximity of the landmarks at this location allowed accurate relocation of the sites of the historical photographs. This, coupled with the relatively high number of photographs makes Orpheus Island and Great Palm Island the best studied locations in the Project.

The historical photographs show a reef-flat very similar to that at Great Palm Island and the modern photographs show little, if any, change.

#### Fantome Island

One historical photograph of this location from circa 1890 was found, however, there was insufficient time during the Palm Islands field work to take a new photograph. However, the reef-flat was observed as the tide was rising and it was similar to the reef-flat of 100 years ago. The benthic community is similar to those at Great Palm Island and Orpheus Island, being dominated by a mixture of soft corals and massive hard corals (mostly faviids). Although this location is considered as one with no evidence of change, this conclusion is weaker than for Great Palm Island and Orpheus Island because there is only one historical photograph from Fantome Island.

#### Fitzroy Island

One historical photograph of Fitzroy Island from around 1910 has been found. This shows a high cover of various growth forms of branching *Acropora* and scattered colonies of massive corals. This reef was badly affected by cyclone Joy at the end of 1990. When visited in 1995, all the coral growth forms visible in the historical photograph were observed, but the cover was

much lower. Soft corals were also seen on the reef, although they are not depicted in the historical photograph. The majority of the substrate on the reef-flat was coral rubble and soft coral. As this reef-flat continues to develop after cyclone Joy it will be interesting to document whether the benthic community returns to that depicted in the historical photograph or not.

#### Green Island

Of the twelve historical photographs from Green Island that have been found, six are of particular interest.

Two of these historical photographs were taken on the reef-flat to the north-east of the island. One of these was taken circa 1958 and shows many large colonies of branching *Acropora*. The second was taken circa 1963 and shows large areas of soft corals, with no colonies of *Acropora* visible in the photograph. Today, the dominant organisms on this area of the reef-flat are soft corals, with the modern reef-flat appearing identical to the circa 1963 photograph. A small number of mostly very small (< 20 cm diameter) colonies of *Acropora* are present.

The four remaining historical photographs were taken at the far south-eastern edge of the reef pre-1968. The photographs depict a diverse benthic fauna comprised of soft corals, several different growth forms of *Acropora* and tridacnid clams. Because of the nature of the landmarks in the photographs, it was not possible to relocate the site of these photographs exactly. However, large areas of this section of Green Island reef were found to have very similar benthic fauna when the area was revisited.

Thus, although there is evidence of change from the north-east of the island, there is no such evidence from the south-east. This observation of spatial differences is confounded by temporal differences because the photographs from the south-east are probably more recent than those from the north-east.

#### Double Island

Two historical photographs from Double Island have been replicated. One photograph from 1970 shows colonies of branching *Acropora*. Similar patches of coral are common on this area of the reef-flat today, despite a thick layer of mud covering much of the reef-flat. However, the second historical photograph, taken further south along the edge of the same reef-flat shows an area completely covered in alcyoniid soft corals. Unfortunately, the date of this photograph has not been determined yet. When visited in 1995 no part of this area of reef-flat was dominated by alcyoniid soft corals. Occasional, solitary adult colonies and several dense patches of small (about 2 cm diameter) alcyoniid colonies were the only soft corals observed. This represents the only case of an observed decrease in soft coral cover during the course of the project.

#### Michaelmas Reef

Three historical photographs of this location were found. All three were taken on the same day in the mid-1950s. One of them appears on a postcard written in 1958, therefore the photographs must have been taken prior to this year. During the field work at Michaelmas Reef, it was possible to determine that the sites of the historical photographs were on the reef-flat to the south of the cay, however, the weather was poor and it was not possible to see the landmarks. In the third photograph, the only landmark is a sand spit that was presumably part of the cay. Because the sand around a coral cay is so mobile, the sand spit does not provide a landmark that can be used to relocate the site of the historical photograph. Therefore, the exact sites of the three historical photographs could not be located. However, a series of general photographs of the reef-flat to the south of the cay were taken. The historical photographs show assemblages

including branching hard corals and soft corals in approximately equal proportions. The modern reef-flat has almost no hard coral of any description and is dominated by alcyoniid soft corals.

The evidence from the historical photographs suggests that there has been significant change on the reef-flat at Michaelmas Cay.

#### Low Isles

Twelve historical photographs of Low Isles have been found, all taken during the scientific expedition of 1928-29. However nine of these are of relatively little use because they show only elevated banks of coral rubble, reef-flat from a great distance or are too indistinct. Of the three best photographs, one was taken on the seaward edge of the reef-flat to the south of the cay, one was taken in the middle of the reef-flat to the south of the cay and one was taken on the seaward edge of the reef-flat to the north-east of the cay.

The historical photograph from the seaward edge of the reef-flat to the south of the cay shows a dense and uniform cover of branching hard coral. When this area was revisited in 1995, a 10-15 m wide band of similar coral was found along approximately 500 m of this edge of the reef-flat.

The historical photograph from the middle of the reef-flat to the south of the cay shows large, submerged colonies of *Porites* sp. Colonies of this type were also found during the field work in 1995. The reef-flat to the south of the cay was qualitatively described in great detail by Stephenson et al. (1931). The modern reef-flat benthos in this area still contains all the elements described in 1931, including hard corals (e.g. *Acropora* spp., *Montipora digitata*, *Porites* sp.), sea cucumbers (mainly *Holothuria atra*), horses foot clams (*Hippopus hippopus*), seagrasses and sand.

The final historical photograph is from the reef-flat to the north-east of the cay and shows a high cover of *Acropora* spp. of different growth forms. No soft coral is visible in the historical photograph. Although this historical photograph can only be relocated approximately due to a description of the area in the original publication, this area of reef is now dominated by alcyoniid soft corals, with the cover of *Acropora* spp. being much lower than depicted in the historical photograph. This observation is supported by the work of Bell and Elmetri (1995) who replicated a transect from the 1928-29 expedition on this area of reef-flat. Modern density of hard coral colonies was found to be only 4.9% of that recorded in 1928-29.

Thus the Low Isles reef shows mixed results, with some areas showing little/no change and at least one area showing a marked change in benthic community structure.

#### Pickersgill Reef

Three photographs from Pickersgill Reef, north of Port Douglas, taken in the late 1960s and early 1970s show diverse reef-flat communities of alcyoniid soft corals, robust growth forms of *Acropora* and smaller numbers of massive hard corals. When visited in 1995 this reef-flat showed large areas of almost identical benthic communities. Thus there is no evidence of change from the three historical photographs.

#### Discussion

Comparisons between historical and modern photographs can provide information that is useful in the management of the GBRWHA. Such comparisons can be used to distinguish between

reef-flats that should be of concern to managers and others that may require less attention. However, using comparisons between modern and historical photographs as a measure of reef-flat health is a coarse tool with several important limitations. These limitations must be considered when analysing photographic comparisons.

Firstly, historical photographs only show reef-flats. Irrespective of the degree of change observed on the reef-flat, conclusions about the state of any other part of the reef cannot be drawn. In addition, only photographs of reefs that are within sight of a significant landmark can be used in this project. Thus all reefs studied in this way will be close to the mainland, a continental island or a coral cay.

Clearly, a collection of historical photographs from a particular location does not represent results of a sampling design incorporating random sampling. Most photographers will have been attempting to illustrate a particular point when taking a photograph and it is impossible for us to know how representative any single photograph is of the whole reef-flat. This problem is worst when only one photograph from a reef-flat exists and is reduced when several photographs from one reef-flat at one time are available for study.

Photographs taken at an oblique angle to the substratum do not allow the substratum to be quantified easily. Without complicated geometric analysis of the photograph, the best that can be achieved is a qualitative, subjective impression of the substratum shown in the photograph.

Comparison of historical and modern photographs only provides two snap-shots of a continuous process of reef change. The comparison provides no information about the state of the reef-flat in the years between the two photographs. Thus, when comparing two apparently identical photographs of the same reef-flat that are separated by 100 years, it is not known whether or not the reef-flat has changed during that time period. It is equally possible that the reef-flat has remained unchanged over the last 100 years or that the reef-flat has changed but that in recent years it has returned to the state of 100 years ago. In addition, if comparison of modern and historical photographs does show a change in the reef-flat, this supplies no information as to the cause(s) of the observed change.

These problems of photographic comparisons should be considered when reading the accounts of individual locations.

From the results of this project, comparisons between historical photographs and modern observations of reef-flats can be made for 14 locations. These locations can be subdivided into three groups: locations at which

- no evidence of change was found (six locations),
- evidence of change was found at all sites (four locations),
- evidence of change was found at some sites, but not at others (four locations).

The locations in each of these groups are shown in Table 2 and Fig. 1. There is no consistent geographical pattern in which locations show evidence of change and which do not, e.g. inner shelf v. mid-shelf or north v. south. However, this observation is tentative due to the small number of locations involved.

In all but one case (one photograph from Double Island) where evidence of change was found, the change was a decrease in cover of branching hard coral and an increase in cover of alcyoniid soft coral and/or algae and/or coral rubble. No location showed a change involving an increase in the cover of hard coral. However, the significance of this observation must be considered carefully in light of the fact that the original photography is likely to have been

heavily biased in favour of hard corals because these make for more beautiful and spectacular photographs.

**Table 2.** Summary of evidence found for change/no change at each location

<b>No change</b>	<b>Change</b>	<b>Mixture</b>
Daydream Island	Stone Island	Hayman Island
Magnetic Island	Bramston Reef	Double Island
Great Palm Island	Fitzroy Island	Green Island
Fantome Island	Michaelmas Cay	Low Isles
Orpheus Island		
Pickersgill Reef		

Where evidence from historical photographs indicates that cover of living hard coral has decreased at a location, there is still no information about what caused this decrease. Potential causes of hard coral mortality on reef-flats that need to be considered include cyclones, predation by crown-of-thorns starfish (COTS), increased sediment load, increased nutrient load, freshwater from storms, reef-walking, anchor damage and climate change. Some of these factors are natural while others could be due to human activity. Unfortunately there is no way to tell from the photographs which factors have caused the observed changes.

The storms of 1918 caused massive mortality of reef-flat benthos over a wide area including reefs around Bowen (e.g. Stone Island and Bramston Reef), Daydream Island and Hayman Island (Rainford 1925). However, as early as 1925, differences in the degree of recovery between reefs were apparent, with Hayman Island reef-flat being markedly more advanced than others (Rainford 1925). Photographs from the 1940s from Daydream and Hayman Islands indicate renewed hard coral growth on the reef-flats and this growth, for the most part, is present today. It therefore seems unlikely that the current absence of hard corals from Stone Island and Bramston Reef reef-flats is due only to the storms of 1918.

Despite observed decreases in hard coral cover on some reefs, previous studies that have used historical photographs primarily or exclusively as evidence of hard coral mortality (e.g. Endean 1976; Bell and Elmetri 1995) are only seeing part of the picture. These studies have concentrated on sites of apparent reduction of hard coral cover at Stone Island, Magnetic Island and Low Isles. However, this trend is far from uniform when a larger number of reefs or a larger number of sites within a reef are examined. The Historical Photographs Project represents the most thorough and wide-ranging study of its kind to date but, even so, out of approximately 2900 reefs in the GBRWHA comparisons are available for only 14. Given the limitations of this technique, comparisons between historical photographs and modern reef-flats can never provide definitive, stand-alone proof one way or the other in the debate over whether or not the GBR is undergoing a steady decline. However, from the results of the Historical Photographs Project so far, the number of locations that do not appear to have changed since the historical photographs were taken throws doubt on the proposition that the GBR is subject to broad scale decline, whatever the proposed cause.

### **Acknowledgments**

Firstly, thanks to Jamie Oliver for giving me the opportunity to carry out this project.

Special thanks go to Andrew Elliott. His help was invaluable in all aspects of the project, particularly during the field work.

Many thanks to the following people who have helped with finding old photographs and relocating the sites: Karen Adler, Claude Azzopardi, Isobel Bennett, Ray Berkelmans, Mr G.K. Bolton, Jon Brodie, Rozel Brown, Inara Bush, Don Cameron, John Collins, Suzie Davies, John de Campo, Christine Dolliver at Bolton Inprint, Bob Endean, Geoff Ferguson, Nannette Fraser, Don Gordon, Lloyd Grigg, Anne Hoggett, Steve Hillman, Mike Huber, Geoff Iliff, Julie Jones, Ian Kerr, Gordon La Praik, Warren Lee Long, Andrew Lewis, Bob MacKay, Hamish Malcolm, Lockie Markwell, Kerry McGregor, Jenny McIlwain, Jamie Oliver, Pete Raine, Peter Saenger, Glen Shields, Mike Short, Shiranthi Siyambalapitiya, Roger Steene, Sarah Strawbridge, Virginia Townton, Snowy Townton, Lyle Vale, Olive Vlassoff and the crew of the *Ocean Spirit*.

Thanks to Ray Berkelmans, Christine Dalliston, Lyndon DeVantier and Steve Hillman for reviewing earlier drafts of the manuscript.

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# Centuries-long records of coral growth on the Great Barrier Reef

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## Abstract

Detailed observations and measurements of coral reefs began only about 20 years ago. Centuries-long records of annual growth contained in massive coral skeletons provide a means to objectively identify background variability in coral growth allowing recent growth trends to be assessed against a historical perspective.

Skeletons of massive corals include annual density banding because the corals deposit skeleton of varying density during the year. Annual growth rate, annual average density and annual calcification were measured in cores removed from 35 very large colonies of the reef-building coral, *Porites*. The longest record started in AD 1479. The 10 largest colonies provided data covering the common period, 1746 to 1982. Average calcification for these 10 colonies is significantly related to sea-surface temperature (SST) variations on the Great Barrier Reef (GBR) during the 20<sup>th</sup> century. The long coral record can, therefore, be viewed in two ways: 1) a proxy for SST variations on the GBR and 2) a measure of the performance of a major-reef building coral. In both cases, the 237-year long record dramatically lengthens our perspective on long-term variability. Features of the 237-year record of calcification in these 10 colonies, which cover the length of the GBR, include high calcification (= high SSTs) in the late 18<sup>th</sup> century and low coral calcification (= low SSTs) in the early 19<sup>th</sup> century. This low growth period is not matched in any of the subsequent record. There is no indication of recent, unusual declines in the annual calcification that might be attributed to human activities. Indeed, the 20<sup>th</sup> century witnessed the second highest 50-year period (1927-1976) and the third highest 10-year period (1964-1973) of calcification across the full record. A decline of average calcification since this peak may simply represent a return to long-term average conditions. Calcification and, possibly reef performance, appear to be highly variable at time scales much longer than decades.

## Introduction

Concern about the impact of global environmental change on coral reef ecosystems such as the Great Barrier Reef (GBR) has highlighted our lack of knowledge of the natural range of variability expressed by constituent organisms. Detailed observations and measurements of coral reefs began only about 20 years ago. Trends or variations in reef communities and reef performance observed in recent decades may be responses to abnormal environmental change or natural variations in the system. Separation of unnatural change from natural variability requires long records. Centuries-long records of annual growth in massive coral skeletons provide a means to objectively identify background variability, allowing recent growth trends to be assessed against a historical perspective.

Annual density banding in massive corals was discovered nearly 25 years ago (Knutson et al. 1972). These authors suggested two potential applications: (i) development of long-term coral growth histories and, recognising the similarities with tree rings, (ii) reconstruction of paleoclimatic records. In this report we use the first application as a tool to retrospectively monitor the GBR. The growth characteristics of *Porites* provide insights into the spatial and

temporal variability of a major reef-building coral of the GBR. The report summarises the results of several studies (e.g. Lough and Barnes 1992; Lough and Barnes, submitted).

### **Materials and methods**

The Australian Institute of Marine Science (AIMS) has collected cores from very large colonies of *Porites* since the early 1980s. Growth characteristics are examined for 35 of these cores from sites covering the length and breadth of the GBR (Fig. 1). These records range in length from 49 to 507 years (see Lough and Barnes, submitted) and provide a perspective on the temporal variability of *Porites* growth on the GBR. AIMS has also collected over 300 whole *Porites* colonies from known environmental gradients of the GBR. These colonies provide records 15-50 years in length and provide a perspective on the spatial variability of *Porites* growth on the GBR. Growth characteristics are presented for an inshore to offshore transect of the central GBR (Lough and Barnes 1992) and for an inshore to offshore transect of the northern GBR (Lough and Barnes, in prep.).

Slices, 6-7 mm thick, were removed from the coral cores or colonies. The slices were X-radiographed to reveal the annual density banding pattern characteristic of massive corals from the world's reefal areas (Fig. 2). Skeletal density was measured along a central track on each slice using a gamma densitometer (Chalker and Barnes 1990). The high density band portion of annual density bands in *Porites* from the GBR appears usually to form during the Southern Hemisphere summer. Peaks in the density profile were successively counted backwards from the last (outermost or youngest) peak. Density was assumed to peak in January and the most recent peak was dated from the date of collection of the coral sample. Dates were then assigned to all peaks in the series. Time series of the following skeletal density parameters were then obtained for each coral sample:

- average annual density ( $\text{g CaCO}_3 \text{ cm}^{-3}$ )
- annual linear extension measured between high density peaks ( $\text{cm yr}^{-1}$ )
- annual calcification ( $\text{g CaCO}_3 \text{ cm}^2 \text{ yr}^{-1}$ ): the product of annual average density and annual linear extension

Any record in a coral skeleton is biased and distorted by coral growth processes and the 3-dimensional architecture of the coral skeleton (e.g. Barnes and Lough 1990, 1993). Representative measures of coral characteristics can be obtained, using existing techniques by appropriate averaging over space or time. The spatial growth characteristics presented here are averages over common time periods for several colonies from a particular location. Temporal characteristics presented here are based on 5-year gaussian filtered series.

### **Results**

#### **Spatial variations of *Porites* growth characteristics on the Great Barrier Reef**

The coral density banding literature includes considerable evidence that coral growth (density, extension and calcification) varies across environmental gradients, over time and that it changes in response to changes in the marine environment (see Lough and Barnes, submitted, for recent review). A considerable amount of work is needed, however, before we can begin to understand and, hopefully, predict which growth characteristics of which species is likely to respond to a given environmental change in a particular location.



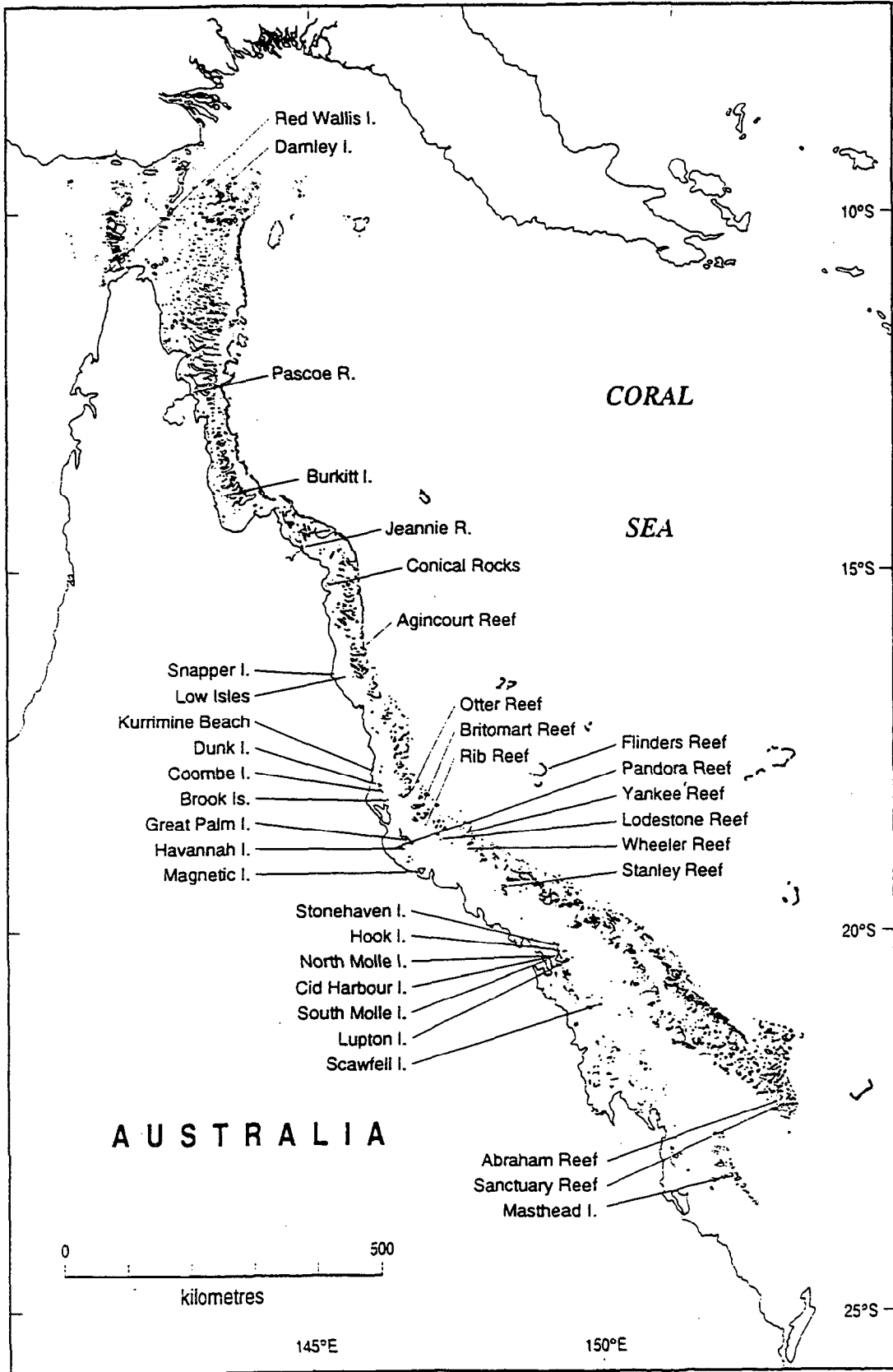
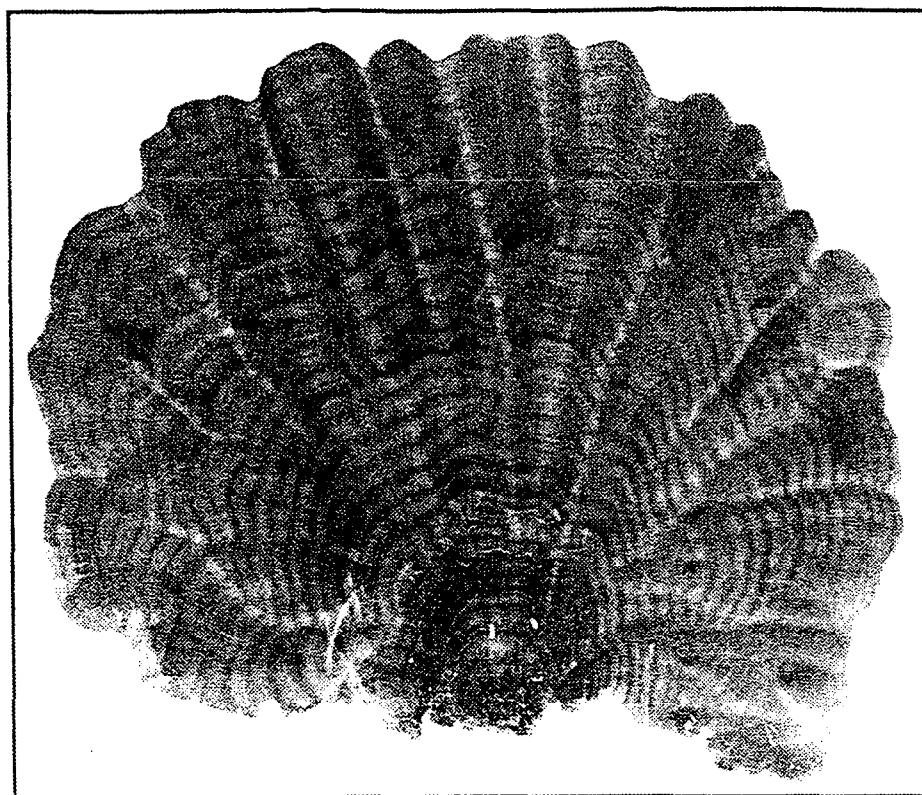


Figure 1. Location of 35 reef sites on the Great Barrier Reef at which large *Porites* were cored



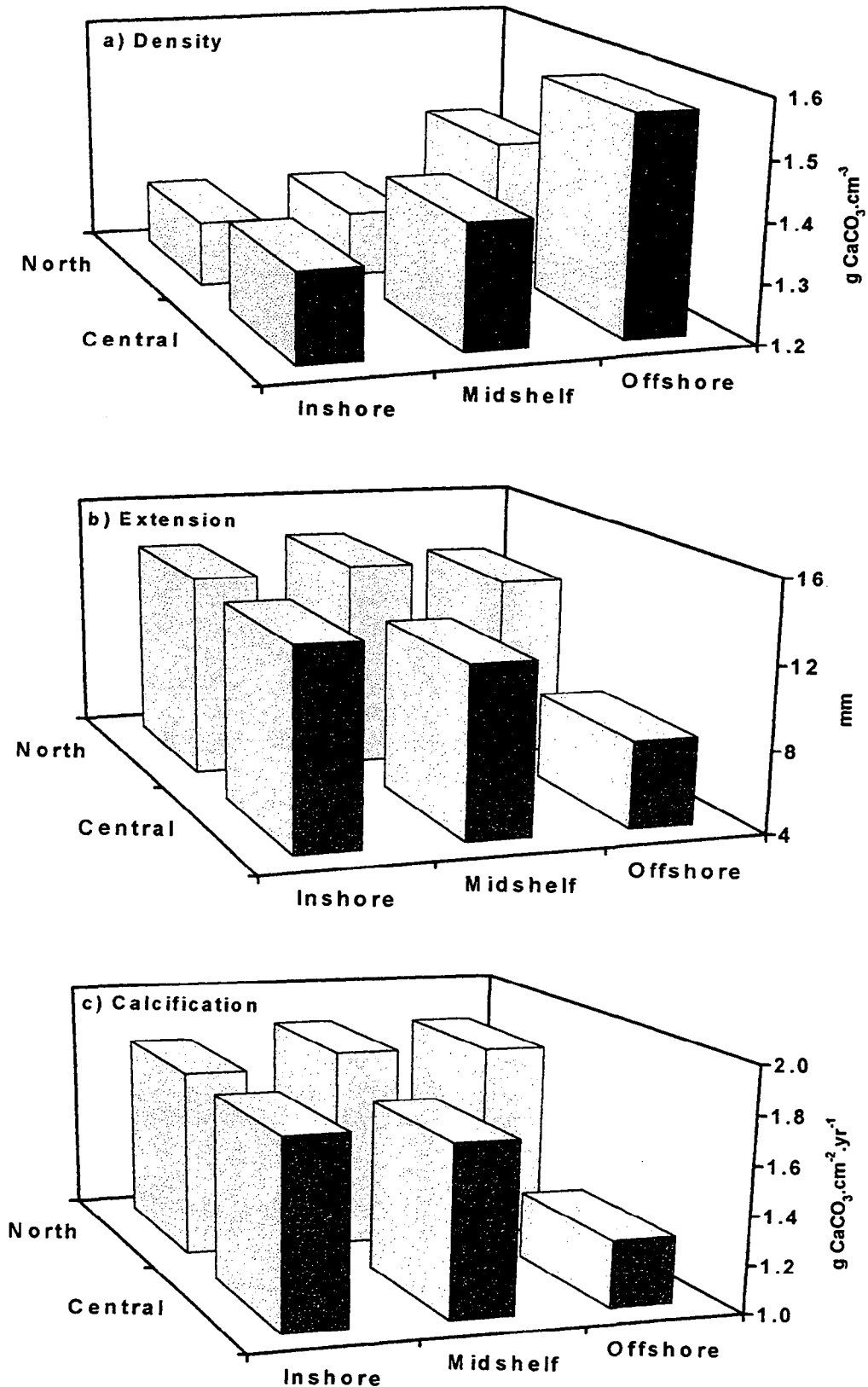
**Figure 2.** X-ray positive of a 7 mm slice cut from a colony of *Porites lobata* from 13-055 Reef, a mid-shelf reef in the northern Great Barrier Reef. Alternating dark and light bands represent dense and less dense skeleton, respectively. Consecutive dark and light bands represent growth over a year.

In response to this need to establish 'baseline' data we have been measuring average growth of similar-sized colonies of *Porites* from various environmental gradients on the GBR. Figure 3 summarises average density, extension and calcification for colonies collected along inshore - offshore transects across the central and northern GBR. All colonies were collected in shallow water (>5 m) towards the rear of the windward reef flat.

Across both transects, density significantly increased from inshore to offshore (Fig. 3a). Density in colonies from the central transect was significantly higher than in colonies from the northern transect. Linear extension was lowest at offshore sites in both transects. Changes in extension rate across the transects were significant only for the central region (Fig. 3b). Average extension was significantly higher in colonies from the northern transect (cf., Isdale 1981). Calcification was significantly lower at the offshore site in the central GBR whereas it did not change significantly across the northern transect (Fig. 3c). Calcification was significantly higher in colonies from the northern transect.

#### Temporal variations of *Porites* growth characteristics on the Great Barrier Reef

Density, extension and calcification were measured in massive *Porites* colonies from the 35 sites shown in Fig. 1. The longest record began in 1479 and came from a 7.5 m high colony at Abraham Reef in the southern GBR. The shortest record began in 1934 and came from a 3 m high colony at Snapper Island in the northern GBR. Average growth characteristics for the period common to all 35 cores, 1934-1982, are summarised in Table 1.



**Figure 3.** Average growth characteristics for 25 colonies of *Porites* in inshore, mid-shelf and offshore locations of the central Great Barrier Reef (18-19°S) and 69 colonies of *Porites* in inshore, mid-shelf and offshore locations of the northern Great Barrier Reef (12-13°S) for a) average annual density, b) annual linear extension and c) average annual calcification.

**Table 1.** Mean and s.d., over the period 1934-1982, of coral growth variables for cores extracted from coral colonies at 35 reefs

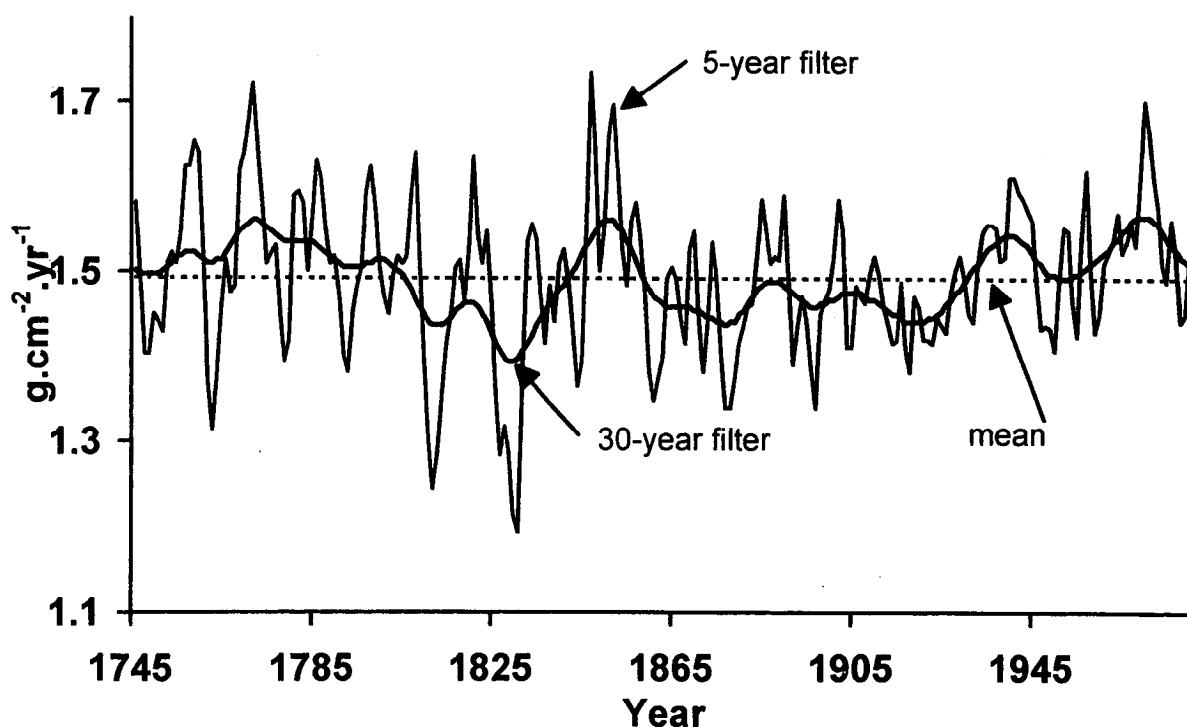
Core	Density g.cm <sup>-3</sup>	Extension cm.yr <sup>-1</sup>	Calcification g.cm <sup>-2</sup> .yr <sup>-1</sup>
Darnley Is.	1.39±0.06	1.32±0.39	1.83±0.51
Red Wallis Is.	1.14±0.06	1.73±0.45	1.96±0.51
Pascoe River	1.12±0.06	1.30±0.39	1.45±0.44
Burkitt Is.	1.17±0.07	1.94±0.63	2.26±0.68
Jeannie River	0.99±0.03	1.16±0.39	1.15±0.38
Conical Rocks	1.17±0.07	1.87±0.65	2.17±0.71
Agincourt Reef	1.06±0.07	1.91±0.59	2.02±0.62
Snapper Is.	1.16±0.11	2.17±0.67	2.49±0.76
Low Isles	1.20±0.08	1.99±0.44	2.36±0.49
Flinders Reef	1.24±0.06	1.14±0.30	1.40±0.36
Kurrimine Bch	1.21±0.04	1.09±0.39	1.32±0.46
Dunk Is.	1.21±0.05	1.76±0.60	2.13±0.74
Coombe Is.	1.34±0.07	1.15±0.39	1.53±0.47
Otter Reef	1.12±0.06	1.76±0.45	1.96±0.51
Brook Is.	1.26±0.07	1.36±0.30	1.70±0.35
Britomart Reef	1.21±0.04	1.31±0.35	1.58±0.41
Rib Reef	1.22±0.04	1.41±0.48	1.72±0.59
Yankee Reef	1.07±0.08	1.52±0.22	1.62±0.25
Great Palm Is.	1.02±0.05	1.89±0.39	1.94±0.39
Lodestone Reef	1.17±0.06	1.46±0.38	1.70±0.44
Wheeler Reef	1.25±0.09	1.52±0.50	1.90±0.60
Pandora Reef	1.20±0.05	1.53±0.26	1.85±0.30
Havannah Is.	1.22±0.04	1.21±0.33	1.47±0.40
Magnetic Is.	1.01±0.11	1.45±0.36	1.45±0.34
Stanley Reef	1.21±0.08	1.74±0.53	2.10±0.66
Hook Is.	1.25±0.09	1.43±0.35	1.77±0.43
Stonehaven Is.	1.30±0.09	1.61±0.43	2.09±0.58
N. Molle Is.	0.99±0.07	1.63±0.55	1.61±0.56
S. Molle Is.	1.03±0.07	1.23±0.44	1.27±0.46
Cid Harbour	1.17±0.05	0.98±0.33	1.16±0.39
Lupton Is.	0.98±0.05	1.58±0.33	1.55±0.34
Scawfell Is.	1.12±0.08	1.62±0.26	1.82±0.26
Sanctuary Reef	1.26±0.06	0.94±0.35	1.18±0.44
Abraham Reef	1.10±0.06	1.30±0.40	1.42±0.45
Masthead Is.	1.30±0.05	0.88±0.29	1.14±0.37
Mean	1.17	1.48	1.72
s.d.	0.10	0.32	0.36
Maximum	1.39	2.17	2.49
Minimum	0.98	0.88	1.14

The 10 longest coral records cover the 237-year period, 1746-1982. These 10 corals had twice as much variance in common as would be expected by chance. This is a strong indication that some large-scale environmental factor, such as climate, is influencing *Porites* growth on the GBR. The 10 coral records were averaged together to form a single record of calcification in *Porites* for the GBR (Fig. 4). This series is significantly positively correlated with the instrumental record of sea surface temperature (SST) on the GBR over the period 1906-1982

(30% variance in common). Thus, longer-term variations in *Porites* calcification reflect variations in SST with higher calcification occurring at higher temperatures.

The record presented in Fig. 4 can be interpreted in two ways: (i) as a proxy record of SST on the GBR for the past 237 years, and (ii) a history of growth in a major reef-building coral on the GBR. There is considerable concern about the degradation of reefs in various places around the world. Management of the GBR must involve an ability to monitor the system and recognise unnatural change. The history of *Porites* growth presented here shows features which are especially relevant to monitoring for change on the GBR.

The 237-year record shows that calcification in *Porites* is highly variable on a range of time scales. The data suggest that it would be unwise to compare growth characteristics for individual years and rash to compare individual years in different decades without considering the long-term trends. Long-term trends in calcification also show considerable variability. *Porites* calcification was high on the GBR in the late 18<sup>th</sup> century and low in the early 19<sup>th</sup> century. Low growth in the early 19<sup>th</sup> century is not matched in any of the subsequent record. Calcification in *Porites* shows no indication of a recent, unusual decline which might be attributed to human activities. In fact, the 20<sup>th</sup> century has witnessed the 2<sup>nd</sup> highest 50-year period (1927-1976) and the 3<sup>rd</sup> highest 10-year period (1964-1973) of calcification across the full record. The data indicate that recent reports of a decline in coral performance on the GBR may simply reflect a return to 'average' conditions rather than the effects of human activities.



**Figure 4:** Average annual calcification for 10 *Porites* colonies on the Great Barrier Reef, 1746-1982.

These data also have implications for long-term monitoring of coral reefs because they indicate the temporal scale of variability in performance of a major reef-building coral. The data indicate it might take 30-50 years of monitoring to establish average conditions. This is comparable to the length of time required to establish average climatic conditions. Given

current concern about change in, and rapid degradation of, reefs, long-term monitoring may not be able to establish a useful, baseline against which to assess reports of change.

### **Summary**

Massive corals characterised by annual density bands, such as *Porites*, contain a history of themselves and their environment. Information about coral growth obtained from density bands (density, extension and calcification) provides a tool for retrospectively monitoring reef environments over the past several centuries.

Growth characteristics obtained for whole, 15-50 year-old, colonies of *Porites* from the Great Barrier Reef (GBR) provide baseline information about average growth rates and their variation from inshore to offshore reefs and with latitude. The three coral growth variables (density, extension and calcification) do not necessarily respond in the same way to gradients and changes in environmental conditions (see Dodge and Brass 1984). Average coral growth characteristics presented here (Fig. 3) represent an early stage in our attempt to provide a picture of spatial variations in *Porites* growth on the GBR. Such baseline data about coral growth characteristics is necessary to fully develop their application to retrospective monitoring of coral reef environments. Comparisons are also needed between measures of coral performance obtained from skeletal growth histories and other measures of reef health.

Growth characteristics obtained for large colonies of the GBR provide a temporal perspective on the natural variability exhibited by a major reef-building organism. Again, such data provides new information about the average status of the major reef-building coral *Porites* on the GBR. Average calcification in *Porites* is highly variable, from year-to-year and over longer timescales. The 20<sup>th</sup> century has witnessed the 2<sup>nd</sup> highest 50-year period of *Porites* growth during the past 237 years. Evidence of a recent decline in coral calcification is tempered by the occurrence of similar declines and recoveries over the past few centuries. The present decline may well represent a return to 'average' conditions.

### **Acknowledgments**

We thank Monty Devereux and Barry Tobin for skilled technical assistance and Samruai Tobin for laboratory assistance. The long cores used in this study were obtained by P.J. Isdale of AIMS. This work was partly supported by the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef.

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# Crown-of-thorns starfish (*Acanthaster planci*) populations in the Great Barrier Reef World Heritage Area: status report 1995-96

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## Abstract

Crown-of-thorns starfish (*Acanthaster planci*) populations have increased on many reefs in the Cairns Section of the Great Barrier Reef (GBR) Marine Park over the last 2-3 years. The increases have been reported by Reef-users through the Great Barrier Reef Marine Park Authority's (GBRMPA) 'COTSWATCH' scheme, the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef's (CRC Reef) fine-scale surveys and the Australian Institute of Marine Science (AIMS) Long Term Monitoring Program (LTMP). Both reef-wide and localised (spot) outbreaks now exist on a high proportion of mid-shelf reefs in this section of the GBR Marine Park.

The significance of these population increases is that they are occurring at a time and in a place that is consistent with the possibility of another GBR-wide outbreak cycle - a repeat of the 1962-1975 and 1979-1991 episodes. Both of these episodes probably originated in the central to northern part of the Cairns Section (around 14°S to 16°S).

In the absence of detailed historical data on both the characteristics of pre-outbreaking *A. planci* populations and regional hydrodynamics, interpretation of the significance of these latest increases is problematic. However, with developing outbreaks on reefs in the lower part of the Cairns Section where the East Australia Current (EAC) strongly influences larval transport and dispersal, another GBR-wide outbreak episode is becoming increasingly likely.

## Introduction

Twice in the last 35 years, major outbreaks of *A. planci* on the GBR have originated on reefs in the Cairns Section of the Marine Park. Outbreking populations were first recorded on Green Island Reef off Cairns with a number of surrounding reefs also being affected at about the same time (Moran 1986). Dedicated surveys of starfish populations were initiated only several years later, when the outbreaks had probably progressed several hundreds of kilometres from their geographic origin (Dight et al. 1990; Moran et al. 1992). Although the recorded infestations have been described as initial or primary outbreaks (Birkeland and Lucas 1990), their exact spatial and temporal origin remains largely unknown.

Historically, surveys of crown-of-thorns starfish (COTS) populations on the GBR and in other parts of the Indo-Pacific have employed a variety of different monitoring techniques, including timed swim searches (Pearson and Endean 1969; Kenchington 1978), spot checks (Pearson 1972), manta tows (Moran 1986; Moran et al. 1988) and, on relatively few occasions, benthic belt transects (Mapstone 1990; Mapstone and Ayling 1994). Few of these surveys have provided accurate estimates of population densities (Birkeland and Lucas 1990). Population modelling studies have suffered from the resulting lack of detailed information on the structure and dynamics of, in particular, pre-outbreking populations. Such information is, however, critical for improving our understanding of the factors and mechanisms involved in initiating outbreaks.



### Broad-scale surveys (AIMS)

Since 1985, the AIMS has employed the manta tow technique to determine Reef-wide patterns of *A. planci* distribution and abundance (Bass et al. 1988, 1989a, 1989b; Baker et al. 1990, 1991, 1992; Bainbridge et al. 1994; Oliver et al. 1995). The aim of these surveys is not only to determine the extent of the activity of the starfish but also to describe its general impact on coral communities. The resultant data base is extensive and has provided a better understanding of the large scale effects of the starfish's activities on the GBR. While the technique provides a cost-effective means of monitoring a large number of reefs in a relatively short period of time and is capable of detecting actively outbreaking populations, it is considered inadequate for assessing low density populations with substantial numbers of juvenile starfish (Moran and De'ath 1992; Bass and Miller 1995).

Broad-scale survey data indicate that the impact of COTS outbreaks on reefs during the second outbreak episode was highly variable. AIMS surveys have shown that some  $17 \pm 4\%$  of reefs in the GBR region had been affected to varying degrees. The central parts of the GBR recorded both the highest densities of *A. planci* and the greatest coral mortality (Moran et al. 1993) with starfish activity peaking in 1989. The majority of reefs recovering from past outbreaks are currently located in the Cooktown/Lizard Island, Cairns, Innisfail, Townsville and Cape Upstart monitoring sectors (Fig. 1a) (Moran et al. 1993).

### Fine-scale surveys (CRC Reef / GBRMPA)

Because of their cryptic behaviour and nocturnal feeding habits, juvenile *A. planci* (< 15 cm) are not easily sampled and are rarely seen in the field (Johnson et al. 1991). The detection of the initial stages of an outbreak requires the use of a sampling technique that maximises the likelihood of the smaller size classes being accurately recorded. Ayling and Ayling (1991) showed that transect-based benthic surveys are suitable for accurately censusing juvenile and low density populations. A new transect-based program of dedicated *A. planci* surveys was initiated in 1994-95. The main aims of the fine-scale surveys are to (i) describe the status and characteristics of *A. planci* populations on mid-shelf reefs in the Cairns Section, and (ii) to identify characteristics of pre-outbreaking *A. planci* populations that may assist in the early identification of future outbreaks.

### Reef-user monitoring scheme 'COTSWATCH'

In addition to the above mentioned quantitative surveys, the GBRMPA has been promoting a largely qualitative Reef-user monitoring scheme called 'COTSWATCH'. The scheme relies on voluntary support from regular visitors to the Reef such as dive staff employed by tourism operations and Marine Park rangers working for the Queensland Department of Environment (QDoE). In 1993, COTSWATCH reports from some popular dive sites on a small number of reefs in the Cairns Section indicated an apparent increase in the numbers of *A. planci* (Lassig and Engelhardt 1994). These reports provided reef managers with the first indications that *A. planci* densities in this part of the Reef were again starting to build up.

This status report provides a summary of the most recent findings of both fine- and broad-scale surveys of *A. planci* conducted on the GBR, with particular emphasis on the current status of *A. planci* populations in the Cairns Section.

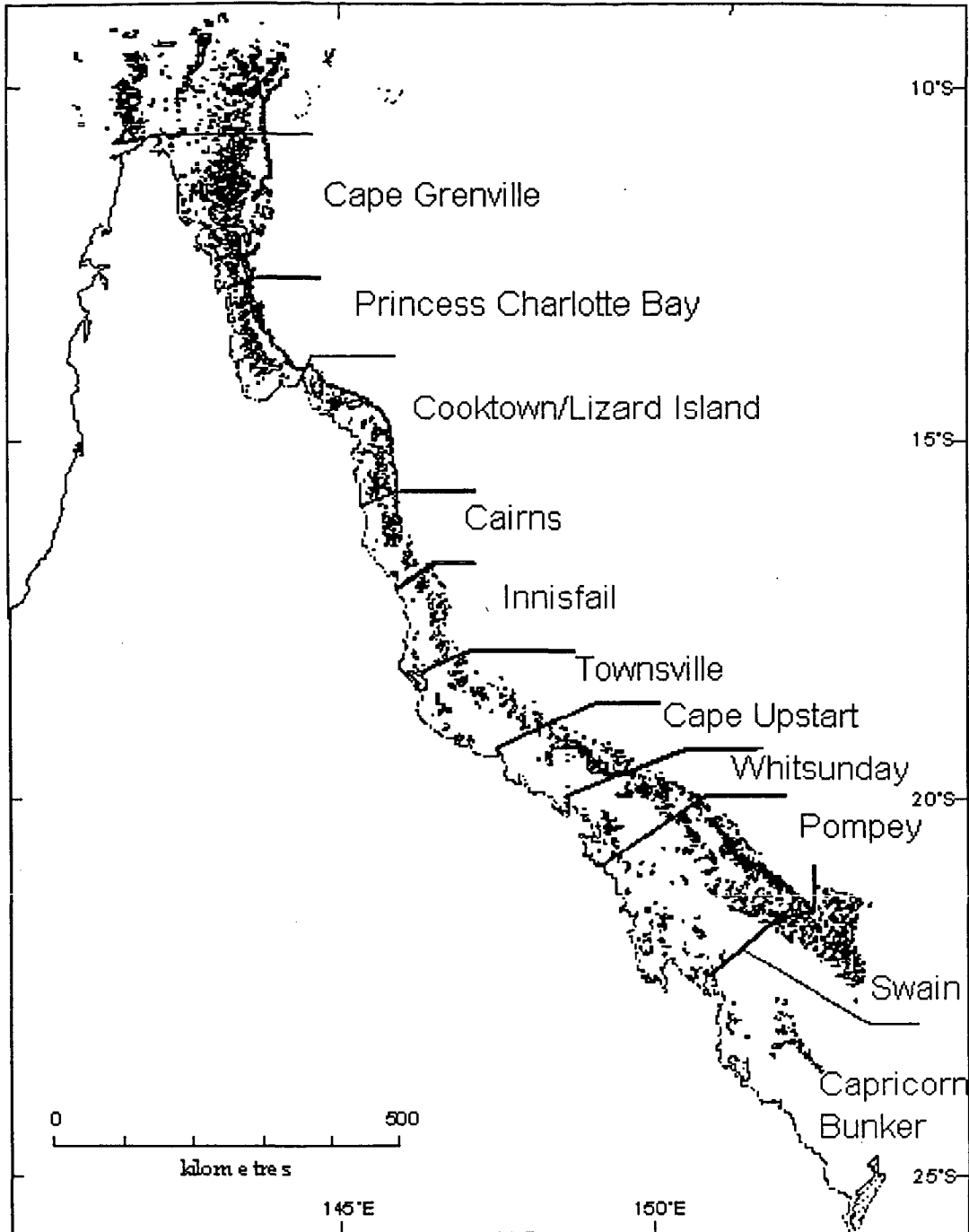


Figure 1a. Map of the Great Barrier Reef showing AIMS long term monitoring sectors

### Materials and methods

#### Broad-scale surveys (GBR-wide)

A detailed description of the manta tow technique as employed by the AIMS LTMP to assess both *A. planci* and corals is provided in a standard operational manual (Bass and Miller 1996).

### Fine-scale surveys (Cairns Section)

Currently, fine-scale surveys of *A. planci* populations are restricted to reefs located in the Cairns Section. The sampling procedure for these surveys has only recently been developed and is described here in some detail.

### Selection of survey reefs

To identify geographic (latitudinal) differences in *A. planci* population characteristics throughout the Cairns Section, a series of reefs was selected haphazardly along a mid-shelf transect spanning nearly three degrees of latitude from 14°40' S (*Lizard Island*) to 17°20' S (*off Innisfail*) (Fig. 1b). Mid-shelf reefs were selected because modelling of the hydrodynamic characteristics of the Central (Black and Moran 1991; Burrage et al. 1994; Bode et al. 1992) and, to a lesser degree, the Cairns Section of the GBR Marine Park (Bode et al. 1992) have identified strong but variable connectivity between mid-shelf reefs. In contrast, inner and outer shelf reefs were found to be hydrodynamically more isolated (Bode et al. 1992; Black and Moran 1991), suggesting that these reefs are seldom exposed to competent *A. planci* larvae from upstream sources. AIMS manta tow surveys and 'COTSWATCH' Reef-user reports also indicate a propensity for mid-shelf reefs to support larger numbers of COTS than either inner or outer shelf reefs. To reduce the likelihood of inducing biases due to seasonal variability in starfish feeding or behaviour, all reefs were surveyed between the months of October and March.

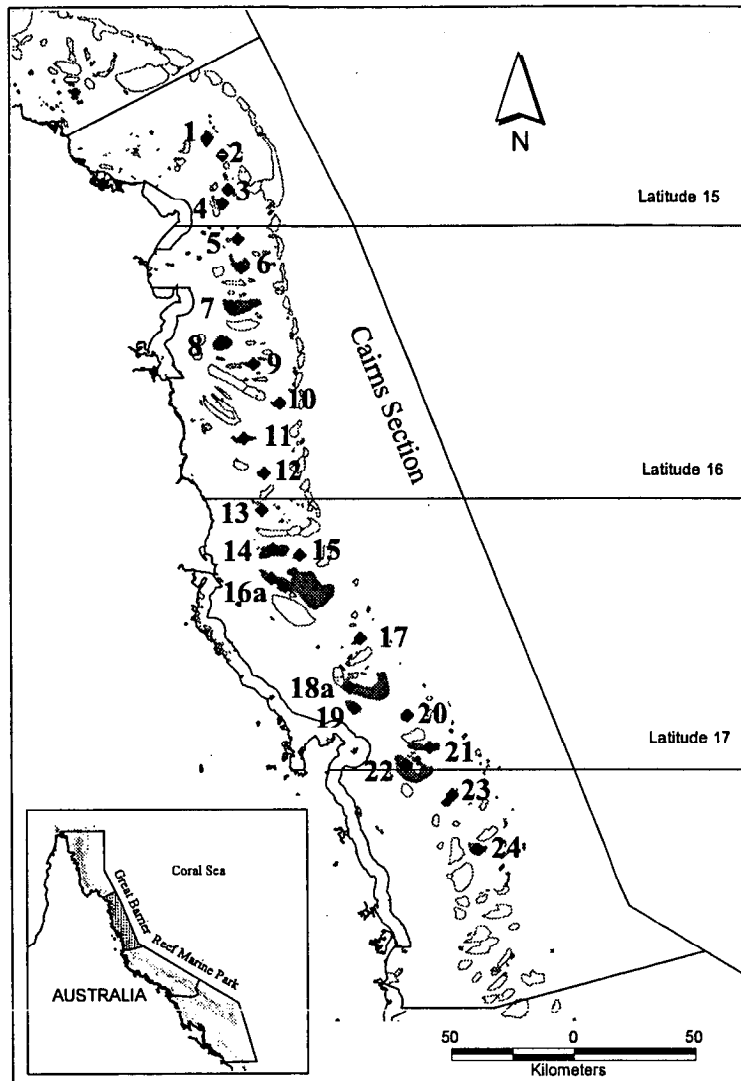
### Benthic transects

A comprehensive methodological study by Mapstone and Ayling (1994) showed that, for visually assessing the abundance of discrete benthic organisms such as *A. planci*, belt transects measuring 50 x 5 metres provide the least biased density estimates. Accordingly, 50 x 5 metre transects were chosen to sample fine-scale survey reefs.

At each of the survey reefs, two teams of SCUBA divers were used to survey a total of 10 individual sites in front reef slope as well as back reef zones. Two replicate 50 x 5 metre transects were laid out at each of the haphazardly selected sites.

Transects were placed at an oblique angle down the reef slope from as shallow as possible (approximately 1-2 metres) to a maximum depth of 15 metres. To improve the accuracy of starfish density estimates, observers were required to search transects intensively as two 2.5 metre wide lanes. Where necessary, the position of marginal individuals relative to the transect was confirmed using a 2.5 metre tape measure placed at right angles to the transect line.

For each transect, observers recorded the number and size(s) of *A. planci* present. Starfish size was measured as maximum body diameter (central disc plus extended arms) to the nearest centimetre. Accurate size measurements using rulers or tape measures were obtained where starfish were exposed and easily accessible, while sizes were estimated where starfish were partially hidden.



**Figure 1b.** Map of the Cairns Section of the Great Barrier Reef Marine Park. Mid-shelf reefs surveyed for *A. planci* in 1994-95 and 1995-96 are shown as shaded reef outlines with their assigned reef number.

#### Determination of reef status

Reefs were classified as sustaining outbreaking populations of *A. planci* if average densities (minus 1 standard error) exceeded 0.75 individuals per 250 m<sup>2</sup> (area of sampling units). This threshold is based on in situ observations and calculations of *A. planci* feeding rates. Keesing (1990) and Keesing and Lucas (1992) suggested that a density of between 10 and 15 adult *A. planci* per hectare (10 000 m<sup>2</sup>) could be sustained in areas with 20-50 % live coral cover. Our increased threshold of 30 *A. planci* per ha<sup>-1</sup> (equivalent to 0.75 individuals per 250 m<sup>2</sup>) takes some additional variables, such as possibly higher coral cover and seasonally reduced feeding rates, into account.

Age-specific subsets of the data were used to define both the current and likely future status of survey reefs. Density estimates calculated for adult *A. planci* (> 26 cm, aged three and older) were used to determine whether or not a reef had an active outbreak, while incipient outbreaks were defined on the basis of density estimates calculated for the combined adult and sub-adult (≥ 14 cm, aged two and older) components of the observed populations.

Active and incipient reef-wide outbreaks (AO, IO respectively) were defined on the basis of the calculated mean densities of *A. planci* over all transects (*reef mean*), while active and incipient spot outbreaks (ASO, ISO respectively) were determined based on density estimates obtained for individual reef zones only (*zone means*).

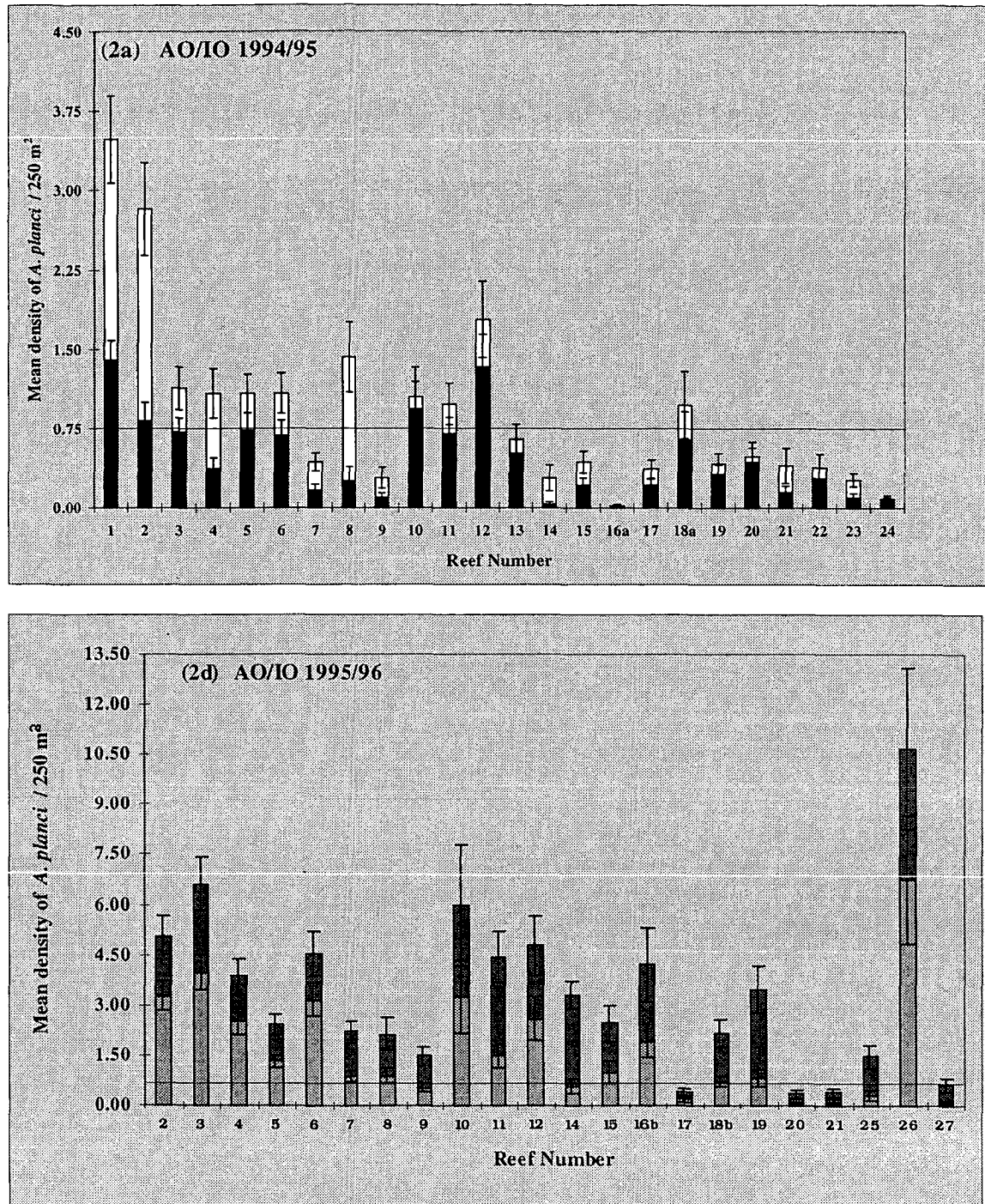
## Results

### Fine-scale surveys (Cairns Section reefs only)

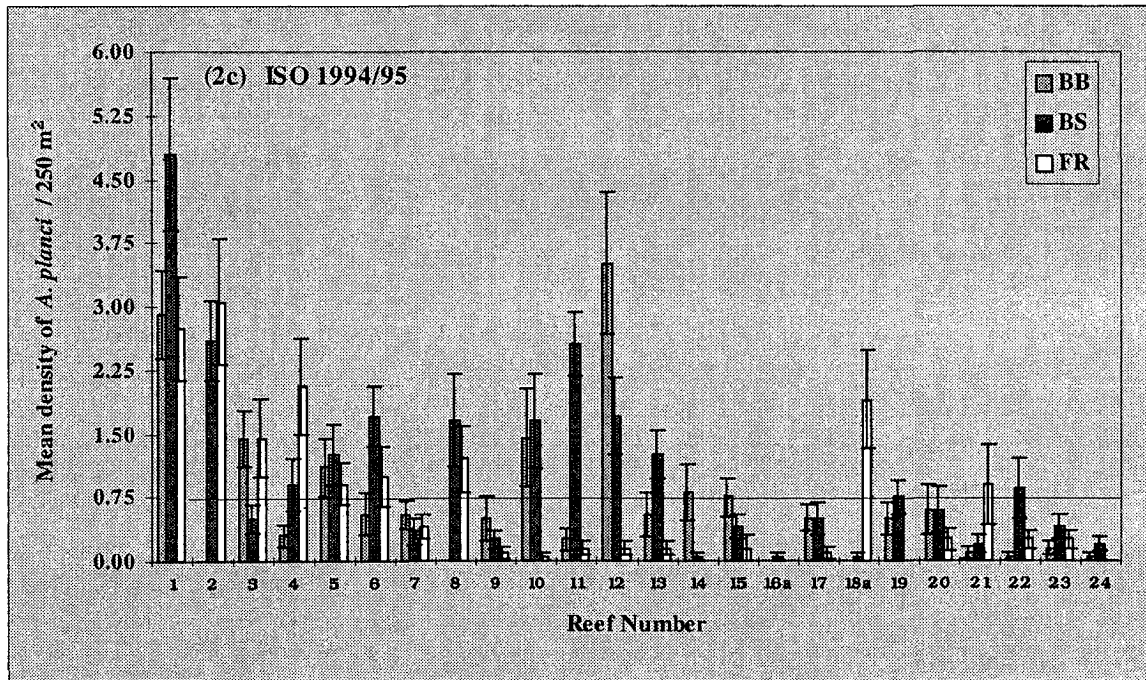
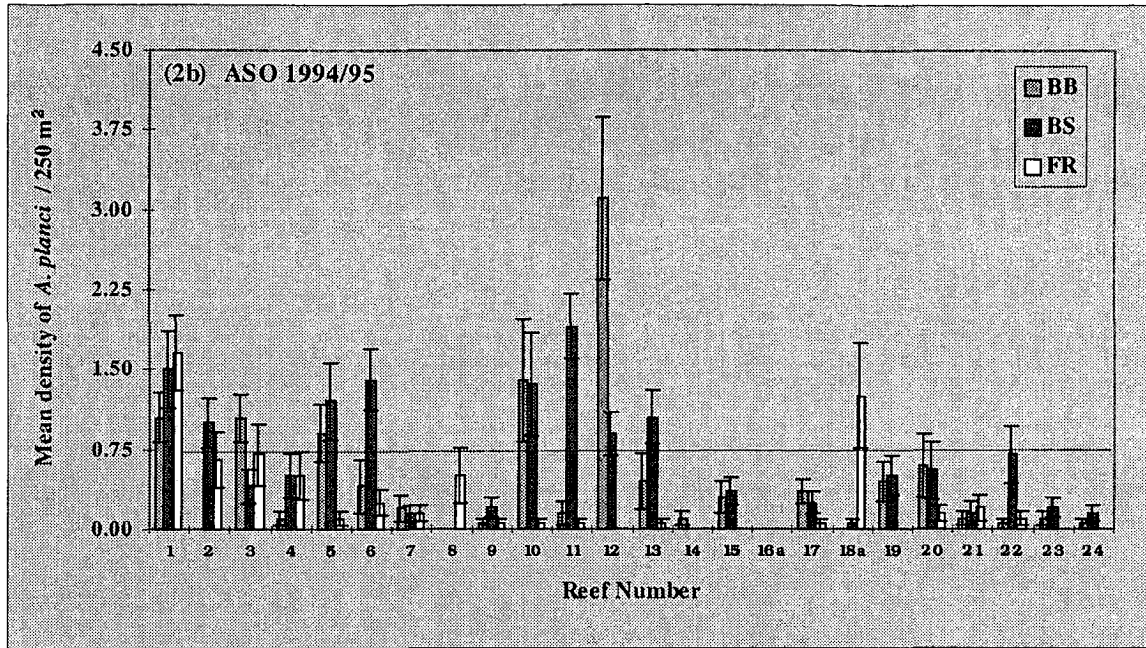
In 1994-95 we recorded a total of 1786 *A. planci* on the 24 reefs surveyed. A total of 1265 individuals were found inside the 1380 transects sampled, with an additional 521 starfish located outside the transects. Reef mean densities of adult *A. planci* ranged from 0.0 at Reef No. 16a to the highest values of  $1.4 \pm 0.18$  and  $1.33 \pm 0.31$  per 250 m<sup>2</sup> (Reef No's 1 and 12 respectively, Fig. 2a). Densities recorded on the latter two reefs were approximately two times higher than what is considered to be sustainable. Based on the combined sub-adult and adult components (incipient classification), projected reef mean densities for adult *A. planci* in 1995-96 were calculated as high as  $3.48 \pm 0.41$  individuals per 250 m<sup>2</sup> (Reef No. 1), approximately five times above the upper limit of a sustainable population (Fig. 2a). Two reefs (Reef No's 1, 12) were classified as sustaining active, reef-wide outbreaks (AO, Fig. 2a), with a further eight reefs (Reef No's 2, 3, 5, 6, 10, 11, 13, 18a) being classified as having active spot outbreaks (ASO, outbreaking densities in at least one of the reef zones sampled, Fig. 2c). Incipient, reef-wide outbreaks (IO, Fig. 2a) were identified on eight survey reefs (Reef No's 2, 3, 4, 5, 6, 8, 10, 11), with twelve reefs classified as non-outbreaking. We did not record any incipient spot outbreaks (ISO, Fig. 2e) in 1994-95.

The 1995-96 surveys detected 4217 individual *A. planci* on 22 reefs. A total of 3472 starfish were located inside the 960 transects sampled, with a further 745 *A. planci* recorded outside the transects. Reef mean densities of adult starfish were up to nine times above sustainable levels (e.g. Reef No. 26 with  $6.75 \pm 1.91$  *A. planci* per 250 m<sup>2</sup>), with projected densities for 1996-97 as high as  $10.65 \pm 2.43$  adult individuals (also Reef No. 26) (Fig. 2c). Reef mean densities of adult starfish had increased on 14 of the 17 reefs resurveyed in 1995-96. The total number of actively outbreaking reefs was thirteen, six of which were reef-wide outbreaks (AO, Fig. 2b) (Reef No's 2, 3, 4, 5, 6, 26), with a further seven reefs being classified as active spot outbreaks (ASO, Fig. 2d) (Reef No's 7, 9, 10, 11, 12, 16b, 18b). Five of the eight incipient outbreaks (IO) identified in 1994-95 (Fig. 2a) had developed into active, reef-wide outbreaks (AO) by 1995-96, with a further two IOs having developed into more localised active spot outbreaks (ASO). Again, the 1995-96 surveys identified a number of new incipient outbreaks (IO, Fig. 2b) (Reef No's 7, 8, 9, 10, 11, 12, 14, 15, 18b, 19) and one incipient spot outbreak (ISO, Fig. 2f) (Reef No. 25). Four reefs were classified as non-outbreaking (Reef No's 17, 20, 21, 27). A summary of reef classifications with regard to *A. planci* populations observed in 1994-95 and 1995-96 is provided in Table 1.

Limited hindcasting of recent recruitment events indicates that most mid-shelf reefs surveyed have received regular recruitment over a number of consecutive years. Selected examples of size-frequency distributions of *A. planci* observed in 1994-95 are consistent with multiple and, in many cases, consecutive cohorts of starfish (Fig. 3).

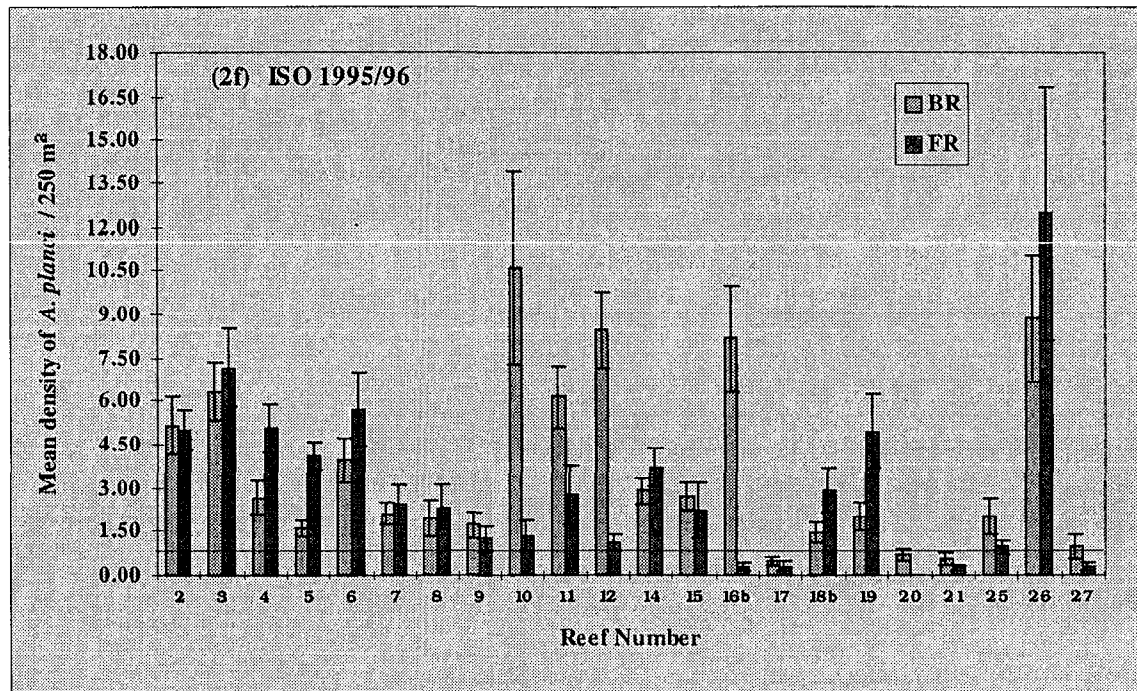
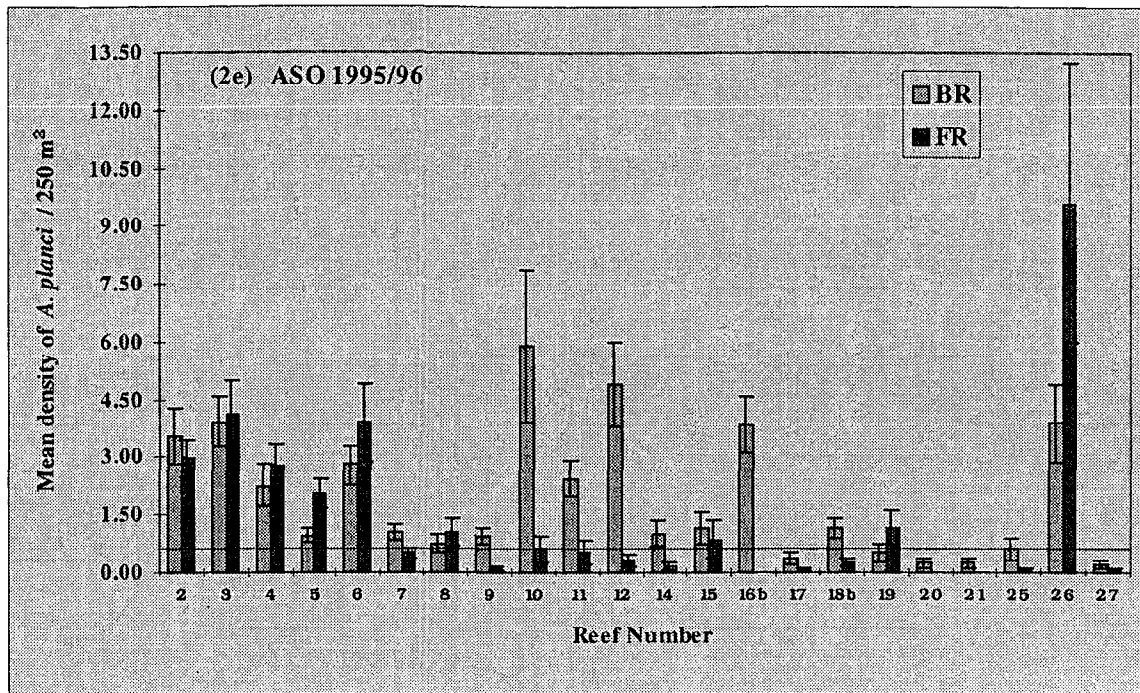


**Figure 2.** Estimated reef mean densities of *A. planci* on reefs surveyed in 1994-95 (2a) and 1995-96 (2d). Estimates of adult densities (starfish aged three and older) are shown as lower bars, with combined adult and sub-adult density estimates (starfish aged two and older) shown as upper bars. Horizontal lines at 0.75 *A. planci* per 250 m<sup>2</sup> transect indicate the upper limit of a sustainable, non-outbreaking population.



**Figure 2 cont.** Estimated zone mean densities of *A. planci* on reefs surveyed in 1994-95 (2b, 2c), where (BB) is the back reef bommie zone, (BS) is the back reef slope zone, (BR) is the back reef zone including both slopes and bommies, and (FR) represents the front reef slope zone. Estimates of adult densities (ASO, starfish aged 3 and older) are shown in plots (2b, 2e), with combined adult and sub-adult density estimates (ISO, starfish aged 2 and older) shown in plots (2c, 2f). Error bars show standard errors ( $\pm 1$  SE). Note that some survey reefs differ between the two years.



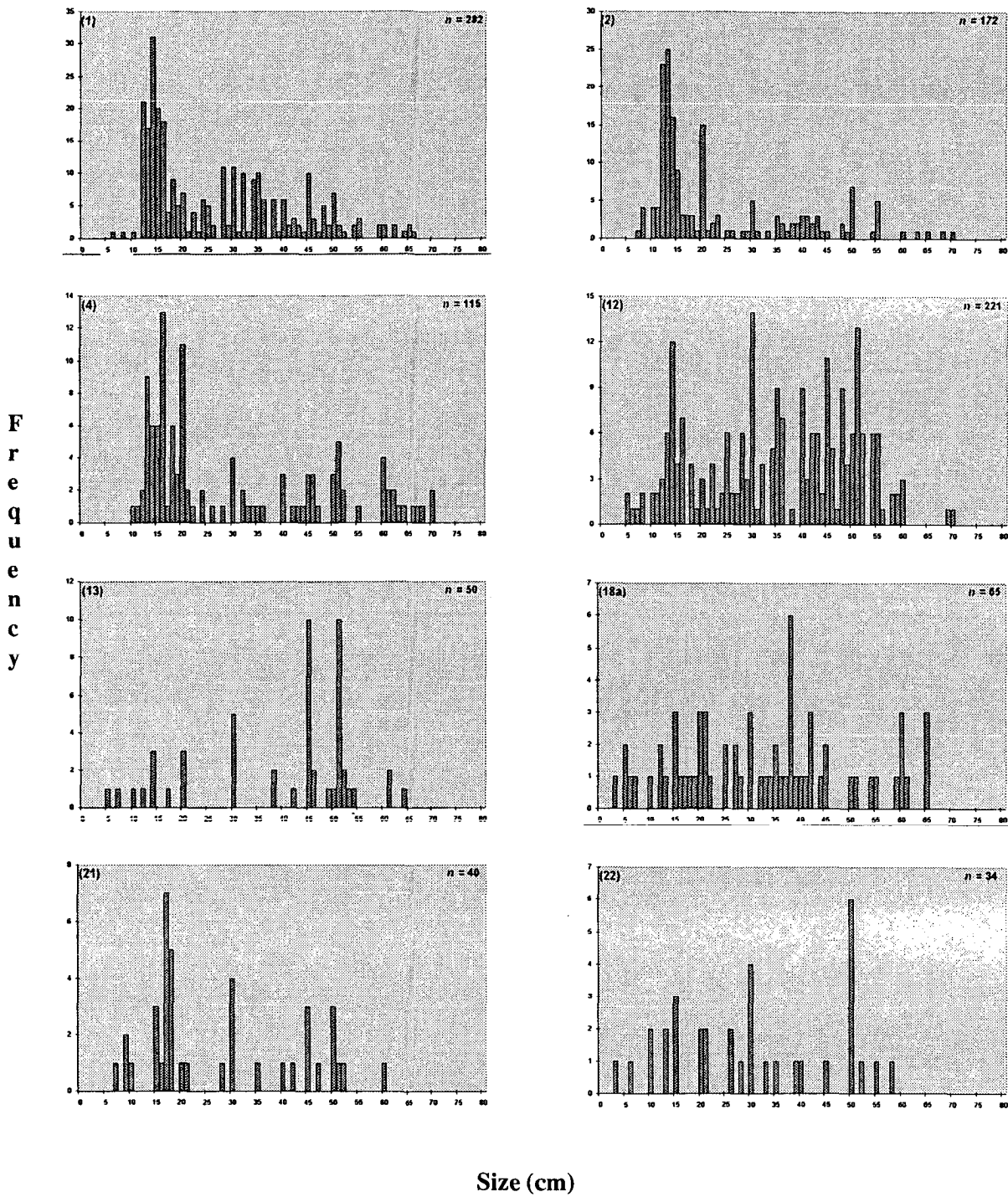


**Figure 2 cont.** Estimated zone mean densities of *A. planci* on reefs surveyed in 1995-96 (2e, 2f), where (BR) is the back reef zone including both slopes and bommies and (FR) represents the front reef slope zone. Estimates of adult densities (ASO, starfish aged three and older) are shown in plots (2b, 2e), with combined and sub-adult density estimates (ISO, starfish aged two and older) shown in plots (2c, 2f). Error bars show standard errors ( $\pm 1$  SE). Note that some survey reefs differ between the two years.



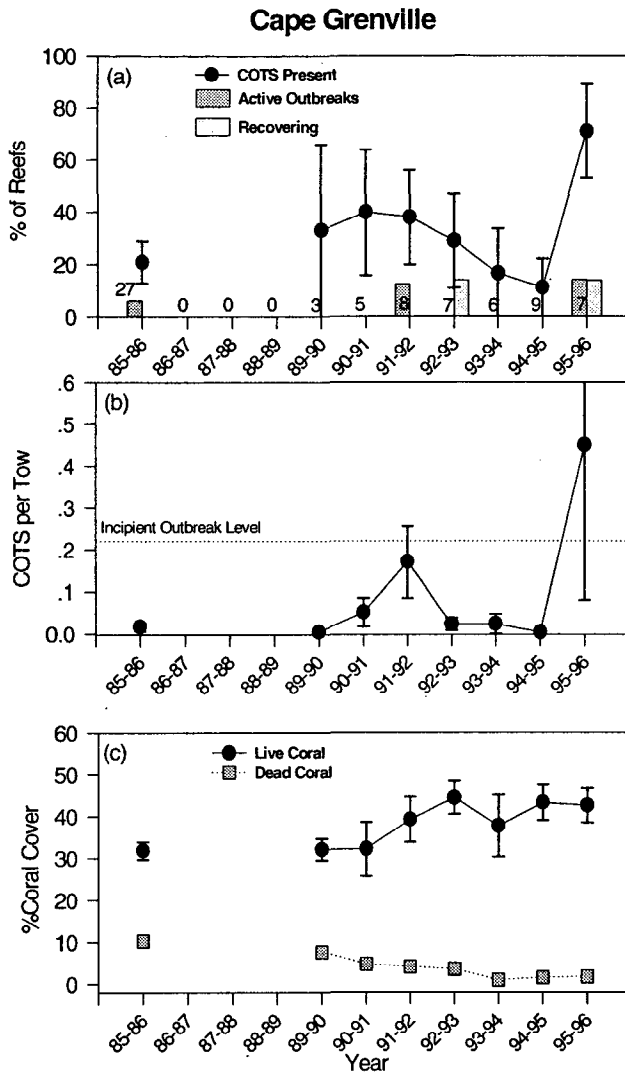
**Table 1.** Summary table of location and status of mid-shelf reefs surveyed for *A. planci* in 1994-95 and 1995-96. (AO - Active Outbreak, ASO - Active Spot Outbreak, IO - Incipient Outbreak, ISO - Incipient Spot Outbreak, NO - No Outbreak)

<i>Reef No</i>	<i>GBRMPA Reef Gazetteer ID</i>	<i>Reef Name</i>	<i>Latitude</i>	<i>Longitude</i>	<i>Status 94-95</i>	<i>Status 95-96</i>
1	14-116	Lizard Island Reef	14°41'S	145°28'E	AO	-
2	14-143	North Direction Reef	14°45'S	145°31'E	ASO/IO	AO
3	14-132b	Rocky Islets Reef (b)	14°52'S	145°29'E	ASO/IO	AO
4	14-133	U/N	14°55'S	145°31'E	IO	AO
5	15-019	Long Reef	15°03'S	145°34'E	ASO/IO	AO
6	15-024	Mackay Reefs	15°08'S	145°34'E	ASO/IO	AO
7	15-033	Lark Reef (East)	15°17'S	145°35'E	NO	ASO/IO
8	15-043	U/N	15°26'S	145°31'E	IO	IO
9	15-070	U/N	15°30'S	145°37'E	NO	ASO/IO
10	15-084	Irene Reef	15°39'S	145°43'E	ASO/IO	ASO/IO
11	15-089	Endeavour Reef (East)	15°46'S	145°36'E	ASO/IO	ASO/IO
12	15-095	Evening Reef	15°54'S	145°40'E	AO	ASO/IO
13	16-015	Mackay Reef	16°03'S	145°39'E	ASO	-
14	16-023	Rudder Reef (East)	16°12'S	145°42'E	NO	IO
15	16-024	U/N	16°13'S	145°48'E	NO	IO
16a	16-026	Tongue Reef (West)	16°19'S	145°53'E	NO	-
16b	16-026	Tongue Reef (East)	16°19'S	145°53'E	-	ASO
17	16-057	Hastings Reef	16°31'S	146°01'E	NO	NO
18a	16-064	Arlington Reef (West)	16°41'S	146°04'E	ASO	-
18b	16-064	Arlington Reef (East)	16°41'S	146°04'E	-	ASO/IO
19	16-049	Green Island Reef	16°46'S	145°59'E	NO	IO
20	16-068	Thetford Reef	16°49'S	146°11'E	NO	NO
21	16-073	Elford Reef (East)	16°55'S	146°15'E	NO	NO
22	17-001	Sudbury Reef	16°58'S	146°12'E	NO	-
23	17-006	Maori Reef	17°06'S	146°21'E	NO	-
24	17-016	McCulloch Reef	17°17'S	146°26'E	NO	-
25	17-004	Scott Reef	17°04'S	146°11'E	-	ISO
26	17-011	Coates Reef	17°12'S	146°23'E	-	AO
27	17-034	Feather Reef	17°32'S	146°23'E	-	NO



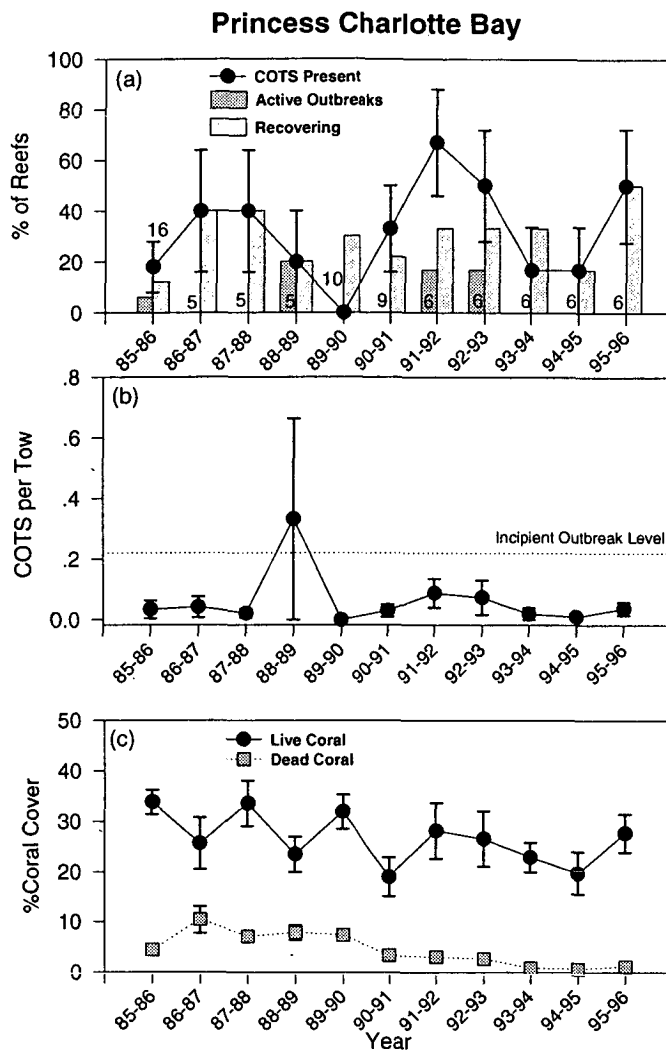
**Figure 3.** Examples of size-frequency distributions observed in *A. planci* populations on selected survey reefs in 1994-95 indicating the widespread existence of multiple year classes

Broad-scale surveys (GBR-wide)



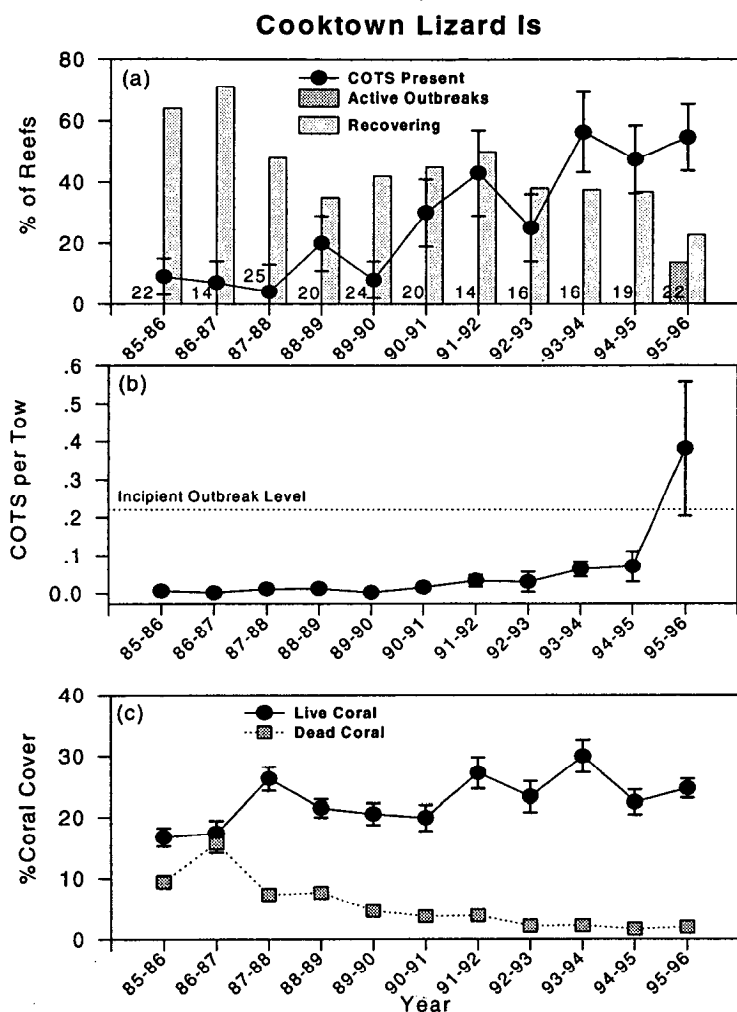
**Figure 4a.** Broad-scale survey results for the *Cape Grenville* sector showing: a) % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); b) COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); c) averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Broad-scale surveys in this sector indicate that coral cover on reefs is generally high (30-50%). These results are consistent with those obtained from previous surveys which indicate a general increase in live coral cover over time. Low levels of COTS populations have been detected in this sector over all survey years. However recent surveys indicate an increase in COTS activity in this sector. Curd Reef is currently experiencing an active outbreak of COTS while Forbes Reef is considered to be an incipient outbreak.



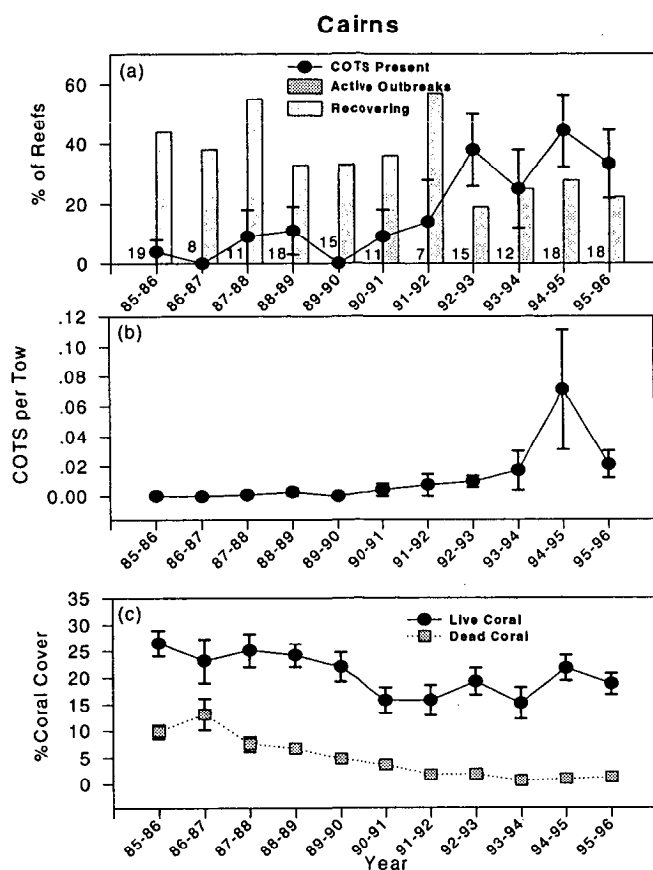
**Figure 4b.** Broad-scale survey results for the *Princess Charlotte Bay* sector showing: a) % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); b) COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); c) averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

For those reefs surveyed in this sector live coral shows a small general decline. Overall live coral cover remains moderate (10-30%). The exception is Davies Reef which has shown a marked decline in coral cover from when it was last surveyed in 1989-90 (down from a median of 30-50%). This may be due to poor recovery from storm damage induced by cyclone Ivor which passed through this region in March 1990. COTS densities remain low for all years except 1988-89 where large numbers were detected on Clack Reef. COTS have been recorded in low numbers on reefs in this sector during most survey years, and single active outbreaks have been recorded on three separate occasions.



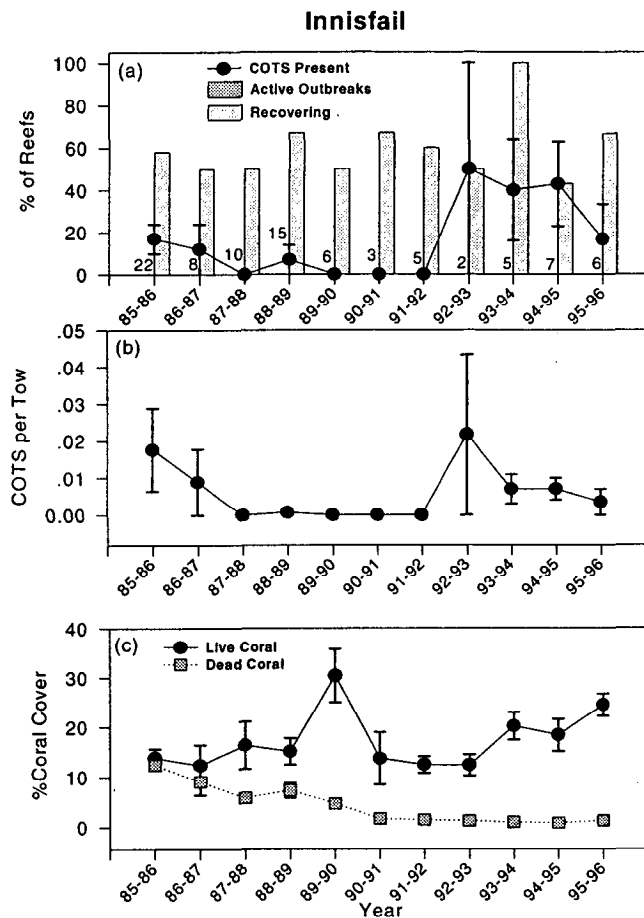
**Figure 4c.** Broad-scale survey results for the *Cooktown - Lizard* sector showing: a) % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); b) COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); c) averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Initially this sector was characterised by very low numbers of starfish on just a few reefs. Recent surveys indicate that of the 23 reefs surveyed 3 (Helsdon, Lizard Island and Two Isles), may now be considered to have Active Outbreaks of COTS while a further 3 (Linnet, MacGillivray and Rosser) are considered Incipient Outbreaks. Although the average coral cover in this sector has shown some increase since the commencement of broadscale surveys (currently 20-30%) recent increases in the number of COTS observed suggest this trend may change in the future. It is interesting to note that the elevated COTS populations occur in an area between approximately 15° S and 16° S. This is currently considered the likely epicentre for the primary outbreaks that lead to the last two series of outbreaks recorded on the GBR (see Moran et al. 1992).



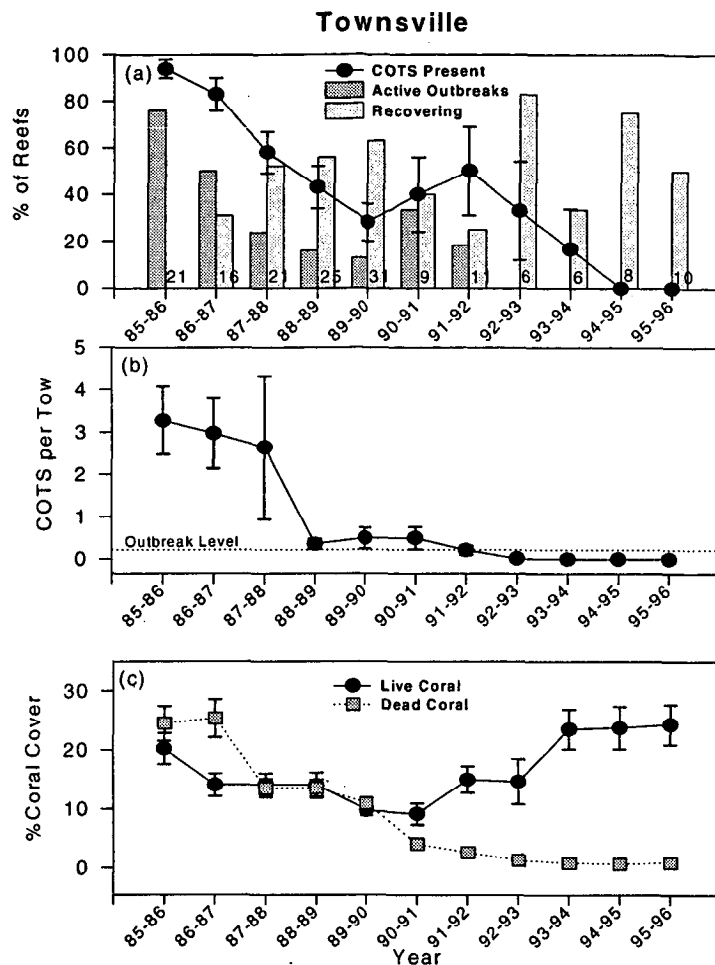
**Figure 4d.** Broad-scale survey results for the *Cairns* sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Although there were several outbreaks in the years preceding the initiation of the COTS monitoring program, generally few COTS have been recorded in this sector since the beginning of surveys and no active outbreaks have been recorded. This is despite Green Island's notoriety for harbouring extremely large COTS populations during the last two outbreaks to have affected the GBR. The importance of this sector is indicated by the number of reefs classified as recovering suggesting substantial prior COTS activity. Trends in the broadscale survey data shows the situation in this sector may be changing in regard to COTS activity with a trend of increasing COTS numbers recorded from this sector over the last few years. This is supported by SCUBA search data from reefs in this sector which indicate recent COTS recruitment. Significantly it appears that in the absence of obvious COTS activity live coral cover while moderate (10-30%) on reefs in this sector has shown a general decline. This would indicate that reefs in this sector have not recovered significantly since the last series of outbreaks. If COTS numbers are building then this may signal a further decline in coral cover for reefs in this sector.



**Figure 4e.** Broad-scale survey results for the *Innisfail* sector showing: a) % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); b) COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); c) averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

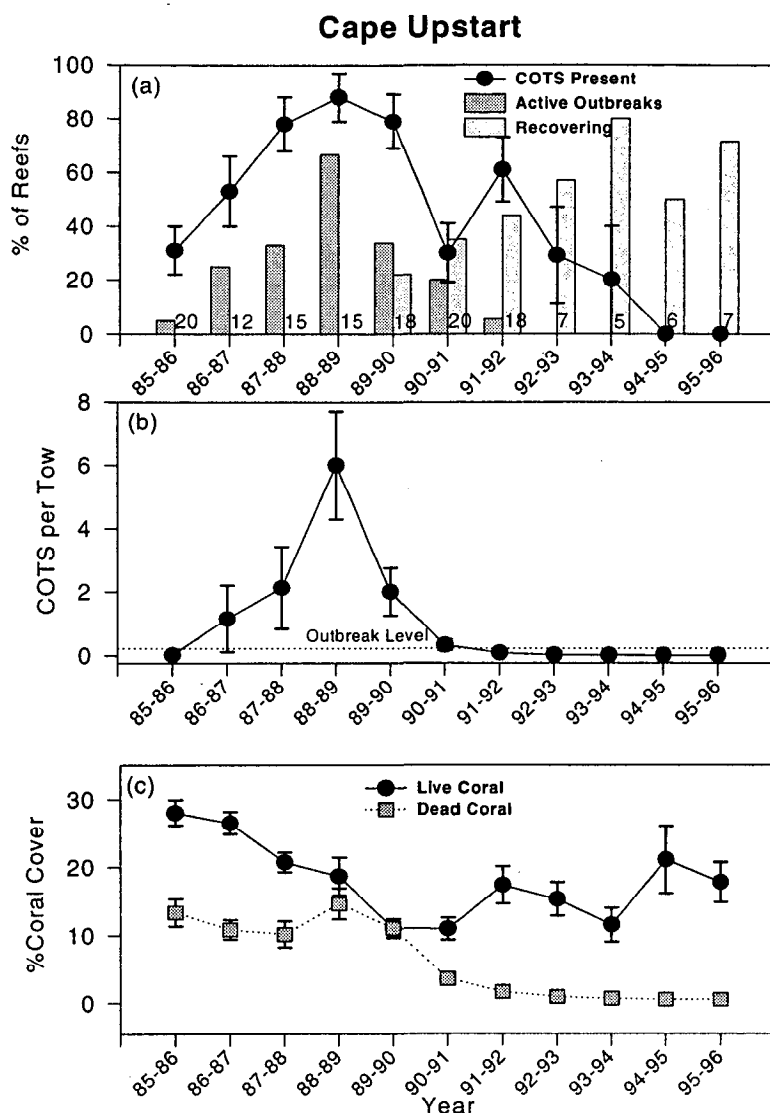
Very few COTS have been recorded in this sector since the beginning of broadscale surveys and no active outbreaks have been recorded. Somewhat over half of the reefs have been classified as Recovering, indicating substantial prior COTS activity. Densities of COTS showed a small decrease in the first 3 years but are still very low compared to outbreak levels. General trends through time show little change in this sector with respect to coral cover and COTS activity. Coral cover on reefs in this sector remains moderate between 10-30% with some indication of a recent gradual increase. There has been a small increase in COTS activity in the last few years however this is only a very small change and COTS populations remain well below what is considered an outbreak level.



**Figure 4f.** Broad-scale results for the *Townsville sector* showing: a) % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); b) COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); c) averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

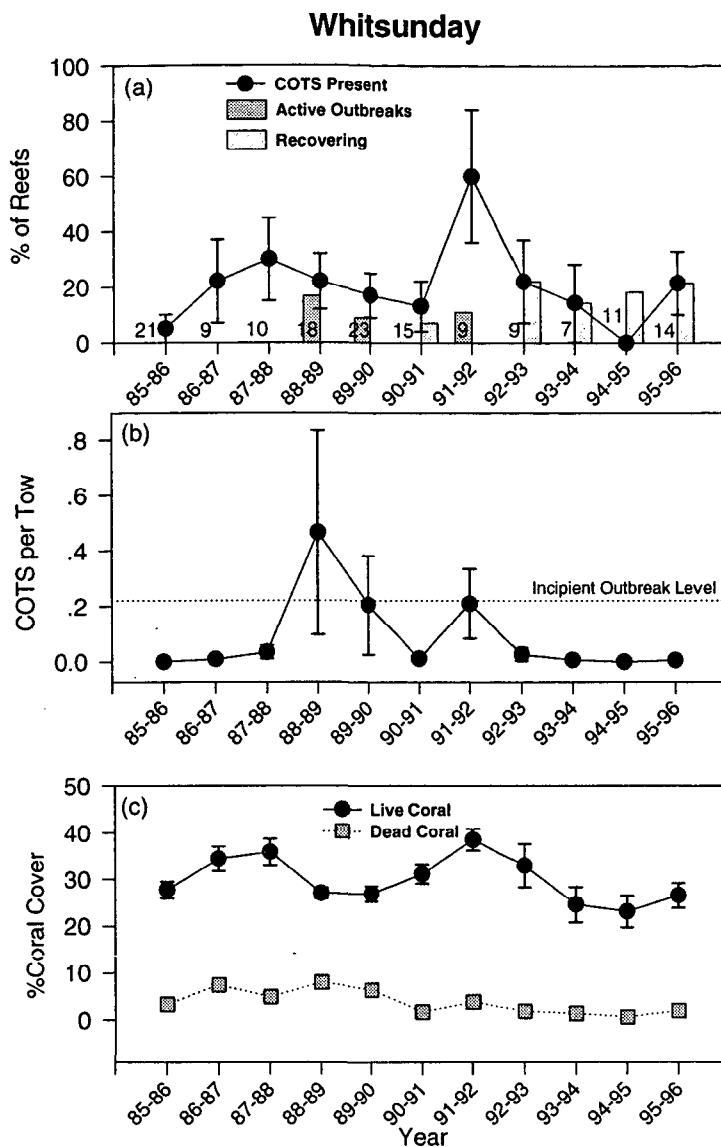
General trends in this sector show a marked decline in COTS activity since the beginning of surveys when nearly 80% of reefs surveyed were classified as having Active Outbreaks. COTS densities, frequency of occurrence on reefs and percentage of reefs with active outbreaks all show a general decline in subsequent surveys, while recovering reefs have increased proportionally. No COTS were recorded during surveys conducted in 1995-96. The previous year was the first time COTS have not been recorded in this sector since the commencement of broad-scale surveys. Live coral cover shows a gradual increase (current level moderate at 20-30%) with a corresponding drop in dead coral from a 10-30% cover in 1985-86 to a current level of less than 5%.





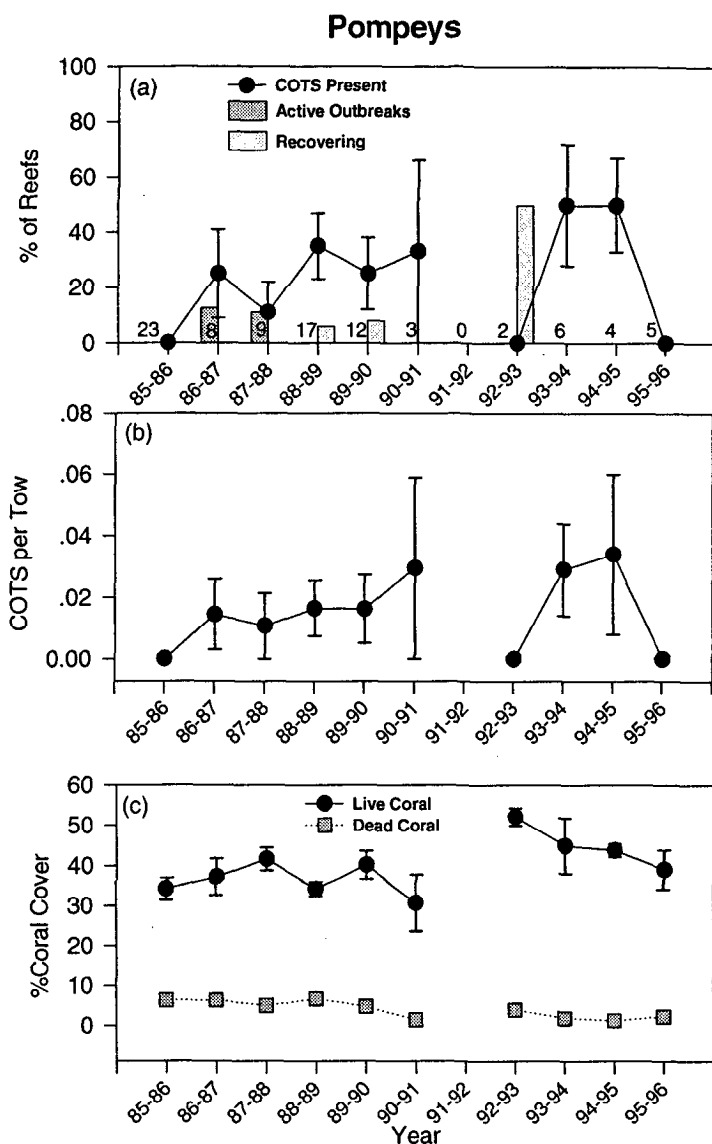
**Figure 4g.** Broad-scale survey results for the *Cape Upstart* sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Survey results from this sector show a significant build up of COTS from pre-outbreak levels beginning in 1985-86, peaking in 1988-89 and then showing a marked decline. Since the 1992-93 survey year no reefs have been considered to be outbreaking. Reflecting this pattern there has been a corresponding drop in live coral cover over this time from a level of nearly 30% to approximately 10% towards the end of outbreaks in 1990-91. Data from the last few years survey show a some increase in coral cover since the end of outbreaks in 1991-92. The current coral cover in this sector is generally moderate at 10-30%. Recent surveys failed to detect any COTS in this sector.



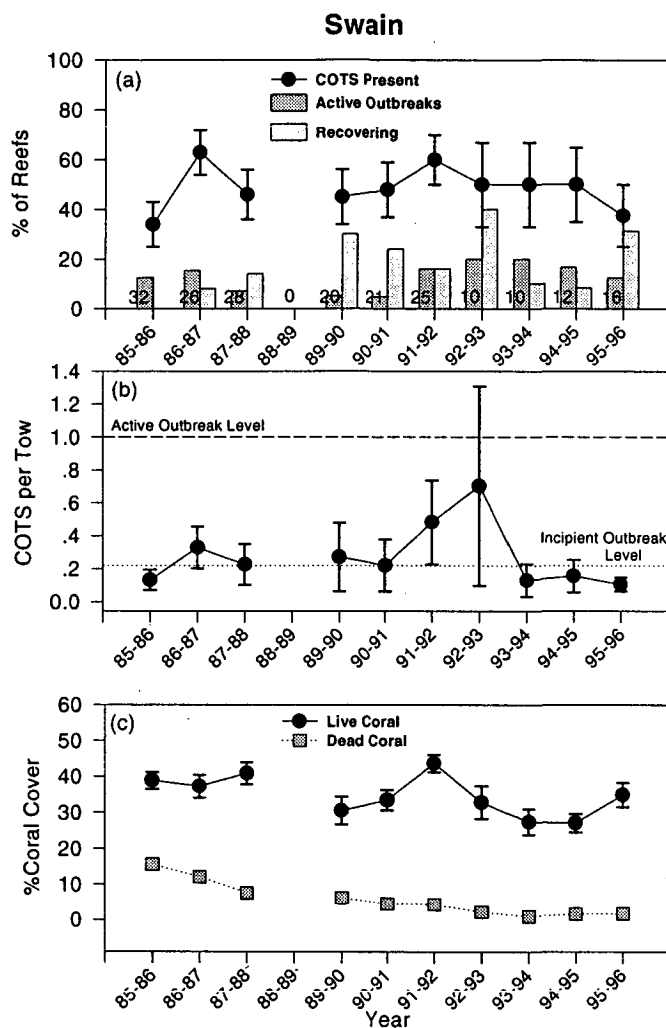
**Figure 4h.** Broad-scale survey results for the *Whitsunday* sector showing: a) % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); b) COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); c) averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Patterns of COTS outbreaks have shown a similar, though lagged, trend as compared to the Cape Upstart sector. COTS activity increased and peaked between 1988-89 and 1991-92 and has declined since. Recent surveys in this sector has revealed minimal COTS activity. Coral cover in this sector has shown little change since the commencement of broadscale surveys and is currently moderate at 10-30%.



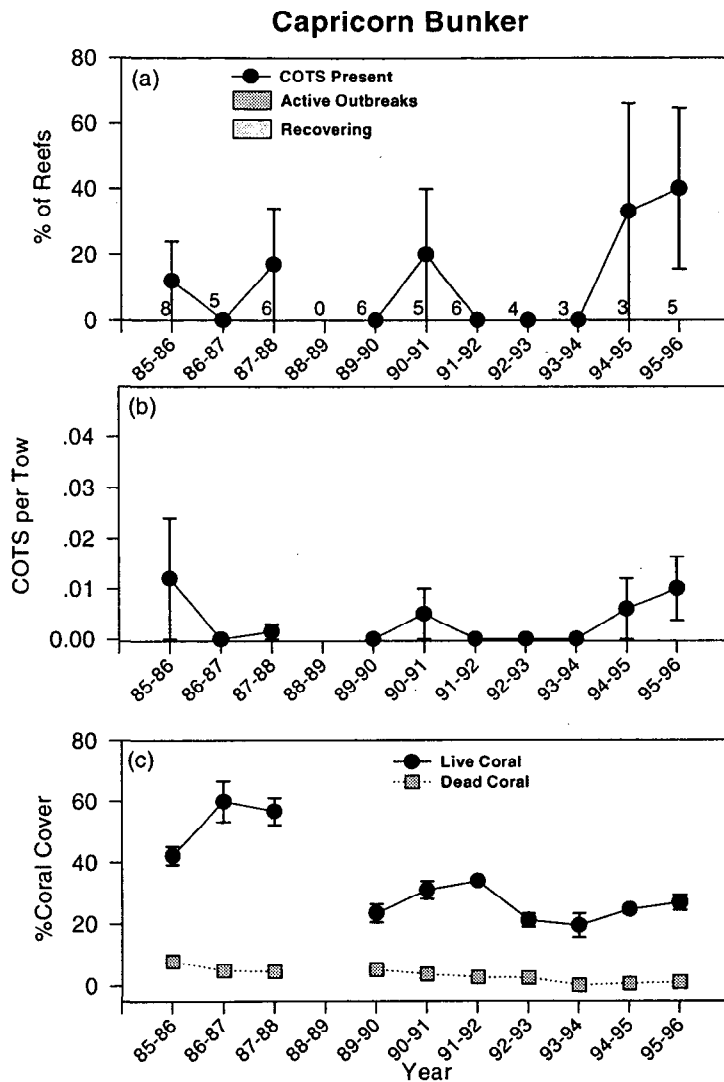
**Figure 4i.** Broad-scale survey results for the *Pompey sector* showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Though COTS have been generally found to be present in this sector since the beginning of broadscale surveys active outbreaks have not been detected since 1986-87. There has been little change in coral cover on reefs surveyed with coral cover remaining generally high (30-50%). Recent trends are difficult to assess due to a low sampling effort, but there are no indications of any COTS activity at present.



**Figure 4j.** Broad-scale survey results for the *Swain sector* showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

The Swain sector is an interesting region compared to the rest of the GBR in regard to COTS activity. Active outbreaks have been recorded in this sector on all years that surveys have been conducted. COTS populations in the Swains are considered to be independently derived from those further north (Moran et al. 1992). COTS in this sector have not been recorded in densities comparable to those observed in the Townsville or Cape Upstart sectors. Thus the drastic changes in coral cover observed in reefs in the Townsville and Cape Upstart sectors during the last series of outbreaks has not been observed in the Swains sector. Coral cover in this sector remains generally high (30-50%). Two reefs (Snake and Horseshoe) are currently considered to have Active Outbreaks of COTS.



**Figure 4k.** Broad-scale survey results for the *Capricorn Bunker* sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Few COTS have been recorded from this sector since the beginning of surveys and although very low numbers of COTS have been recorded during the two survey years populations remain well below those that would be considered to cause significant coral mortality. Of special interest for reefs in this sector is the large drop in coral cover (from a very high level of 50-75% to a moderate level of 10-30%) recorded between 1987-88 and 1989-90. The lack of COTS recorded from this sector and the lack of large amounts of dead standing coral indicate that COTS were probably not the responsible agents. At this stage the exact cause for this reduction in coral cover remains uncertain. Coral cover in this sector remains moderate (10-30%) and there is some indication that reefs in this sector are beginning to recover.

## Discussion

### The origin of primary outbreaks

Fine-scale survey data show that *A. planci* populations on many survey reefs are characterised by the presence of several distinct cohorts or year classes. This pattern suggests that the identified active outbreaks are the result of consecutive successful recruitment events that have led to a build up in numbers over recent years. It is suggested that at least some of the observed high density populations the Cairns Section represent primary outbreaks. The geographically widespread nature of primary outbreaks is not supportive of the notion of a single source reef triggering off secondary outbreaks downstream, nor is it consistent with outbreaks originating from a single major recruitment event. Rather it would appear that primary outbreak events are the result of regional-scale phenomena affecting geographically separate populations concurrently over a period of several years.

Comparisons with previous surveys conducted in the Cairns Section through the AIMS broad-scale surveys (Oliver et al. 1995), GBRMPA's *COTSWATCH* scheme (Engelhardt, unpublished data) and transect-based surveys (Mapstone and Ayling 1994) show that, for the period from 1985 to 1992, reefs in this Section generally supported only low density populations of *A. planci*. None of the above mentioned monitoring studies detected any active outbreaks of *A. planci* during this period. In 1989-90, Mapstone and Ayling (1994) used belt transects for detailed benthic surveys on 24 reefs between Innisfail and Lizard Island and recorded a total of 24 *A. planci*. On 75% of reefs surveyed the observers did not find any starfish, while the remainder supported very low numbers of starfish. Follow-up surveys conducted in 1990-91 again recorded only low numbers of starfish on 47 reefs (Mapstone, unpublished data). These results clearly indicate that the observed outbreaks have resulted from successful recruitment events that have occurred since the 1989-90 spawning season.

### Likely future trends

Given the high proportion of juvenile and sub-adult *A. planci* recorded on many of the survey reefs, it appears highly probable that reproductively mature populations of starfish may persist in this region for at least another 3-5 years.

Given the typically southward moving currents in the southern half of the Cairns Section, larval dispersal from existing populations of *A. planci* is likely to be in a similar direction. This suggested dispersal pattern is further supported by previously recorded secondary outbreaks on mid-shelf reefs that have generally followed the path of the main water currents (Kenchington 1978; Johnson et al. 1985; Moran 1986; Dight et al. 1988; Black and Moran 1991; James and Scandol 1992).

The biggest hurdle to making accurate projections from the current situation is the lack of comparable detailed information on *A. planci* populations prior to the previous two outbreaks. Dedicated surveys of starfish populations were only undertaken several years after the outbreaks were first detected. It is possible that the observed outbreaks were derived from earlier primary outbreaks. Primary populations of *A. planci* may have originated some six years before outbreaks were first detected and 7-11 years before dedicated surveys were initiated. A variety of techniques (manta tow, spot checks and swim searches) and survey units were used in these earlier surveys. Reefs were occasionally confused and published locations ambiguous. Some survey data were aggregated into such broad categories as to defy meaningful ecological interpretation. A lack of consistent definitions of outbreaks and objectives in conducting the surveys compounds the confusion.

The other major element contributing to the vagary in forecasting from the current situation is the lack of hydrodynamic data for the area. The Ribbon Reefs appear to form an effective barrier to the South Equatorial Current, minimising the functional impact of the EAC in the lagoon and reef matrix. While the EAC has been monitored for the past seven years, currents inside the Ribbon Reefs have not. Currents in the mid-shelf region are probably wind forced and as a result, highly variable. Given the variability in summer wind velocities (and the presumed current velocities) as well as uncertainty over the exact spawning times of *Acanthaster*, larval transport distances and directions are unpredictable.

### **Conclusions**

Assuming that the observed outbreaks in the Cairns Section are the beginnings of a third major outbreak episode, recent fine- and broad-scale survey data provide the clearest evidence yet that the northern part of the Cairns Section may in fact be the main seed area of major outbreak cycles on the GBR. The apparently unique status of Cairns Section reefs is further illustrated by the absence of similar trends in the other AIMS monitoring sectors.

The results of the first two years of fine-scale surveys have shown that intensive visual monitoring of reef benthos using belt transects can reliably detect signs of *A. planci* population increases much earlier than has previously been possible. Fine-scale surveys have provided both a detailed baseline to assess the dynamics of starfish populations, as well as new insights into the characteristics of primary outbreaks in this area.

The high proportion of juvenile starfish detected on many of the survey reefs suggests that further increases in *A. planci* densities are likely to occur in the near future. However, due to a lack of understanding of primary outbreak events and the inherent variability in the ecological factors controlling population spread, we can not predict future events with any degree of certainty.

### **Management implications**

*A. planci* outbreaks are responsible for the greatest, documented ecological impact on the GBR system. If human activities are implicated in causing or exacerbating outbreaks, many other management challenges may fade into insignificance. Both targeted research into the causes of outbreaks and monitoring are essential for providing the necessary information upon which effective management can be based.

In the absence of satisfactory evidence implicating human activities in the causation of starfish outbreaks, the GBRMPA's policy of limited intervention remains a logical and realistic approach to managing this issue. Currently, control activities are limited to small areas of particular significance to tourism operations and/or science. Permits may be issued by the GBRMPA only when affected parties can demonstrate a clear economic risk to the viability of their operations. Generally, control operations have to be conducted using environmentally acceptable means of control (i.e. manual removal or injection with biodegradable compounds that are toxic only to the target organism).

Reef managers will have to weigh up the risks associated with (i) the remaining uncertainties as to the ultimate causes of the outbreaks, as well as (ii) the effectiveness of current management actions. The quality and magnitude of ecological data that is now becoming available will, for the first time, allow to more formally evaluate the various management options in a risk assessment framework. The potential dangers that the COTS phenomenon poses to maintaining the long-term ecological structure of the GBR ecosystem requires a concerted effort to ensure

that management can make informed and correct decisions based on reliable scientific information.

### **Acknowledgments**

Both broad- and fine-scale surveys were funded by the Australian Cooperative Research Centres Program through the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef, the Great Barrier Reef Marine Park Authority and the Australian Institute of Marine Science. CEDAM International and 'Reef Promotions - The Adventure Company' provided valuable additional field time and staff support. Our sincere thanks to the crews of the vessels 'Booby Bird', 'Floreat', 'Marlin I' and 'Pacific Adventure' and a great number of dedicated volunteers who put their time and effort into making the fine-scale surveys possible.

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# Status of seagrasses in the Great Barrier Reef region

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## Abstract

Broad-scale surveys of the Great Barrier Reef (GBR) province have found seagrasses in estuaries, shallow coastal bays and inlets, on fringing and barrier reef platforms and in deep, inter-reef waters. Coastal and island waters have been mapped for all of Queensland, but knowledge of seagrasses on reef platforms and in deep water (> 15 m) is limited. Large areas of seagrass at depths between 10 and 30 m in the Cairns and Far Northern Sections and in Hervey Bay, have been associated with large dugong populations.

Approximately 3000 km<sup>2</sup> of coastal seagrass habitat has been mapped in the GBR region to date, and at least 2000 km<sup>2</sup> of deepwater seagrass habitat has been estimated so far. Fourteen known seagrass species were recorded from surveys of Queensland coastal, island and reef waters, but increases in the species list for the Genus *Halophila* are likely with surveys of new habitats. Some species reach the latitudinal limits of their distribution in Queensland and at least two *Halophila* species may be endemic to either the GBR region or northeastern Australia.

Estuarine and shallow coastal seagrass meadows appear to be much more important than deepwater seagrasses as nursery habitat for juvenile prawns and fish. Seagrasses in the GBR are also sources of food to dugong and green sea turtles - species listed as threatened or endangered. The distribution and ecological importance of seagrasses on reef platforms and in deep water (> 10 m) requires attention.

Natural events such as cyclones and floods can cause widespread loss of seagrasses in shallow and deep water. Current agricultural land-use practices may exacerbate the effects of these natural events, as well as slow recovery processes. Localities which provide shelter and water conditions ideal for productive seagrass habitat are often targets for port development, and at the downstream end of heavily impacted catchments. Far Northern Section seagrasses do not yet face the same immediate threats from urban and agricultural runoff, or coastal and Barrier Reef development, that occur in southern, more populated regions.

We have little understanding of the scale and ecological consequences of natural year-to-year change in most of these seagrasses. Anthropogenic impacts on seagrasses in the GBR currently appear low to moderate, but land-use practices and coastal management need careful attention to minimise adverse impacts of increasing population and development. Integrated catchment management may be one of the most important programs to help ensure survival of seagrass systems in the GBR region. Marine Parks and fishing industry closures help protect valuable inshore seagrass prawn nursery and dugong feeding habitat, but recently discovered deepwater seagrasses do not yet receive such formal protection measures. There is a need for research to describe the responses of seagrass to natural and human impacts and to establish acceptable levels of changes to seagrass meadows and the acceptable levels of water quality conditions which cause those changes.

## Overview

Seagrasses in the coastal waters of the GBR province were mapped from broad-scale surveys of separate regions from 1984 to 1989 (Coles et al. 1985; Coles et al. 1987a,b; Coles et al. 1992; Lee Long et al. 1992). Seagrasses have been found in estuaries, shallow coastal bays and inlets, on fringing and barrier reef platforms and in deep water. Coastal and island waters have been mapped for all of Queensland, but surveys of deeper water (more than 15 m), inter-reef and barrier reef platform areas have only recently begun. Seagrasses have been found to depths of 58 m in the Cairns and Far Northern Sections (Lee Long, McKenzie and Coles 1996), and large areas of *Halophila* species at depths between 15 and 30 m (Lee Long et al. 1989), have been associated with large dugong populations (Marsh and Saalfeld 1989). Major areas of seagrass habitat identified from initial broadscale surveys in the 1980s are shown in Fig. 1 and Table 1 (from Lee Long et al. 1993).

Approximately 3000 km<sup>2</sup> of coastal (< 15 m depths) seagrass habitat has been mapped in the GBR region to date (Lee Long, Mellors and Coles 1993), and at least an additional 2000 km<sup>2</sup> of deepwater seagrass habitat has been estimated so far (Lee Long et al. 1996). Fourteen known seagrass species were recorded from surveys of Queensland coastal, island and reef waters between 1984 and 1989 (Lee Long, Mellors and Coles 1993). Most of these species are common to the Indo-West Pacific region, but some reach the latitudinal limits of their distribution in Queensland (Lee Long, Mellors and Coles 1993) and at least two species (*Halophila tricostata* and *Halophila* sp.) may be endemic to the GBR. One new species (*Halophila capricorni*, Larkum 1996) has since been described and taxonomic studies of additional undescribed plants in the Genus *Halophila* will likely lead to further increases in the species list for the GBR (Kuo, pers. comm.).

All seagrasses are important in primary production and therefore in supporting complex marine food webs. They are often valuable nursery grounds for commercially and recreationally important species of prawns and fish. Estuarine and shallow coastal seagrass meadows appear to be much more important as nursery habitat for juvenile prawns and fish (Derbyshire et al. 1995). Seagrasses in the GBR are also sources of food to dugong and green sea turtles - species listed as threatened or endangered. Meadows dominated by *Halophila* and *Halodule* species are preferred dugong feeding areas. Seagrasses in coastal regions play important roles in maintaining sediment stability and water clarity. Their physical role in deep water (> 10 m) is less understood.

## Pressures on seagrasses in the Great Barrier Reef

Natural events such as cyclones and floods can cause widespread loss of seagrasses in shallow and deep water, with devastating effects on dugong populations and some fisheries (Preen et al. 1995; Preen and Marsh 1995). Current land-use practices may exacerbate the effects of these natural events through increased soil erosion and nutrient run-off. Continued urban and agricultural expansions present a chronic threat and land run-off impacts may also affect the recovery of seagrasses after loss. Integrated Catchment Management programs seek to address these issues and are seen as an important part of good management for continued survival of seagrasses in the GBR.

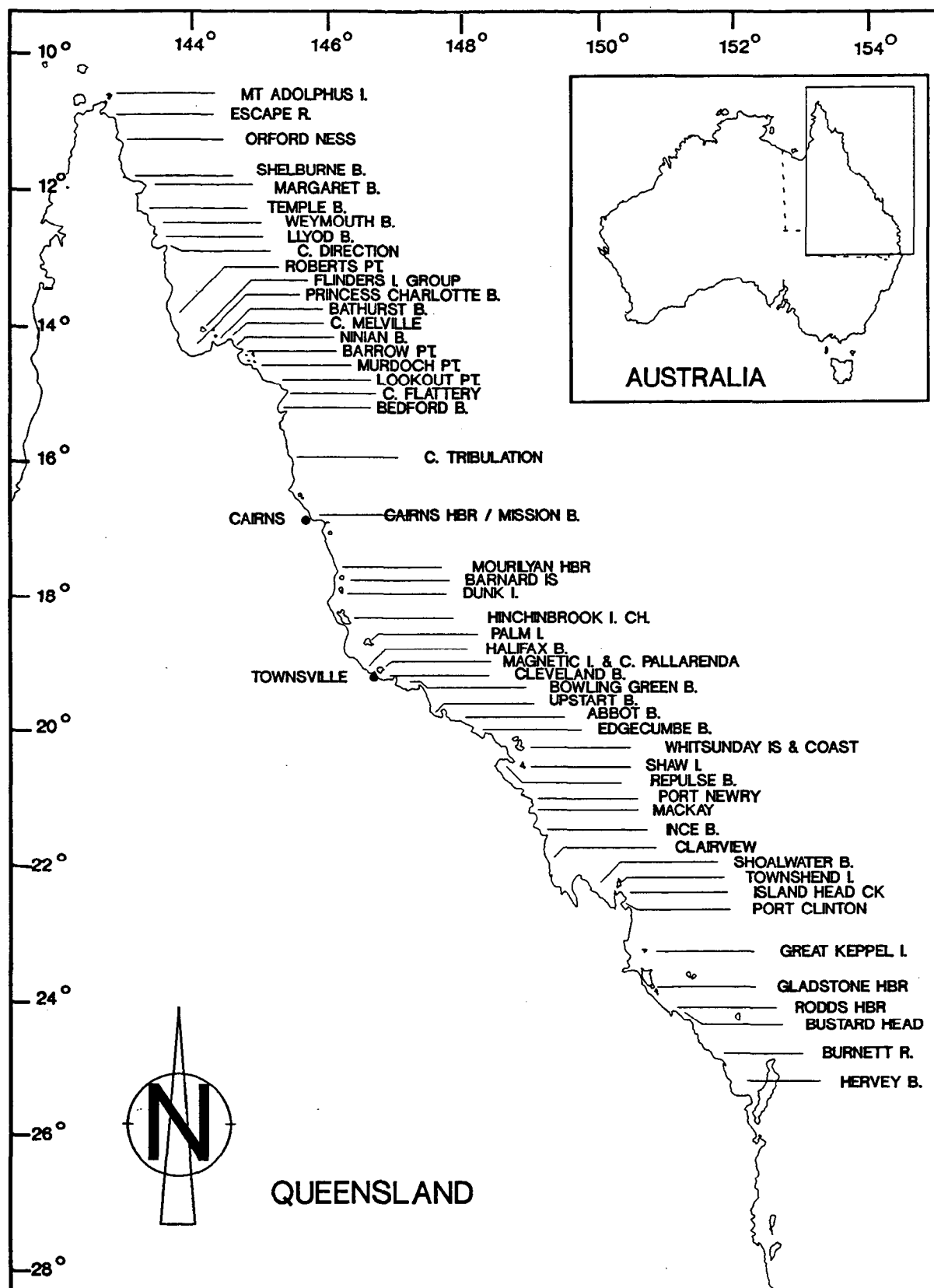


Figure 1. Major areas of seagrass habitat identified from initial broadscale surveys in the 1980s

Table 1. Summary of seagrass areal cover for major habitats along the Queensland coast

Geographical Location	Area of seagrass cover (km <sup>2</sup> )			Total												
	<10%	10-50%	>50%		Halophila ovalis	Halodule uninervis-wide	Halophila spinulosa	Halodule uninervis-thin	Halophila decipiens	Cymodocea ovata	Zostera serrulata	Syringodium pinifolia	Halophila capricorni	Thalassia isoetifolium	Thalassia tricoostata	Cymodocea hemprichii
MT ADOLPHUS I.			0.98	0.98												
ESCAPE R.		4.18		4.18												
ORFORD NESS	2.12	4.95		7.07												
SHELBURNE B.		1.50	11.10	16.70												
MARGARET B.	4.02	5.81	6.08	15.91												
TEMPLE B.	24.64			24.64												
WEYMOUTH B.			4.14	4.14												
LLOYD B.	3.92	8.08		12.00												
C. DIRECTION	48.07	71.32		119.39												
ROBERTS PT.			159.00	159.00												
FLINDERS I. GROUP	5.68		10.15	15.83												
PRINCESS CHARLOTTE B.		51.04	16.08	67.12												
BATHURST B.	68.75		118.28	187.03												
C. MELVILLE		13.41		13.41												
NINIAN B.			28.24	28.24												
BARROW PT. - MURDOCH PT.	107.07	211.51	43.17	361.75												
MURDOCH PT - LOOKOUT PT.	534.29	502.22	167.52	1204.03												
C. FLATTERY	2.16	8.51		10.67												
BEDFORD B. - C. TRIBULATION	2.16	1.07	2.53	5.76												
CAIRNS HBR.	1.37	7.79	11.85	21.01												
MOURILYAN HBR.	0.19	1.12		1.31												
BARNARD IS.	3.74	4.60		8.34												
DUNK I. & COAST	1.39	3.93		5.32												
NTH HINCHINBROOK I.	19.19	9.05		28.24												
HINCHINBROOK I. & CH.	19.70	5.53	5.15	30.38												
PALM I.	1.43	2.05		3.48												
HALIFAX B.	16.95	3.44		20.39												
C. PALLAREDA	5.92	9.12		15.04												
MAGNETIC I.	6.54	4.78	1.56	12.88												
CLEVELAND B.	3.22	56.95		60.17												
BOWLING GREEN B.	7.15			7.15												
UPSTART B.	6.20	20.64	32.33	59.17												
ABBOT B.	14.44	15.91	3.00	33.35												
EDGE CUMBE B.	7.16	3.66	13.35	24.17												
WHITSUNDAY COAST	12.41	4.11		16.52												
WHITSUNDAY ISLANDS	9.74	7.17	13.06	29.97												
SHAW I.	1.22	2.53		3.75												
REPULSE B.	4.47	2.28		6.75												
PORT NEWRY	4.88	2.53		6.74												
MACKAY	5.47	1.64		7.11												
INCE B.	5.75	5.49		11.24												
CLAIRVIEW	12.93	7.39		20.32												
SHOALWATER B.	15.93	21.25		37.18												
TOWNSHEND I.	9.96	4.15		14.11												
ISLAND HEAD CK	0.60	4.14	0.45	5.19												
PORT CLINTON	0.61	3.64	9.68	13.93												
GREAT KEPPEL I.	4.44	1.25	0.45	6.14												
GLADSTONE HBR	2.85	10.27	4.04	17.16												
RODDS HBR	4.29	2.89	0.27	7.45												
BUSTARD HEAD		3.07		3.07												
BURNETT R.		2.07		2.07												
HERVEY B.		225.50	779.68	1026.34												
TOTALS	1034.18	1343.54	1442.14	3819.86												

Seagrasses are common in sheltered areas where coastal developments are concentrated and bring increased threats of urban and industrial runoff, dredging or burial. Impacts which increase water column sediments and nutrients, or phytoplankton or epiphyte density can lead to greater attenuation of light and reduced seagrass survival at the deep end of its distribution (Dennison et al. 1993). These threats are greatest in semi-enclosed bays and ports where water exchange rates are low. Far Northern Section seagrasses do not yet face the same immediate threats from urban and agricultural runoff, or coastal and Barrier Reef development that occur in southern populated regions.

Damage to inshore seagrass meadows by trawling activity should be minimal under the fishery management policy of strip closures, and dense meadows in deep water are usually avoided by trawlers when possible. Low density seagrass meadows in deep water, which are dugong feeding habitat, receive no special zoning or protection from trawling and may be at risk of damage.

Increases in shipping traffic along eastern Queensland will lead to increased threats from oil spills. Oil spills may cause severe and immediate damage to intertidal seagrass meadows but subtidal seagrasses may be at lesser risk (Jackson et al. 1989; Kenworthy et al. 1993). Impacts on the invertebrate and fish communities which seagrasses support can be severe, but may respond positively to subsequent regeneration of seagrasses.

#### **Status of seagrasses in the Great Barrier Reef region**

Seagrass habitat information was not available when most initial Marine Park zone plans were drawn. Limited information from Queensland Department of Primary Industries (QDPI) initial broad-scale surveys was the only seagrass data available for use in formulating the original Far Northern Section (FNS) zoning plan. Data from these surveys are now very dated and distribution patterns are likely to have changed since the time of surveys. In 1989, for example (four years after the original FNS zoning plan), approximately 1500 km<sup>2</sup> of predominantly deep water seagrass habitat were mapped between Lookout Point and Barrow Point (Lee Long et al. 1989). This area coincides with one of the largest populations of dugongs on the eastern Queensland coast (Marsh and Saalfeld 1989), and improved the evidence for a correlation between dugong population size and seagrass habitat area. It so far receives no formal protection from trawling activity. Further seagrass habitats have been recently discovered at 15-60 m depths, including trawl-fishing areas of the Far Northern, Cairns and Central Marine Park Sections (Coles et al. 1995). The seagrasses (*Halophila tricostata* and *H. decipiens*) in trawl areas appear to be mostly ephemeral (spring/ summer) species, and their ecological importance is not understood. Management of these areas needs further information on their importance to dugong and turtles, and to prawn fisheries.

Recent discoveries of large areas of deepwater seagrasses provide evidence for a more complex inter-reef soft-bottom habitat than previously assumed (Lee Long, McKenzie and Coles 1996). Additional *Halophila* species (cf. *H. capricorni*) plants have been found associated with reef habitats to 35 m depths in the Far Northern and Cairns Sections (QDPI, unpublished information) and in the Mackay/Capricorn Section (Larkum 1996). The importance of these small meadows on reef slopes is not yet clear, but not likely to be great.

There is very little information regarding seagrasses on reef platforms (of barrier and fringing reefs), but ad hoc surveys have found these habitats to be valuable as prawn nursery habitat and for dugong and turtle feeding. They may also play a part in reducing the sediment and nutrient impacts on the adjacent coral reef habitat. Formal surveys and studies will help to establish the value of these seagrasses to coral reef ecology.

Very few studies have examined impacts of sediments or nutrients on seagrasses of the GBR region. Preliminary studies indicate seagrasses in many coastal and reef localities are still nutrient limited and respond positively to additions of nutrients (Mellors and Udy, pers. comm.). The few monitoring programs at specific ports and bays (e.g. QDPI surveys), also indicate only low-to-moderate levels of human impacts (e.g. industry, mining and agricultural land runoff) on most coastal and deep water seagrasses, but these should be carefully examined as development (particularly urban and agricultural expansion) in catchments and on the coast proceeds. Port developments and coastal mariculture (e.g. prawn, fish and pearl shell) operations require planning to minimise adverse impacts on nearby seagrasses, particularly where important prawn nursery or dugong/turtle feeding areas are threatened. Individual operations and developments can appear insignificant in potential impact, but the total impact of incremental increases in pressure needs overall planning and management. Some localised planning programs are in place but need to be monitored for effectiveness.

The paucity of information on year-to-year or long term change in seagrass distribution and abundance for most of the GBR region has left zoning plans and management programs potentially incomplete. Seagrasses are the main food source for dugong, so information on long term change in seagrass abundance is paramount to refinement of management plans for dugong conservation. The influence of seagrass losses to annual prawn production is also poorly understood.

### **Management and responses**

Management plans, and responses to impacts, for GBR region seagrasses are designed primarily around the maintenance of seagrasses for commercial prawn fisheries and for dugong and turtle populations. The Great Barrier Reef Marine Park Authority (GBRMPA) and Port Authorities at Cairns, Mourilyan, Gladstone and other areas, support seagrass management measures which also consider the broader ecological importance of seagrasses in maintaining coastal water quality, sediment stability, and as the basis for other marine fisheries and food-webs.

#### Relevant existing zoning provisions and policies

In 1990, the Queensland Fish Management Authority (QFMA), in consultation with fishing industry, acknowledged the value of seagrasses to tiger and endeavour prawn stocks, and added to the seasonal prawn closures with a coastal strip closure system to protect juvenile prawns and their seagrass habitat. Almost all shallow, coastal seagrass habitat in the Far Northern and Cairns Sections north of Cape Tribulation, is thus currently in areas zoned as free from trawling activity, either within the QFMA policy of coastal strip closures or within GBRMPA zoning. An extension of this reasonably effective strip closure system to coastal seagrasses south of Cape Tribulation is also being considered for evaluation by Queensland trawl fisheries management.

Important dugong feeding areas inshore between the Starcke River and Barrow Point receive special protection through scientific and preservation zones. Deep water seagrasses in this area are important dugong feeding habitat (e.g. Lee Long et al. 1989), but are not afforded complete protection through zoning. There may be other unsurveyed areas of deep water seagrasses in the GBR important to dugongs and green sea turtles, but which receive no special protection. Seagrasses are listed as protected marine plants under Section 51 of the Queensland Fisheries Act 1994, to enable prosecutions for wilful and irresponsible damage to seagrass habitat.

Integrated catchment management programs are gaining wider acceptance across Queensland and should be encouraged from a seagrass conservation perspective, since seagrasses are at the



'downstream end' of catchment run-off. This may be one of the most reliable management measures for successful seagrass conservation. Point-source discharges are also being addressed and effluent controls are being slowly introduced at reef locations to help minimise impacts on seagrasses and corals. We strongly recommend greater community education, awareness and involvement in land-use practices which minimise downstream impacts on seagrasses. The incremental increases in all of the above impacts, associated with an expanding population, are the most serious threat to long term survival of seagrasses in the GBR region. Planning and management of these increasing pressures must be acknowledged by the whole community. This would help speed the implementation of programs to minimise and limit land run-off impacts.

#### Existing consultative mechanisms for seagrass research and management

Mechanisms or structures for directing research and management of seagrasses in the GBR region include the interchange of information at annual GBR and CRC researcher conferences, and at ad hoc workshops and meetings. The GBRMPA, the QFMA, the Queensland Department of Environment (QDoE), and the QDPI are the major organisations responsible for seagrass management in marine park and fisheries areas. The Cooperative Research Centre for Sustainable Development of the Great Barrier Reef (CRC Reef Research Centre) supports new initiatives in seagrass studies for obtaining information of direct use toward management of the GBR. Research on GBR region seagrasses is conducted primarily by the QDPI, the James Cook University's Tropical Environment Studies and Geography group and the University of Queensland's Marine Botany group. Requests from the above organisations, and initiatives from scientists, are currently the major avenue for generation of research and monitoring, and information gained on seagrass habitat distribution and ecology is distributed to these organisations and extended for public consumption.

The GBRMPA holds an archival GIS database using Arc-Info to store QDPI data on survey sites and seagrass distribution for research and management use. The QDPI's MapInfo GIS databases include full sets of the raw data generated from a series of fine- and broad-scale mapping and monitoring programs.

#### Research and monitoring in progress

Initial QDPI surveys conducted in the 1980s and 1990s provided information on seagrass distribution and abundance for large parts, but not all, of the GBR region. Collection of preliminary information on deep water and reef platform seagrass distributions is an immediate priority and ongoing surveys will eventually cover most of the GBR.

This information is now very dated and should be used with some caution in future zone planning. There is also a paucity of information on year-to-year change in seagrass distribution and abundance for most areas of the GBR. The CRC Reef Research Centre is now conducting studies on a) growth responses to natural and human impacts, and b) mechanisms of seagrass recovery after loss.

There is no formal strategy or program in place for monitoring seasonal or long term change in seagrass distribution and abundance in any part of the GBR. Measures of long term changes in seagrass distribution and abundance since the original seagrass surveys will require a large resource base. Studies of year-to-year change at specific coastal and deep water sites in the Cairns Section are currently supported by some port authorities and by the CRC Reef Research Centre.

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# The state of the algae of the Great Barrier Reef: what do we know?

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## Introduction

Lack of information about the distribution, abundance and ecological roles of the benthic algae constitutes a major gap in our knowledge of the state of the Great Barrier Reef. Benthic algae are major contributors to reef growth and geomorphology, as sediments and cements (Borowitzka 1983; Davies 1983; Marshall 1983; Smith 1983; Cribb 1990). They contribute major proportions of reef primary production and nitrogen fixation (Wiebe et al. 1975; Larkum 1983; Larkum et al. 1988; Hatcher 1988; 1990; Cribb 1990, Klumpp and McKinnon 1989, 1992). Reef degradation due to eutrophication or herbivore reduction commonly involves replacement of hard corals by macroalgae (seaweeds; Smith et al. 1981; Maragos et al. 1985; Kinsey 1988; LaPointe 1989; LaPointe and O'Connell 1989; Carpenter 1990; Hughes 1994). Possible reef degradation due to eutrophication is currently attracting considerable attention and funding in the Great Barrier Reef region (Bell 1992; Baldwin 1992; Brodie 1995), yet there is so little extant information on the distribution patterns of macroalgae on the Great Barrier Reef that even a major shift in these patterns would be difficult to identify.

We here review the state of knowledge of the large-scale distribution and abundance of benthic macroalgae on the Great Barrier Reef. We summarise first the available information and the work in progress on the patterns of distribution and abundance of algae on the Great Barrier Reef, then provide a brief review of studies addressing the causes of those patterns. Finally, we review the resources available to scientists and managers for identifying Great Barrier Reef algae. We use the term macroalgae to refer to species whose individuals are visible to the naked eye, thus including filamentous and turf species.

## State of knowledge of the benthic algae of the Great Barrier Reef

Despite the apparent acceptance of algae as crucial elements of reef communities, there is very little information published on the benthic algae of the Great Barrier Reef. Literature searches suggest that algae receive far less research effort than corals or fish, and this is reflected in the distribution of research funding from both scientific and management sources. Searching the Aquatic Sciences and Fisheries Abstracts for the years 1978 to June 1995, using the search terms 'Great Barrier Reef' and 'algae' or 'macroalgae', recovered 121 references. Of these, only about 80 were relevant to benthic algae and probably less than 40 had benthic algae as a focus of the work. In contrast, there were 248 references recovered using 'fish' and 'Great Barrier Reef' and 765 using 'coral' and 'Great Barrier Reef'. In particular, there is very little information on algal distributions, although the geographic distributions of corals, fish and other taxa have been documented for some time (Done 1982; Williams 1982; Williams and Hatcher 1983; Dinesen 1983; Russ 1984; Wilkinson and Cheshire 1988). Similarly, population and community level studies have attempted to explain distributions and roles of fish and corals (e.g. Done 1988, 1992; Williams 1991), but very few studies have addressed the causes of algal distributions (see below).

## **Distribution and abundance of macroalgae of the Great Barrier Reef**

The Great Barrier Reef region has a diverse macroalgal flora, reflecting the exceptional latitudinal extent, the diversity of reef and substrate types and water conditions, and the consequent habitat diversity. Endemism is low, as most Great Barrier Reef species are relatively widespread throughout the Indo-West Pacific biogeographical region. The uniqueness of the algal flora stems from the extent of the Great Barrier Reef as a single, relatively contiguous system of reefs, in both geographic/ecological and management terms. We estimate there are 400-500 species of macroalgae on the Great Barrier Reef, although an accurate estimate will require considerably more survey and taxonomic work. Cribb (1973) reported 230 species from the Capricorn-Bunker group, based on relatively intensive, but exclusively intertidal, sampling over several years. On this basis he extrapolated a figure of 330 species for the Great Barrier Reef as a whole, but this figure apparently excluded both mainland and subtidal areas. Womersley (1990) estimated that 400 species occurred in Queensland, and Lewis (1984, 1985, 1987) listed almost 800 taxa of benthic macroalgae (excluding blue-green algae) for all of northern Australia, based on synthesis of published records. The flora is dominated by red algae (Rhodophyta), with about twice the number of brown (Phaeophyta) or green (Chlorophyta) algal species. However, the taxonomy of most groups is so poorly studied that these figures remain very approximate.

Do we have the baseline information to recognise an unnatural bloom of benthic algae on the Great Barrier Reef? Almost certainly not, given that, to the authors' knowledge, there has been no large-scale survey of benthic algal distributions for the Great Barrier Reef. Table 1 summarises the published data on floristic composition for Great Barrier Reef algae. There are only a few accounts with any degree of taxonomic resolution, and those are largely restricted to a few, isolated islands (often research stations), to the intertidal or shallow subtidal (several workers did not SCUBA dive or even snorkel). Cribb's (1990) review of the algal vegetation of the Great Barrier Reef is based on work in the Capricorn-Bunker group, and is restricted to small-scale (within reef) intertidal zonation. Morrissey (1980) provides a detailed description of zonation within a single fringing reef at Magnetic Island, but again the survey is restricted to intertidal zones. Few of these studies provide data on seasonality or longer term changes. I. R. Price is currently collaborating with Dr J. Phillips (University of Queensland and Queensland Herbarium) to integrate these various taxonomic records into up-to-date check-lists of Queensland macroalgae. A report on the Phaeophyta (brown algae) is nearly complete (Phillips and Price in prep.).

There are a number of large scale surveys and monitoring studies (e.g. AIMS 1985-6; AIMS 1986-7; Oliver et al. 1995; Kaly et al. 1994) which quantify abundance of macroalgae on reefs as part of general benthos, but they have little taxonomic and seasonal resolution (as dictated by the scale and focus of the surveys). These surveys generally assess benthic algal cover in broad categories, such as 'Macroalgae', 'Turfs' or '(Crustose) Coralline Algae'. *Sargassum* or *Halimeda* may be distinguished from 'Other Macroalgae'. In contrast, most of these surveys assess hard corals and often fish with considerable taxonomic resolution.

These large scale surveys (AIMS 1985-6; AIMS 1986-7; Oliver et al. 1995) probably provide the best information presently available for detecting any gross changes in benthic algae (such as massive blooms), since they cover the length and breadth of the reef. However, they are obviously very limited as algal surveys. Many focus on coral dominated zones, such as reef fronts and crests, in which algae are rare or cryptic, and ignore back reefs and reef flats, zones which currently often have large areas dominated by algae (unpubl. data). Lack of taxonomic resolution severely limits the resolution of any comparisons between reefs or sampling dates. 'Other Macroalgae' can often include brown algae or taxa indicative of poor reef state, or species of red and green algae which are common on healthy reefs. Even lumping apparently

similar groups may prevent detection of important differences or changes. For example, most species of *Sargassum* are restricted to inshore reefs, whereas species of the related and morphologically similar *Turbinaria* are currently widespread on offshore reef flats (unpubl. data). Recording the two genera together as 'Macroalgae', rather than separately, could mean that surveys would fail to detect an invasion of offshore reefs by *Sargassum*. Similarly, lack of seasonal information could lead to false rejection or false detection of shifts in algal abundance (e.g. Kaly et al. 1994), since both inshore and offshore reef zones have seasonally highly variable abundance of several algal communities (see below).

**Table 1.** Published information on the floristic composition and distribution of macroalgae in the Great Barrier Reef (GBR) region

Geographic location	Source	Taxonomic data	Ecological data
Thursday I. area	Cribb 1961	annotated species list; intertidal only	
Lizard I.	Price et al. 1976	annotated species list; intertidal and subtidal	
Low Isles	Stephenson et al. 1931	species lists; intertidal only	descriptive; intertidal only
Central GBR	Drew 1983	species list; intertidal and subtidal	<i>Halimeda</i> ecology; intertidal and subtidal
Central GBR; shelf reefs	Scott and Russ 1987	species list; subtidal	
Central GBR	Price and Scott 1992	turf algal monograph (Rhodophyta); intertidal and subtidal	
Central GBR; rocky shores, fringing reef, mid-shelf reef	Price 1989	species records; intertidal and subtidal	Seaweed phenology; intertidal and subtidal
Townsville rocky shores	Ngan and Price 1979  Ngan and Price 1980	annotated species list; intertidal only	
Magnetic I., fringing reefs	Morrissey 1980  Vuki and Price 1994 Martin-Smith 1993	species list; intertidal only	distribution; intertidal only zonation; intertidal only <i>Sargassum</i> phenology; intertidal only <i>Sargassum</i> phenology; subtidal
Heron I. reef flat	Cribb 1966	species list; intertidal only	distribution; intertidal only
One Tree I.	Borowitzka et al. 1978	species list	colonisation, succession, productivity, seasonality
Capricorn Section	Cribb 1984	species list; intertidal only	
Swains	Saenger 1979	annotated species list; subtidal	

In order to redress this lack of baseline information on algal distributions, we are currently undertaking a series of large scale surveys of algal distributions and abundance. Surveys have been made at nearly 300 sites at over 55 reefs in the Central and Cairns Sections (38 reefs between Cairns and Lizard Island). In the Central Section, 15 reefs in two cross-shelf transects north of Townsville have now been surveyed in three seasons (June, October/November and March), estimating abundance of all macroalgal taxa for reef slope, crest and flat at three sites

per reef. The surveys are hampered by the limited background taxonomic work, which necessitated compromises between taxonomic resolution and coverage.

The results have not yet been analysed in detail, but several important points have emerged. It appears that simple patterns in algal distribution will be difficult to extract from the overall complexity. Cross-shelf differences are dramatic quantitatively but not simple, clearcut or easy to define. Inshore reefs usually have abundant brown algae (Phaeophyta), especially fucaleans such as *Sargassum*, whereas several groups of red algae (Rhodophyta) are more abundant offshore. The patterns are confounded by within-reef zonation, latitudinal differences and occasional distributional outliers (such as individuals of *Sargassum* or *Padina* on outer reef fronts). The fucalean brown alga *Turbinaria* is often common on mid- and outer shelf reef flats. Dominance by non-turf forming macroalgae is seasonally common on offshore reef flats. Even outer shelf reef fronts commonly have a surprisingly large number and abundance of erect seaweed species, especially red algae (Rhodophyta). These are often quite cryptic, occurring in underhangs and caves and at the base of reef slopes.

In contrast to dominant benthic fauna such as corals, many reef algae are strongly seasonal in abundance, and sampling at different times of the year is essential. Not only is the abundant *Sargassum* of inshore reefs highly seasonal in abundance, but it appears that on mid- and outer shelf reef flats, there is a highly seasonal abundance of blue-green algae (Cyanophyta), red algae such as *Spyridia* sp., *Laurencia* spp., *Galaxaura* spp. and *Liagora* spp., and green algae (Chlorophyta) such as *Boodlea*. As indicated earlier, this seasonality has major implications for the ability of surveys and monitoring programs to detect changes in the benthos. This is important not just in large scale surveys, but particularly for environmental impact assessments (e.g. Kaly et al. 1994). In combination with the high taxonomic and geographic/spatial diversity which also complicate assessments of other reef biota, the seasonal variations in the algae make comparisons between sites or sampling dates especially complex.

Our surveys can only provide preliminary rather than definitive descriptions, given the limitations of spatial and seasonal coverage and field identifications. Indeed, their most valuable outcome may be a solid basis for optimising taxonomic resolution in general benthic surveys.

Other current work includes the recent large scale surveys of vegetation in deep water, soft-bottom inter-reefal areas, using towed video cameras (R. Coles and W. Lee Long, Queensland Department of Primary Industries, Cairns, pers. comm.). Although these surveys show that rhizoid-anchored macroalgae are very abundant in these areas, the surveys focus on seagrasses and lack the resources to quantify macroalgae with any degree of taxonomic resolution (Coles and Lee Long pers. comm.).

### **Causes of macroalgal distribution on the Great Barrier Reef**

There is also a lack of published information on the processes which cause the patterns of algal distribution on the Great Barrier Reef, at all scales, although there are a number of studies currently underway. Attention has focused on possible effects of water quality (primarily sediments and the nutrients nitrogen and phosphorus) and herbivory, since work in other areas has demonstrated that increases in sediment or nutrient inputs or reductions in herbivory can lead to shifts from coral to algal dominance (see Introduction, more detailed review by McCook in press). On the Great Barrier Reef, recruitment, productivity and abundance of algal turfs (as epilithic algal community) have been shown to depend on herbivory (Hatcher and Larkum 1983; Sammarco 1983; Wilkinson and Sammarco, 1983; Scott and Russ 1987; Klumpp and McKinnon 1989, 1992) and to some degree on nutrients (Hatcher and Larkum 1983; Russ unpubl. data). Of these studies, only Russ' work addresses the causes of large-scale

distributions, suggesting roles for both herbivory (Scott and Russ 1987) and water quality (unpubl. data) in the cross-shelf differences in turf algae. Other work has focussed on chemical mediation of competition (de Nys et al. 1991) and herbivory (Steinberg et al. 1991).

More recently, several studies have suggested that herbivory has a stronger direct impact on the distribution of larger macroalgae than does water quality. Transplant experiments have shown that fish herbivory significantly reduces the survival of *Sargassum* both on offshore reefs (McCook in press) and on inshore reef slopes (McCook in review), whereas differences in water quality had no direct effect on survival. Manipulation of sediments on a fringing reef showed that *Sargassum* was directly inhibited by sediments, despite being generally more abundant on reefs with greater sediment loads (Umar et al. in review). Similarly, preliminary experiments in large aquaria suggested that *Sargassum* growth and recruitment were directly inhibited by long-term, high level nutrient enhancement (McCook and Klumpp unpubl. data). Culture experiments show *Sargassum* growth in isolation to be stimulated by moderate nutrient enhancement but inhibited at higher levels (B. Schaffelke, Australian Institute of Marine Science (AIMS) unpubl. data). It is important to note, however, that these results form a very incomplete picture. Water quality is very likely to have major indirect effects on algal distributions, perhaps partly by affecting fish abundances.

Nutrient effects on reef biota have also been recently examined in the collaborative 'ENCORE' experiment, which used a factorial combination of nitrogen and phosphorus supplements in small microatolls at One Tree Island (Steven and Larkum 1993; Larkum and Steven 1994). Interestingly, preliminary results suggest that, as with *Sargassum*, algal turfs did not show strong direct effects of enhanced nutrient input (Steven pers. comm.).

#### **Reference resources for the identification of Great Barrier Reef macroalgae**

Both descriptive and experimental ecology are severely hampered by the lack of taxonomic resources. There is a need both for expert taxonomic floras, and for identification guides suited for field researchers. Currently available reference materials are very limited in scope (Table 2), and these in turn are severely limited by the lack of basic taxonomic accounts and research. Even widely studied and abundant taxa, such as *Sargassum*, have not been yet resolved taxonomically (work on *Sargassum* is underway by K. Edyvane, Sth. Aust. Research and Development Institute; I. R. Price has recently completed a taxonomic revision of *Caulerpa*).

A small proportion of the species included in *The marine benthic flora of southern Australia* (Womersley 1984, 1987, 1994) also occur in Great Barrier Reef waters.

There are only two taxonomic monographs relevant to Great Barrier Reef macroalgae, both restricted in coverage (Table 2). Cribb (1983) covers red algae only, the southern Great Barrier Reef only and is largely limited to intertidal species. Price and Scott (1992) is restricted to red turf algae. Thus the brown, green and blue-green algae, non-turfing species and the central and northern Great Barrier Reef still lack comprehensive monographs. The various field guides are also very limited in scope, and the descriptions are often insufficient for unequivocal identifications. One reference includes a photograph labelled 'Unidentified algae, probably a filamentous blue-green', a description which is of limited use even to casual natural historians.

Given the paucity of reference material, two cautionary notes need to be made about the degree of taxonomic resolution used in studies of reef algae. Firstly, researchers should avoid the trap of identifying algae to species (or higher) level, without an adequate basis for that degree of taxonomic resolution. To illustrate this point, several of the guides in Table 2 describe species with no indication of similar species, particularly congeners (e.g. *Padina*, *Sargassum*, crustose corallines). We have seen several accounts which identify *Padina australis* to species



level, apparently based on field identification. It is not possible to identify *Padina* to species without microscopic examination of fertile material. Secondly, the lack of taxonomic resources suggests that the identities of species in published studies should be treated with caution, if that identity affects the interpretation of the results.

**Table 2.** Sources for identifying species of macroalgae in the Great Barrier Reef region

Source	Coverage	Format
Cribb 1983	southern Great Barrier Reef (mainly Capricorn-Bunker group) <b>intertidal only</b>	detailed, comprehensive, illustrated taxonomic monograph of red seaweeds (Rhodophyta only)
Price and Scott 1992	entire Great Barrier Reef region Intertidal and subtidal	detailed, comprehensive, illustrated taxonomic monograph of turf algae (Rhodophyta only)
Cribb and Cribb 1985 <b>out of print</b>	Great Barrier Reef region <b>intertidal only</b>	68 species, coloured photographs and brief descriptions; selected common and distinctive species of Cyanophyta, Rhodophyta, Phaeophyta and Chlorophyta
Cribb 1993	Great Barrier Reef <b>intertidal only</b>	line diagrams and brief notes; common species of Rhodophyta, Phaeophyta and Chlorophyta
Saenger 1977 <b>out of print</b>	Great Barrier Reef intertidal and subtidal	line diagrams and brief notes; common species of Rhodophyta, Phaeophyta and Chlorophyta
Allen and Steene 1994	Indo-Pacific reefs intertidal and subtidal	Field guide with coloured photographs only, some misleading or unclear; 39 common taxa of Rhodophyta, Phaeophyta, Chlorophyta and Cyanophyta
Fuhrer et al. 1981	Australia <b>intertidal only</b>	Coloured photographs and brief notes: about 15 reef Rhodophyta, Phaeophyta and Chlorophyta included
Lewis 1984, 1985, 1987	Northern Australia	Comprehensive checklist and bibliography only of taxa recorded for northern Australia. No descriptions include

We hope to address the lack of taxonomic references with two specific contributions: a reliable and easy-to-use 'field guide' to the more common and distinctive seaweeds of the Great Barrier Reef; and completion of the Turf Algal Flora of the Great Barrier Reef (Part II: Phaeophyta and Chlorophyta, to complement Price and Scott's Part I: Rhodophyta). The field guide could be produced as part of a computer-based identification system. Commitment to such algal reference works is essential if reef studies are to resolve the ecological roles of this major component of reef benthos and provide an adequate foundation for sustainable management of the Great Barrier Reef.

### Summary

The ecology of macroalgae warrants particular attention from researchers concerned with the sustainable management of the Great Barrier Reef, especially given that water quality is a major concern on the Great Barrier Reef, and that benthic algal blooms are a common consequence of eutrophication. In order to detect changes in reef biota, there is a need for (i) improved baseline descriptions of macroalgal species distributions and abundances; (ii) improved knowledge of the processes which lead to those distributions etc; and (iii) improved taxonomic descriptions and identification resources as necessary tools for obtaining better information about algal distributions.

## Acknowledgments

This is AIMS publication number 864, produced with the support of the Cooperative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef.

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# The status of reef fishes on the Great Barrier Reef

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## Abstract

This paper synthesises information from the Australian Institute of Marine Science (AIMS) Long Term Monitoring Project (LTMP), which involves making annual visits to about 50 reefs from north of Cooktown to the Capricorn-Bunker Group. Visual censuses of fish assemblages on reef fronts show clear cross-shelf differences at the family level and some north-south differences. Taxa showing cross-shelf differences include lutjanids and siganids being more common inshore and acanthurids, scarids and zancids increasing in number offshore. Acanthurids, scarids, lutjanids and zancids decline in abundance from north to south. As a family, pomacentrids show different cross-shelf distribution patterns at different latitudes. This is also true of most of the constituent genera. Building on this, inshore, and offshore fish assemblages were identified, as well as a group with a general distribution. The existence of these groups should be reflected in conservation initiatives.

Reef fish assemblages have been shown to recover from major habitat losses due to storms or *Acanthaster planci* outbreaks, presumably through larval recruitment from unaffected areas. Recent research suggests that larval dispersal is more localised than has previously been accepted.

## Introduction

Coral reef fishes must rank among the most studied of animal groups inhabiting coral reefs. A significant proportion of all studies are from the Great Barrier Reef (GBR), but few of them address the status of reef fish populations on the GBR in any direct way. Fish assemblages certainly constitute some of the 'superlative natural phenomena' of the region (UNESCO 1972). The status of populations of most reef fishes is unknown, so much of what follows is based on bio-geography, natural history and logic. Among the great diversity of fishes on the GBR are a few species that are subject to human exploitation in the form of commercial and recreational fishing (Ayling and Ayling 1994; Williams and Russ 1994; Russ et al. 1995; papers by Ayling, by Elmer and by Higgs in this volume). Another set of species are targeted by aquarium collectors (Butler 1991). We do not deal with these specific impacts in this review, rather we aim to:

1. Give a broad picture of the distribution of fish taxa across most of the GBR;
2. Identify coherent groups of species that tend to co-occur in the region;
3. Discuss some processes that will affect particular taxa at certain times.

## Fish communities of the Great Barrier Reef

No authoritative estimate for the number of species that occur in the GBR region is available. We are indebted to Drs Jeff Leis and Doug Hoese of the Australian Museum, whose inspection of the Australian catalogue suggests that 1500-2000 described species is a realistic estimate, depending on the definition of the GBR province and whether species trawled from habitats between reefs should be included.

## **A broad picture of the geographic patterns of distributions of fish across the Great Barrier Reef**

Williams (1991) has reviewed knowledge of the patterns in the distribution of fishes on various scales from the GBR. There are published accounts of the distribution of a range of species on reef fronts across the Central GBR (Williams 1982; Williams and Hatcher 1983). The most comprehensive study is Williams' own still largely unpublished work involving visual surveys of many species on the fronts of reefs across the GBR lagoon at eight latitudes (Williams 1983, 1986, 1991). The information on distributions provided here comes from the AIMS LTMP.

This program currently involves annual visual censuses of an extensive but prescribed list of species (see Tables 1 and 2) at fixed sites in one reefal habitat: outer slopes with a NE aspect, of approximately 50 reefs. The program and data from a sub-set of these reefs are described by Oliver et al. (1995). Sample reefs were chosen to represent one of three cross-shelf positions (inner, mid- and outer shelf) at six latitudes (sectors) from 14°S to the southern end of the reef. These sectors do not cover the whole GBR south of Lizard Island but do allow examination of latitudinal differences. The six sectors are: Cooktown-Lizard (from 14°S to Cooktown), Cairns (from Port Douglas to just south of Cairns), Townsville (from Hinchinbrook Island to Cape Bowling Green), Whitsundays (from Gloucester Island to Mackay), the Swain Reefs and the Capricorn-Bunker Group. Where possible, three reefs have been chosen from each combination of shelf position and latitude. Larger, more mobile, fish are counted using transects 5 m wide while pomacentrids are counted on 1 m wide transects. Full details of sampling methods are given in Halford and Thompson (1994). The data presented here were collected over the summer 1994-95.

### Geographic patterns of species richness

There is little comparative information on geographic variation in species richness (the number of species present) for the GBR except for the work of Williams and Hatcher (1983) and Russ (1984b) from reefs across the shelf near Townsville. Data from the AIMS LTMP provide some indications at least of relative species richness though these need to be interpreted carefully because only a prescribed list of species is sampled from one reef habitat. For larger more mobile species (Table 1) the pattern of species richness across the shelf varies among sectors (significant statistical interaction). Though species richness is lower at inshore locations in all sectors, the interaction indicates that the relative difference varies (Fig. 1). The highest values occur on northern mid-shelf and outer shelf reefs. The Capricorn-Bunker reefs have significantly lower species richness than outer shelf reefs in the other sectors. This is certainly due at least in part to a dramatic drop in coral cover over much of the region in the late 1980s possibly due to sub-cyclonic storm activity (Doherty et al. in press). It is not clear whether there is an underlying regional effect as well. Pomacentrids show different cross-shelf patterns of richness in different sectors (Fig. 1), rather than just differences in degree of change across the shelf. The variation with latitude is less consistent too, though once again the Capricorn-Bunker reefs have significantly lower species richness than outer shelf reefs in the other sectors. Both groups were only sampled on NE outer slopes of reefs; other reef zones may show different patterns. Russ (1984b) found that the ranking of zones within reefs in terms of species richness of three families of herbivorous fishes was not consistent between mid-shelf and outer shelf reefs. Williams and Hatcher (1983) give species richness for a number of families that were obtained by explosive sampling outer slopes of reefs in the central GBR. Their figures for Pomacentridae show a similar pattern for the region: 17 spp. on inner shelf reefs, 43 spp. on mid-shelf reefs and 30 spp. on outer shelf reefs. For all other species (obtained by subtraction) the numbers were 93, 158 and 133 spp. respectively.



**Table 1.** Numbers of species recorded in each family counted in 50 x 5 m transects. Note that two groups of species are treated as single categories

Family	No. of Species	Notes
Acanthuridae	24	Incl. <i>Ctenochaetus</i> spp. grouped
Chaetodontidae	34	
Labridae	9	
Lethrinidae	13	
Lutjanidae	18	Incl. <i>Macolor</i> spp. grouped
Scaridae	25	
Serranidae	7	
Siganidae	9	
Zanclidae	1	
<b>Sum</b>	<b>140</b>	

**Table 2.** Number of species in each genus of Pomacentrids counted in 50 x 1 m transects

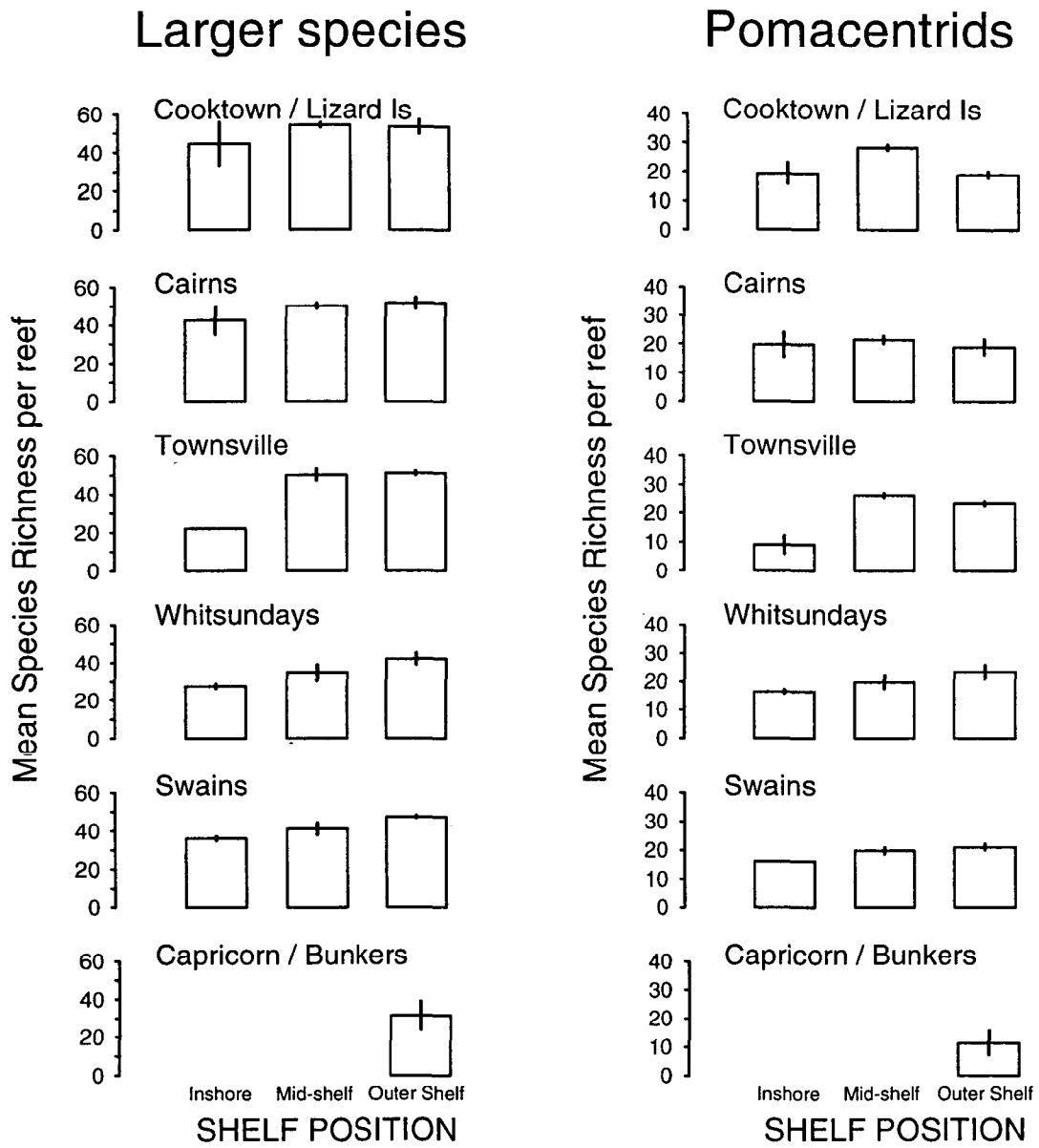
Genus	No. of Species
<i>Acanthochromis</i>	1
<i>Amblyglyphidodon</i>	3
<i>Amphiprion</i>	6
<i>Chromis</i>	17
<i>Chrysiptera</i>	6
<i>Dascyllus</i>	4
<i>Dischistodus</i>	4
<i>Neoglyphidodon</i>	3
<i>Neopomacentrus</i>	3
<i>Plectroglyphidodon</i>	3
<i>Pomacentrus</i>	17
<i>Pomachromis</i>	1
<i>Premnas</i>	1
<i>Stegastes</i>	3
<i>Hemiglyphidodon</i>	1
<b>Sum</b>	<b>73</b>

#### Geographic patterns of density of some taxa

The data in the previous section concerned the presence or absence of species on the sample reefs. This section considers patterns in density of taxa across the GBR. For analysis, the counts have been summed over 250 m of transect, giving an estimate of density from three sites in the one area of each reef. This seems an appropriate sampling scale for mobile organisms such as fishes. For initial presentation, larger species have been grouped to family (Fig. 2).

Pomacentrids were counted on 1 m transects, they are included as a family in Fig. 2 and displayed by genus in Fig. 3. Two analyses of variance, each consisting of a series of contrasts, were used to examine whether there is systematic geographic variation in density of the groups that can be attributed to latitude or cross-shelf position. The geographic distribution of reefs along the GBR complicates such analyses: in the four northern sectors there are generally identifiable inner, mid- and outer shelf reefs, subject to progressively less coastal and more oceanic influences respectively. The Swains sector reefs can be expected to show a different pattern, for while the oceanic influence decreases from outer shelf Swain reefs to inner ones,

coastal influences will be much less on inner Swain reefs than for instance, inner shelf reefs of the Whitsunday sector. Finally, all the reefs in the Capricorn-Bunker sector are outer shelf reefs, leading to a separate analysis involving only outer shelf reefs from each sector.



**Figure 1.** Mean species richness (number of species present) per reef displayed by Sector and shelf position for larger species and for pomacentrids. Error bars are standard errors. Note that these figures are based on a prescribed list of species on NE outer slopes. There are no inner or mid-shelf sample reefs in the Capricorn/Bunker sector.

The results of the analyses are summarised in Tables 3 and 4. The first point to be made is that there are relatively few instances where a significant amount of variation could be attributed to some geographic factor. Since the analyses involve a large number of statistical tests 5% of which will show significance simply through variation among reefs which is unrelated to geography, any apparent patterns must be treated sceptically unless they have been confirmed by sampling other reefs in a similar design. Looking at the level of families, only lethrins showed significantly different cross-shelf patterns at different latitudes. Only pomacentrids varied in density among sectors when all reefs in sectors other than the Capricorn-Bunkers were considered. When only outer shelf reefs were considered and the Capricorn-Bunkers were included, six of the ten families occurred at different densities at different latitudes. Since the pomacentrids as a family showed different cross-shelf patterns at different latitudes, it is not surprising that seven of the 12 pomacentrid genera did so as well. Of the remaining five genera, one showed variation in density both among latitudes and across the shelf. Another, *Dischistodus*, occurred at significantly lower densities on outer shelf reefs. When only outer shelf reefs were considered, nine of the 12 genera varied in density among latitudes.

There are certainly differences in the geographic distributions of individual species within taxa, for instance *Chaetodon aureofasciatus* is the most abundant butterflyfish on inshore reefs in northern and central regions of the GBR (Anderson et al. 1981, Williams 1982), but does not occur on outer shelf reefs, even though chaetodontids as a group show no clear cross-shelf pattern (Fig. 2). This is also shown among the pomacentrids by Williams (1982) who gives data for ten species of *Chromis* whose distributions vary from inshore to mid-shelf (*C. nitida*) to *C. chrysurus*, *C. iomelas* and *C. amboinensis* that were only recorded on exposed reefs.

The general conclusions are that cross-shelf patterns in abundance and probably species richness are more clear than any variation among latitudes. Previous workers have also found strong cross-shelf variation. Examining herbivorous fishes on outer slopes of reefs in the central GBR near Townsville, Russ (1984a) found that acanthurids showed increasing abundance with distance offshore, though Williams (1982) found that this was not the case for all species. Scarids were uncommon inshore compared with mid-shelf and outer shelf reefs (Russ 1984a) while siganids showed little change across the shelf. In a preliminary analysis, Williams (1983) demonstrated that north-south variability was less than cross-shelf variability in reef fish assemblages on five cross-shelf transects.

Are there distinct communities?

Multivariate ordinations provide a way to summarise geographic patterns in communities by integrating the distributions of numerous taxa. Principal components ordinations (using presence/absence of species having more than two individuals on at least three reefs) were used. Groups of reefs that support similar assemblages when the distributions of many species are considered simultaneously should map close together. As expected from the univariate analyses, there are indications of relatively strong cross-shelf patterns (inner, mid- and outer shelf reefs form groups with limited overlap) and weaker latitudinal ones (Fig. 4).

These analyses have followed the traditional approach of looking for cross-shelf and latitudinal patterns. In Figs. 2 and 3, several taxa show consistent cross shelf patterns, but while there are differences among sectors, few taxa show consistent latitudinal trends that might, for instance, indicate that climatic variables are the driving force. Cross-shelf position is also the sum of a number of factors balancing coastal and oceanic influences. A cursory look at a map indicates that the breadth of the continental shelf, which should be inversely related to terrestrial influence, and the integrity of the barrier (that might exclude oceanic influences) do not vary in a simple fashion along the length of the GBR.

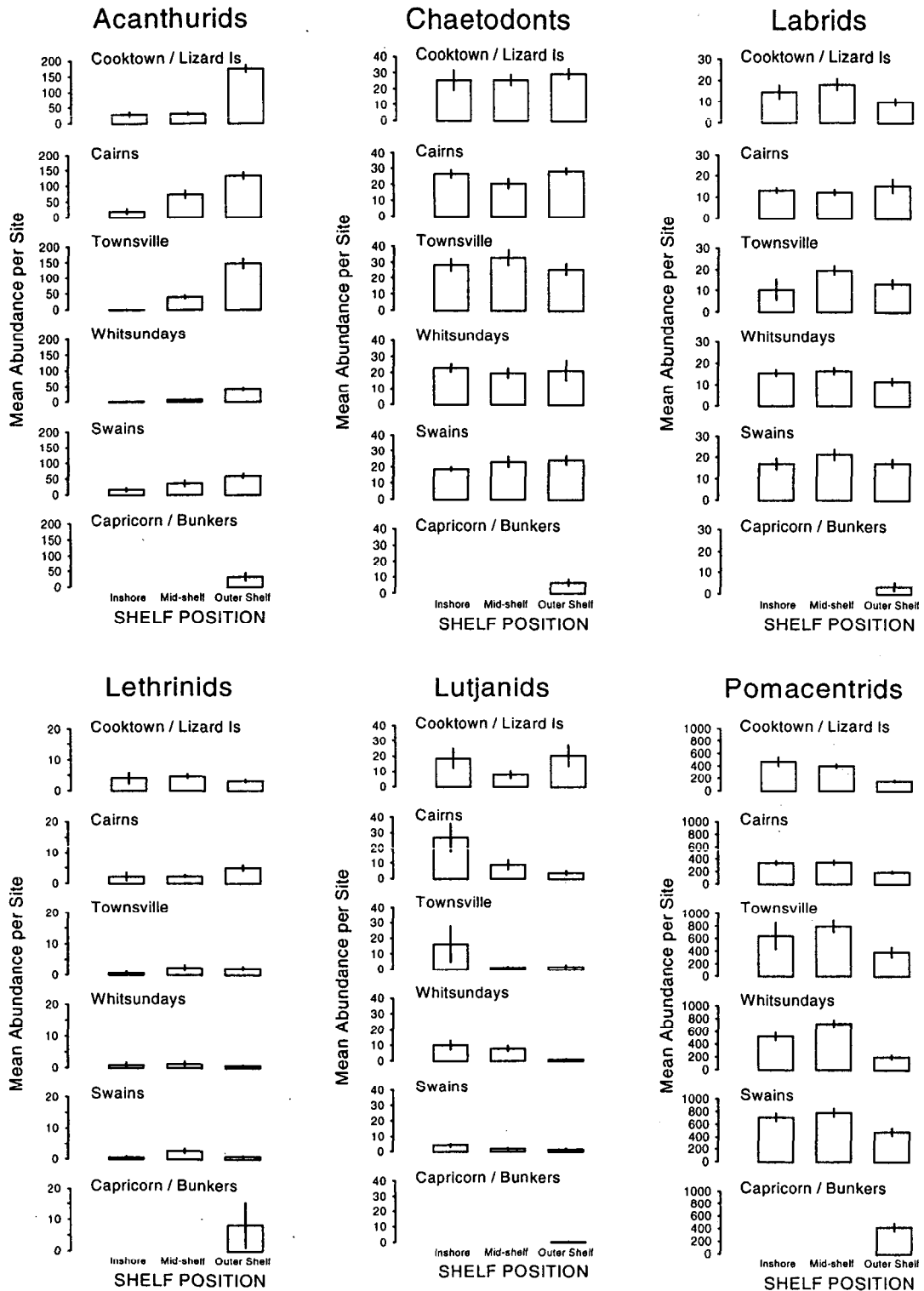
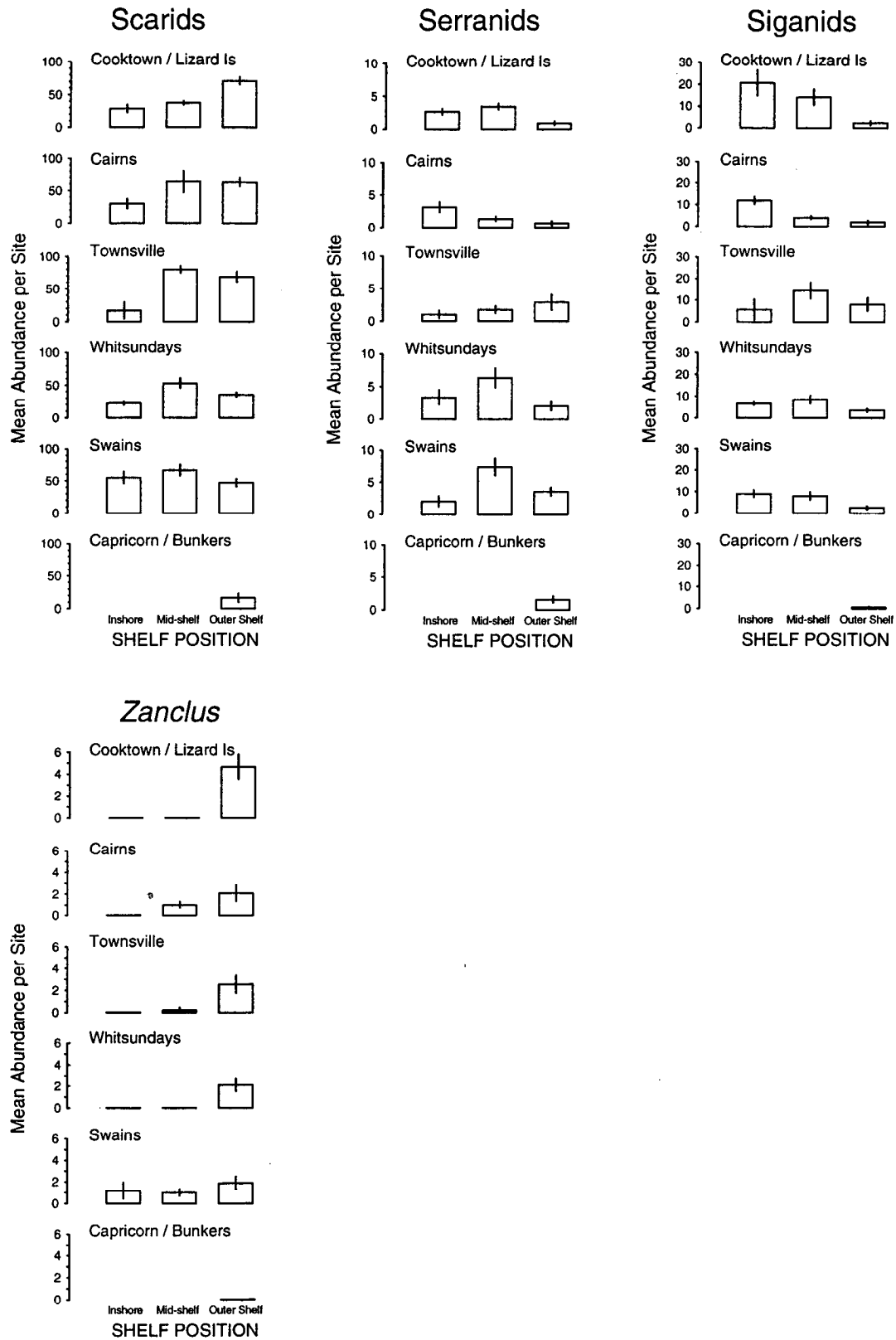


Figure 2. Mean number of individuals per site for nine families of larger fish counted on 5 m wide transects and pomacentrids counted on 1 m wide transects. Error bars are S.E.

Figure 2 cont.



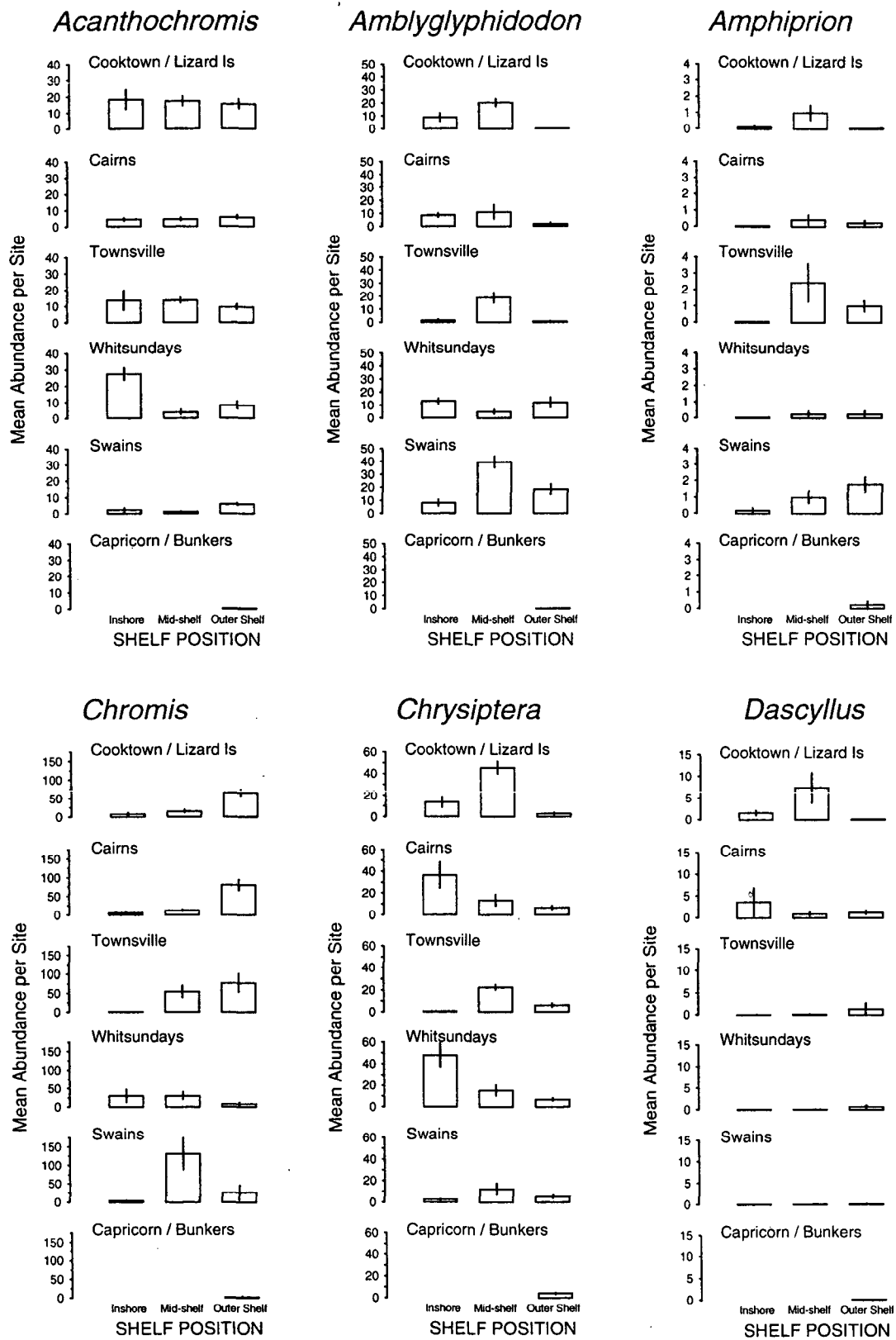
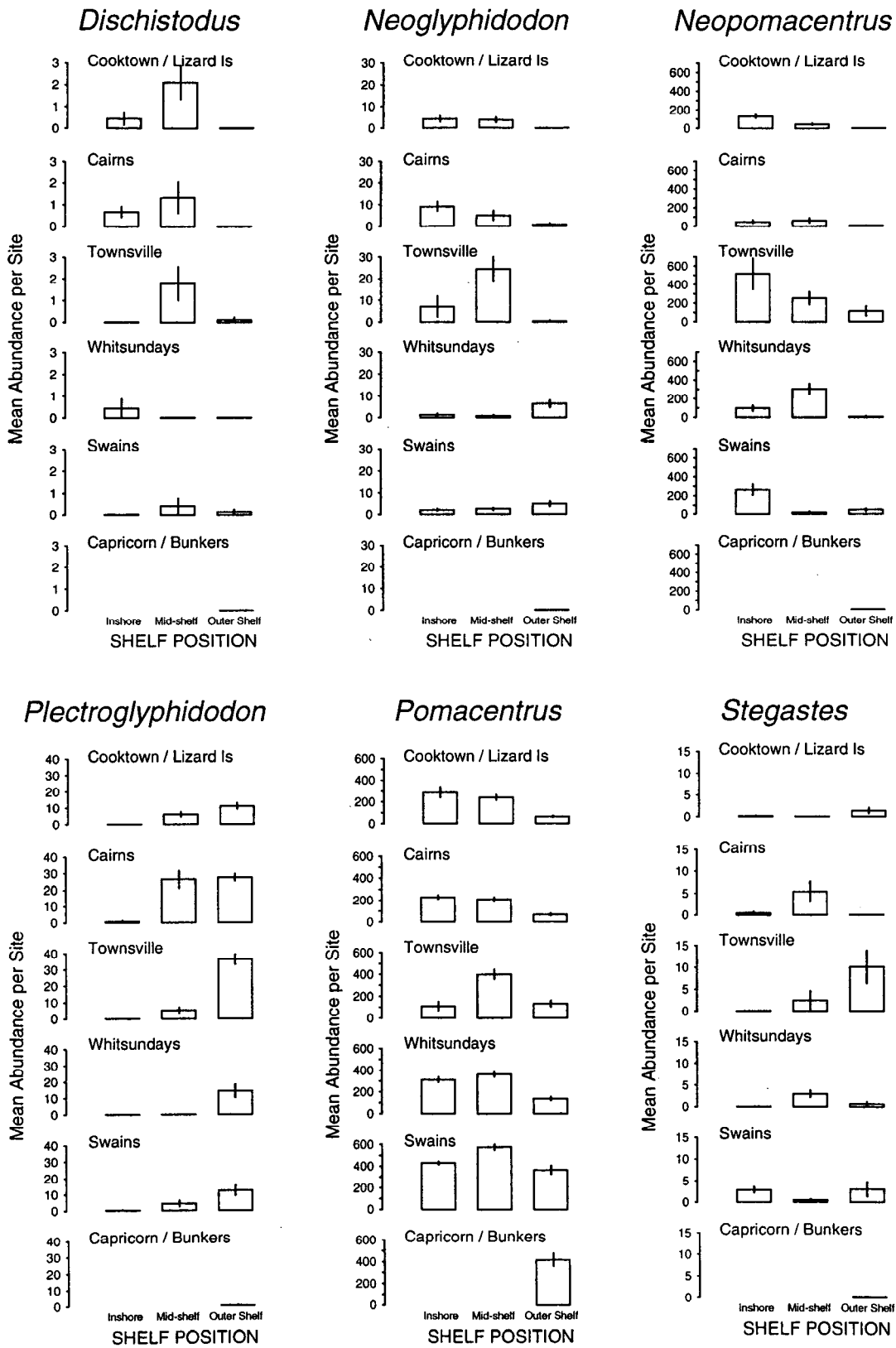


Figure 3. Mean number of individuals per site for 12 genera of pomacentrids counted on 1 m wide transects. Error bars are S.E.

Figure 3 cont.



**Table 3.** Summary of geographic statistically significant patterns in abundance for fishes grouped by family

<b>Acanthurids</b>	Higher overall abundance in northern sectors Consistent cross-shelf patterns with lower abundances inshore and higher abundances on outershelf reefs Abundances on outer reefs vary among four northern sectors
<b>Chaetodontids</b>	No clear patterns in overall abundance in five northern sectors or across shelf Abundances on outer reefs similar in all sectors except the Capricorn/Bunkers where abundances are lower
<b>Labrids</b>	No clear patterns in overall abundance in five northern sectors or across shelf Abundances on outer reefs similar in all sectors except the Capricorn/Bunkers where abundances are lower
<b>Lethrinids</b>	Relative abundance across shelf varies among four northern sectors No distinct variation in abundance on outer reefs among sectors (but very variable)
<b>Lutjanids</b>	No clear differences in overall abundance among five northern sectors Higher overall abundances on inner shelf reefs Abundances on outer reefs vary among four northern sectors
<b>Pomacentrids</b>	Overall abundance varies among sectors, high in Townsville and Whitsundays Higher overall abundance on mid-shelf reefs in five northern sectors Abundances on outer reefs vary among sectors
<b>Scarids</b>	No clear patterns in overall abundance among the five northern sectors Clear cross-shelf patterns in abundance with lower abundances on inner reefs Abundances on outer reefs are generally higher in the north
<b>Serranids</b>	No clear patterns in overall abundance with shelf position or sector No clear patterns in abundance on outer reefs
<b>Siganids</b>	No clear differences in overall abundance among the five northern sectors Higher abundances on inner and midshelf reefs generally No clear patterns in abundance on outer reefs
<b>Zanclids</b>	No clear differences in overall abundance among five northern sectors Higher abundances on outer reefs generally No clear differences in abundance on outer reefs of five northern sectors, but absent from Capricorn/Bunkers

To refine the sector by shelf position categorisation to reflect the underlying process more closely, each sample reef was categorised by two other characteristics:

1. Exposure: a three level classification relating exposure to wave energy.
  - Low: no swell and moderate chop.
  - Moderate: slight influence of swell and moderate to heavy chop.
  - High: exposed to full swell.
2. Slope: four level factor relating to the estimated average angle of the reef slope.
  - Broken: slope has varied structure with large areas of unconsolidated substrate.
  - Flat: slope generally consolidated with a gradient of less than 20 degrees.
  - Moderate: generally consolidated with a gradient of between 21 and 60 degrees.



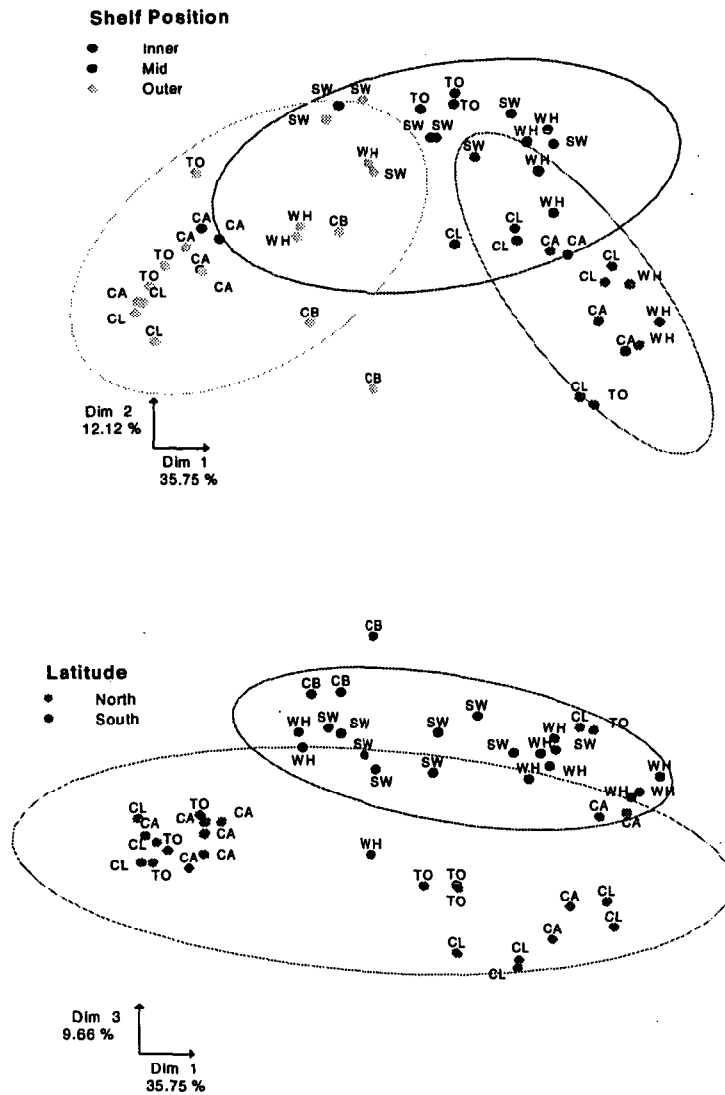
- Steep: generally consolidated with a gradient in excess of 60 degrees.

When the same ordinations are replotted with the reefs categorised by exposure (Fig. 5), the separation of categories is more distinct than those by shelf position (Fig. 4). This implies that exposure to wave energy or its correlate, oceanic water quality, is a major forcing factor for cross shelf distributions. Categorisation by slope did not produce clear groupings.

**Table 4.** Summary of statistically significant geographic patterns in abundance for pomacentrid fishes grouped by genus

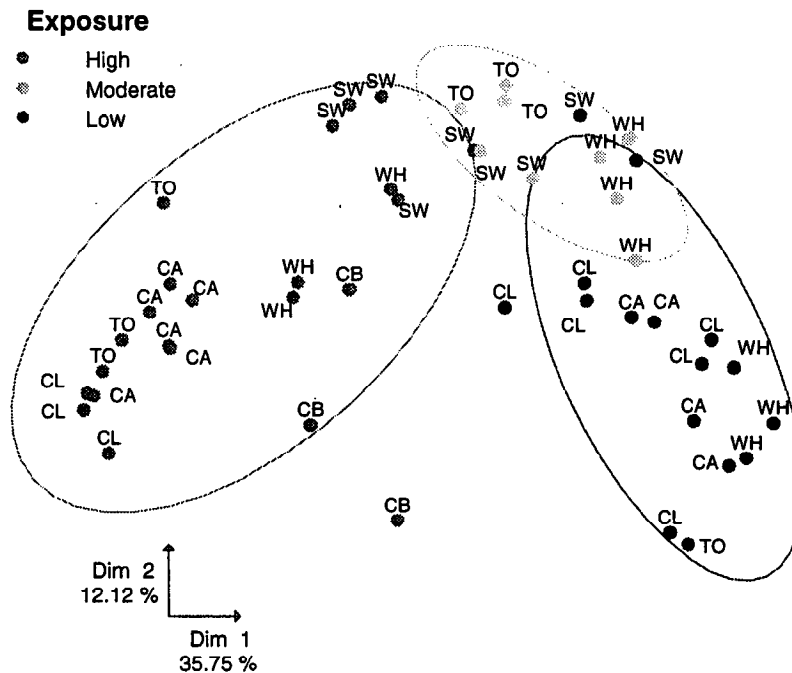
<i>Acanthochromis</i>	Abundances in general lower in Swains than in four northern sectors No clear patterns in overall abundance across shelf Abundance on outer reefs varies among sectors
<i>Amblyglyphidodon</i>	Variation in relative abundance across the shelf among sectors. Abundance on outer reefs varies among sectors
<i>Amphiprion</i>	Relative abundance across the shelf differs in the Swains compared with other sectors Abundance on outer reefs varies among sectors
<i>Chromis</i>	No clear patterns in overall abundance among the five northern sectors No clear patterns in overall abundance across shelf Abundance on outer reefs varies among sectors
<i>Chrysiptera</i>	Clear variation in relative abundance across the shelf among sectors. No differences in abundance on outer reefs among sectors
<i>Dascyllus</i>	No clear geographic patterns in abundance
<i>Dischistodus</i>	No clear differences in abundance among sectors Abundances generally lower on outer reefs No differences in abundance on outer reefs among sectors
<i>Neoglyphidodon</i>	Clear variation in relative abundance across the shelf among sectors. Variation in abundance on outer reefs among sectors
<i>Neopomacentrus</i>	Overall abundance varies among four northern sectors Relative abundance across shelf in the Swains differs from other sectors Abundance on outer reefs varies among sectors
<i>Plectroglyphidodon</i>	Overall abundance varies among four northern sectors Overall abundance varies with shelf position (higher offshore) Abundance on outer reefs varies among sectors
<i>Pomacentrus</i>	Clear variation in relative abundance across the shelf among sectors. Abundance on outer reefs is higher in the south
<i>Stegastes</i>	Clear variation in relative abundance across the shelf among sectors. Abundance on outer reefs varies among sectors

Factor analysis was used to see if the abundances of fish species on reefs could be used to identify general factors that contribute to fish distribution. Each species was then tested to see if presence or absence on a reef was related to the exposure scale (contingency table, exact probabilities found by monte carlo simulation). When species showed non-random distributions relative to exposure, the corresponding loadings of that species on the first three factors were examined. In this way, three species assemblages were identified: those that occur in sheltered conditions (preponderance on sheltered reefs and large positive loading on Factor 1), those that occur in exposed conditions (preponderance on exposed reefs and large negative loading on Factor 1) and the rest showing no preference (Tables 5 and 6).



**Figure 4.** Principal component plots showing groupings by shelf position and latitude. Plots are based on abundances of all species present as more than two individuals on three or more reefs. All data column centred to account for differences in abundance among species. Ellipses are 'confidence ellipses' which will on average include 80% of points in a group if the data are multivariate normal. Sector codes: CL = Cooktown-Lizard, CA = Cairns, TO = Townsville, WH = Whitsundays, SW = Swains and CB = Capricorn-Bunkers.

There is also a weaker effect of latitude (Fig. 4) related to Factor 3. Three groups with different distributions by latitude emerge among the pomacentrids, however only three species show predominantly southern distributions, eight show northern distributions and the rest show little effect of latitude (Table 6). The latitudinal effect is even weaker in the larger taxa with 52 of the species showing no discernible effect of latitude, the other eight occurring predominantly in the more northern sectors (Table 5). Although weak, this gradient is reasonably distinct in the ordinations (Fig. 4).



**Figure 5.** Principal component plots showing groupings by exposure. Plots are based on abundances of all species present as more than two individuals on three or more reefs. All data column centred to account for differences in abundance among species. Ellipses are 'confidence ellipses' which will on average include 80% of points in a group if the data are multivariate normal. Sector codes: CL = Cooktown-Lizard, CA = Cairns, TO = Townsville, WH = Whitsundays, SW = Swains and CB = Capricorn-Bunkers.

#### Patterns of endemism

In his review of one of the best-studied families of reef fishes, the damselfishes, Allen (1991) recorded 91 species on the GBR and identified only four species as endemic. These were: *Chromis nitida*, *Stegastes apicalis*, *Pomacentrus australis* and *Pomacentrus wardi*. All of these have southern distributions and occur on the New South Wales coast. *Chromis nitida* has been recorded at Lord Howe Island. *Chromis nitida* and *P. australis* are confined to the southern section of the GBR but *S. apicalis* and *P. wardi* occur at least as far north as Lizard Island (14°40'S). One salient species with a curious distribution is *Lethrinus miniatus*, a commercial species that is common in the southern GBR and on the reefs off Townsville but very rarely seen on reefs near Cairns or further north. In the context of the GBR itself, species belonging to a number of groups occur only in the north, but this is because the area is peripheral to more equatorial centres of distribution.

**Table 5.** Larger species categorised by exposure regime and latitude on the basis of exact tests. Columns represent species common to each exposure regime given in column headings, <sup>N</sup> denotes species with a largely northern distribution.

Non-pomacentrid species (Groups defined by exposure)		
Low exposure	No trend with exposure	High exposure
<i>Chaetodon aureofasciatus</i>	<i>Acanthurus blochii</i>	<i>Acanthurus lineatus</i>
<i>Chaetodon rainfordi</i>	<i>Acanthurus dussumieri</i>	<i>Acanthurus nigrofuscus</i>
<i>Chelmon rostratus</i>	<i>Acanthurus nigricauda</i>	<i>Chaetodon citrinellus</i>
<i>Cheilinus fasciatus</i>	<i>Chaetodon baronessa</i>	<i>Chaetodon pelewensis</i>
<i>Choerodon fasciatus</i>	<i>Chaetodon melannotus</i>	<i>Chaetodon trifascialis</i>
<i>Lethrinus nebulosus</i>	<i>Chaetodon plebeius</i>	<i>Chaetodon unimaculatus</i>
<i>Lutjanus carponotatus</i>	<i>Chaetodon trifasciatus</i>	<i>Forcipiger flavissimus</i>
<i>Lutjanus quinquelineatus</i> <sup>N</sup>	<i>Chaetodon vagabundus</i> <sup>N</sup>	<i>Gomphosus varius</i>
<i>Lutjanus vitta</i> <sup>N</sup>	<i>Ctenochaetus spp.</i>	<i>Halichoeres hortulanus</i>
<i>Scarus flavipectoralis</i>	<i>Epibulus insidiator</i>	<i>Hemigymnus fasciatus</i>
<i>Scarus ghobban</i>	<i>Hemigymnus melapterus</i>	<i>Hemitaenichthys polylepis</i>
<i>Scarus rivulatus</i>	<i>Hipposcarus longiceps</i>	<i>Naso lituratus</i>
<i>Siganus doliatus</i>	<i>Lutjanus fulviflamma</i>	<i>Naso tuberosus</i>
<i>Siganus vulpinus</i>	<i>Lutjanus gibbus</i> <sup>N</sup>	<i>Scarus chameleon</i>
	<i>Lutjanus lutjanus</i> <sup>N</sup>	<i>Scarus frenatus</i>
	<i>Monotaxis grandoculis</i> <sup>N</sup>	<i>Scarus globiceps</i>
	<i>Naso unicornis</i>	<i>Scarus oviceps</i> <sup>N</sup>
	<i>Plectropomus leopardus</i>	<i>Scarus psittacus</i>
	<i>Scarus altipinnis</i>	<i>Siganus corallinus</i>
	<i>Scarus microrhinos</i>	<i>Zanclus cornutus</i>
	<i>Scarus niger</i>	<i>Zebrasoma scopas</i>
	<i>Scarus schlegeli</i>	<i>Zebrasoma veliferum</i> <sup>N</sup>
	<i>Scarus sordidus</i>	
	<i>Scarus spinus</i>	

**Table 6.** Pomacentrids categorised by exposure regime and latitude on the basis of exact tests. Columns represent species common to each exposure regime given in column headings, <sup>N</sup> denotes species with a largely northern distribution, <sup>S</sup> denotes species with a largely southern distribution

Pomacentrid species (Groups defined by exposure)		
Low exposure	No trend with exposure	High exposure
<i>Amblyglyphidodon curacao</i>	<i>Acanthochromis polyacanthus</i>	<i>Chromis lepidolepis</i> <sup>N</sup>
<i>Amblyglyphidodon leucogaster</i>	<i>Amphiprion akindynos</i> <sup>S</sup>	<i>Chromis margaritifer</i>
<i>Chrysiptera rollandi</i>	<i>Chromis atripectoralis</i>	<i>Chromis vanderbilti</i>
<i>Neoglyphidodon nigroris</i>	<i>Chromis atripes</i> <sup>N</sup>	<i>Chromis xanthura</i> <sup>N</sup>
<i>Neopomacentrus bankieri</i>	<i>Chromis nitida</i> <sup>S</sup>	<i>Chrysiptera rex</i>
<i>Pomacentrus adelus</i> <sup>N</sup>	<i>Chromis ternatensis</i> <sup>N</sup>	<i>Pomachromis richardsoni</i>
<i>Pomacentrus amboinensis</i> <sup>N</sup>	<i>Chromis weberi</i> <sup>N</sup>	<i>Plectroglyphidodon dickii</i>
<i>Pomacentrus brachialis</i>	<i>Chrysiptera talboti</i>	<i>Plectroglyphidodon johnstonianus</i>
<i>Pomacentrus grammorhynchus</i>	<i>Dascyllus reticulatus</i> <sup>N</sup>	<i>Plectroglyphidodon lacrymatus</i>
<i>Pomacentrus moluccensis</i>	<i>Neoglyphidodon melas</i>	<i>Pomacentrus bankanensis</i>
<i>Pomacentrus nagasakiensis</i>	<i>Pomacentrus coelestus</i>	<i>Pomacentrus philippinus</i>
<i>Pomacentrus wardi</i>	<i>Pomacentrus lepidogenys</i>	<i>Stegastes fasciolatus</i>
	<i>Pomacentrus vaiuli</i>	
	<i>Stegastes apicalis</i> <sup>S</sup>	

### **Some processes relevant to changes in reef fish populations and their management**

Maintaining self-perpetuating populations and assemblages of reef fishes may be best served by a combination of regulating human impacts and exploitative pressures and insuring against natural impacts by maintaining broadly dispersed areas of reef as reservoirs, sources for recolonisation. With the exception of large oil spills, the processes with the broadest geographic impacts are natural ones. These include physical destruction by cyclones, while the extent of anthropogenic influences on sedimentation from floods and the depredations of *Acanthaster planci* is disputed. Clear evidence of the effects of habitat destruction on reef fish assemblages comes from Williams (1986) and subsequent unpublished work. Williams monitored fish assemblages and annual recruitment on three mid-shelf reefs near Townsville: Rib, John Brewer and Lodestone reefs. Study sites were on N.E. outer slopes of reefs at depths to 12 m and were monitored over a period of 14 years. Early in that time, the reefs were infested with crown of thorns starfish, *A. planci*, and the live coral cover dropped from about 70% to less than 1% and has since recovered to more than 60%. Williams (1986) found that populations of a few species of fish that were obligate coral feeders (some chaetodonts) decreased noticeably in less than 12 months. A few other species such as *Pomacentrus moluccensis* and *Chromis atripectoralis* decreased in number in less than two years (Williams, pers comm.), presumably due to recruitment failure, since these species are associated with living branching corals as juveniles. As the coral has returned to previous levels of cover, the assemblages of such fishes have converged on their initial state (Williams, pers. comm.). Only species that were directly dependent on living coral appeared to be affected; there was no detectable increase in species that use algal turf or dead coral substrates. It is important to note that the dead coral colonies remained in place for a long time so that the structural complexity of the habitat was retained. While only species that are directly dependent on living coral are affected by its loss, the effect of loss of habitat complexity such as might occur if tropical storms followed the starfish outbreak, has not been quantified in nature and is potentially much more disruptive.

A small scale study by Sano et al. (1984) is relevant here. First these authors examined two sets of coral heads, one set substantially dead due to *A. planci* and another set of live coral heads. The number of species and individual fishes was greater on the living coral heads in summer and the following spring. A number of the dead coral heads collapsed before the second census. In a second experimental study, two coral colonies (1 m<sup>2</sup> by 0.2 m high) were censused daily for 21 days then killed and replaced and censused for a further 28 day period. Death of the coral resulted in a decline in coralivores, but no clear decline in numbers of species though there were fewer individuals. There was no consistent increase in herbivores though small schools of parrotfishes visited occasionally when algae began to cover the colony surface. Two other colonies were censused daily and then their structural complexity was reduced by breaking off branches before replacing them and continuing the censuses. Loss of structural complexity lead to fewer species and individuals. The small scale and lack of simultaneous controls weaken these experiments, but the implication is that loss of structure has general effects on fish assemblages, where as loss of living coral only affects species that depend specifically on that resource. In contrast, a much larger scale experiment involving physical destruction of coral on patch reefs with areas > 100 m<sup>2</sup> led to little change in the assemblage of fishes in the short term (A.R. Lewis, unpublished).

#### The spatial scale of replenishment processes

Williams' long term study shows that recolonisation by fishes can track coral regeneration. Much of this must be due to recruitment of larvae that were spawned elsewhere. The issue of stocks and larval dispersal in reef fish is an area of active research. At a simple level, the duration of larval phases of reef fish life cycles (usually three weeks or more, Wellington and

Victor 1989, Thresher et al. 1989) would be sufficient for currents such as the Eastern Australian Current to transport passive particles for hundreds of kilometres. The presence of juvenile reef fishes on the coast of New South Wales as far south as Sydney at the end of summer shows that this can occur. On the other hand, how passive are larval fishes? Some late stage larvae are strong swimmers (Stobutzki and Bellwood 1994) and swim directionally (Leis et al. 1996). The case of Clipperton Island, an extremely isolated reef in the eastern Pacific Ocean, is illuminating: the reef supports at least eight endemic fish species whose geographic range in the entire world sums to about four hectares (D.R. Robertson, pers. comm.). Unless these species have aberrant life-cycles their larvae must either be able to maintain position close to the island or to orientate very precisely over large distances.

There is other evidence that the population of fishes on a reef may be self recruiting to a significant extent. The work of Jones and Milicich (1996) provides direct evidence from marking embryonic otoliths with tetracycline that a detectable proportion of larval damselfish spawned on a reef do settle subsequently on that reef. The proportion may be as high as 18% for *Pomacentrus amboinensis* at Lizard Island, the one site where this has been attempted (Milicich, pers. comm.) though Meekan et al. (1993) have argued that the enclosed nature of the GBR lagoon in the Lizard Island region may increase the likelihood of larval retention compared to other areas of the GBR. The effect of self recruitment will be to introduce a degree of negative feedback into population recovery.

#### The time scale of population replenishment

The recruitment of coral reef fishes to any location varies widely over time (Doherty and Williams 1988; Doherty 1991). Even small species may live several years (e.g. Doherty and Fowler 1994) and natural populations on a reef may be dominated numerically by cohorts from large recruitment events years after that event occurred (e.g. Doherty and Fowler 1994; Russ et al. 1995). This means that it may be several years following a major disturbance before a significant recruitment event occurs.

#### Summary

In conclusion, there are clear differences among fish assemblages across the shelf and to a lesser extent, from north to south. These should be considered in the selection process for protected areas. The long term effects of major disturbances are likely to be minimal if sources of larvae exist for recolonisation. Recent findings suggest that dispersal distances may be less than was previously thought. Since the most destructive impacts are likely to be largely natural in origin the scope for their management is limited.

#### Acknowledgments

We thank Glenn De'ath for allowing us to use his multivariate EDA program 'Sophie'.

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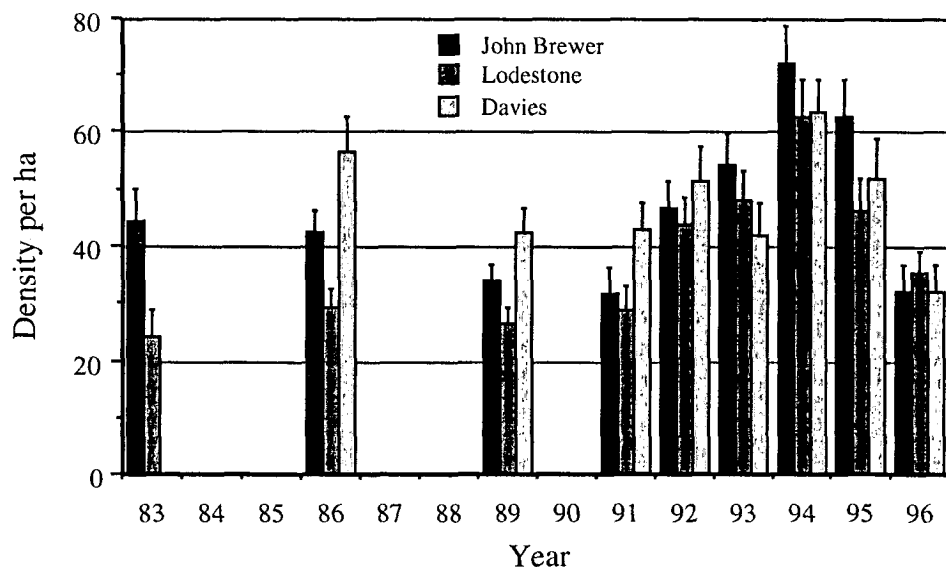
# Long-term trends in reef fish abundance in the Great Barrier Reef World Heritage Area

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Visual counts of a number of reef fish groups have been made in a wide range of Great Barrier Reef (GBR) sites since 1982. A variety of methods have been used but the majority of counts have utilised strip transects of either 50 x 20 m or 50 x 5 m (see Ayling and Ayling 1986a, 1996 for full descriptions of the count techniques). Counts have been made of all coral trout species *Plectropomus* spp., other fishing targeted groups such as lethrinids and lutjanids, and all chaetodontids. Long-term series of counts on the same reefs are available in a number of areas and can be used to investigate trends in reef fish abundance. The following paper discusses results from surveys made by the author only, with the emphasis on surveys of fishing target species. Some other long term studies of fish abundance have been made in the GBR region, notably by J.H. Choat on herbivorous fish species, but these are not discussed here.

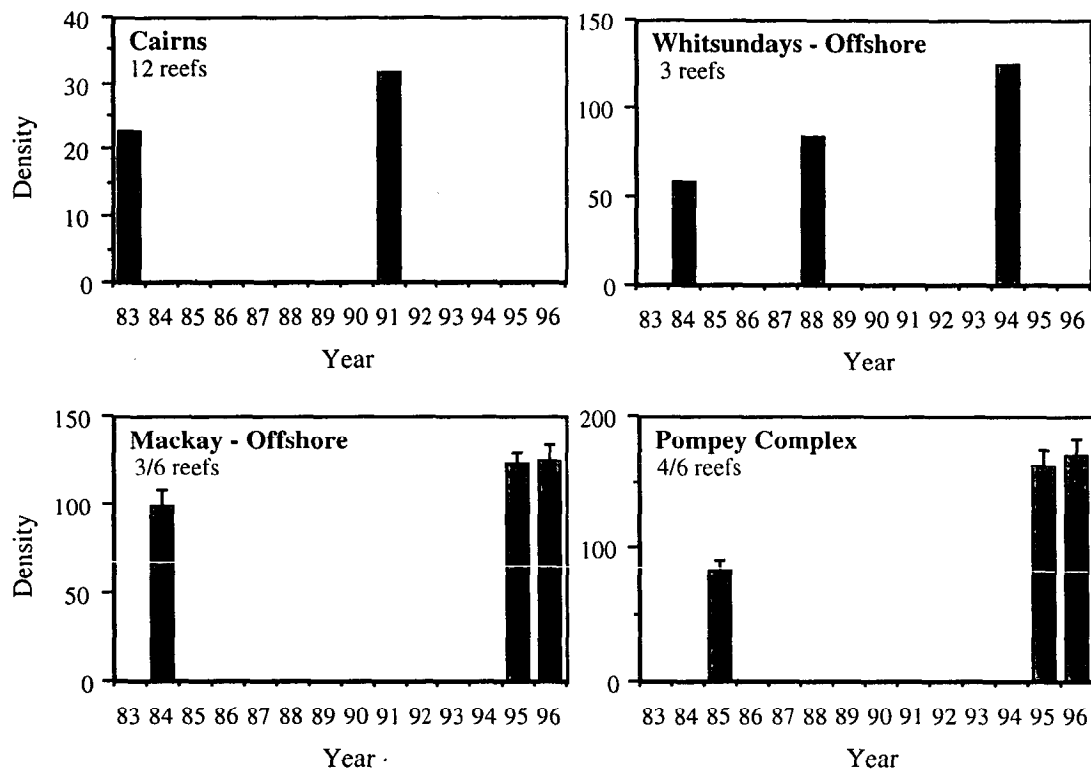
The most comprehensive time series is available from three general use reefs off Townsville, where counts have been made on John Brewer, Lodestone and Davies Reefs on 11 occasions between 1983 and 1995 (Ayling and Ayling 1986b, 1996). Grand mean common coral trout (*Plectropomus leopardus*) density on these three reefs has fluctuated over the years but has shown no downward trend as might be expected if coral trout were being consistently over-fished (Fig. 1). The peak in abundance between 1993 and 1995 on these reefs was primarily due to several good recruitment events.



**Figure 1.** Coral trout density changes on three reefs off Townsville. Mean density per ha is shown from surveys made in the May-June period each year. Error bars are standard errors.

Over the past 13 years, repeat counts on the same reefs, or in the same limited area, have also been made in some other locations. In the Cairns Section, counts were made on twelve reefs in 1983 (Ayling and Ayling 1986b) and again in 1991 (Mapstone and Ayling unpublished data). Common coral trout density increased over this period (Fig. 2). Off the Whitsundays, on the

three reefs Hook, Line and Hardy, mean density of coral trout increased between 1984 (Ayling and Ayling 1986b), and 1988 (Ayling and Ayling 1989) and again between 1988 and 1994 (Ayling and Ayling 1994a). In the Hydrographers Passage area off Mackay counts were made on the back reef slope of three reefs in 1984 (Ayling and Ayling 1986b), and on the back of six reefs in the same area as part of the CRC Effects of Fishing experiment in 1995 and 1996 (A.M. Ayling unpublished data). Mean coral trout also increased in this area (Fig. 2). Toward the south end of the Great Barrier Reef, in the Pompey Complex counts were made on the back of four reefs in 1985 (Ayling and Ayling 1986a) and on the back of six reefs in the same area, including two of the same reefs, in 1995 and 1996 (Fig. 2). In all these cases, covering much of the length of the GBR, total density of the common coral trout has increased over the past 13 years.



**Figure 2.** Long-term coral trout density changes from GBR locations. Graphs show grand mean density per ha from groups of 10 to 30 counts per reef. Error bars are standard errors. See text for sources.

Is the protection that has been afforded some reefs by Marine Park zoning preventing overall coral trout numbers from declining in the face of continuing fishing pressure? Counts that have been made on protected and fished reefs since 1986 suggest that this is not the case. In 1986, coral trout were counted on 12 reefs in the Capricorn-Bunker Group off Gladstone (Ayling and Ayling 1996a). Six of these reefs had been closed to fishing for an average of about five years, while the other six were open to fishing. There were more coral trout on the closed reefs than on the fished reefs but this difference was not significant (Table 1). In 1991 fish were counted on a large number of reefs in the Cairns Section (Dunk Island up to Lizard Island). Of these reefs, 29 were open to fishing and 18 had been closed to fishing for seven years. Coral trout density on the two groups of reefs was almost exactly the same (Mapstone and Ayling unpublished data). In 1992 another set of counts was made in the Cairns Section, using five different closed reefs and five fished reefs (Ayling and Ayling 1992). Once again there was no difference in density between the two groups of reefs (Table 1). The 1996 CRC Effects of

Fishing count of coral trout on 24 reefs between Lizard Island and the Swain Group, recorded fish numbers on 16 closed reefs and 8 fished reefs. This survey found more common coral trout on the fished reefs than on the protected reefs, but this difference was also not significant (Table 1).

**Table 1.** Summary of common Coral Trout density on closed and fished reefs. Figures show mean density per ha from between 10 and 30 transects per reef. For sources see text.

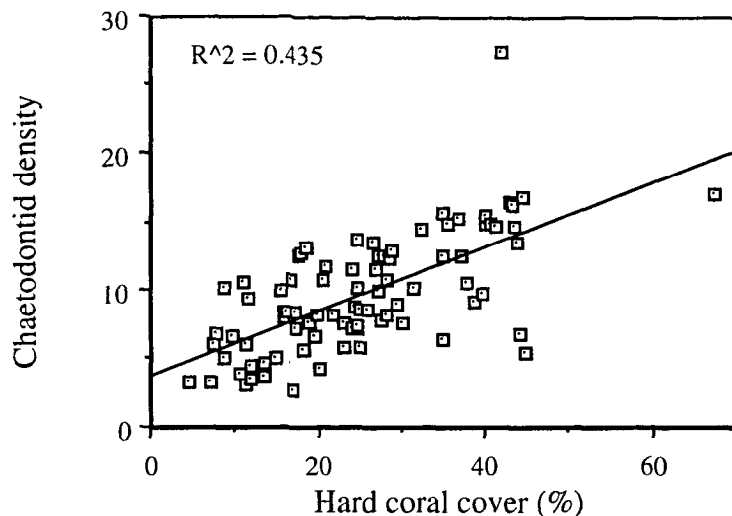
Location	Date	No. protected reefs	Protected density	No. fished reefs	Fished density
Capricornia	Jan 1986	6	57.0	6	49.0
Cairns	1991	18	33.9	29	34.6
Cairns	1992	5	28.4	5	27.8
GBR	1996	16	100.9	8	117.7

The level of protection currently offered by the GBR Marine Park is not having any effect on the density of common coral trout. This may either be because regular illegal fishing is still carried out on protected reefs or because coral trout populations are naturally resilient in the face of fishing pressure, or a combination of these two factors. In spite of this the overall density of this species is apparently increasing over much of the GBR region. The available evidence suggests that common coral trout populations are not being depleted by current levels of fishing. However, a recent study has shown that intensive fishing pressure has the potential to reduce adult coral trout numbers dramatically (Ayling and Ayling 1996). When the Bramble Reef replenishment area was opened to fishing in July 1995, after being closed for 3.5 years, 60% of the available adult coral trout were removed by fishermen within two months, and over 80% within 12 months. The fishing pressure in this case was severe, with 19 commercial fishing boats and a large number of private boats being present on the reef for the opening.

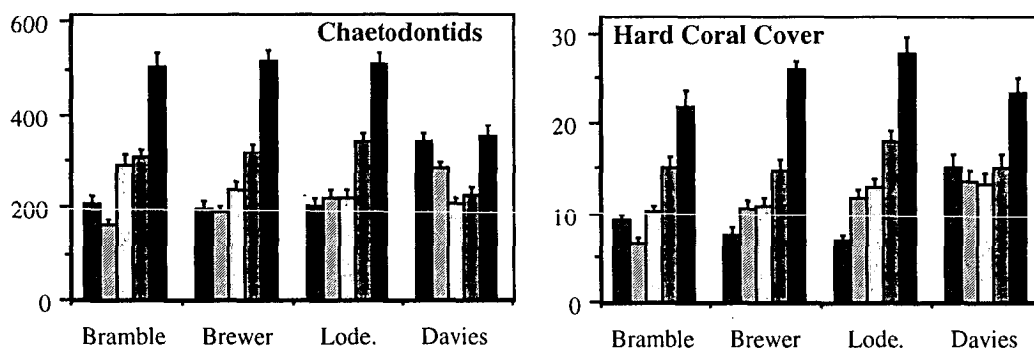
Although counts of lethrinids and lutjanids have only been made on some reefs over a six year period, numbers have been remarkable stable over that period (Ayling and Ayling 1996). A comparison is possible between counts of *Lethrinus miniatus* made on 11 reefs in the Swain Group and southern Pompeys in 1986 (Ayling and Ayling 1986a), and those made in the southern Pompeys as part of the CRC survey in 1996 (A.M. Ayling unpublished data). Mean density was 25.5 (s.e. 3.1) in 1986 and 22.9 (s.e. 2.5) in 1996. There has been some evidence from studies in the Innisfail to Townsville region that the red-throat sweetlip *Lethrinus miniatus* may be adversely affected by fishing pressure (Ayling and Ayling 1994b, 1996). However, recent counts of this species made on more southerly reefs where they are naturally more abundant (this species occurs very rarely on reefs north of about Innisfail and is found at relatively low densities north of the Whitsunday Islands) suggest that current protection regimes are also having no affect on the density of this species (A.M. Ayling unpublished CRC data). In 1996 the mean density of this species from the 16 protected CRC reefs was 14.4 per ha, compared with 14.3 on the eight fished reefs. Preliminary evidence suggests that lethrinids and lutjanids are also not being adversely affected by current fishing levels on the GBR.

Of the species for which long term data is available, only chaetodontids are not subject to fishing pressure, except for the negligible impact of aquarium fish collectors. Many chaetodontids are obligate hard coral feeders and the density of this group on any reef is always positively correlated with hard coral cover (Ayling and Ayling 1985, 1986a, 1996, Fig. 3). Hence densities of this group have fluctuated markedly on the reefs where long time series of

counts are available, a result of fluctuations in coral cover caused by crown-of-thorns outbreaks and subsequent recovery (Fig. 4).



**Figure 3.** Relationship of chaetodontid density to hard coral cover. Data from May 1995 survey of seven reefs off Townsville, with 12 sites per reef and five transects per site. Relationship at the site level is shown.



**Figure 4.** Changes in chaetodontid and hard coral cover on four reefs off Townsville: 1991-1995. Data from 12 sites of five transects on each reef. Error bars are standard errors.

There is concern that reef fish populations are being degraded by existing levels of fishing pressure. Although there is evidence that extreme fishing pressure can cause a rapid decline in targeted species, the available data suggest that populations of these species over the GBR region have not been reduced in the past decade by current exploitation levels. In the event that fishing pressure is, at some time, deemed to be a concern, the best management response in my view would be more effective enforcement of more concentrated and limited protected areas. The present system fails in having inadequate enforcement of widely scattered protected areas; regular fishing does take place on most supposedly protected reefs.

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# Long-term monitoring of reef fishes: effects of crown-of-thorns starfish

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Adults of a diverse range of reef fishes have been monitored on the outer slopes of reefs in the central Great Barrier Reef off Townsville since 1980. A nearshore reef (Pandora), an outershelf reef (Myrmidon) and four mid-shelf reefs (Rib, John Brewer, Lodestone and Davies) were initially censused in 1980. All reefs except Davies were re-censused in 1983. Davies was re-censused in 1984, 1986 and annually since. Rib, John Brewer and Lodestone have been censused annually since 1983. Pandora and Myrmidon reefs, which have been unaffected by crown-of-thorns starfish and whose fish communities have been changing less than those on the mid-shelf reefs, have been re-censused three times since 1983.

A standard technique has been used for all censuses. Approximately 146 species are counted including all species of butterflyfish (Chaetodontidae) in the area, the majority of the common damselfishes (Pomacentridae), virtually all surgeonfishes (Acanthuridae) and parrotfishes (Scaridae) plus selected wrasses (Labridae), fusiliers (Caesionidae) and rabbitfish (Siganidae). A census dive involves a 45-minute SCUBA swim along the reef slope, swimming a zig-zag pattern up and down the reef face from the surface to a depth of 13 metres and recording the presence of species and their abundance (on a log five abundance scale) along oblique transects estimated 5 metres either side of the diver. Five censuses of non-overlapping areas of reef slope are made on each reef and each 45-minute swim covers approximately 150 metres of reef face. On each reef except Davies, three permanently marked sites are located within the areas censused for adults where recruitment of all species has been annually monitored since 1983.

During 1983 a crown-of-thorns starfish outbreak occurred on the mid-shelf study reefs (except Davies). Live coral cover prior to the outbreak, measured in the recruitment sites, was approximately 70% (e.g. Davies Reef, Fig. 1). Subsequent to the outbreak, this cover dropped to less than 10% over 1-3 years (depending on the reef). Coral cover changed little until about 1992 when it started to increase geometrically. By 1995 coral cover on the Rib and John Brewer sites was back to pre-crown-of-thorns starfish outbreak levels. These circumstances provide a unique opportunity to examine the response of reef fish communities to the impacts of a crown-of-thorns starfish outbreak.

Preliminary analyses clearly suggest that the very high loss in coral cover had a highly selective impact on the fish communities. Not surprisingly, densities of species that are obligate coral feeders, such as certain butterflyfishes, fell dramatically following the loss of live coral (e.g. *Chaetodon aureofasciatus*, Fig. 2). So too did the density of some species such as the damselfishes *Pomacentrus moluccensis* and *Chromis atripectoralis*. While the adults of these species appeared not to be directly affected by the loss of coral, recruitment of both species fell dramatically because new recruits only settle into live coral and subsequently adult densities fell dramatically as a result of natural mortality and very low recruitment. Many species appeared unaffected by the loss of coral including, for example some butterflyfishes that are not obligate coral feeders (e.g. *Chaetodon trifasciatus*, Fig. 3). The density of herbivorous fishes, expected to increase in numbers due to the very large increase in the amount of algae available on the dead coral, did not increase.

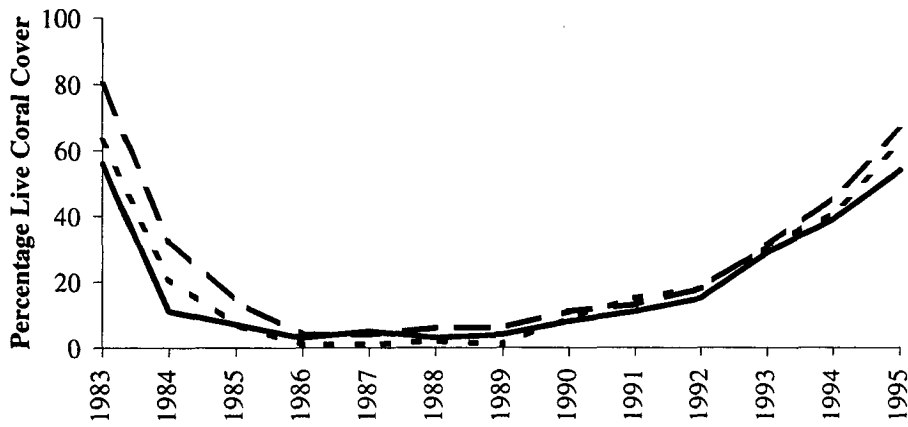


Figure 1. Trends in coral cover at three sites from Davies Reef

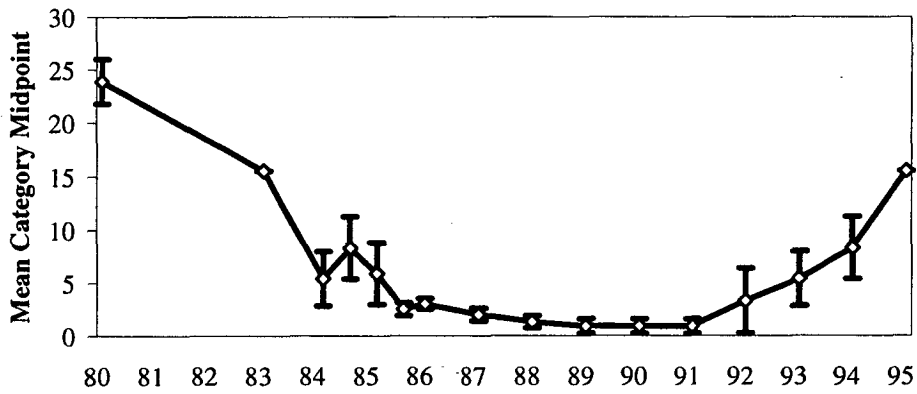


Figure 2. Abundance of *Chaetodon aureofasciatus* at John Brewer Reef

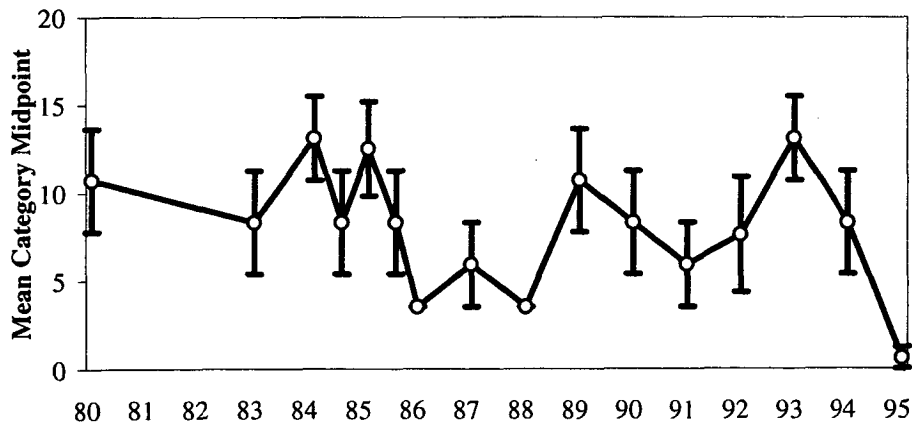


Figure 3. Abundance of *Chaetodon trifasciatus* at John Brewer Reef

Some of the species which showed a rapid decline in response to the crown-of-thorns starfish outbreak have returned to pre-crown-of-thorns starfish densities at a similar rate to the live coral recovery (e.g. *Chaetodon aureofasciatus*, Fig. 2). The same species on different reefs have not necessarily shown the same response. I hypothesise that the fish communities on the reefs examined may be highly resilient (at decadal time scales) to the effects of a crown-of-thorns starfish outbreak but only if recruitment is available from an external source, i.e. upstream reefs. More detailed analyses of these data sets are presently underway to test this hypothesis and to examine in more detail the response of the dynamics of the fish communities in response to large, reef-scale decreases and increases in live coral cover.



# The status of the dugong in the Great Barrier Reef Marine Park

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## Abstract

One of the World Heritage values of the Great Barrier Reef Region is that it contains major feeding grounds for large populations of the endangered species, *Dugong dugon*. Dugongs are vulnerable to anthropogenic impacts because they are long-lived slow breeding animals with a specialised diet. Their dependence on seagrass means that dugongs have an obligatory association with coastal habitats which are often under pressure from human activities. The rate of dugong population change is most sensitive to changes in survivorship and mortality from traditional hunting or incidental drowning in gill nets must be less than about 2% of females per year to be sustainable. The sustainable harvest rate will be even lower in areas where the pre-reproductive period and/or calving interval are lengthened by food shortage as a result of habitat loss or pollution. Dugong numbers appear to have been stable over the last decade in the Great Barrier Reef Region north of Cape Bedford. On the urban coast south of Cooktown, dugong numbers have declined by approximately 50% over the past eight years. Over a large section of the region, this decline is over 80%. Anecdotal evidence suggests that the decline has probably been occurring since the 1960s or even earlier. As a result of this decline, Indigenous groups have decided not to hunt along the urban coast of the Region and there is now no permitted traditional hunting of dugongs south of Cooktown. Fishers have agreed to support an Endangered Species Education Program and the Queensland Shark Control Program is being reviewed with a view of reducing by-catch. It will be necessary to introduce additional measures to decrease the incidental capture of dugongs in gill nets. Habitat deterioration remains a major unresolved threat to dugongs in the Great Barrier Reef Region.

## Introduction

Australia has international responsibilities for the management of dugongs in the Great Barrier Reef Region. One of the World Heritage values of the Region is that it 'provides major feeding grounds for large populations of the endangered species *Dugong dugon*' (Great Barrier Reef Marine Park Authority 1981). In addition, the dugong has high biodiversity value as the only species in the Family Dugongidae and one of only four species in the Order Sirenia, all of which are listed as vulnerable to extinction by the International Union of the Conservation of Nature (IUCN 1990). Prospects for the survival of the dugong are better than for any of the three species of manatee, as each manatee species has a more localised distribution than that of the dugong (in the West Indian region, the Amazon and in West Africa respectively; Reynolds and Odell 1991). In addition, the estimates of dugong abundance in Australia are much greater than has been recorded or suggested for any species of manatee (unpublished data). These factors mean that the conservation of dugongs in the Great Barrier Reef Region is significant not only for the survival of the dugong but for sirenians in general.

## Taxonomic status

The dugong (*Dugong dugon*) is remarkable as the only herbivorous mammal that is strictly

marine. The three species of manatee all use fresh water to varying degrees. The only other recent Sirenian, the 7 m long Steller's sea cow *Hydrodamalis gigas*, was hunted to extinction within 40 years of its discovery in the eighteenth century (Stejneger 1887).

#### Life history

Almost all information on dugong life history has been obtained from the analysis of animals accidentally drowned in shark nets or killed by native hunters. Age has been estimated by counting the dentinal growth layers in the tusks, the deposition rate being deduced from the seasonal pattern of growth layer deposition (Marsh 1980). Life history parameters are summarised in Marsh et al. (1984). Dugongs are long-lived animals with a low reproductive rate, long generation time and a high investment in each offspring. Longevity is approximately 70 years, with a pre-reproductive period of at least nine and sometimes as long as 17 years. Gestation is about 13 months. The calf suckles for at least 18 months and the period between calving is believed to be three to seven years. Population simulations indicate that even with the most optimistic combinations of life history parameters (e.g. low natural mortality and no human-induced mortality) a dugong population is unlikely to increase at more than about 5% per year (Marsh 1995a). This makes the dugong vulnerable to over-exploitation and justifies its IUCN classification.

#### Diet

Dugongs are seagrass specialists. They were believed to feed opportunistically on available seagrasses (Marsh et al. 1982; Lanyon et al. 1989). Recent work by Preen (1993) suggests that dugongs select seagrasses which are lower seral or 'pioneer' species. Species of the genera *Halophila* and *Halodule* are favoured in many areas. Diet selection is correlated with the chemical and structural composition of seagrass (Lanyon 1991). The most frequently selected species are lowest in fibre and highest in available nitrogen and presumed digestibility (Lanyon 1991). The highly specialised dietary requirements of the dugong suggest that only certain seagrass meadows may be suitable as seagrass habitat. Marine algae are also eaten, but this is believed to occur only when seagrass is scarce (Spain and Heinsohn 1973). Anderson (1989) and Preen (1995a) have evidence that dugongs may deliberately forage for macro-invertebrates near the southern limits of their range in both western and eastern Australia. However, examination of stomach and faecal samples (Preen 1995a) suggests that dugongs do not deliberately forage on macro-invertebrates in more tropical areas in Australia such as the Great Barrier Reef Region.

#### Habitat

Dugongs frequent coastal waters. Major concentrations of dugongs in the Great Barrier Reef Region occur in wide shallow protected bays, wide shallow mangrove channels and in the lee of large inshore islands (Heinsohn et al. 1979). These areas are coincident with sizeable seagrass beds. Dugongs are also regularly observed in deeper water further offshore especially in the Far Northern Section of the Great Barrier Reef Marine Park. Marsh and Saalfeld (1989) sighted dugongs up to about 60 km from the coast of eastern Cape York in water up to 37 m deep. This distribution reflects that of deepwater seagrasses like *Halophila spinulosa* (Lee Long et al. 1993). Further verifying the use of deepwater meadows by dugongs, their feeding trails have been observed at depths of up to 24 m in the Great Barrier Reef Region (Lee Long et al. 1989).

Shallow waters, such as tidal sandbanks (Marsh et al. 1984) have been reported as sites for calving in the Great Barrier Reef region. Anderson (1981) has suggested this may be a strategy to avoid sharks.

## Movements

Most movements of the more than 30 dugongs that have been tracked using VHF or satellite transmitters were localised to the vicinity of seagrass beds (Marsh and Rathbun 1990; Preen 1993). However, some individuals undertake long-distance movements within the Great Barrier Reef Region. One individual moved between two localities in the Central Section of the Great Barrier Reef Marine Park, a straight line distance of 140 km, three times in six weeks (Marsh and Rathbun 1990). Of the 10 dugongs fitted with satellite transmitters in Shoalwater Bay in the Mackay/Capricorn Section of the Great Barrier Reef Marine Park by Tony Preen (pers. comm. 1996), four have made substantial trips out of the Bay. Two made return trips: one to Clairview 100 m north, the other 220 km north to Hay Point near Mackay. The other two other animals journeyed 400 km south to Hervey Bay where their transmitters came off.

## Stock identity

There is little information on stock boundaries. A morphometric study by Spain and Marsh (1981) demonstrated that the skulls of dugongs from Mornington Island, in the Gulf of Carpentaria, can be statistically separated from those from Townsville, which is approximately 1850 km away by sea. However, these differences could be a result of environmental influences.

Molecular techniques are being used to determine the stock structure of dugongs in Australian waters (Tikel 1994). Preliminary results suggest restricted gene flow between a northern group and southern group and a high level of gene flow within each of these groups. The northern group comprises populations from widely separated localities from the northern coast between Exmouth Gulf in Western Australia and the southern Queensland coast. The southern group includes animals from Hervey Bay and Moreton Bay in Queensland. The haplotype diversity is much greater in the northern group than in the southern. This accords with the larger population sizes in the northern areas in comparison with Hervey Bay and Moreton Bay and emphasises the importance of the Great Barrier Reef Region in maintaining gene flow between the northern populations and those in south eastern Queensland.

## Pressures on dugongs in the Great Barrier Reef Region

### General

Dugongs are vulnerable to anthropogenic impacts because of their life history and their dependence on seagrass. This dependence means that dugongs have an obligatory association with coastal habitats which are often under pressure from human activities. The rate of population change is most sensitive to changes in survivorship. Even a slight reduction in adult survivorship as a result of traditional hunting or incidental drowning in nets, can cause a chronic decline in a dugong population. Marsh (1986, 1995a) suggested that the maximum rate of increase under optimum conditions could not exceed 5% per year even when natural mortality is low (< 5% per year). The maximum rate of increase must be lower in areas where there is mortality due to Indigenous hunting and incidental drowning in gill nets. The sustainable harvest is likely to be in the order of 1–2% of the female population per year. The sustainable harvest rate will be lower in areas where the pre-reproductive period and/or calving interval are lengthened due to food shortage (Marsh in press). Dugongs may be short of food for several reasons including habitat loss, seagrass dieback, decline in the nutrient quality of available seagrass or a reduction in the time available for feeding due to boat traffic.

Pressures which reduce survivorship

*Traditional harvest*

In the Great Barrier Reef Region, dugongs are hunted by members of remote communities such as Hopevale and Lockhart River on the coast of Cape York and by the Indigenous inhabitants of the urban coastal communities from Cooktown south. Dugong hunting is culturally significant and some Indigenous informants have told us that they consider it an important expression of their Indigenous identity. Dugongs are caught for their meat and for their oil which is extracted by boiling the parts of the dugong not used for food, such as the head. Dugong oil is used as a panacea for almost any ache, pain or illness. A dugong yields about 35% of its body weight in useable meat and fat (Nietschmann 1984) and on average about 18 litres of oil (Smith 1987). The meat of dugongs often ranks highest among traditional foods and no celebration is considered complete without dugong on the menu. The skilled hunter enjoys considerable prestige in the community.

There are few hunting statistics from the Region and most of them are out of date. Records between September 1989 to December 1990 indicate that 27 female dugongs were taken by the Lockhart River community (Lockhart resident, pers. comm.): Over one weekend in November 1995 at least eight and possibly 12 dugongs were taken from the area between Lockhart River and Night Island, by people from the Lockhart River and Bamaga communities (Lockhart resident, pers. comm). The adjacent area had an estimated population of  $577 \pm \text{s.e. } 343$  dugongs at that time. The sustainable take from a population of 600 animals would be approximately six females (or 12 animals of both sexes) per year. Dugongs are also taken from the Pascoe River region by residents of Western Cape York (Smith and Marsh 1990). Between January 1984 and February 1987, 74 dugongs were taken by the Hopevale community from the Starcke River region (Smith and Marsh 1990).

Hunting in the northern region of the Great Barrier Reef is not only conducted by residents of Hopevale and Lockhart River communities. Men from both Bamaga and Weipa also use the area to hunt which places additional pressure in some localities. Dugong hunting in this region is limited by weather and the small size of boats used. Extensive travel to hunting grounds is not possible while road access remains limited. However, new roads can dramatically alter the pattern of hunting pressure. The construction of a road from Cape Flattery to Lookout Point in 1991 caused a significant increase in the number of dugongs hunted by the people of Hopevale during the winter months in 1992 (Ross Williams pers. comm.). The encouragement of the outstation movement will change the spatial pattern of dugong hunting effort. This is likely to result in hunting pressure on dugongs in areas currently unaffected by Indigenous hunting. Also, some funding for outstation development has gone into larger vessels (Lockhart resident, pers. comm.), the impact of which is impossible to judge at present. Establishing outstations in areas which are remote from current hunting effort could remove the refugial value of these areas.

The contemporary cultural significance of the dugong to urban Aboriginal and Torres Strait Islander people in Queensland has not been studied formally. However, it appears to be considerable and widespread despite many impediments to urban dwelling Indigenous people participating in dugong hunting (Ponte 1996). Hunting pressure has presumably changed spatially in the last 30 years or so (Ponte et al. 1994) as a result of the migration of Torres Strait Islanders to mainland Australia in large numbers. Some 10 500 Indigenous males now reside in the southern half of the Great Barrier Reef Region (Ponte et al. 1994) including many Islanders who are used to having dugong in their diet (Johannes and MacFarlane 1991; Harris et al. 1994). This is almost ten times the number of Indigenous males in the northern Great Barrier Reef. How many urban Indigenous males aspire to hunt dugongs is unknown. Over two and a

half years in the early 1990s, 70 permits were issued for dugong hunting between Cape Bedford (near Cooktown) and the southern boundary of the Great Barrier Reef Marine Park. Most hunters applied for a permit only once suggesting that hunting is not overtly dominated by a few individuals. (However, it may be dominated by a few defined groups. F. Ponte pers. comm. 1994). There is an established tradition of selling dugong meat in at least one city (Mackay), even though this is illegal (Mackay and Juperdilli Councils of Elders, pers. comm. 1996).

#### *Commercial gill-netting*

The by-catch of dugongs in gill nets is a significant source of anthropogenic mortality for these animals in the Great Barrier Reef Region. Although the magnitude of this impact has not been quantified, anecdotal evidence suggests that it is not sustainable. For example, of 14 dugong carcasses reported to management agencies between April and September 1996, at least eight were probable net kills (J. Slater pers. comm.). Net kills are difficult to confirm unless the animal is actually observed in the net as not all dugongs which have drowned in nets exhibit net marks).

There are 1024 fishers with net endorsements to work the east coast of Queensland; 272 fishers with endorsements for barramundi netting. Some (if not most) of the barramundi fishers are a subset of the net fishers (L. Gwynne pers. comm. 1995). According to the log-book program maintained by the Queensland Fisheries Management Authority, the commercial gill netting effort for the Great Barrier Reef Region was 7905 km net days in 1995: of which 1823 km net days were north of Cooktown, 6082 south of Cooktown. The effort in Shoalwater Bay where there has been a great deal of concern about dugongs drowning in nets was approximately 276 km net days, less than 4% of the total. These statistics assume a net length of 600 m. The actual effort will be less than this as: (1) many fishers set less than 600 m; and (2) these data refer to all 17 types of net used by commercial gill netters in Queensland, of which only two or three are recognised as particularly threatening to dugongs (G. Mandelkow pers. comm.).

The relationship between tides, bottom topography, turbidity and patterns of gill netting is likely to lead to increased mortality in relatively shallow bays such as Shoalwater Bay where seagrass is largely restricted to intertidal areas because of the large tidal range and high turbidity. Both dugongs and gill netters are forced to utilise intertidal areas on the high tide, which increases the chances that dugongs will be caught in nets there. Also, due to acoustic pollution from vessel engines (see below), dugongs are likely to be discouraged from utilising these seagrass meadows, and if they do, may be more at risk from vessel strikes.

Despite the beliefs of many members of Aboriginal communities, there is little evidence that many dugongs drown in commercial prawn trawls.

#### *Recreational gill netting*

Anecdotal evidence suggests that recreational gill netting is relatively common in northern Queensland waters despite its illegality. There are no data on these nets as a source of dugong mortality but we regard some such mortality as inevitable.

#### *Queensland Shark Control Program*

The Queensland Government spends in the order of \$1 000 000 per year on shark meshing contracts (Anon. 1992). Since nets were introduced in the mid 1960s, 541 dugongs have been caught in the Great Barrier Reef Region (Baden Lane, Queensland Department of Primary Industries, Forestry and Fisheries (QDPIFF) pers. comm. 1996), most of which died (Paterson 1990). Of these, 161 dugongs were caught off Cairns, an area where there are now so few

dugongs that the population cannot be estimated (Marsh and Saalfeld 1989, Marsh et al. 1994a); 241 were caught off Townsville (Paterson 1979). Currently, the effort in the Great Barrier Reef Region (Baden Lane, QDPIFF pers. comm. to P. McGinnity, Great Barrier Reef Marine Park Authority February 1996) for the shark meshing program is 720 km net days/year. All nets have been removed from Tannum Sands, Bundaberg and Rockhampton over the past three years. Nets remain at five locations near Cairns, two near Townsville and three near Mackay.

#### *Vessel strikes*

Vessel strikes are a major cause of mortality for Florida manatees (Marsh and Lefebvre 1994, Wright et al. 1995). Although there are few records of dugong deaths due to vessel strikes in Australian waters, increasing vessel traffic increases the likelihood that this will change. Areas where there are extensive shallow areas used by regionally important populations of dugongs close to existing or planned recreational boating facilities (e.g. in the Hinchinbrook Island region, north Queensland) are particularly at risk.

Pressures which could reduce the reproductive rate

#### *Habitat loss*

Seagrass ecosystems are very sensitive to human impact as reviewed by Fonseca (1987), Shepherd et al. (1989) and Poiner and Peterkin (1995). Seagrass beds may be destroyed directly by mining and trawling (Silas and Bastion-Fernando 1985), or lost through the effects of disturbances such as dredging, inland and coastal clearing and land reclamation. Other threats include herbicide runoff, input of sewage, detergents, heavy metals, hypersaline water from desalination plants and other waste products. Natural events such as cyclones and floods can cause extensive damage to seagrass communities through severe wave action, shifting sand, adverse salinity changes and light reduction (Heinsohn and Spain 1974; Kenyon and Poiner 1987; Preen et al. 1993; Preen and Marsh 1995; Preen et al. 1995). Most losses, both natural and anthropogenic, are attributed to reduced light intensity due to sedimentation and/or increased epiphytism from nutrient enrichment. In some cases, factors such as poor catchment management and sediment instability interact to make the processes more complex so that it is often difficult to separate natural and anthropogenic causes of seagrass loss. Recovery and recolonisation from large-scale losses of tropical seagrasses may take a decade or more (Poiner and Petersen 1995).

Experience from other parts of northern Australia, suggests that episodic large-scale losses of seagrass are likely to occur in the Great Barrier Reef Region in association with extreme weather events. In 1992-93, more than 1000 km<sup>2</sup> of seagrass disappeared from Hervey Bay adjacent to the southern boundary of the Great Barrier Reef Region (Preen and Marsh 1995). The cause of this loss is not known although it is thought that high turbidities resulting from the flooding of the Mary and Burrum Rivers and run-off from cyclone Fran were responsible (Preen et al. 1995). Similar diebacks have not been reported from the Great Barrier Reef Region, however, the absence of such reports does not mean that diebacks have not occurred. One of the features of seagrass diebacks is a reduction in the calving rate of the associated dugong populations. For example, the proportion of dugongs with calves declined in Hervey Bay from 22% in 1988 to 2.2% in 1993 (Preen and Marsh 1995) and 1.5% in 1994. In contrast to other surveys in which 11-13% of dugong sightings were calves, no calves were observed during the 1992 aerial survey of the southern Central Section in 1992. These results suggest that a dieback of seagrass of the magnitude and intensity of that in Hervey Bay had occurred in this area. The Burdekin flood of 1991 may have caused some seagrass dieoff and resultant local lowering of the calving rate.

Approximately 3000 km<sup>2</sup> of coastal (< 15 m) seagrass have been mapped in the Great Barrier Reef Region to date and at least 2000 km<sup>2</sup> of deepwater seagrass have been estimated so far. The area of seagrass on the tops of reefs has not been estimated. Virtually all of these areas are potential dugong habitat. Lee Long and Coles (this volume) rate the impacts on seagrasses in the Great Barrier Reef Region as low to moderate. The area north of Cooktown has by far the largest areas of seagrass meadows in the Region. Most are remote from known anthropogenic influences other than trawling (Morissette 1992) and almost all the shallow coastal seagrass in this Region is zoned as free from trawling. Other anthropogenic activities tend to be concentrated in three areas: near the Flinders Island Group, the Lockhart River area and in the Escape River. All existing activities apparently have a minimal influence on the surrounding seagrass beds.

In contrast, of the meadows known to support dugongs along the urban coast of the Great Barrier Reef Region south of Cooktown, only those in Bowling Green, Upstart and Shoalwater Bays are relatively free from anthropogenic disturbance (Marsh et al. 1994b). Twenty-seven percent of meadows are within 5 km of a development or a waste outlet (Morissette 1992). The most prominent industrial sources occur near Lucinda (sugar loading jetty), Townsville (Greenville Nickel Refinery), Abbott Point (coal loading facility), Mackay (sugar mills) and Gladstone (refineries and port). Continual urban and agricultural expansions present a chronic threat in this region. There have been anecdotal reports of loss of seagrass beds along the urban coast during recent years. This is coincident with a period of rapid development and resultant expansion of boating facilities (Morissette 1992). The effects of trawling on dugong habitat in the southern Great Barrier Reef are considered minimal as it does not occur near the major seagrass beds in the region.

#### *Chemical pollutants*

Dugongs in northern Australia accumulate high levels of heavy metals (Denton et al. 1980), but have low levels of organohalogen compounds (Heinsohn and Marsh 1978) in their bodies. There is no evidence to suggest that the accumulation of heavy metals is unnatural or particularly harmful to dugongs, as it appears to be a response to the manner in which seagrasses store these minerals. However, metal levels can be so high that some dugong organs may be unsuitable for human consumption. Where ports to load metal ores are established in areas with significant populations of both dugongs and Indigenous hunters this is an issue that needs to be addressed in environmental impact studies. This issue has largely been neglected in the Great Barrier Reef Region to date even though both Townsville and Gladstone are major ports for metal transfer.

Four dugongs from Townsville were analysed for pesticides in 1978. Lindane was detected in livers of all animals. Low levels of dieldrin were detected in the liver of two animals (Heinsohn and Marsh 1978).

#### *Acoustic pollution*

There has been no attempt to study any effect of acoustic pollution from boat traffic in the Great Barrier Reef Region. However, in Moreton Bay near Brisbane, dugongs seem to avoid shallow areas where the level of vessel traffic is high, despite some areas being historically important sites for commercial exploitation of dugongs (Preen 1993). It appears that the noise of vessel traffic discourages dugongs from using these areas. Acoustic pollution could be particularly important in areas such as the Mackay/ Capricorn Section where the tidal range is high and there is little seagrass below the low tide mark as high levels of vessel traffic could prevent dugongs from being able to utilise available intertidal seagrass meadows.

Defence Force exercises are conducted at several locations within the Great Barrier Reef Region. The use of explosives in Shoalwater Bay, the most important dugong habitat in the Great Barrier Reef Region south of Cape York, is of most concern to dugong conservation. The exercises include surface and underwater explosion of bombs, amphibious landings and firing of shells (Great Barrier Reef Marine Park Authority 1996). There have been no reports of direct mortality to dugongs from undersea detonations. Such explosions have the potential to cause indirect effects including injury or social disturbance to the dugongs or habitat damage (Dunstan and Lewis 1980).

State

Research to determine status

*Aerial survey methodology: transect technique*

Aerial surveys have been conducted Great Barrier Reef Region since the 1970s as a part of ongoing studies of the distribution and abundance of dugongs in Australian waters. The early surveys mainly consisted of a single flight parallel to the coast and the data were presented as uncorrected counts. This technique was replaced in the mid-1980s, by strip transects flown at constant height and speed as detailed by Marsh and Sinclair (1989a, b) and in the reports of the surveys. With the revised technique, the population estimates have been corrected for perception bias (the proportion of animals visible in the transect which are missed by observers) and standardised for availability bias (the proportion of animals below the surface that are invisible due to water turbidity) using survey-specific correction factors. Because the availability correction factors are conservative, the population estimates are underestimates. The corrections for availability bias do not completely compensate for differences in sightability due to weather conditions even though all surveys have been conducted in good weather conditions (Beaufort Sea State less than three). Accordingly, the bias has been further adjusted using Beaufort Sea State as a covariate in comparisons of repeat survey results of the same area.

*Problems in detecting trends*

Dugong densities when measured at the spatial scale of aerial survey blocks (hundreds of km<sup>2</sup>) are generally low (< 1 per km<sup>2</sup>, Marsh et al. 1994a). Thus the number of individuals occupying a management unit such as a bay is typically several hundred or fewer. If decisions about the status of the dugong are to be made at temporal and spatial scales useful to management, it would be useful to be able to detect chronic declines in local populations of several hundred dugongs before numbers have been seriously depleted.

Marsh (1995b) used the data from 91 survey blocks from 13 surveys for dugongs to estimate the minimum detectable rate of decline that would be detected with high statistical power ( $\beta=0.05$ ) for 10 annual surveys for dugong populations of various sizes. The minimum detectable rate of decline is high for small populations. For example, for a population of 1000 animals the minimum rate of decline detectable by 10 annual surveys would be 8.1% per year ( $\alpha=0.05$ ). After 10 surveys (nine years), the population would have declined to 47% of its size at the time of the first survey.

A low level chronic decline in a small population of dugongs will take many years to detect even if surveys are conducted every month. For example, Marsh (1995b) calculated that it would take 10.1 years of monthly surveys to detect a 5% p.a. decline in a population of 100 dugongs within the accepted levels of statistical error. These figures indicate that using present survey techniques it will be impossible to detect a chronic low-level decline in dugong numbers



at a local scale within an acceptable time without a very high frequency of surveys and intensity of sampling.

### *Status*

For logistical reasons, the aerial surveys to determine the status of the dugong in the Great Barrier Reef Region have been conducted in two series: one covering the remote coasts north of Cape Bedford near Cooktown, the other the urbanised coasts south of Cape Bedford.

#### *Northern Great Barrier Reef - Hunter Point to Cape Bedford*

This region was surveyed in 1984, 1985, 1990 and 1995 using the same techniques. In 1995, the survey resulted in a minimum population estimate of  $9444 \pm \text{s.e. } 1381$  dugongs at an overall density of  $0.37 \pm \text{s.e. } 0.054$  dugongs  $\text{km}^2$  for the entire region (Corkeron and Marsh 1996) compared with  $8110 \pm \text{s.e. } 1037$  dugongs in 1985 and  $10\ 471 \pm \text{s.e. } 1578$  dugongs in 1990. This region is the most important dugong habitat within the Great Barrier Reef and one of the most important in Australia (Marsh and Saalfeld 1989; Marsh et al. in press).

There was no significant difference between dugong densities in 1985, 1990 and 1995 suggesting that dugong numbers are being maintained in the northern Great Barrier Reef. However, the survey techniques employed are appropriate for depicting only macroscale trends and cannot accurately detect changes on a local spatial scale. For instance, it would be inappropriate to use these macroscale aerial survey techniques to provide definitive evaluations of changes in dugong populations in the areas that are used for hunting by the Hopevale and Lockhart River communities.

Dugongs tend to occur in inshore waters throughout the region. Extensive deepwater seagrass meadows are also important to dugongs in the northern Great Barrier Reef, especially in Princess Charlotte Bay and in the Starcke River area (Lee Long et al. 1993; Coles et al. 1995). Dugongs have also been sighted on some midshelf reefs. In 1995, the highest densities were observed in the areas off the mouth of the Starcke River, the inshore area in the vicinity of Campbell Point and Cape Sidmouth and in Shelbourne Bay. Marsh et al. (in press) rate the status of the dugong in this region as 'lower risk - conservation dependent' in the belief that Indigenous hunting could lead to local depletions of dugongs in areas close to hunting communities if a co-management regime is not developed with local Indigenous groups as a matter of urgency.

#### *Cooktown - southern boundary*

Aerial surveys were conducted in this area during 1986, 1987, 1992 and 1994. The number of dugongs sighted between Dunk Island and Cape Bedford was insufficient to estimate the population size in either 1986 or 1992 and was not attempted in 1994. These surveys indicate that the number of dugongs in the region has declined by over the past eight years from an estimated  $3479 \pm \text{s.e. } 459$  in 1986-87 to  $1857 \pm \text{s.e. } 292$  in 1992 and  $1682 \pm \text{s.e. } 236$  in 1994 (Marsh et al. 1995a). The population estimate derived from the 1994 surveys was only 48.4% of the 1986-87 population estimate. Comparison of the results of the 1986-87, 1992 and 1994 surveys indicates that the decline in dugong numbers was spread throughout much of the region, but was most serious between Cape Cleveland and Broad Sound.

In general, dugongs were sparsely dispersed throughout this region. This is not surprising as the known area of inshore seagrass (about  $550 \text{ km}^2$ ) is small in comparison with the northern regions (over  $4400 \text{ km}^2$ , Lee Long et al. 1993; Coles et al. 1995) and individual beds are relatively small. The largest numbers of dugongs were found near Hinchinbrook Island and in

Shoalwater Bay, the latter being the most important dugong habitat in the southern Great Barrier Reef Region.

Marsh et al. (in press) rate the status of the dugong in this region as 'critically endangered' because dugong numbers have declined by approximately 50% over the past eight years. Over a large section of the region, this decline is over 80%. Other evidence (catches in shark nets, reports from Aboriginal hunters, comparisons with earlier reports by scientists) suggests that the decline has been occurring since the 1960s or even earlier. If a population of animals has an 'observed, estimated, inferred or suspected reduction of at least 80% over the last 10 years or three generations, whichever is longer' (IUCN 1995, p. 15) it qualifies for this category. Three generations of dugongs equates to at least 90 years, as according IUCN Red List criteria, a generation is 'the average age of parents in the population' (IUCN 1995, p. 10).

### **Response**

Generic conservation measures.

Because of the complex jurisdictional arrangements and the dugong's use of intertidal, subtidal and estuarine habitats, the management of dugongs in the Great Barrier Reef Region relies on a close working arrangement between the Great Barrier Reef Marine Park Authority, the Queensland Department of Environment, the Queensland Department of Primary Industries, Fisheries and Forestry, the Queensland Fisheries Management Authority and stakeholder groups including local government, Indigenous peoples, commercial and recreational fishers, conservation groups and local communities. There is an urgent need to acknowledge that the dugong is an animal of special significance to Indigenous peoples and that their interest extends far beyond the management of hunting. They must be empowered to take a leading role in the development of all dugong management initiatives. This has not been done to date.

Various management agencies have prepared documents relating to dugong conservation in the Great Barrier Reef Region. The following documents are in draft format to enable discussion and comment:

- A Management Program for the Conservation and Management of the Dugong (*Dugong dugon*) in Queensland 1994–1999 has been prepared by the Queensland Department of Environment (Queensland Department of Environment 1994);
- The Turtle and Dugong Conservation Strategy for the Great Barrier Reef Region prepared by the Great Barrier Reef Marine Park Authority (Ellis 1994). This document has effectively been adopted as policy by the Authority;
- An Action Plan for Dugong Conservation in Australia has been sponsored by the Australian Nature Conservation Agency (Marsh et al. in press);
- Plan of Management for the conservation of dugong (*Dugong dugon*) in Shoalwater Bay prepared by the Great Barrier Reef Marine Park Authority (1996).

These documents acknowledge that as it is impossible to disaggregate the relative importance of the multiple impacts on dugongs in the Great Barrier Reef Marine Park, it is necessary to address all of them. This approach is also necessitated by the reluctance of the stakeholders causing the impacts to respond unilaterally. The responses to date are outlined and evaluated below. The Dugong and Turtle Review Group established by the Great Barrier Reef Marine Park Authority is scheduled to meet regularly to develop further an interagency program for dugong recovery in the Region. The role of Indigenous people in the development of this program has not been clarified.

## Responses to specific pressures

### *Traditional harvest*

In the Great Barrier Reef Region, traditional hunting can be carried out under permit in all zones except Preservation Zones. A large inshore Preservation Zone was established primarily to protect dugongs in the Far Northern Section of the Park in the region south of Cape Melville. Some modifications of the boundaries of this Zone are likely as a result of the rezoning of this Section but hunting will still be banned in coastal waters over at least one third of the coast between Murdoch Island and Cape Melville. Discussions will also be held between traditional owners and the Queensland Department of Environment with a view to citing some key dugong areas in the Great Barrier Reef as critical habitats under the Queensland *Nature Conservation Act 1992*.

In conjunction with the Queensland Department of Environment, the Great Barrier Reef Marine Park Authority has been consulting with Aboriginal and Torres Strait Islander groups for over a decade regarding the traditional use of dugongs. Consultation initially focused on the Hopevale and Lockhart River communities in Cape York (Smith and Marsh 1990) but has recently involved other groups including urban Indigenous peoples. In view of the development of the outstation movement and the improvement of roads on Cape York, the future sustainability of Indigenous dugong hunting in the remote areas of the Great Barrier Reef Region will depend on the development of effective co-management arrangements. These need to be developed as a matter of urgency.

The Great Barrier Reef Marine Park Authority entered into discussions with Indigenous groups in urban Queensland and established Councils of Elders to address traditional hunting issues (Cook 1994) in response to local dissatisfaction about lack of involvement in the management of the Park. These Councils now handle individual applications for traditional hunting of dugongs and turtles and are responsible for issuing Authorities to hunters. The hunters are required to submit data returns to their Council which hands them to the management agencies who, in turn, supply the Councils with relevant information (Cook 1994). Since they became aware of the decline of the dugong in the southern Great Barrier Reef Region, most Councils have voluntarily agreed not to harvest dugongs and there is currently no permitted take south of Cooktown. The Darumbal–Noolar Murree Aboriginal Corporation for Land and Culture of Rockhampton have signed a formal agreement with the Great Barrier Reef Marine Park Authority and have agreed that it would be inappropriate for Indigenous hunting to occur in that part of the Great Barrier Reef Marine Park within the Shoalwater Bay Military Training Area. The Agreement will be reviewed by both parties following the aerial survey of the region scheduled for 1999.

There is an urgent need to develop culturally appropriate education programs regarding dugong conservation for Indigenous peoples throughout the Reef Region.

### *Gill-netting*

At least one non-government conservation organisation has indicated an intention to prepare a nomination for gill-nets as key threatening process under the *Endangered Species Protection Act 1992*. The dugong is not currently listed under this Act but two non-government organisations have nominated that it be listed as vulnerable, a recommendation also made by Marsh et al. (in press).

Gill-netting is banned in some inshore waters of the Great Barrier Reef Region as a result of Commonwealth or State Marine Park Zoning. Since 1995, gill-netting in Shoalwater Bay has

been subject to stricter control under Queensland fisheries legislation. These controls will be reviewed on the basis of the results of current research to document the usage of Shoalwater Bay by dugongs. The effectiveness of all these arrangements is compromised by the complex jurisdictional arrangements across the dugong's inshore habitats.

The Queensland Commercial Fishermen's Association has acknowledged that the incidental capture and drowning of dugongs in gill-nets is a problem. This organisation has advocated the development of an education program to inform commercial fishers on aspects of dugong conservation biology and management and on methods to minimise dugong take. This program is being developed with the assistance of the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef. It is hoped that attendance at this program will become part of the Trainee Master Fisherman's course and compulsory for Master Fishermen with net endorsements. This initiative is important as many fishers do not appreciate the seriousness of the 'dugong problem' or the way it threatens the future of gill netting in the Great Barrier Reef Region.

The Queensland Commercial Fishermen's Association has also suggested that mechanisms be developed to enable commercial fishers to donate accidentally drowned dugongs to local Indigenous groups. While this initiative is welcomed, it will need to be carefully monitored.

Reduction in the number of dugongs killed in gill nets will require measures to reduce the probability of: (1) dugongs tangling in gill nets, and (2) tangled dugongs drowning. Research is in progress to identify the areas where dugong density and gill netting effort are both high as a prelude to developing management measures to minimise dugong capture. This may include the closure of some areas where it is impossible to police fisheries regulations effectively. However, the use of closures without a consequent reduction in fishing effort will move rather than solve the problem (as has been shown for Hector's dolphin in New Zealand, E. Slouten, pers. comm. 1996). Solving the second problem will require extensive negotiations with fishers in order to produce effective changes in fishing practices. It will be critical to involve the fishers in the solution of the 'dugong problem' as it is relatively easy for them to dispose of dugong carcasses in order to give the impression that the problem has gone away.

The management planning program currently being coordinated by the Queensland Fisheries Management Authority provides an opportunity to introduce measures to minimise dugongs drowning in gill nets. Management measures that need to be considered include:

- reducing latent effort through a buy-back scheme or restricting gill netting endorsements to fishers 'who could demonstrate a significant commercial level of involvement over a three year period' (Recreational Fishing Consultative Committee 1993, p. 18);
- introducing area restrictions on individual gill netting endorsements to solve the problem of fishers encountering dugongs when they move into areas which they do not know well;
- gear modifications;
- reducing the use of illegal gill nets by tagging commercial gill nets with individual identifiers;
- introducing an amnesty period for the surrender of illegal gill nets;
- closing areas where regulations cannot be enforced.

#### *Queensland Shark Control Program*

After this Program was reviewed in 1992, nets were replaced with drumlines at several locations in the Great Barrier Reef. All nets were removed from Tannum Sands, Bundaberg and Rockhampton. The Program is currently being reviewed again with a view to addressing the issue of dugong by-catch.

### *Vessel strikes*

There have been no specific measures introduced to minimise vessel strikes. A boat management plan has been promised for the Hinchinbrook Channel which is the area of dugong habitat in the Region most similar to the intracoastal waterways in Florida where boat strike is the major source of manatee mortality (Wright et al. 1995). This plan is to be based on detailed information on dugong habitat use in the area obtained from dugongs fitted with satellite transmitters.

### *Habitat loss*

Coastal dugong habitats in the Great Barrier Reef north of Cape Bedford are generally highly protected by current zoning arrangements. Over 76% of the seagrass beds that were known prior to 1995 from this region have a protection equivalent to or higher than a terrestrial national park. Most of the coastal seagrass beds without protection lie inshore to the west of the Great Barrier Reef Marine Park boundaries. These beds are scheduled to be protected by the Queensland Cape York Marine Park. In contrast, the extensive beds of seagrass offshore which have been identified recently are relatively poorly protected (Coles et al. 1995). Overall the habitat is protected in only 59% of the area in which dugongs have been sighted in the northern region of the Park and only 32% of this area has the protection equivalent to or higher than a terrestrial park.

Seventy-two percent of the known seagrass meadows in the southern half of the Great Barrier Reef Region are protected by Queensland Marine Parks, the Great Barrier Reef Marine Park Authority or Queensland Fisheries Habitat Reserves (Morissette 1992). In addition, the Commission of Inquiry into the Shoalwater Bay area, established under Section 11 of the Commonwealth *Environment Protection (Impact of Proposals) Act 1974* recommends that the marine parts of the Shoalwater Bay areas should be incorporated into marine parks and management responsibility should be shared between the Great Barrier Reef Marine Park Authority and the Queensland Department of Environment according to existing agreements between those agencies.

However, 38% of the habitats where dugongs have been sighted during aerial surveys in the region south of Cape Bedford are not currently protected from trawling as they lie outside of a Marine Park or Reserve or within General Use 'A' zones. Only 4% of the habitats where dugongs have been sighted have a protection of greater than General Use 'B' as compared to 32% in the northern Great Barrier Reef. Dugong habitats in this region are not nearly as well protected as in the northern Reef even though the anthropogenic impacts are much greater in the south. A dugong sighted in the northern region in the early 1990s was 11 times more likely to be protected by a zone with a higher protection than General Use 'B' than a dugong in the southern region (Marsh et al. 1995a).

The Great Barrier Reef Marine Park Authority propose to fund the resurvey of seagrass meadows in key dugong areas off the urban coast of Queensland to determine their extent and status. The development of a cost-effective protocol to monitor the status of seagrass beds in the Great Barrier Reef Region is urgently required.

### *Chemical pollutants*

We know of no contemporary research or management actions to examine whether chemical pollution is a problem for dugongs in the Great Barrier Reef Region.

### *Acoustic pollution*

We know of only two attempts to address this impact in the Great Barrier Reef Region:

- a recent cessation of Defence activities involving underwater explosions in important seagrass meadows around Triangular Island in Shoalwater Bay; and
- the promise of a management plan to control the increase in boat traffic that is expected to follow the development of marinas in the Hinchinbrook Island Region.

### **Conclusion**

The failure to maintain dugong numbers along the urbanised coast of the Great Barrier Reef Region indicates that the dugong and its seagrass habitats require additional protection if Australia is to meet its international responsibilities for the management of dugongs. As it is not possible to disaggregate the relative importance of the various threatening processes, it will be necessary to address the problems of habitat loss, traditional hunting and incidental mortality in commercial gill nets and in shark nets set for bather protection simultaneously. This requires interagency cooperation to develop coordinated programs of management, education and research as a matter of urgency.

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# Crocodiles in the Great Barrier Reef World Heritage Area

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## Abstract

The Great Barrier Reef World Heritage Area is not normally considered to be crocodile habitat; however, crocodiles do inhabit the area. A data set for the area has been compiled from several sources, including incidental observations, published records and surveys of islands of the northern Great Barrier Reef. Records indicate that crocodiles occur at low density over a wide area of the Far Northern Section of the Great Barrier Reef. The majority of sightings are of crocodiles basking on remote coral rubble banks, coral cays and continental islands; no nesting has been recorded on any offshore island. The crocodiles sighted on the reef are usually in the 1-2 m size range with only an occasional report of a larger crocodile, usually near shore. Crocodiles found on the reef are considered temporary migrants from the coastal river systems.

Given the biological and habitat requirements of crocodiles, the Great Barrier Reef World Heritage area is an inappropriate geopolitical area in which to focus extensive efforts for the conservation management of crocodiles in eastern Queensland. The primary habitat for crocodiles on eastern Cape York Peninsula occurs below the 250 m contour of the Great Dividing Range north of Cooktown with Lakefield National Park and Jardine River National Park providing critical habitat. The continued survival of crocodiles depends on the conservation management of coastal habitat and the amelioration of threatening processes including the reduction of incidental and intentional mortality.

## Introduction

Although the Great Barrier Reef World Heritage Area (GBRWHA) is not normally thought of as being crocodile habitat, the estuarine crocodile, *Crocodylus porosus*, does occur in the area because of its proximity to primary crocodile habitat.

The primary habitat of *C. porosus* in Queensland occurs in the coastal wetlands and rivers of the Gulf of Carpentaria and Cape York Peninsula (Taplin 1987). The myriad of mangrove lined rivers provide complex habitat for crocodiles and their prey; coastal wetlands provide areas for reproduction and suitable habitat for smaller crocodiles. On the eastern coast, populations north of Cairns remain relatively undisturbed by human activity; however, populations south of Cairns have been fragmented by development in the coastal zone through alteration of wetland drainage patterns, agriculture, reclamation, recreational use and by direct management of 'problem crocodiles' (Taplin 1987).

Taplin (1987) provided a detailed analysis of the distribution and factors influencing the survival of estuarine crocodiles in Queensland but he did not consider *C. porosus* in the Great Barrier Reef (GBR) province. This report reviews records of *C. porosus* in the northern portion of the GBRWHA and considers them in the context of pressure, status, response and management within the GBRWHA.

## Methods

Records of *C. porosus* occurring in the GBRWHA have been compiled from several sources, including personal observations, published records and unpublished observations made during

surveys of island fauna and flora by Queensland Department of Environment staff. The records are considered to be incomplete because most sightings by fishers and travellers go unreported and because survey coverage of the islands is uneven. However, a sufficient number of records from reliable sources have been accumulated to provide a basis for generalisation. Records of crocodiles at the mouth of coastal rivers and/or adjacent to the mainland coast have been excluded.

Even though crocodiles are easy to recognise, their total length is often over estimated, particularly for larger individuals; among smaller individuals length is usually estimated more accurately (see Choquenot and Webb 1987 for discussion). Calculations based on estimated length have been made using the lowest value in the estimated size range (e.g. for an estimated total length of between 1.5 and 2 m, the value of 1.5 m was used in calculations) to correct for over estimation; where necessary the length estimated by the original observers was converted to metres. Often the only evidence of the presence of crocodiles on an island is a set of tracks (or a slide) in the sand; such evidence is proof of occurrence but is not reliable for estimating size. These are reported as tracks only.

The distance from the location of a crocodile to the nearest island to the west and to the nearest point on the mainland was measured using callipers on Great Barrier Reef Marine Park Authority zoning maps (Cockburn, BRA Q102; Weymouth Bay, BRA Q103; Tjou Reef BRA Q104; Princess Charlotte Bay, BRA Q105). Distances were rounded to the nearest 0.5 km.

All means are reported  $\pm$  their standard deviation, range and sample size (n values).

## Results

Of the 84 sighting reports of crocodiles (or their tracks) on GBR islands and cays covering the period between December 1976 and May 1995, 55 (65.5%) were of crocodiles, rather than just tracks (34.5%).

Crocodiles (or their tracks) have been recorded on 29 coral cays and continental islands of the Far Northern Section of the Great Barrier Reef Marine Park extending from Frigate Cay (10°47.8'N, 142°58'E) near the northern boundary to Clack Island (14°04'N, 143°02.2'E) in Princess Charlotte Bay (Table 1). The distribution of crocodiles in the GBRWHA probably extends further south than the four degrees of latitude indicated by the available records.

The types of islands on which crocodiles (or their tracks) were found included sand cays (n=18), low wooded islands (n=5) and high continental islands (n=6) (Table 1); the general vegetation of the islands varied from grass and sand (n=12 islands) to forest surrounded by sandy beach (n=6 islands) to fringing mangroves (n=11 islands) (Table 1).

The mean area of islands on which crocodiles (or their tracks) were found was 17.3 ha ( $\pm$  6.48, range=0.5-182.1 ha, n=29). With four exceptions (Sir Charles Hardy Group, 182.1 ha; Gore Island, 68.8 ha; Raine Island, 40.5 ha; Clerke Island, 32.5 ha) the islands used by crocodiles were less than 30 ha in area (Table 1).

Most of the islands on which crocodiles were reported were within sight of another island to the west, the direction toward the mainland. The mean distance from the location of the crocodile to the nearest island to the west was 7.6 km ( $\pm$  6.8, range=0.5-28, n=26), indicating that most crocodiles did not cross vast distances of open water to reach the place where they were recorded.

**Table 1.** Crocodiles found on islands of the Great Barrier Reef World Heritage Area during the redbill survey of 31 islands, (arranged North to South by Latitude). Type Codes: LW = Low Wooded, VSC = Vegetated Sand Cay, HC = High Continental, (MV) = Minimal Vegetation, (G) = Grassland, (F) = Forested, (G/S) = Grass and Shrub. \* = No Data Available. KM to Island = Kilometres to nearest island to the west; KM to Land = Kilometres to nearest point of the mainland to the west

ISLAND	LAT (S)	LONG (E)	GAZETTAL NUMBER	DATE	TYPE	AREA	KM to Island	KM to Land	#	NOTES
Frigate Cay	10 47.8	142 58	10-338		VSC (G)	1	28	34	2	Tracks only
Sinclair Island	11 06.6	143 01.1	11-026	28/10/94	VSC (G)	4.1	7	25	1	Track only
Unnamed Reef Cay	11 09.7	143 04.5	11-034	4/12/87	VSC (G)	<2	7	30.5	1	1.5m
Milman Islet	11 10.1	143 00.8	11-035	11/12/76	VSC (F)	22.7	8	24	2	1x2.2 m, 1x1.8 m
Milman Islet	11 10.1	143 00.8	11-035	6/12/78	VSC (F)	22.7	8	24	4	1x2 m, 3 track
Milman Islet	11 10.1	143 00.8	11-035	19/06/91	VSC (F)	22.7	8	24	1	Track only (40 cm width)
Milman Islet	11 10.1	143 00.8	11-035	14/01/94	VSC (F)	22.7	8	24	1	2m
Aplin Islet	11 11.0	143 01.0	11-035	15/02/91	LW (F)	4.9	3	26	1	1.5-2m
Douglas Islet	11 14.1	142 59.7	11-038	8/12/85	VSC (F)	2.8	7.5	20	2	1x1-1.25m, 1x1.5-2m
Cairncross Islets	11 14.5	142 55.6	11-010	21/06/91	VSC (F)	20.2	5.5	13.5	4	3x1 m, 1x1.25 m
Bushy Island	11 14.9	142 52.3	11-009	9/05/95	VSC (F)	10.1	*	8.5	1	1.2m, under 25 reef heron nests
Chomondeley Islet	11 22.6	143 03.5	11-052	13/02/91	VSC (G)	0.5	3.5	21	2	Tracks only, 1 x large, 1 x small
Chomondeley Islet	11 22.6	143 03.5	11-052	5/04/92	VSC (G)	0.5	3.5	21	1	Track only
Jardine Islet	11 22.8	143 01.9	11-053	2/12/89	VSC (G)	5.3	7.5	18	1	Track only
Halfway Islet	11 22.9	142 57.9	11-013	9/12/85	VSC (F)	2.5	*	11	1	1.2m
Wallace Islet	11 27.0	143 02.2	11-055	9/12/85	VSC (G/S)	2.2	3.7	20	2	1x1-1.2m, 1x2-2.5m
Wallace Islet	11 27.0	143 02.2	11-055	30/03/86	VSC (G/S)	2.2	3.7	20	1	2.75m
Wallace Islet	11 27.0	143 02.2	11-055	13/12/88	VSC (G/S)	2.2	3.7	20	2	1x2.5 m, 1x Track (larger)
Wallace Islet	11 27.0	143 02.2	11-055	2/12/89	VSC (G/S)	2.2	3.7	20	1	Track only
Wallace Islet	11 27.0	143 02.2	11-055	22/06/91	VSC (G/S)	2.2	3.7	20	2	Tracks only (1x30 cm and 1x 20 cm width)
Wallace Islet	11 27.0	143 02.2	11-055	6/12/93	VSC (G/S)	2.2	3.7	20	1	Track only
Wallace Islet	11 27.0	143 02.2	11-055	28/10/94	VSC (G/S)	2.2	3.7	20	1	2-2.5m
Wallace Islet	11 27.0	143 02.2	11-055	10/05/95	VSC (G/S)	2.2	3.7	20	1	1.5m
Little Boydong Island	11 28.8	143 02.0	11-061	2/12/87	VSC (G)	2.8	1.5	21	1	Track only
Little Boydong Island	11 28.8	143 02.0	11-061	5/04/92	VSC (G)	2.8	1.5	21	1	Track only
Boydong Island	11 29.2	143 01.6	11-062	12/02/91	LW	10.5	13.7	20	1	1.5-2m
Boydong Island	11 29.2	143 01.6	11-062	10/12/85	LW	10.5	13.7	20	2	1x1.5-1.8m, 1x1-1.2m
Boydong Island	11 29.2	143 01.6	11-062	13/12/88	LW	10.5	13.7	20	1	2.5m
Boydong Island	11 29.2	143 01.6	11-062	10/05/95	LW	10.5	13.7	20	1	1.5m
Boydong Island	11 29.2	143 01.6	11-062	24/08/95	LW	10.5	13.7	20	1	2m

Table 1 cont.

ISLAND	LAT (S)	LONG (E)	GAZETTAL NUMBER	DATE	TYPE	AREA	KM to Island	KM to Land	#	NOTES
Hannibal West Island	11 35.5	142 56.0	11-136	11/05/95	LW	0.8	4	9.5	2	1x1.8-2m, 1x1.5-1.8m
Raine Island	11 36	144 1	11-243	3/12/77	VSC (G/S)	40.5	20	96	1	1.35 m
Saunders Islet	11 42.2	143 10.8	11-165	8/06/90	VSC (MV)	8.1	13	24	1	1.5m
Saunders Islet	11 42.2	143 10.8	11-165	12/05/95	VSC (MV)	8.1	13	24	2	1x1 m, 1x1.8 m
Bushy Islets	11 43.7	142 59.0	11-138	11/05/95	VSC (MV)	10.1	3	13	1	2-2.5m
MacArthur Islands	11 43.7	142 59.0	11-138a	18/07/85	LW	12.2	4	15	5	1x1.2 m, 4xTracks
MacArthur Islands	11 43.7	142 59.0	11-138a	9/06/90	LW	12.2	4	15	1	1.5m
Bird Island (North)	11 46.0	143 05.4	11-167	8/12/76	LW	202	11	15	2	1x1.8 m, 1 track
Bird Island (North)	11 46.0	143 05.4	11-167	11/02/91	LW	202	11	15	1	1.25-1.75m
Bird Island (North)	11 46.0	143 05.4	11-167	18/07/85	LW	20.2	11	15	1	1.2m
Bird Island (North)	11 46.0	143 05.4	11-167	11/12/85	LW	20.2	11	15	1	1.2m
Bird Island (North)	11 46.0	143 05.4	11-167	8/06/90	LW	20.2	11	15	1	2m
Bird Island (North)	11 46.0	143 05.4	11-167	11/05/95	LW	20.2	11	15	1	1.8-2m
Magra Islet	11 51.6	143 17.1	11-174	30/11/87	VSC (G/S)	3.6	11.5	0.4	4	Tracks only
Magra Islet	11 51.6	143 17.1	11-174	2/04/89	VSC (G/S)	3.6	11.5	0.4	1	1m
Sir Charles Hardy Group	11 54.3	143 27.8	11-184	12/12/85	HC	182.1	20.5	25	1	1.8m
Sir Charles Hardy Group	11 54.3	143 27.8	11-184	29/11/87	HC	182.1	20.5	25	1	1.5m
Sir Charles Hardy Group	11 54.3	143 27.8	11-184	6/12/87	HC	182.1	20.5	25	2	1x2.4 m, 1x1.8 m
Clerke Island	11 58.5	143 17.2	11-188	25/12/84	HC	32.5	2.5	5	2	1x1.6-1.8m, 1x1-2m
Gore Island	11 59.3	143 15.0	11-194	26/12/84	HC	68.8	1	1.5	1	0.6m
Gore Island	11 59.3	143 15.0	11-194	19/07/85	HC	68.8	1	1.5	1	1.2-1.5m
Orton Island	11 59.8	143 14.4	11-195	25/10/94	HC	8.1	1	1.5	1	2-2.5m
Farmer Island	12 14.6	143 13.5	12-012	10/07/88	VSC (F)	2.4	2	12.5	1	Track only
Farmer Island	12 14.6	143 13.5	12-012	15/06/91	VSC (F)	2.4	2	12.5	1	1-1.2m
Rocky Island	12 53.2	143 32.8	12-125	25/11/87	HC	6	0.5	3	1	1.5m
Wilkie Island	13 46.5	143 38.2	13-091	9/07/92	VSC (MV)	8.1	*	10.5	1	Track only
Clack Is.	14 04	144 15.6	14-017	25/06/88	HC	7	8.5	24	1	2m
Clack Is.	14 04	144 15.6	14-017	12/07/89	HC	7	8.5	24	1	2.5m

On average, the mainland was just over twice the distance away from the location of the crocodile than the nearest island. The mean distance from the location of a crocodile to the nearest point on the mainland to the west was 18.9 km ( $\pm 17.3$ , range=0.5-96 km, n=29), indicating that most crocodiles were located on islands that were close to the mainland. However, crocodiles do occur on cays along the outer reef edge, at least occasionally, as indicated by a 1.5 m *C. porosus* captured at Raine Island (and photographed with the tower in the background) approximately 96 km from the mainland (Limpus 1980). If the distance to Raine Island (96 km) is excluded from the calculation, the mean distance to the mainland changes to 16.2 km ( $\pm 9.1$ , range=0.4-28 km, n=28); the reduction in the standard deviation indicates that the majority of islands on which crocodiles have been found are located close to the mainland.

Crocodiles occur at low numbers on the islands in the GBRWHA (Table 1). Individual crocodiles (or their tracks) were reported on islands 35 times (71% of records). Two crocodiles (or recent signs that could be linked to different individual crocodiles) on the same island were recorded 11 (22%) times and four crocodiles on the same island were reported twice (4%). The greatest number of crocodiles found on any island was five (one sighted, four different tracks) on MacArthur Island.

Crocodiles do not occur on every island in the northern GBRWHA; crocodiles were encountered on about 25% of the islands examined during systematic surveys. For example, during a survey of fauna on 12 GBR cays (nine inner, three outer), Limpus (1980) reported crocodiles (or evidence of crocodiles) from two inner (22%) and one outer (33%) reef islands, including one 1.5 m crocodile captured at Raine Island. During a 1991 survey of flora and fauna on 22 inner GBR islands from Chapman Island north to Johnson island (Miller et al. 1995) crocodiles (or evidence of crocodiles) were found on six (27%) islands (Table 1).

The crocodiles sighted on the reef are usually in the 1-2 m size range with only an occasional report of a larger crocodile (Table 1). The larger animals tend to be located only close to the mainland. Based on the minimum size of the 55 crocodiles for which total length was estimated, only one was less than 1 m; among the others 19 (34.5%) were 1-1.5 m, 20 (36.3%) were 1.5-2 m, 11 (20%) were 2-2.5 m and 4 (7.3%) were greater than 2.5 m (Fig. 1). A total of 40 crocodiles (72.7%) were less than 2 m in total length; 15 (27.3%) were longer.

No nesting was recorded on any of the 29 islands for which crocodile records exist.

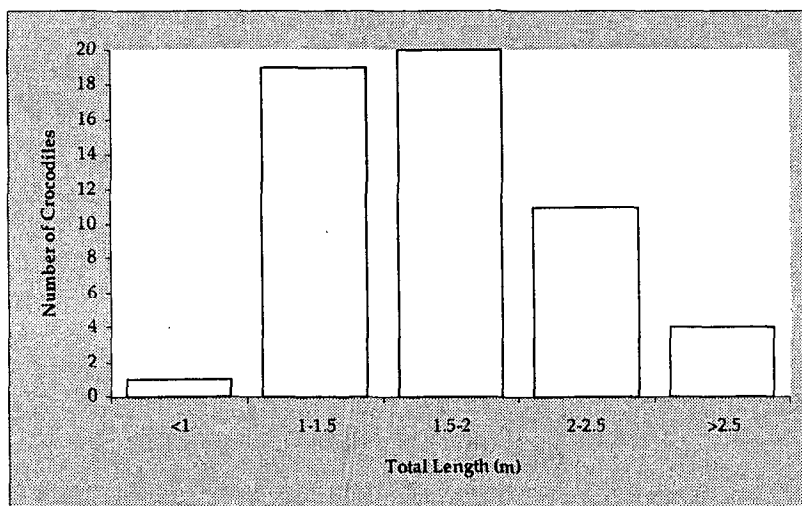


Figure 1. Size classes of crocodiles recorded on Great Barrier Reef islands

## Discussion

The natural distribution of estuarine crocodiles along the eastern Queensland coast extends southwards from the tip of Cape York Peninsula to the Tropic of Capricorn, covering approximately 12 degrees of latitude ( $\approx$  1650 km) and is restricted to the rivers and wetlands below the 250 m contour of the Great Dividing Range (Taplin 1987). The eastern flowing rivers are relatively short (usually less than 100 km in length); most rivers that reach the sea have only narrow bands of suitable crocodile habitat (including wetlands) near the mouth.

The northern areas of eastern Queensland support higher densities of crocodiles than southern areas (Taplin 1987). This is a result of both better habitat to support the population(s) and the lower level human interaction with the crocodiles. The mangrove swamps around the Escape and Lockhart Rivers and at Temple Bay provide good crocodile habitat and support seasonal breeding. The rivers in the Princess Charlotte Bay area provide reasonable habitat for larger crocodiles but are subject to flooding which reduces the reproductive success. The coastal area from Cape Melville southward to Cooktown includes very large wetlands which may support large numbers of crocodiles in moderate density; the actual importance of this area to crocodiles on the eastern coast has not been quantified. The coastal area south of Cooktown and extending to Ayr hosts fragmented populations of crocodiles; no large aggregations are known in the area. This coastal area has experienced extensive habitat modification via agriculture, urbanisation and recreation.

The National Parks of eastern Queensland, (e.g. Jardine River NP, Iron Range NP, Cape Melville NP, Lakefield NP and Endeavour River NP, provide critical *C. porosus* habitat at the edge of the GBRWHA. These areas and Aboriginal reserves on the eastern side of Cape York Peninsula contain the majority of the crocodile population of the eastern cape because they provide nesting, developmental and foraging habitat in the context of low human interaction, minimal agricultural and pastoral development, limited access, and restricted fishing (primarily gill netting) in coastal rivers (Taplin 1987).

The majority of records of crocodiles in the GBRWHA come from remote northern islands close to shore; however, it seems likely that crocodiles will, at least occasionally, occur on more southerly islands in the GBRWHA.

Given their biological and habitat requirements (see Webb and Manolis 1989; Webb and Smith 1987), crocodiles found on the reef are considered temporary migrants from the coastal river systems. Limpus (1980) suggested that the crocodiles had '...probably dispersed from populations breeding in the small coastal streams and swamps of eastern Cape York Peninsula'. This outward movement is consistent with data from Darwin Harbour in the Northern Territory from which about 100 crocodiles are removed annually with relatively steady replacement from the rivers that flow into it (Webb and Manolis 1989). Unfortunately, the behavioural and population demographic pressures on crocodiles that result in the outward movement of crocodiles from the coastal rivers and wetlands to the islands of the GBR are unknown (Lang 1987; Webb and Manolis 1989). Whether these individuals ever return to the coastal areas after having spent time on the islands is also unknown.

Female crocodiles reach sexual maturity at a total length of about 2.3 m (approximately 12 years of age); males grow to about 3.3 m in total length before becoming sexually mature (approximately 16 years) (Webb and Manolis 1989). A total of 40 (72.7%) of the crocodiles seen in the GBRWHA were less than two meters in estimated total length and were probably immature individuals. Of the remaining crocodiles, 11 (20%) were in an estimated size class that could include some sexually mature females and four (7.3%) were estimated to be in a size class that could include sexually mature males. Unfortunately, no information on sex or sex

ratio is available for crocodiles in the GBRWHA. However, unless there were strong demographic pressures (e.g. number of individuals, size structure, severe shortage of available space for territories and/or nesting habitat or there was restricted social space in the rivers and wetlands (Lang 1987; Webb and Manolis 1989)), it seems unlikely that reproductively mature crocodiles would venture out to the islands, particularly during the breeding season (October-May). It seems more likely that the larger crocodiles of the GBRWHA are non-breeding animals and/or individuals that may have been displaced from mainland habitats.

Because the GBRWHA does not contain extensive areas of important habitat, does not host large numbers of crocodiles and does not support nesting, it is an inappropriate geopolitical area for the primary conservation management of the estuarine crocodile population along the eastern coast of Cape York Peninsula. The continued survival of crocodiles living along the eastern coast of Cape York Peninsula depends primarily on the conservation management of coastal habitat; in particular, the occurrence of crocodiles on the islands of the GBR depends on the management of eastern Queensland coastal zone habitat.

The state of the crocodiles within the GBRWHA can be summarised in five points:

1. Crocodiles do occur within the GBRWHA;
2. Crocodiles occur in low density on continental islands and coral cays;
3. Crocodiles on the islands are small to medium sized (< 2 m);
4. No current sign or records of breeding have been found;
5. Population is not contained within the GBRWHA.

Because no historical data exist concerning numbers or density of crocodiles within the GBRWHA, population trends cannot be identified. Because the status of crocodiles in the GBRWHA is linked to the status of the population occurring in the rivers and wetlands of eastern Cape York Peninsula, whatever influences the populations and/or their habitat along the eastern side of the cape will also have an impact on the crocodiles using the island and cays.

The population of eastern Cape York Peninsula is under unquantified pressure (probably low but steady) from incidental mortality (resulting from entanglement in discarded nets, ingestion of debris, etc.) and intentional mortality (killing for 'sport' or other reasons) (Taplin 1987). Incidental and intentional mortality add to existing pressure on the population resulting from changes in mainland habitat, albeit low at this time. An increase in the recreational use of islands and cays in the GBRWHA will put more pressure on crocodiles by increasing the number of interactions between crocodiles and people. No one can say what the impact of repeated disturbance of crocodiles at a basking site may have on their behaviour; however, crocodiles do become increasingly wary of interactions with humans (such as close approach and/or capture) with repeated exposure (Lang 1987). The probable future trend of the GBRWHA crocodile population will be a decrease in the number of crocodiles utilising islands and an increase in mortality. However, the rate of change will depend on the type of pressure and its rate of increase.

The management response by conservation agencies that deal strictly with the island and reef ecosystems of the GBR will have little impact on the long term conservation of crocodiles, either in the GBRWHA or along the eastern coast of the cape. This is because the estuarine crocodiles that occur in the GBRWHA are outliers of the main population that inhabits the wetlands of eastern Cape York Peninsula. However, a management response directed at reducing human impact on individual crocodiles that are encountered in the GBRWHA would be beneficial. Public education may have a positive effect by reducing the intentional killing and reducing incidental mortality on immature individuals that may eventually find their way back to the habitats on the mainland coast. The Great Barrier Reef Marine Park Authority could assist the efforts of the Queensland Department of Environment by providing information on



'crocodile-wise' behaviour for reef users and assist the efforts of the Queensland Fisheries Management Authority in promoting better fishing practices which reduce incidental mortality of crocodiles.

### **Conclusion**

A low number of immature crocodiles are infrequently encountered on islands over a wide area of the northern GBRWHA. They utilise a variety of island types (including sand cays, low wooded isles and continental islands) and habitats (including bare sand or grass and mangrove areas). The population in the GBRWHA is marginal to the main population that occurs on the eastern side of Cape York Peninsula. The number of crocodiles within the GBRWHA is considered to be reasonably stable but under threat from continued (and potentially increasing) disturbance by humans. The population is predicted to decline as human use of the northern GBR increases.

### **Acknowledgments**

The efforts of field staff of NPWS and Marine Parks who recorded crocodile sightings are gratefully acknowledged. M. Read provided useful comments on the manuscript.

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# Marine turtles of the Great Barrier Reef World Heritage Area

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The Great Barrier Reef World Heritage Area is one of the few remaining strongholds for marine turtles globally with internationally significant populations for four of the six species present. All species are characterised by slow growth to maturity, long distance migration from feeding to breeding sites, high fidelity to traditional breeding sites, non annual breeding, temperature dependent sex determination and low recruitment rates to adult populations.

*Chelonia mydas* (Green turtle). Conservation status: Australia and Queensland = vulnerable. Most *Chelonia mydas* within the Great Barrier Reef originate from the two independent breeding units of the Great Barrier Reef - one which breeds in the northern Great Barrier Reef (> 30 000 females annually), the other which breeds mostly in the southern Great Barrier Reef (approximately 8000 females annually, mostly within conservation parks). Smaller numbers originate from the breeding units of New Caledonia and north Papua New Guinea. Short term trends in population numbers are masked by large interseasonal fluctuations in nesting numbers caused by a response to El Niño Southern Oscillation effects with a two year lag time. These nesting populations come from areas within a 2600 km radius of the nesting beaches, with more than half of migration tag recaptures occurring in neighbouring countries. The largest sources of anthropogenic mortality is hunting by coastal indigenous peoples, mostly of large females, in northern Australia and neighbouring countries. Total harvest within the migratory range of these turtles appears to be non-sustainable. When additional mortalities in east Australia from boat strike, fishing industry by-catch, ingestion of fishing line, entanglement in line and rope are considered, the conclusion must be that there is a high probability that significant declines in population levels can be expected in the Great Barrier Reef World Heritage Area within the next 25 years. Current management within the migratory range of these stocks is not ensuring sustainability.

*Caretta caretta* (Loggerhead turtle). Conservation status: Australia and Queensland = endangered. Almost all breeding in the southern Pacific region occurs within the south Great Barrier Reef and adjacent mainland. This stock of approximately 1000 nesting females annually (mostly in conservation parks) does not interbreed with the other Pacific stock that breeds in Japan or with the Western Australian stock. The south Queensland stock draws on feeding populations within a 2600 km migration range. This stock has declined by 50-80% in the number of nesting females annually since the late 1970s. The decline has been attributed primarily to fisheries by-catch mortality with additional mortality from boat strike, ingestion of synthetic debris, entanglement in ropes and traditional hunting in Papua New Guinea. Most anthropogenic mortality occurs within Australia.

*Eretmochelys imbricata* (Hawksbill turtle). Conservation status: Australia and Queensland = vulnerable. The largest remaining population in the Pacific region breeds in the north Great Barrier Reef, Torres Strait and NE Arnhem Land (several thousand nesting females annually. Great Barrier Reef rookeries are mostly conservation parks). This stock is genetically distinct from other Indo-Pacific stocks. Migration of *Eretmochelys imbricata* resident in the Great Barrier Reef World Heritage Area to breed in the Solomons and from Indonesia to the Great Barrier Reef is documented. It is extensively hunted in neighbouring countries for tortoiseshell and meat. Census data from Milman Island indicates a declining north Great Barrier Reef stock. The large harvests in neighbouring countries are expected to be reducing the size of

resident populations within the Great Barrier Reef World Heritage Area. Limited census and demographic data and almost total lack of quantified mortality data are impeding management.

*Natator depressus* (Flatback turtle). Conservation status: Queensland = vulnerable. This eastern Australian stock, comprising approximately 1000 nesting females annually, breeds mostly on continental islands of central Queensland (approximately 10% of this Australian endemic species). Most nesting occurs in conservation parks. They migrate from feeding areas from within the Great Barrier Reef World Heritage Area - probably the only stock of any marine turtle globally whose entire population is contained within a single management area.

Anthropogenic impacts appear to be limited to unquantified mortality in the east coast prawn fishery and some harvest and predation by feral pests of eggs. Census data (15 yr) suggest that a population decline may have commenced. No demographic data available except for breeding females.

*Dermochelys coriacea* (Leatherback turtle). Conservation status: Australia = vulnerable, Queensland = endangered. A rare species within the Great Barrier Reef World Heritage Area, both as resident turtles and breeding females. Population levels will be affected by egg harvests in Papua New Guinea and by open seas gill net and long line fisheries.

*Lepidochelys olivacea* (Olive ridley turtle). Conservation status: Australia = vulnerable, Queensland = endangered. An uncommon species within the Great Barrier Reef World Heritage Area. The origin of the resident turtles is unknown. Impacted by trawling by-catch mortality. No census data are available.

Table 1 summarises pressure, state and response (DEST 1994) for marine turtles.

#### **Reference**

Department of the Environment, Sport and Territories 1994. State of the Environment Reporting: Framework for Australia. Department of the Environment, Sport and Territories, Canberra. 42 pp.

**Table 1.** Summary of pressure, state and response (DEST 1994) for marine turtles. With all turtle species, the actions need to be directed across the distribution of the management unit. In most cases, this will involve concurrent actions inside and outside the Great Barrier Reef World Heritage Area. For each species, quantification of demographic parameters is required, e.g. survivorship, mortality rates from anthropogenic factors, age/size structures, fecundity, breeding rates. These data are available to only a limited degree for each stock.

<b>Species</b>	<b>Pressure</b>	<b>State</b>	<b>Response</b>
Green	Indigenous hunting inside and outside Australian waters. Disease, boat strike and fishery by-catch are secondary pressures.	Population stability difficult to determine. Populations expected to decline substantially if unsustainable harvest continues.	Liaise with neighbouring countries/states/agencies to reduce mortality to a sustainable level.
Loggerhead	Fishery by-catch. Boat strike, debris ingestion, PNG hunting and fox predation are secondary pressures.	Population has suffered a major decline in the last 15 years, recovery possible if management measures are successful.	Reduce turtle mortality in fishing gear- especially in trawls. Reduce boat strike mortality.
Hawksbill	Harvest in Indonesia, PNG and Solomon Islands. Egg harvest in Torres Strait is secondary pressure.	Data indicate start of population decline. Continued decline likely.	Liaise with neighbouring countries to reduce mortality to a low level.
Flatback	Fishery by-catch, egg loss through harvesting and pig predation.	No apparent decline. Population possibly stable.	Monitor the impact of pig predation and trawl by-catch.
Leatherback	Indonesia and PNG egg harvest.	Population assumed to be declining, leading to eventual extinction.	Liaise with neighbouring countries (Indonesia and PNG) to manage egg harvest at sustainable level.
Olive Ridley	Fishery by-catch.	No data on population. Future unknown.	Identify anthropogenic mortality levels and gather demographic data.

# Current status and trends of seabirds on the Great Barrier Reef

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## Abstract

The Great Barrier Reef (GBR) has more than 25% of the breeding population of Australia's tropical seabird species. The distribution and abundance of these species shows a latitudinal as well as a longitudinal pattern. Most major colonies are in two sections of the GBR Marine Park: Far Northern and Mackay/Capricorn. This is because their preferred island type (coral cays) are concentrated in these two areas.

The pressures that affect the viability of seabird populations are of anthropogenic or non-anthropogenic origin. For example, pressures from increased human activity in the GBR are in addition to those exerted by climatic effects such as reduced food supply caused by El Niño events, cyclones and gales; and biological interactions. The pressures of anthropogenic origin can be managed to a large degree, whereas those of non-anthropogenic origins cannot. Therefore management of seabird populations and their habitats must be affected by controlling the pressures exerted by human activities.

Just how much control is required is not yet clear for most localities because our knowledge of the trends in the population sizes of various species and the reasons for those trends is inadequate. This is in part a result of inadequate knowledge about which population model best fits some species and the lack of essential data such as rates of increase, extent of migration between colonies, and the main causes of mortality of each age group.

The current status of management of seabird populations is that it is under review. The management and research priorities are being determined. One of the focuses of the review is to develop standardised seabird monitoring procedures and data sharing arrangements between Commonwealth and State Agencies.

The lack of vital statistics such as recruitment rates, amount of exchange between colonies, and age-specific mortality make it difficult to determine the most appropriate management plan. In this context it would be wise to adopt a flexible management approach. An Adaptive Management Framework provides that flexibility. One of the key elements of such an approach is monitoring to determine the effects of the management actions taken so that they may be refined or altered to produce the desired outcomes.

## Introduction

This paper examines the current status of seabirds on the GBR and trends in their population sizes. For example, are the populations decreasing, remaining constant or increasing? It discusses possible causes for these trends, and management strategies necessary to ensure the continued survival of the seabirds?

The paper is structured in four sections. In the background, we first examine the role of seabirds in the GBR ecosystem, then the importance of the GBR for seabirds breeding in Australia, and finally, the relationship between the distribution of seabird colonies and the geographic distribution of each type of island on the GBR.

In the second section, we identify and discuss the pressures on GBR seabirds. These pressures are categorised as climatic, biological or anthropogenic. Then we consider how these affect the population dynamics of seabirds.

In the third section, trends in seabird numbers are examined using four species as case studies to illustrate the difficulties in detecting trends.

In the fourth section, we briefly discuss the current approach to management and the possible use of an Adaptive Management Framework.

## **Background**

### Role of seabirds in the Great Barrier Reef ecosystem

Seabirds play a variety of important roles in the GBR ecosystem. They affect the development of vegetation on coral cays and are attractive to human visitors. Therefore they can contribute significantly to the aesthetic appeal of a trip to the GBR.

Vegetation has several important ecological functions on coral cays. Vegetation reduces erosion and facilitates deposition (Hulsman and Kikkawa 1993) which raises the substrate further above the high water mark. This is essential if the vegetation's chances of survival are to increase because high tides and storm surges can destroy vegetation on low lying cays. Vegetation also creates microhabitats that can be colonised by other plants and animals. Thus a community of organisms is built up.

Seabirds on the GBR eat predominantly fish. The main prey of most seabirds are pelagic species. Therefore seabirds transfer nutrients from the pelagic part of the system to the island and reef system. These nutrients are deposited as dropped fish, guano and dead birds (chicks and adults). Decomposition makes the nutrients available and utilisable by vegetation. The amount of nutrients from guano can be high. For example, Black Noddies (*Anous minutus*) deposit an estimated four tonnes of guano per annum on Heron Island (Allaway and Ashford 1984). In addition, burrowing seabirds such as the Wedge-tailed Shearwater (*Puffinus pacificus*) carry organic matter (leaves, grass etc.) into their burrows to line their nest chambers (Dyer and Hill 1992), thereby distributing organic matter to lower parts of the developing soil profile.

Seabirds also disperse seeds between cays. They transport seeds primarily on their plumage and to a lesser extent in their gut (Heatwole and Walker 1989). The two functions of transporting seeds and providing them with nutrients are complementary.

Seabirds may also have a negative effect on pedogenesis and development of vegetation. For example, shearwaters mix the substrate's profile and probably slow pedogenesis. Seabirds such as boobies and cormorants destroy saplings by building their nests or roosting on them (King 1985). Grasses and succulents are also damaged by nesting seabirds. Some seabirds dig scrapes for their nests and thus uproot vegetation and the area is often left coated in a crust of guano. However, this type of destruction is temporary as the vegetation usually recovers within a short period.

Proportion of the total number of Australian seabirds on the Great Barrier Reef

Seabird species which breed on the GBR constitute about 2.4% of the total population of breeding seabirds in Australian waters. If the Short-tailed shearwater is excluded, then the GBR has just over 10% of Australia's breeding population of seabirds. These calculations are based on totals for all states and territories (Ross et al. 1995), excluding those on the GBR. Data for the GBR were obtained from the Seabird Database of the Queensland Department of Environment. This ranks the GBR Region fifth in Australia in terms of the numbers of breeding pairs of seabirds (see WBM Oceanics and Claridge 1995).

Proportion of Australian population of each species breeding on the Great Barrier Reef

The importance of the GBR for breeding seabirds increases when the type and range of breeding species are considered. More than 25% of Australia's tropical seabirds nest on the GBR (Table 1). These include more than 50% of Australia's Roseate Terns (*Sterna dougallii*), Lesser Crested Terns (*Sterna bengalensis*), Black-naped Terns (*Sterna sumatrana*) and Black Noddy, and about 25% of its Wedge-tailed Shearwaters, Brown Boobies (*Sula leucogaster*), Masked Boobies (*Sula sula*) and Red tailed Tropicbirds (*Phaethon rubicauda*). More than 20% of Australia's Crested Terns (*Sterna bergii*), Bridled Terns (*Sterna anaethetus*) and Common Noddies (*Anous stolidus*) and more than 10% of its Least Frigatebirds (*Fregata ariel*), and Sooty Terns (*Sterna fuscata*) also nest on the GBR.

**Table 1.** Proportion of the Australian breeding population of each seabird species breeding on the GBR. Australian population data from WBM Oceanics and G. Claridge 1995. GBR population data from Seabird Database Queensland Department of Environment. ? = unknown

Species	Total number of breeding pairs		% of Australian population
	GBR	Australia	
Wedge-tailed Shearwater	351 276	1 384 400	25.4
Great Frigatebird	20	1 611	1.2
Lesser Frigatebird	2 447	19 631	12.5
Brown Booby	18 611	73 840	25.2
Masked Booby	1 102	4 270	25.8
Red-footed Booby	172	4 987	3.4
Australian Pelican	270	1 701	15.9
Red-tailed Tropicbird	101	381	26.5
Caspian Tern	67	2 049	3.3
Roseate Tern	7 307	13 370	54.7
Crested Tern	26 023	115 635	22.5
Lesser Crested Tern	6 341	8 169	77.6
Little Tern	51	568	9.0
Black-naped Tern	3 891	2 076	>100
Sooty Tern	48 000	464 500	10.3
Bridled Tern	13 887	57 819	24.0
Common Noddy	46 004	214 100	21.5
Black Noddy	210 240	175 000	>100
Silver Gull	765	306 740	0.2
White-bellied Sea-eagle	34	?	?
Osprey	61	?	?
Herald Petrel	3	3	100.0
Black winged Petrel	1	3	33.3
<b>Total</b>	<b>736 588</b>	<b>2 850 853</b>	<b>25.8</b>

#### Distribution of each type of island on the Great Barrier Reef

There are over 1000 islands and cays on the GBR (King 1993; Ogilvie and King 1993). The GBR has been divided into four biogeographical regions: Torres Strait; Northern; Central; and Southern Regions to assist in the planning for the conservation requirements of seabirds (Ogilvie and King 1993). However, the GBR has also been divided into four management sections by the Great Barrier Reef Marine Park Authority, and these do not coincide with the biogeographical regions. These four management sections (Far Northern, Cairns, Central and Mackay/Capricorn) are used for the purposes of this paper because of its management orientation.

There are eight types of island in the GBR Region. They are high continental, low wooded, mangrove, rock, sand cay, vegetated sand cay, shingle cay, and vegetated shingle cay (see Hopley 1982; King 1993).

High continental is the most common island type in the GBR region (73.2%, Fig. 1), and it is the most common type in each of the four management sections. High continental islands are more numerous toward the southern half of the GBR than in the northern half (Fig. 1). Unvegetated and vegetated sand cays (8.3 and 8.0% respectively) are the next most numerous island types followed by low wooded islands (7.0%). These islands occur mostly in the northern and/or southern extremities of the GBR (Fig. 1, Hopley 1982 [Fig. 11.21]). The remaining types are comparatively rare.

Cays are most numerous on the inner shelf of the Far Northern Section, then the mid shelf of the Mackay/Capricorn Section, and the outer shelf in the Far Northern Section (Hulsman 1996). The bulk of the High continental islands are on the inner shelf in each section except for the Mackay/Capricorn Section where they are more common on the mid-shelf (Table 2; Hulsman 1996).

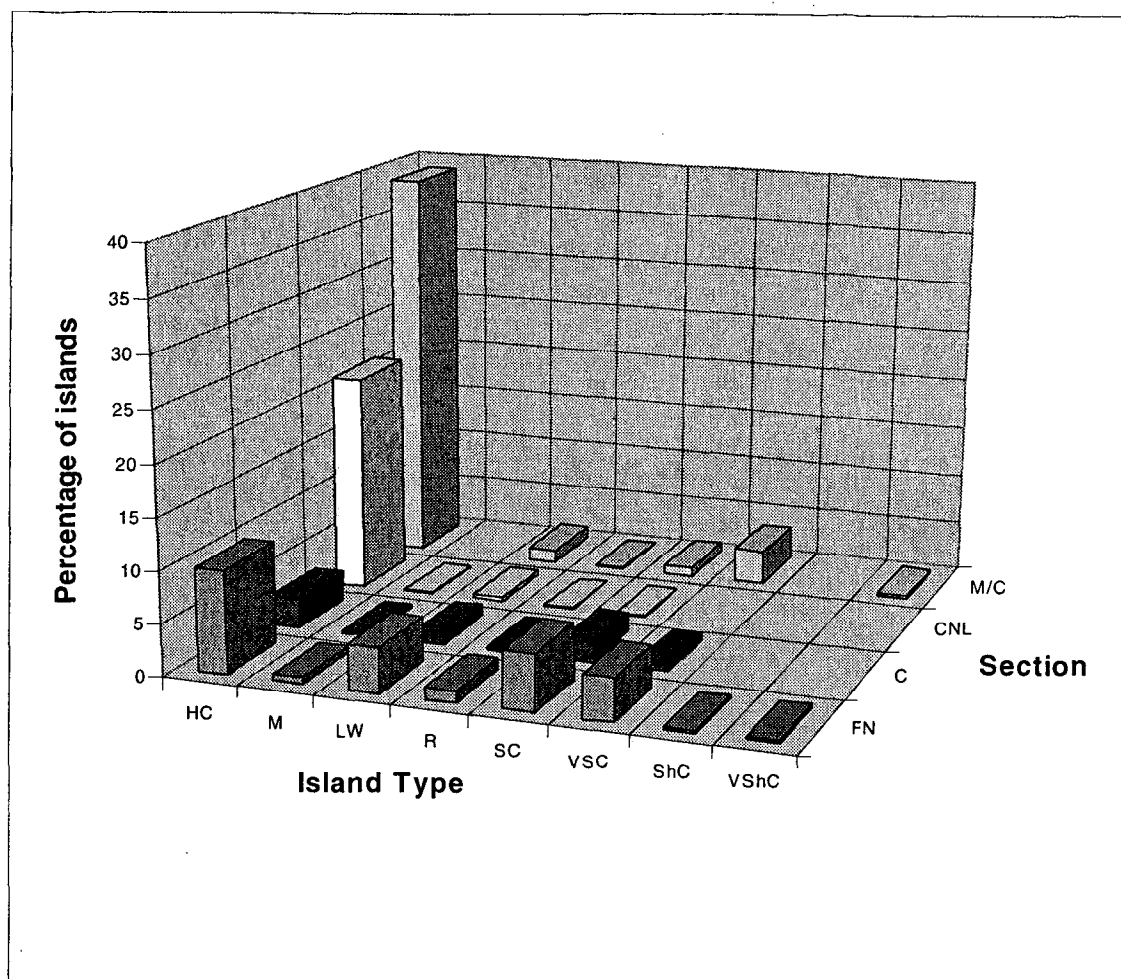
The relationship between the percentage of islands occurring in each section and major seabird colonies is not very strong (Table 3). However, there is a pronounced relationship between the percentages of cays (vegetated, unvegetated sand and shingle cays) and major seabird colonies (i.e. monotonically increasing, Table 2). This association alludes to a number of questions regarding the distribution of seabird colonies in relation to island type and location on the continental shelf.

Proportion of each type of island (in each section and position on continental shelf) with seabird colonies (major/minor)

Habitat requirements of seabirds include access to suitable areas for breeding and foraging (Hulsman 1980). The habitat requirements for breeding and foraging are intertwined because without an adequate food supply the parents are unable to raise their young to independence.

Habitat requirements for breeding differ in detail between species, but they have basic needs in common. They require: 1) an area free of disturbance by terrestrial predators, humans (directly and indirectly), storms and the tide; 2) conspecifics, including potential mates; and 3) suitable access to foraging grounds.





**Figure 1.** Distribution and abundance of each type of island on the Great Barrier Reef. FN - Far Northern Section; C - Cairns Section; T/W - Townsville/Whitsunday Section; M/C - Mackay/Capricorn Section. Island Type: HC - high continental; LW - low wooded; M - mangrove; R - rocky; SC - sand cay; VSC - vegetated sand cay; ShC - shingle cay; VShC - vegetated shingle cay (nomenclature from King 1993)

Seabirds primarily utilise cays for breeding. There are 55 major colonies (King 1993; Ogilvie and King 1993) and 20 minor colonies of seabird species on the GBR (King 1993). According to Ogilvie and King (1993), the major colonies are mostly on cays (41) followed by continental islands (10) and low wooded islands (4). The figure on the number of cays can be further subdivided into vegetated sand cays (28), unvegetated sand cays (10), and vegetated shingle cays (3). There are, in fact, 11 continental islands with major seabird colonies on them based on data in King (1993) and D. Hopley's Island Database. Thus there is a total of 56 major seabird colonies on the GBR. The minor colonies occur mostly on vegetated sand cays and high continental islands.

Figure 1 shows clearly that most sand cays (vegetated and unvegetated) occur in two of the four management sections: Far Northern and Mackay/Capricorn. Given the strong preference of seabirds for sand cays, most of the significant seabird colonies tend to be concentrated in those two sections (Fig. 2, Walker 1990; King 1993). Thus there is a latitudinal pattern of seabird distribution evident along the GBR.

**Table 2.** The mean number of species from pelagic, offshore and inshore feeders in relation to island type and its location on the continental shelf. Abbreviations are as per Fig. 1

Island type and location on shelf	Section	Pelagic	Offshore	Inshore	Mean species richness
<i>Continental</i>					
inner	FN	2.0	3.0	3.0	8.0
	C	0.0	1.0	3.3	4.3
	CNL	1.0	1.0	2.0	4.0
	M/C	0.0	1.0	2.0	3.0
	<b>mean</b>	<b>0.6</b>	<b>1.1</b>	<b>2.4</b>	<b>4.7</b>
mid-shelf	CNL	0.0	0.3	2.7	3.0
	M/C	0.0	1.0	1.0	2.0
	<b>mean</b>	<b>0.0</b>	<b>0.4</b>	<b>2.6</b>	<b>3.0</b>
<i>Low wooded</i>					
inner	FN	0.0	1.5	1.8	3.25
<i>Sand Cay</i>					
mid-	M/C	1.0	1.0	3.3	5.3
outer	FN	0.7	2.2	0.5	3.3
<i>Vegetated Sand Cay</i>					
inner	FN	0.2	0.7	4.6	5.4
mid	FN	0.0	0.0	4.0	4.0
	C	0.0	1.0	5.0	6.0
	M/C	0.9	1.8	2.5	5.2
	<b>mean</b>	<b>0.7</b>	<b>0.8</b>	<b>3.1</b>	<b>4.5</b>
outer	FN	3.0	2.8	3.0	8.8
	C	1.0	3.0	5.0	9.0
	M/C	1.0	1.5	1.5	4.0
	<b>mean</b>	<b>2.4</b>	<b>2.7</b>	<b>3.0</b>	<b>8.4</b>
<i>Vegetated Shingle Cay</i>					
outer	M/C	0.3	1.7	2.0	4.0

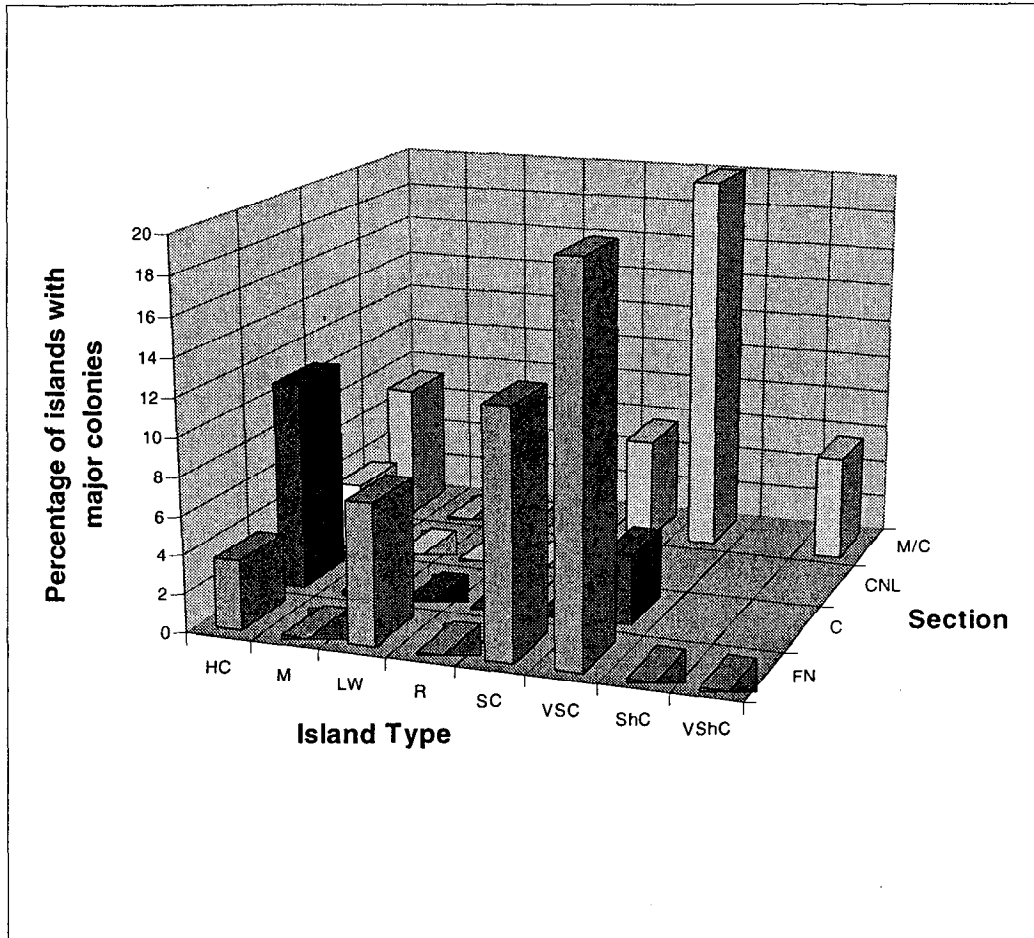
**Table 3.** Percentage of islands in each of the four sections of the Great Barrier Reef Marine Park and the percentage of major seabird colonies in each of those sections

Section	% Islands	% major colonies	% cays
Mackay/Capricorn	44.5	40.4	26.0
Far Northern	25.8	42.1	60.0
Central	22.2	3.5	0.6
Cairns	3.5	14.0	15.4

Walker (1990) recognised four general breeding distributions for the numerically important species. First, Silver Gulls (*Larus novaehollandiae*), Crested, Black-naped and Bridled Terns breed in colonies scattered along the entire length of the GBR. Second, Common Noddies, Lesser Crested and Sooty Terns breed almost entirely in the northern half of the GBR. Third, Wedge-tailed Shearwaters and Black Noddies breed almost entirely in the southern end of the GBR. Fourth, Least Frigatebirds, Roseate Terns, Brown and Masked Boobies breed at the northern and southern ends of the GBR.

Seabirds may be divided into inshore, offshore and pelagic feeders on the basis of a suite of characteristics (see Hulsman 1988). The adaptations of the birds enable them to venture away from their young for short periods (inshore feeders), for long periods (offshore feeders) and very long periods (pelagic feeders). These different adaptations affect how far from the colony

parents may forage, the feeding rates and hence the growth rates of their young (Lack 1968; Hulsman 1988). How these adaptations affect the impacts that climatic effects have on the seabirds will be addressed shortly. Their relevance here is that they affect the longitudinal pattern (i.e. cross shelf) of seabird distribution (see Walker 1990; Hulsman 1996).



**Figure 2.** Distribution of major seabird colonies on the Great Barrier Reef in relation to type of island and section of the Great Barrier Reef Marine Park

The basic longitudinal pattern of seabird distribution on the GBR is that close to the mainland (inner shelf) seabird communities are dominated by inshore feeders, but some offshore and pelagic feeders may be present. Further offshore (mid-shelf and outer shelf) more offshore and pelagic feeders occur (Walker 1990, 1994). This pattern, as expected, relates to accessibility of prey habitat types. This is further supported in the Far Northern Section, where the continental shelf is less than 40 km wide. Here large numbers of pelagic species breed on inner shelf islands, e.g. Quoin Island.

Other biogeographic factors may modify where seabird breeding concentrations occur across the continental shelf. For example, the species composition of the Swain Reefs' cays has been likened to that of the Coral Sea cays (Limpus and Lyon 1981), with more pelagic species than other areas in the southern GBR such as the Capricorn and Bunker Groups. Although the Swain Reefs are remote and distant from the mainland, they are spread over a large area with the cays between 50 and 130 km from the edge of the continental shelf. In contrast, the cays in the Capricorn and Bunker Groups are much closer to the mainland but within 40 km of the edge of the continental shelf. This apparent paradox of having more pelagic species nesting in an area

further from the edge of the shelf is at least partly caused by large differences in the total width of the shelf in these two areas. Differences in latitude, variations in reef morphological influences on availability of prey, and proximity to the Coral Sea probably all have some influence on species composition, and help illustrate the range of modifying factors that may influence where seabirds breed.

A greater percentage of islands in the Cairns and Far Northern Sections are occupied by major seabird colonies than in the Central and Mackay/Capricorn Sections. The occupancy rates are not only affected by the need for specific island types for nesting, but also by the numbers of each island type. For example, there are a large number of continental islands and a very small number of vegetated shingle cays. It is also evident that vegetated shingle cays have a higher occupancy rate than sand cays, vegetated sand cays, low wooded and continental islands (Table 2), but because there are so few vegetated shingle cays on the GBR these figures may be misleading.

Occupancy rates of different island types can be useful in providing insights into the effects that island type and location on the continental shelf (proximity to areas suitable for foraging) have on the selection of nesting islands by seabirds. It should also be noted that the 54 major seabird islands are distributed on the various island types in the following proportions: vegetated sand cays (50.0%), sand cays (16.7%), high continental islands (20.4%), low wooded islands (7.4%) and vegetated shingle cays (5.6%).

Continental islands, irrespective of their location on the continental shelf, are not preferred breeding areas. Further, it is not an island's location alone that determines whether seabirds nest on it in large numbers. For example, the vegetated sand cays on the inner shelf in the Far Northern Section had a lower occupancy rate than those on the mid shelf in the Far Northern Section and outer shelf in the Mackay/Capricorn Section (Table 2). There is probably something about the topographical and vegetational features of the cays that affects whether they are suitable for a major colony.

Habitat characteristics such as height above the high water and the presence of suitable vegetation in terms of height, strength and abundance are important for successful breeding. Heatwole et al. (1981) showed that the height of the herb layer affected where terns nested on One Tree Island. The Crested Tern, with its longer tarsi, could nest in sites where the herb layer was too high for Black-naped and Roseate Terns. However, where the herb layer was high enough to nest under it was utilised by Roseate Terns, but not Crested Terns. Bridled Terns nested under the shrubs and small trees. The matching of different habitat requirements of species to the characteristics of habitats and the area that it occupies on a specific island also affects whether a given species will nest there in significant numbers.

It is important to note at this stage that pelagic, offshore and inshore feeders differ in the size of their colonies. Lack (1968) argued that pelagic feeders, because of their ability to venture far from their colonies in search of food and still raise young successfully, are able to select breeding sites far from their foraging grounds. Therefore, they can be more selective about where to nest and for safety and social reasons can nest in very large colonies. In contrast, inshore feeders had a suite of adaptations that do not allow them to venture far from their colonies in search of food. Therefore they nest close to their foraging areas. However, large aggregations of inshore feeders would increase competition for food near the colony, and therefore they tended to nest in small colonies. Offshore feeders fall between these two extremes.

This model accounts for the distribution and abundance of the various seabird species on the GBR. Inshore feeders, such as Black-naped and Roseate Terns, form numerous small colonies

along the GBR. Offshore species, such as Brown Boobies, Bridled Terns and Black Noddies, form larger colonies than the Black-naped and Roseate Terns. Pelagic species, such as Wedge-tailed Shearwaters, form enormous aggregations on a few islands. However, this does not explain why the shearwaters and Black Noddies are so concentrated at the southern end of the GBR and Sooty Terns and Common Noddies are so concentrated at the northern end of the GBR. That requires consideration of what constitutes optimal and marginal habitats (for breeding and feeding) for these species. This idea is not developed any further in this paper. It is simply flagged it as something important, and at some stage will require addressing.

### **What are the pressures on Great Barrier Reef seabirds and our state of knowledge of them?**

#### Climatic effects

##### *Greenhouse effect*

Cays are the most important island types for breeding seabirds on the GBR. Most of these islands are less than 2.5 m above the high water mark and are subject to overwash by cyclonic and storm surges. Even slight increases in sea level are therefore likely to have catastrophic consequences on breeding seabirds because most species nest under or on the ground. Tree nesters are also likely to be ultimately affected because of increased erosion of the islands and the resultant loss of suitable habitat for breeding.

Furthermore, small rises in sea level may affect patterns of erosion and deposition of material and hence the stability of coral cays. These processes of erosion and deposition are affected by the topography of the reef tops (Hopley 1982). Increases in the depth of water covering those reef tops may alter the patterns of erosion and deposition. In other words, existing cays may be eroded but not receive material to build them up. The material may be deposited on other parts of the reef and consequently new cays will be formed elsewhere on the reef platform. The loss of habitat suitable for nesting will have a major adverse impact on breeding seabirds in the area.

Small rises in sea level are not likely to affect the accessibility of seabirds' food. Even though most species obtain their food from the upper 30 cm of the water column, their main prey species occur near the surface irrespective of the water depth (Ashmole and Ashmole 1967; Hulsman 1977, 1988; Smith 1989).

##### *El Niño*

The effects of El Niño Southern Oscillation (ENSO) events are known to affect the food supply of seabirds in the eastern Pacific Ocean (see Murphy 1926, 1936; Vogt 1942), and more recently those in the Central Pacific (Schrieber and Schrieber 1984; Ainley et al. 1990) and the Atlantic Ocean (Robertson 1969; Duffy et al. 1988). Reversal of the prevailing oceanic currents and the accompanying elevated sea surface temperatures and reduced nutrients led to a failure of the food supply causing emigration and mass mortality of adults and chicks (Schrieber and Schrieber 1984; Ainley et al. 1988; Duffy et al. 1988).

Little is known about how ENSO events affect seabirds breeding on the GBR. However, they would affect biological productivity and the distribution of marine organisms that cannot tolerate the warmer waters (Jeffrey et al. 1990). Seabird species most severely affected by ENSO events are those that selectively forage in areas of the ocean where the temperature range excludes that of waters during an ENSO event (see Ainley et al. 1988). In the Swain Reefs area, increased surface temperatures and the resultant reduction in food supply brought

on by successive ENSO events have been implicated in the observed decline in numbers of Brown Booby (Heatwole et al. under review). They may also be responsible at least in part for the observed declines in the breeding populations of Black Noddies in the Capricorn-Bunker Group, and Sooty Terns and Common Noddies at Michaelmas Cay during the same period. This requires further investigation.

#### *Cyclones/gales*

Cyclones and gales can have devastating effects on the reproductive output and population size of seabirds. Strong winds may prevent adults from leaving the island to fish, or prevent them from returning and feed their young and may, therefore, increase the mortality of both adults and immatures. For example, severe cyclones that passed near Michaelmas Cay in 1986 and 1988 significantly reduced the breeding population of Common Noddy, *Anous stolidus* (by 34% and 47% respectively) over four month periods (De'ath 1994). In contrast, Crested and Sooty Tern populations were not significantly affected by these cyclones (De'ath 1994).

The stage of the breeding season, i.e. the stage of development of young birds, when a cyclone or gale strikes a colony affects the severity of impact on seabirds. At One Tree Island, for example, cyclone Simon struck when a cohort of Crested Tern chicks were a few weeks old. Large numbers of chicks died from starvation and chilling as a result (Langham 1986). Those chicks that survived fledged at a reduced body mass (Langham and Hulsman 1986). Young birds that fledge with a reduced body mass have a lower chance of survival in their first year than those with a higher body mass (Gill 1994:487). Thus cyclones and gales depending on when they occur may have a delayed effect on the population size of seabirds.

The duration of gale force or cyclonic winds also affects the mortality rates of chicks. For example, strong winds associated with cyclone David that struck Heron Island in 1976 lasted for four to five days. During that time many adults were prevented from returning to the island and therefore unable to feed their dependent young. After the cyclone passed, the adult noddies returned. However, many of the chicks were so weak from starvation that they were unable to beg intensively enough to elicit a response from their parents. Consequently, large numbers of chicks continued to die of starvation even though the weather was fine and calm, because many parents did not feed their young (Hulsman 1977).

Cyclones also blow noddy chicks out of their nests, which is a particular problem for them because they nest in trees. Not all parents feed their young if they are not in the nest and therefore those chicks die. Furthermore, those that are fed on the ground, have a lower survival rate than those that remain in or adjacent to their nests (M. Preker pers. comm.).

#### Biological interactions

##### *Species interactions*

There is a relationship between seabirds and vegetation. The best known one is perhaps the relationship between *Pisonia grandis* and seabirds. Five species of bird have been documented with *Pisonia* infructescences (whole or part) attached to their plumage (Walker 1991b). The main distributors of the *Pisonia* seeds are the Black Noddy and the Bridled Tern (Walker 1987). There is a very strong relationship between where Black Noddies breed and the distribution of *Pisonia* (Walker 1987). According to Walker (1991b) seabirds are essential for the dispersal of *Pisonia* seeds. He further suggested that the guano from the birds may provide the *Pisonia* trees with a competitive advantage over other plants.

The herb, *Boerhavia repens*, forms meadows at some of the main seabird breeding islands, e.g. Raine Island, Michaelmas and Bell Cays. Seabirds disperse this plant (Walker 1991b).

Heatwole and Walker (1989) found a strong correlation between the number of plant species dispersed by birds and the mean number of Silver Gulls on islands. However, Walker (1991b) did not think that gulls were a major disperser of *Pisonia* along the GBR.

Some seabird species appear to have strong associations with other seabird species. For example, Roseate and Black-naped Terns often nest together and at times forage together in flocks. However, this may simply reflect similar habitat requirements, and the presence of one species breeding may attract others to nest because it indicates a predator-free or disturbance-free site (see Veen 1977; Kharitonov and Siegel-Causey 1988).

Colonial nesters are social animals, and may also use each other for information to locate a patchily distributed but abundant prey. Certainly, in the southern part of the GBR where Black Noddies are abundant, other seabird species are often seen foraging with them (see Hulsman 1988).

Noddies depend on predatory fish such as tuna to make their prey accessible. Offshore, the fish are patchily distributed but occur in large aggregations (see Erwin 1977). The number of noddies and their conspicuousness when contrasted against the light coloured sky are used as a cue by other seabirds to locate patchily distributed but abundant prey. However, gaining access to the prey at the surface can be difficult because of the dense layer of noddies between the other seabirds and the prey. Thus most other species forage towards the periphery of the noddy flocks (Hulsman 1988).

Some species often nest alongside one another. For example, Roseate Terns often nest with Black-naped Terns, and Lesser Crested Terns often nest alongside Crested Terns. However, there seems to be a negative association between Bridled Terns and Wedge-tailed Shearwaters. The nesting density of Bridled Terns decreases with increasing densities of Wedge-tailed Shearwaters. The shearwaters' activities on the surface may interfere with Bridled Tern nesting and therefore the Bridled Terns avoid where shearwaters are active.

#### Anthropogenic effects

##### *Human habitation and visitation*

The effects of human habitation on breeding seabirds on the GBR has been considered by a number of authors especially at Heron Island (e.g. Hulsman 1984; Hill and Rosier 1989; Walker 1991; Hill et al. 1996). However, there is disagreement between these authors about the severity of the effects of human activities and infrastructure on breeding seabirds. The problem stems from how the island is partitioned. Hulsman (1984) divided the cay into thirds, whereas Hill and Rosier (1989) divided it into two. There is no dispute in that there are high nesting densities of Black Noddies in tall *Pisonia* trees around the resort and research station where the birds' access to them has been increased by the decreased density of trees. The disagreement is over whether development has affected the numbers of Wedge-tailed Shearwater and Black Noddy at Heron Island.

Walker (1991a) stated that reproductive success must be measured to determine whether human habitation of the island has adversely affected seabird numbers. More recently, Hill et al. (1996) have found that the hatching success of shearwater pairs was significantly lower in the built habitat than in the less disturbed ones. One of the reasons for the higher mortality is that after heavy rainfall, the runoff floods the burrows around buildings and trails. The more

compacted substrate in this habitat slows the infiltration rate of water and therefore increases the runoff which floods the burrows that remain waterlogged for up to two days. Consequently, eggs and very young chicks drown (M. Preker pers. Comm. and cited in Hill et al. 1996). The on-ground nesting seabirds do not breed on islands with permanent human habitation, e.g. Heron Island, unless the activities of people are strictly controlled, e.g. One Tree and Lady Elliot Islands (Walker 1991a; pers. obs.). Thus some seabird species are less tolerant of people than others.

### *Fishing*

Fishing can have direct or indirect effects on seabirds and these effects may be either negative or positive. Direct effects involve the removal of the birds' prey species. This has been documented in a number of areas around the world such as Peru, where overfishing the anchovy stocks greatly reduced the amount of harvestable food for Peruvian seabirds resulting in their mass mortality (Furness and Monaghan 1987). Other direct effects include the quantity of the fishing industry's by-catch that is harvestable by seabirds. The fishing industry may provide a source of food that otherwise would not have been accessible and therefore not harvestable by seabirds. This has direct benefits to species that are able to utilise the by-catch, but it may have negative effects on other species that compete for limited nesting space on islands. In Hawaii, tuna fisheries have been identified as a threat to seabirds because of the number of seabird species that depend on tuna to drive their prey toward the surface (Harrison 1990). This is an example of an indirect negative effect of a fishery on seabird populations. Interactions between fishing and seabird populations on the GBR have not been studied, and the effects of the existing industry are not known.

There is not a well developed tuna fishery on the GBR and as such it is unlikely to have any significant impact on the numbers of seabird species that rely on tuna to drive their prey to the surface where they can be caught.

### **State of our knowledge of seabird distribution and trends**

There are few islands in the GBR south of Lizard Island where the seabird breeding populations are not subjected to some form of disturbance from human visitation or introduced animals (King 1993). Furthermore by the year 2000 it is possible that the remote Swain Reefs will be the only seabird island group within the GBR Marine Park remaining beyond the day travel capabilities of large tourist vessels (see Stokes et al. 1996).

Seabirds on the GBR have been observed and counted for many years. Ships' logs from some of the earliest explorations of the area included notes on the diversity and abundance of the marine avifauna. In more recent times, numerous papers in ornithological journals and the popular press have described the species and numbers of seabirds present at many localities (e.g. the Corella Seabird Island Series).

Our current knowledge of seabird distribution is good. We know where the major and minor colonies of seabirds are on the GBR. This is evident from the information provided in this paper. However, much of this information has limited use for the detection and understanding of population changes over time. The reasons for the paucity of information are variable, but they are in part related to the difficulties of regular site access and lack of standardisation in data collection.

To understand changes in seabird populations, recognition and separation of human-induced influences from those occurring naturally is necessary. It is widely recognised, however, that the separation of such cause and effect relationships is difficult, even when one uses well



conceived projects running over many years. As outlined above, potential influences on seabird populations are extensive, ranging from biological interactions and anthropogenic effects, to such non-habitat factors such as weather and climate. Apparent changes can also be artefacts of inadequate censusing methodology, and induced by such simple factors as inconsistent time of day at which birds are censused (see Heatwole et al. in press). To detect change reliably, long term data (> 10 years) collected using standardised methods is necessary.

Seabird census data collected on the GBR varies with geographical location, in terms of both regularity of collection and in census methods used. Data availability ranges from long term studies with monthly surveys (e.g. Michaelmas Cay) to studies with various combinations of survey longevity and regularity (e.g. Swain Reefs and Heron Island) to situations where little is known (e.g. inshore islands between Yeppoon and Mackay). In this section, we examine various populations for trends using some of these data.

The best dataset on breeding seabirds is that collected by Department of Environment personnel in the Far Northern Region for Michaelmas Cay. The data have been analysed for trends by De'ath (1994). He showed that the populations of Common Noddy and Sooty Tern have decreased by 45% and 26% respectively during the period 1984-94. The Department of Environment personnel censused the seabirds at Michaelmas Cay monthly for more than a decade. Comparable data do not exist for any other seabird island on the GBR. Consequently, data available for other seabird colonies cannot be analysed for trends in the same way as it has been done for Michaelmas Cay because there are insufficient censuses.

The dataset for seabirds breeding at Heron Island is not as large as that from Michaelmas Cay, but there have been a minimum of 10 censuses of Wedge-tailed Shearwaters and Black Noddies between 1910 and 1996. It is difficult to determine the trend for Wedge-tailed Shearwater's population because researchers have counted the numbers of burrows and the occupancy rate of those burrows may have changed over time. It seems that the Wedge-tailed Shearwater population at Heron has remained relatively stable at around 8500 pairs since at least 1965, or it has fluctuated greatly during the 1980s (see Dyer et al. 1994). Hill et al. (1996) have restricted their conclusions to post 1985. They have found that the numbers of shearwater burrows have remained relatively constant between 1985 and 1993.

The population size of Black Noddy at Heron Island has increased exponentially since 1910 (Barnes and Hill 1989). There has been an obvious change in the number of breeding pairs since the 1960s. What is not certain at this time is whether the population is continuing to increase, remaining constant or starting to decline.

It is the aim of a research project that is currently being conducted by Department of Environment, Griffith University and the Queensland University of Technology Sunshine Coast University College to determine what is the current status of shearwater and noddy populations on Heron Island, as well as those on other islands of the Capricorn-Bunker Group.

What model describes their population dynamics adequately?

In considering the dynamics of seabird populations, no one model adequately describes those of all species that breed on the GBR. This is because different species use different life history strategies.

The basic model of population dynamics of seabirds considers the population is made up of a number of local populations (see Andrewartha and Birch 1954, 1984). Additions to the population size come from two sources (1) natural increase via the birth rate exceeding the

death rate, and (2) immigration. Reductions to the population size come from the numbers of deaths and emigration.

The problem that seabird biologists face is lack of accurate data on the natural rate of increase, or the rates of immigration and emigration for most species at specific colonies. This makes it difficult to predict the population trends at different geographical localities.

Furthermore, not knowing which is the appropriate model to describe the population dynamics of any species over space as well as over time further compounds our problem. We need extended data sets like the one that we have for species that breed at Michaelmas Cay for their other colonies. Without such data we do not know how the GBR population of any species changes spatially and temporally. Without that, management becomes a 'fly by the seat of the pants' operation. Indeed this is an apt description of the status of management of seabirds on the GBR at this point in time.

#### Community characteristics

##### *Species richness and abundance*

Species richness (i.e. number of species) was affected by the type of island and its location on the continental shelf. For example, vegetated sand cays on the outer continental shelf had the highest number of breeding species. Good representations of pelagic, offshore and inshore feeders occurred on these cays (Table 2). Vegetated sand cays on the inner continental shelf were next with a strong representation of inshore feeders but few offshore and pelagic feeders (Table 2). Indeed this pattern held for all other island types and locations on the continental shelf (Table 2).

##### *Biomass*

The Mackay/Capricorn Section has the highest biomass of breeding seabirds on the GBR. It has five times the biomass of the Far Northern Section (Table 4). The Central Section has by far the smallest biomass of breeding seabirds on the GBR.

The mid-shelf has the highest biomass of breeding seabirds, followed by the outershelf and the innershelf (Table 4). The extensive mid-shelf area of the Mackay/Capricorn Section has the largest biomass of breeding seabirds (Table 4). The Wedge-tailed Shearwater contributes a massive 336.5 tonnes and the Black Noddy contributes 45.5 tonnes to the mid-shelf biomass in that section. In contrast, the Sooty Tern has the third highest biomass of breeding seabirds on the GBR contributing 28.4 tonnes to the biomass of outershelf seabirds in the Far Northern Section. Thus the Wedge-tailed Shearwater dominates the biomass of breeding seabirds on the GBR contributing 65.6% of the biomass, Black Noddy 8.9% and Sooty Tern 5.5%. Thus three species account for 80% of the biomass of breeding seabirds on the GBR.

**Table 4 .** Biomass of breeding seabirds (tonnes) in relation to location on Continental Shelf in each section of the Great Barrier Reef Marine Park

<b>Section</b>	<b>inner</b>	<b>mid</b>	<b>outer</b>	<b>Total</b>
Far Northern	8.3	4.6	67.6	<b>80.5</b>
Cairns	1.6	5.6	15.1	<b>22.3</b>
Central	3.8	0.02	0	<b>3.82</b>
Mackay/Capricorn	0.3	387.2	18.6	<b>406.1</b>
<b>Total</b>	<b>14.0</b>	<b>397.42</b>	<b>101.3</b>	<b>512.72</b>

These results are similar to those reported by Walker (1990). The differences probably arise from differences in the weights of birds used and slight differences in the numbers of some species used in the calculations.

The dominance of the Mackay/Capricorn Section in terms of the biomass of breeding seabirds is reflected at the finer scale of islands. Nine islands from each of the Far Northern and the Mackay/Capricorn Sections occur in the top 20 islands ranked according to the biomass of seabirds breeding on them and one each in the Cairns and the Central Sections (Hulsman 1996). The dominance of the Mackay/Capricorn Section in the top five arises primarily from the sheer abundance of Wedge-tailed Shearwaters and Black Noddies breeding on North West, Masthead and Heron Islands. Over 70% of the breeding population of Wedge-tailed Shearwaters on the east coast of Australia nests on North West Island (Hulsman and Walker 1996).

#### Distribution of species

The Far Northern seabird islands have the highest mean number of pelagic species whereas the Cairns seabird islands have the highest mean number of offshore and inshore species (Table 5). However, when translated to population sizes of these species, the greatest numbers of seabirds occur in the Far Northern and Mackay/Capricorn Sections of the GBR Marine Park. What this may mean is that there are so few islands suitable for breeding seabirds in the Cairns Section that the seabirds congregate on the few islands suitable for breeding. In contrast, there are many islands in the Far North and Mackay/Capricorn Sections that the inshore and offshore species have a greater number of islands suitable for breeding from which to choose.

**Table 5.** Mean number of species per feeding category at each seabird island in each of the four sections of the Great Barrier Reef Marine Park

Section	Pelagic	Offshore	Inshore
Far Northern	0.96	1.8	2.4
Cairns	0.8	2.8	4.6
Central	0	0.33	2.7
Mackay/Capricorn	0.76	1.6	2.3

#### Population trends

These will be illustrated with data from four species. Two species that breed in the northern part of the GBR and two species that breed in the southern part. They are the Sooty Tern and the Common Noddy from the north and the Wedge-tailed Shearwater and the Black Noddy from the south.

##### *Sooty Tern and Common Noddy*

Censuses of seabirds breeding at Michaelmas Cay have been carried out on a monthly basis for more than 10 years. This is the most comprehensive data set available on breeding seabirds on the GBR. Analysis of this information by De'ath (1994) for population trends indicates that populations of Sooty Tern and Common Noddy have decreased during the decade since 1984. The decreases in the numbers of Sooty Tern and Common Noddy have been 26% and 45% respectively. The reasons for these declines are not known, but the island is one of the more heavily visited on the GBR. Results of studies of human disturbance on breeding seabirds from other parts of the world suggest that the levels of human visitation and visitor approach distances allowed are likely to lower breeding success by increasing nest desertion, egg mortality from exposure and increased predation (see Erwin 1989; Hockin et al. 1992, Rodgers

and Smith 1995). Another possible reason for the declines is the effects of El Niño. How can one distinguish between the effects of disturbance by people and the effects of El Niño?

The effects of El Niño occur on a grand scale. They can be felt throughout the entire South Pacific Ocean. But there are delays in the effects being felt. They occur first in the Eastern Pacific, then the Central Pacific and finally in the Western Pacific. Therefore El Niño effects would be felt widely along the Queensland coast. Elevated sea surface temperatures associated with severe El Niño events have been shown to have significant negative effects on seabird populations (see Schrieber and Schrieber 1984; Wilson 1991).

Michaelmas Cay is on the northward flowing arm of the East Australian Current. Therefore if El Niño was affecting the seabirds breeding at Michaelmas Cay, it should also affect other colonies on the same current, such as Raine Island. But seabird populations including that of the Sooty Terns at Raine Island have not declined during the period of the decline at Michaelmas Cay (E. Hegerl pers. comm.). Therefore, El Niño is probably not the cause of the decline in the seabird populations at Michaelmas Cay.

But there is another piece of evidence that supports this conclusion. It is known from data from the Central Pacific, that Crested Tern populations are unaffected by El Niño events (Schrieber and Schrieber 1984). This is probably because El Niño decreases the size of pelagic fish stocks which are the main prey of the offshore and pelagic seabird species that are most heavily affected by El Niño events. In contrast, the biomass of the Crested Tern diet is dominated by prey of reef origin (Hulsman 1977a; Hulsman et al. 1989). Coral reef systems are largely self sufficient in that they recycle nutrients and do not rely on upwellings to provide them. Therefore reef fish stocks would be buffered from the adverse effects of El Niño events. Thus if Crested Terns increased the prey of reef origin in their diet during El Niño events they could avoid their adverse effects. That notwithstanding, the Crested Tern population at Michaelmas Cay seems to be declining (De'ath 1994).

By a simple process of exclusion, increased levels of human visitation are left as the likely cause of the declines in seabird populations at Michaelmas Cay. Is there any other evidence available that points to anthropogenic causes for the declines in seabird numbers at Michaelmas Cay?

According to De'ath (1994), the declines started after the peak in numbers of breeding pairs in 1986. They coincide with the increase in human visitation to the cay. The increased visitation rates occurred through a combination of factors. First, Cairns International Airport opened in 1984 bringing more tourists to the area. Second, in 1986, operators started using large catamarans to bring people to Michaelmas Cay. By the early 1990s there were an estimated 68 000 visitors per annum to Michaelmas Cay (King et al. 1992). There were 73 869 and 72 217 visitors per annum respectively in the 1993-94 and 1994-95 financial years. That increased visitation rate has provided a greater opportunity for birds to be exposed to disturbance by people.

A number of cyclones have affected seabird populations at Michaelmas Cay during the decade since 1984 (King et al. 1992). However, De'ath (1994) was able to show that the Sooty Tern population was not significantly affected by the cyclones. In contrast, the Common Noddy population was significantly affected but those effects did not last more than four months (De'ath 1994).

It is difficult to determine the population trend of a given species because the trends at its various colonies differ. At some it may be increasing whereas at others it is remaining steady or decreasing. This is illustrated by the changes in the numbers of the two most abundant species

on the GBR: Wedge-tailed Shearwater and Black Noddy. Therefore it is necessary to consider what the trend is at the larger scale such as at a metapopulation level (see Craig 1994). Therefore in this next part, we consider not only the population trends at the colony level but also at the regional scale which may be a metapopulation level.

#### *Wedge-tailed Shearwater*

The numbers of Wedge-tailed Shearwaters at its three main colonies seem to be remaining steady or increasing. For example, the number of shearwaters nesting at Heron Island seems to have remained relatively constant at about 8500 pairs since at least 1965. Although the numbers of burrows on the island have increased (see Hulsman 1984; Hill and Barnes 1989; Dyer et al. 1995), the occupancy rate of those burrows may have declined. The problem is that this supposition is not testable. Therefore reliable estimates of the shearwater breeding population size can only be obtained since the occupancy rates of burrows have been measured (Hill et al. 1996).

Assuming an occupancy rate of 50% which is about the norm for this area (P. Dyer pers. comm.), there has been little change in the number of burrows at Masthead Island between 1972 (34 895 burrows) and 1984 (32 387 burrows) (see Jahnke 1975; Hulsman 1984). But this was followed by a 18% decrease between 1984 and 1986 (20 100 burrows) (see Hulsman 1984; Hill and Barnes 1989) and a 42.6% increase between 1986 and 1988 (35 012 burrows) (see Hill and Barnes 1989; E. Hegerl unpubl. data). Alternately, the breeding population could have been remaining relatively steady, fluctuating between 15 500 and 17 500 pairs during the past three decades.

An explanation for the variability in the numbers of burrows is that the transects were not fixed between years. Certainly the low estimate of burrow numbers given by Hill and Barnes (1989) for Masthead Island seems to be anomalous. The question this result raises is: Is it a real decrease in numbers of burrows or a sampling artefact? If the difference is real, then the shearwater population at Masthead Island fluctuates by 32.6%. If the low estimate is a result of biased sampling, then the breeding population fluctuates by 11.4%.

It is important to understand how these changes, if real, have occurred. Have they occurred because of changes in recruitment rate to the breeding population, mortality within the breeding population, or a combination of both? The answer will provide some insights into how best to manage the population. For example, if the population changes resulted from increased mortality of breeding individuals then one could investigate what threats are breeding birds exposed to on the breeding grounds. Mortality may be increased during the non-breeding season when most species are absent from their breeding grounds. In such a case, it becomes very difficult to manage without the co-operation of other governments under whose jurisdiction the birds may fall while overwintering. For example, Wedge-tailed Shearwaters overwinter in waters of New Guinea and the Philippines (Marchant and Higgins 1990).

At North West Island, the population has slowly increasing if the occupancy rate has remained constant at 50% from 139 095 pairs in 1983, 141 885 pairs in 1984 (Hulsman 1984 adjusted data), 146 545 pairs in 1985 (Donahue 1986), i.e. a 5% fluctuation in the shearwater numbers.

#### *Black Noddy*

The numbers of Black Noddy at Heron Island have remained at the same level or have been slowly increasing since the turn of the century (Barnes and Hill 1989 [Fig. 3]) at a rate of 7.9% per annum between 1978 and 1984 (see Ogden 1979; Hulsman 1984) and 4.3% per annum between 1983-84 and 1985-86 (see Hulsman 1984; Barnes and Hill 1989). In contrast, its

numbers at other colonies such as Lady Musgrave have significantly decreased from 15 000 pairs to 1 840 pairs over a 20-year period (Hulsman 1984), i.e. 4.4% per annum. Its numbers at Masthead Island have decreased between 1972 (estimate +/- 95% CI, 106 824 +/- 17 579 pairs) and 1983 (70 788 +/- 16 663 pairs)<sup>1</sup>, that is a 3.1% per annum decrease. In December 1988, there were an estimated 60 997 +/- 9 606 pairs (E. Hegerl unpubl. data). That is a decline of 2.8% per annum. Each of these declines is statistically significant ( $P < 0.05$ ). There has been an overall decrease of 42.9% in the size of the breeding population since 1972. At this stage, it is not clear whether the breeding population is continuing to decline at Masthead Island or whether it has maintained itself at its 1988 level.

In the Capricorn-Bunker Group, the breeding population of Black Noddies has declined at Masthead and Lady Musgrave Islands and increased at Heron and One Tree Islands. It may well be that the noddy's breeding population is about the same size as the early 1970s, but breeding pairs are emigrating to other islands and thus redistributing themselves. However, the trend in the population at the largest breeding colony (North West Island) is not presently known. Without this information it is not possible to determine the trend in the breeding population of Black Noddy in the Capricorn-Bunker Group of islands.

### **Approach to management and its practice**

Ogilvie and King (1993) identified the management techniques that had been used to protect seabird populations on the GBR. These techniques included seasonal closures, restricting visitors to specific parts of an island, limiting the number of campers and specifying where they may camp on the island, limiting the number of guests at resorts, and providing training programs for tour operators and resort staff. An important point made by Ogilvie and King (1993) was that commercial operators themselves must assume a greater level of responsibility in protecting the resources that provide their livelihood.

King (1993) outlined the need to strengthen protection of seabirds and their habitats using a combination of legislation, education and enforcement. There is also an unstated recognition among those working with seabirds on the GBR that a more structured approach to population censuses and monitoring is required. Only with a strengthened resolve to increase and focus research efforts towards ways of recognising and ameliorating the effects of human activities on survival and breeding success, can the long term future of seabirds in the area be assured. What is currently being done?

### **Status of Great Barrier Reef Marine Park seabird management**

Seabirds at their breeding islands are highly susceptible to human disturbance. Therefore, following consideration of a paper summarising the management of GBR seabird islands (Stokes et al. 1996), the Great Barrier Reef Marine Park Authority and the Australian Nature Conservation Agency commissioned the development of national guidelines for human visitation to seabird breeding islands. The 1995 report is being prepared for publication. As a result of its submission, the Great Barrier Reef Marine Park Authority convened two inter-agency workshops in November 1995 and April 1996, to focus seabird management and research priorities on the GBR and in the Coral Sea.

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<sup>1</sup> Jahnke (1975) used an area of 19.55 ha to estimate the population size at Masthead Island and a density of 0.388 nests/m<sup>2</sup>. In fact the density should be 0.309 nests/m<sup>2</sup>, i.e. 3861 nests in an area of 12 480 m<sup>2</sup>. Whereas Hulsman (1984) used a density of 0.204 nests/m<sup>2</sup> and an area 44 ha. The vegetated area of Masthead Island is 34.7 ha (Dyer et al. 1995) and using this area, Jahnke's estimate would be 106 824 pairs and Hulsman's estimate would be 70 788 pairs.

In preparation for the workshop, staff from the Central, Northern and Far Northern regions of the Queensland Department of Environment covering the GBR assessed for their regions:

- biologically, the ten most important seabird breeding islands (Table 6);
- from a human use and economic viewpoint, the ten most important seabird breeding islands (Table 6);
- the major management issues facing seabird islands (Table 6);
- the most pressing seabird island management situations (Table 6).

The responses formed a useful assessment of the GBR seabird island management situation.

The criteria used to rank the islands for their biological importance in each section were a mix of species richness, species composition and abundance. For example, Lady Elliot Island was ranked first on the basis of a number of these criteria; 10 species breed there, three of these are breeding at their southern limit, the large colony of Crested Terns and the only breeding colony of the Red-tailed Tropicbird in the Southern GBR. In contrast, Wallace Islet in the Far Northern Section has eight species breeding there (most in small numbers) and the largest colony of Roseate Terns in Queensland waters.

Any island's importance changes with the criteria used to rank it. For example, North West Island is ranked as the second most important biological island and as fifth for human use and economic importance (Table 6).

The two most important management issues facing seabird islands along the length of the GBR seems to be the impact of tourism and recreation on seabirds (Table 6). This is an issue of great concern because of the increasing accessibility of those islands and reefs near the outer barrier (Stokes et al. 1996). More pressure from people will affect those colonies that formerly were not exposed to that type of disturbance. For some species of seabird, the number of potential breeding islands will be greatly reduced and therefore threaten the viability of those species on the GBR.

It was in this context that the November 1995 workshop recommended that:

- the report on guidelines for human visitation to seabird breeding islands be adopted by the Great Barrier Reef Marine Park Authority as guiding principles, from which policies and actions can be developed in consultation with stakeholders, and considered for national adoption; and
- the issues GBR and Coral Sea seabird management should be considered according to the agreed upon options, preferences and priorities.

Consultations to date have set a well-defined platform for future cooperation and management of seabirds on the GBR and in the Coral Sea. A major advance has been the considerable progress in analysing seabird databases and in developing standardised seabird monitoring procedures and data sharing arrangements between the Great Barrier Reef Marine Park Authority, the Australian Nature Conservation Agency and the Department of Environment. It is planned that workshops will continue to be held each May to consolidate this progress and to ensure further collaboration and review of the regional seabird monitoring and management programs.

#### Adaptive Management Framework

Even with agreement between the stakeholders upon options, preferences and priorities, it is important to recognise that given the lack of certain key pieces of information it is difficult to determine which is the most appropriate management plan to implement. Since these key pieces of information such as recruitment rates to the breeding population, the amount of

exchange between colonies take a long time to obtain, it seems prudent to adopt a flexible management strategy. An Adaptive Management Framework provides the required flexibility.

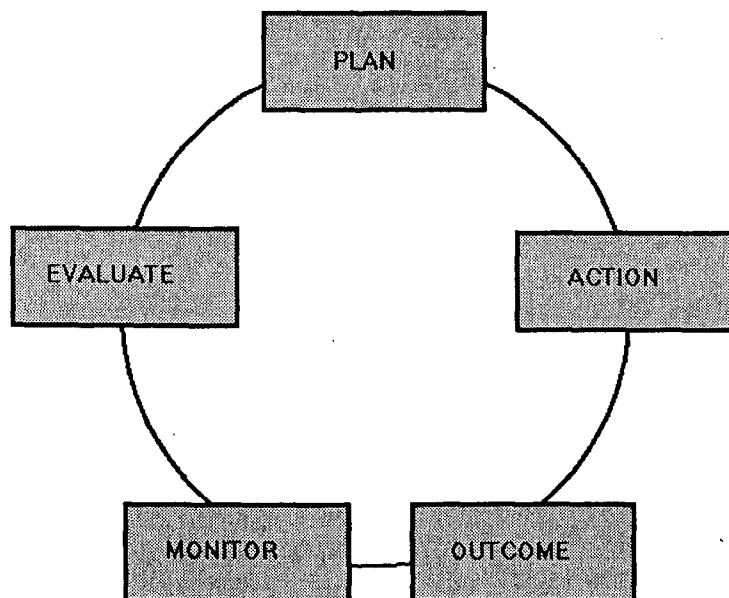
The first stage of the proposed Adaptive Management Framework is to develop a Management Plan (Fig. 3). This is developed in consultation with the various stakeholders as explained earlier. The Plan should have clearly defined and articulated goals. Each of these goals can then be broken down into its component objectives. That is, tasks that can be executed and when executed will produce outcomes that are on a progression towards achieving their 'emergent' goal. It is also important that the goals and their constituent objectives be prioritised according to criteria such as urgency and feasibility.

The second stage in the cycle is to perform some of the tasks that are thought by the planning team to effect the desired goals of the Management Plan. This is the Action stage (Fig. 3).

These actions taken will produce outcomes; the third stage of the cycle. Some outcomes may be desirable whereas others may be undesirable. Nevertheless, these outcomes are important indicators of the system's progress towards the goals of the Management Plan. Therefore it is imperative that the outcomes are monitored; that is the fourth stage of the cycle.

The fifth stage of the cycle is evaluation of the extent to which the actions taken have made progress towards the desired outcomes and ultimately achieving the desired goals. The manner in which a decision is implemented (action) is very important because it affects the outcomes. From this evaluative stage it may be necessary to return to the Management Plan to refine it and take different actions to effect the desired outcomes. This framework is extremely flexible allowing one to collect data necessary for management decisions as well as incorporate data from other sources to modify the existing Management Plan or actions.

The management of seabird populations on the GBR should progress towards a more common sense approach. Involving the stakeholders in the decision-making process and the use of an Adaptive Management Framework are part of a common sense approach. If this type of approach is adopted then appropriate protection of breeding seabirds on the GBR will be achieved.



**Figure 3.** Framework for Adaptive Management Approach



**Table 6.** Assessment of Great Barrier Reef seabird island values and seabird management issues. (Assessed Nov. 1995 by Marine Park management staff of Regional Offices: Mackay, Townsville, Cairns). Ranked in importance greater-to-lesser except that the two issues columns are not ranked for Cairns/FN sections.

MACKAY/CAPRICORN SECTION				CENTRAL SECTION				CAIRNS/FAR NTH SECTIONS			
Biologically most important seabird breeding islands	Human use and economically most important seabird islands	Major management issues facing seabird islands	Most pressing seabird island management issues	Biologically most important seabird breeding islands	Human use and economically most important seabird islands	Major management issues facing seabird islands	Most pressing seabird island management issues	Biologically most important seabird breeding islands	Human use and economically most important seabird islands	Major management issues facing seabird islands	Most pressing seabird island management issues
Lady Elliott Is.	Heron Island	Tourism	Lady Elliott Island	Eshelby Island	Bowling Green Bay/Spit	Tourism	Tourism-North Whitsundays	Raine Island	Michaelmas Cay	Visitor access	Michaelmas Cay
North West Is.	Lady Elliott Is.	Recreation	Camping	Bowling Green Bay/Spit	Brook Islands	Recreation	Tourism - Rest of Whitsundays	Michaelmas Cay	Sandbank No.7 Cay	Grouped island manag't	Raine Island
Swain Reefs cays	Lady Musgrave Is.	Introduced species	Wilson Island	Brook Islands	Holbourne Island	Boating	Ecotourism	Moulter Cay	Sth Barnard Isles	Motorised activity	Research coordination
Fairfax and Hoskin Islands.	One Tree Island	Weather stations activities	Weather/Nav. aid activities	Holbourne Island	White Rock	Fishing	Recreational boating	Quoin Island	Normanby Island	Indigenous egg collecting	Ecotourism
Masthead Island	North West Is.	Nav. aids activities	Research	East Rock	Purtaboi Island	Aircraft	Purtaboi Island	Sandbank No. 8 Cay	Raine Island	Nav. aid activities	Aircraft guidelines
One Tree Island	Wilson Island	Aircraft	Monitoring	Olden Rock	East Rock	Defence activities	Brook Islands	Wallace Islet		Aircraft/Helicopter	
Wreck Island	Masthead Island	Research		White Rock	Little Grassy Is.	Weather stations	Bowling Green Bay			Research	
Wilson Island	Gannet Cay	Fishing		Purtaboi Island	Eshelby Is.	Research					
Erskine Island	North Reef Is.			Little Grassy Is.	Pelican Is.						
Lady Musgrave Island	Irving Island			Eva Island	Double Cone Is.						

## **Acknowledgments**

We thank Professor David Hopley, James Cook University, for permission to use his database on islands of the GBR; Dr Pam Dyer and Myriam Preker for use of their unpublished observations and their help in the field. Our thanks also go to David Elsdon, Eddie Hegerl, Bill Lane, Gale Lorimer, Angus Innes, Ross Mathers, Luba Shinkarenko, Geoff Smith, Sue Barrett, Murray Burrows, Ben Cook, Brent Dadds, Warren Maurer, Craig Strong, Bonnie Thomas, Leonie Thomas and Brent Wise for their help in the field. Also thanks are due to the staff of the Department of Environment based in Gladstone. The Seabird Database of the Queensland Department of Environment was initiated by T.A. Walker and was completed by K. Hulsman after T.A. Walker's untimely death.

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# The status of cetaceans in the Great Barrier Reef Marine Park

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## Introduction

Although they are charismatic megavertebrates, our knowledge of cetaceans in the Great Barrier Reef is poor.

The aim of this paper is to outline what is known, and what needs to be known, about cetaceans in the Great Barrier Reef.

The cetaceans in the Great Barrier Reef can be divided into:

- Baleen whales
- Inshore delphinids
- Pelagic cetaceans

## Baleen Whales

Mostly migratory, in the Great Barrier Reef generally July - November.

Two species merit more detail - humpback and minke whales.

Other rorquals (e.g. blues, fins), may be observed occasionally in the Great Barrier Reef, but Brydes whales (*Balaenoptera edeni*) are probably the most likely to be seen.

Apart from humpbacks, very poorly known.

Humpback whales, *Megaptera novaeangliae*

Their annual migrations from Antarctic waters takes humpback whales into the Great Barrier Reef through the winter months, although there are record of some humpbacks in the Great Barrier Reef throughout the year.

### *Status in the Great Barrier Reef*

The population migrating off eastern Australia is increasing at about 10% per year (at least since the mid-1980s). Recent (1993) information demonstrates that illegal Soviet whaling killed far more whales than previously thought. The latest estimate (1993) of the population on the east coast of Australia is approximately 2500 individuals.

### *Biology*

Northern terminus of migration remains unknown - perhaps diffuse between the Whitsundays and Cairns? Recent behavioural work in south-east Queensland demonstrates that 'breeding ground' behaviour occurs far to the south of the putative terminus of migration - is all of the Great Barrier Reef a 'breeding ground'? Molecular genetic work demonstrates that (at least for mtDNA) east coast and west coast populations off Australia are separate. Molecular genetic, photo-identification and *Discovery* tagging work suggests that the picture in the SW Pacific is more complex.

- Molecular genetics - no significant differences between eastern Australia and Tonga.
- Photo-identification - matches between New Caledonia and Australia, Tonga and Australia.
- *Discovery* tagging - movements between New Zealand and Australia (including a Tasman crossing of about two weeks), Fiji and Australia.

*Management issues*

In the Great Barrier Reef, the major management issue is whalewatching. Data from Hervey Bay demonstrates that whale behaviour changes when in the presence of whalewatching vessels. Some data indicate that the usage of Hervey Bay by whales has changed - but lack of data continuity (due to poor organisation of research funding) means that no definitive statements can be made.

Other management issues are outside the realm of the Great Barrier Reef, e.g. krill fishing, global warming.

*Minke Whales, Balaenoptera acutorostrata*

The minke whales most often observed in Great Barrier Reef waters are dwarf minke. Their annual migrations from Antarctic (?) waters takes minke whales into the Great Barrier Reef through the winter months.

*Status in the Great Barrier Reef*

Unknown

*Biology*

Poorly known

*Management issues*

Unclear

**Inshore Delphinids**

- Indo-Pacific humpback dolphins
- Irrawaddy dolphins
- Bottlenose dolphins

*Indo-Pacific Humpback Dolphins, Sousa chinensis*

*Status*

Unknown

*Biology*

Poorly known - likely that their maximum rate of reproduction is low, and requires very high adult survivorship. Data from the Great Barrier Reef demonstrates that they can occur in shallow offshore waters, a new finding with implications for their conservation.

*Management issues*

Most countries where *Sousa* occur are developing, and lack effective marine wildlife management programs. Australia is one of the only places where it is likely that *Sousa* will survive into next century. Therefore, Australia has a special responsibility to manage human impacts on these animals. The Great Barrier Reef is the largest single management area in the range of *Sousa*, and so there is an urgent need to ensure their survival in the region. There is no estimate of population size of *Sousa* in the Great Barrier Reef, but this could be rectified with work to: (1) improve cetacean species determination on dugong surveys; and (2) estimate availability bias for the surveys. Threats include gill netting, prey depletion due to overfishing, pollution and habitat destruction from coastal development.

Irrawaddy River Dolphin, *Orcaella brevirostris*

*Status*

Unknown

*Biology*

Very poorly known

*Management issues*

As for *Sousa*

Bottlenose Dolphins, *Tursiops truncatus*

The 'definitive' dolphin, occurring throughout the world (other than polar waters).

*Status in the Great Barrier Reef*

Unknown, unlikely to be threatened.

*Biology*

Very poorly known in the Great Barrier Reef, but probably similar to elsewhere in the world. Long lived animals with low maximum rates of reproduction. Relatively localised populations have been found in the (mainly inshore) areas where they have been studied. Taxonomy is still muddled.

*Management issues*

As for *Sousa*, only less urgent, as they occur in other developed countries around the world.

**Pelagic Species**

Species known to include:

- Spinner dolphins, *Stenella attenuata*
- Pantropical spotted dolphins, *S. longirostris*
- False killer whales, *Pseudorca crassidens*
- Killer whales, *Orcinus orca*
- Long-finned pilot whales, *Globicephala macrorhynchus*

## Sperm Whales

Great sperm whale, *Physeter macrocephalus*

## Beaked Wales

Dense-beaked whales, *Mesoplodon densirostris*

Longmans beaked whales, *M. pacificus*

Little is known of pelagic species in the Great Barrier Reef, other than that they occur there. Longmans beaked whale is known only from two skulls.

## Research Required

### Baleen whales

#### *Humpback Whales*

- Maintain land-based surveys.
- Further work on impacts of whalewatching (more aerial surveys in Hervey Bay required for a start).
- Determination of the status of the stocks in the SW Pacific.
- Assess behaviour and habitat requirements in Great Barrier Reef waters, especially females with newborn calves.
- More work on basic biology.

#### *Minke Whales*

- Assess distribution, relative abundance and behaviour in the Great Barrier Reef.

### Inshore Delphinids

- Determine availability bias, improve species identification to derive population estimates from dugong survey data.
- Assess human impacts in selected key areas - using behaviour and behavioural ecology in conjunction with population biology.
- More work on life history of *Sousa* and *Orcaella* required.

### Pelagic cetaceans

- Learn something about them?

## Pressure-state-response model

Table 1 summarises pressure, state and response (DEST 1994) for cetaceans in the Great Barrier Reef Marine Park.



**Table 1.** Summary of pressure, state and response (DEST 1994) for cetaceans in the Great Barrier Reef Marine Park

	<b>Pressure</b>	<b>State</b>	<b>Response</b>
Humpback Whale	Whalewatching	Population increasing	Increased research, continued moratorium on new whalewatching
Minke Whale	Unclear	Unknown	Increased research
Indo-Pacific Humpback Dolphin	Gill netting, prey depletion from overfishing, pollution, habitat destruction	Unknown	Recognise importance, eliminate mortality from gill nets and shark nets, improve fish stocks, reduce pollution through catchment management
Irrawaddy River Dolphin	As for Indo-Pacific Humpback Dolphin	Unknown	As for Indo-Pacific Humpback Dolphin
Bottlenose Dolphin	As for Indo-Pacific Humpback Dolphin	Unknown, unlikely to be threatened	As for Indo-Pacific Humpback Dolphin
Pelagic Cetaceans	Unknown	Unknown	Increased research

### Conclusions

- Cetaceans have been, by and large, ignored by management in the Great Barrier Reef.
- Management recently has been restricted to regulating whalewatching in the Whitsundays.
- Until impacts of whalewatching have been determined, the moratorium on new whalewatching enterprises currently in place (through the Queensland Department of Environment) should remain.
- the importance of the Great Barrier Reef for *Sousa* and *Orcaella* needs to be recognised by management.
- Steps need to be taken to limit and eventually eliminate the mortality due to netting, especially gill nets and the nets set as part of the Queensland Shark Meshing Program.
- Sufficient fish stocks need to remain to provide inshore species with food.
- Catchment management is needed to limit pollutant loads in inshore waters.
- It would be nice to know something, sometime about pelagic cetaceans.

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# **Mangroves in the Great Barrier Reef World Heritage Area: current status, long-term trends, management implications and research**

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## **Abstract**

Mangroves are a coastal marine environment, characteristically biomass-dominated by trees. They support a high biodiversity of marine and terrestrial biota, as well as providing a haven for estuarine fauna, and a nursery ground for other fauna ranging from flying foxes and seabirds, to offshore fish and crustaceans. The uses and benefits of mangroves equate to our direct use of some of these biota but it also includes other indirect benefits such as protection of coastal foreshores and estuarine margins from erosion. Mangrove environments in, and adjacent to, the Great Barrier Reef World Heritage Area are in relatively good condition, although there are clear indications that pressures on them are increasing rapidly. Localised impacts are accumulating to a point where large areas, once thought to be able to withstand change, are now threatened. And, detrimental changes appear to exceed societies' current responses to protect mangrove environments and to reduce the overall impact of the growing number of smaller impacts. Human activities affect the establishment, growth, survival and biodiversity of mangrove plants, and their impacts range from: direct removal and damage of mangrove plants; conversion of mangrove lands to other uses; construction of breakwaters and other alterations to water courses and local hydrology affecting depositional planes and sediment levels; changes to air and water quality as increased dust, turbidity, temperature and the addition of chemicals; catastrophic events of pollution bringing long-term impacts like large oil spills; and the introduction of exotic pests and pathogens from land and sea sources. Pressures on mangrove environments are real, and there is an increasing obligation on environmental management authorities to clearly describe coastal and estuarine areas according to the best scientific advice. Based on these descriptions, the next step would be to apply protection status, and in particular, designating specific areas for total protection with surrounding areas as buffers. There has never been such a profound urgency to have coastal management plans in place if we wish to preserve rare natural stands, especially adjacent to more populated areas in the region. The obligation on management authorities extends to their taking a leading role in advising Governments on the uniqueness, fragility, vulnerability and ecological tolerance of mangrove ecosystems, as well as on their benefits. And, once management authorities and all interest groups have made decisions about which areas are to be preserved, future development proposals cannot be a matter of compromise between special action groups and developers since it is the environment we wish to preserve which ultimately must determine where the limits of change are set. In appreciation of the urgency, it is also recommended that we continue to fill gaps in our knowledge and understanding of mangrove forests by further supporting long-term monitoring programs investigating, in particular: ecological processes; loss of mangrove area; and the restoration of damaged mangrove stands.

## **Importance and value of mangrove ecosystems**

Mangrove forests form a unique ecosystem bordering coastal margins, linking land-based biota with those in the sea. These coastal plants are highly valued and regarded internationally, based on their abilities to thrive in saline conditions of daily tidal inundation, and in their support of a wide range of animals. The canopy of these halophytic, tidal swamp plants is frequented by terrestrial fauna, while other animals walk across the forest floor at low tide. During low tide,

the plants exchange gases with the air, but after the tide returns, a dramatic change takes place. The flooded forests become the domain of estuarine and marine animals. These tidal waters also provide daily nutrition for the trees but they also facilitate the dispersal and propagation of their progeny.

Just as corals form the structural basis for coral reef ecosystems, mangrove plants make up the structural base for this dominant intertidal ecosystem. The complex of roots, stems, branches and foliage support many organisms which would not exist there otherwise. Some animals are full-time residents, while others are transient users, living in mangroves seasonally while still other users of mangroves never live in mangroves but feed offshore on mangrove-reared baitfish and plankton (Cappo 1995a, b). Mangroves are a major and often primary source of carbon and nutrients exchanged offshore into the Great Barrier Reef lagoon (Robertson et al. 1992).

The comparable structural role of mangrove plants and coral colonies, is based on their respective long-lived organisms of each system. Both mangroves and corals mark their growth with seasonal growth rings, although the records for mangroves are expected to be much shorter than those of some corals, in older trees this reaches up to 100 years. A comparison of respective dendrochronologies for mangroves and corals, particularly for associated nearshore communities, might provide further characterisation of longer term trends in coastal rainfall and runoff, past environmental history, and forest demography.

Specifically, mangrove ecosystems are recognised for their abilities: in stabilising coastal foreshore areas, in providing high levels of primary production and atmospheric carbon fixation, and in their role of sheltering and feeding juvenile fishes and crustaceans during seasonal migratory cycles (Robertson and Alongi 1992). A specific account of the values of mangrove wetlands is given by Lugo and Brinson (1978), and the chief points are listed briefly in Table 1.

In this paper, I briefly review the current status of our knowledge of mangrove habitats in and adjacent to the Great Barrier Reef World Heritage Area (GBRWHA). Also included, are recommendations for their management and the direction of future research on mangroves. For convenience, mangroves are described both within the GBRWHA and those bordering its coastal low water boundary since the relationship between mangroves and coastal waters is intimate. For this reason, it is suggested that mapping coastal boundaries using the seaward fringe of the mangrove canopy is inappropriate in defining coastal terrestrial margins since this line matches mean sea level, while for coastal areas without mangroves, the boundary chiefly coincides with highest astronomical tides.

### **The extent of mangroves in the Great Barrier Reef World Heritage Area**

Mangrove forests and saltmarsh vegetation occupies approximately 4000 km<sup>2</sup> of the coastline bordering north-east Queensland and within the GBRWHA. The distribution of forested stands is analogous to the distribution of reefs in this region, where isolated reefs and coral islands of the Great Barrier Reef form an archipelagous string extending north-south. Mangroves also form an impressive string of stands, although they chiefly hug the coast, filling the mouths of coastal estuaries and bordering embayment enclaves along coastal margins, as well as nearshore islands.

The extent of intertidal vegetation, notably mangrove and saltmarsh, in sections of the GBRWHA was estimated partially by a number of authors (Table 2) although their estimates differ. It seems likely that these values reflect differences in interpretation of remote sensing images, or in the relative accuracy of measurements, but it is not believed they indicate any real

changes in vegetation coverage. Galloway (1982) provided a complete series of estimates for mangrove vegetation in seven coastal regions in the GBRWHA, totalling around 2069 km<sup>2</sup>; being approximately 18% of the total area of mangroves in Australia from the same study. Estimates of mangrove area by Dowling and McDonald (1982) appear to under-estimate stands in both Princess Charlotte Bay (Region 3), Hinchinbrook (Region 4) and south of Lucinda (Region 5), and to over-estimate those in the southern region (Region 6); total areas are similar however. Estimates for particular regions by Danaher (1995) and Ebert (1995) support the specific regional estimates for mangroves scored by Galloway (1982). The Danaher (1995) values also demonstrate the importance of making clear distinctions between saltpan and mangrove areas. Ideally, both areas need to be estimated for each region since they together occupy the intertidal area. Furthermore, their relative extent is influenced by climatic factors, and a relationship between mangroves and saltpan area is inversely correlated, such that in areas of low rainfall, the area of saltpans are proportionally larger (Fosberg 1961).

**Table 1.** A qualitative list of values of saltwater wetlands (Lugo and Brinson 1978)

Water	<ul style="list-style-type: none"> <li>- store flood waters</li> <li>- conserve water during drought periods</li> <li>- desalinate salty water</li> </ul>
Organic productivity	<ul style="list-style-type: none"> <li>- high primary productivity</li> <li>- high secondary productivity (e.g. commercial and sport fisheries)</li> <li>- high export of organic foods to other ecosystems</li> <li>- high wood production in mangroves</li> </ul>
Biogeochemical	<ul style="list-style-type: none"> <li>- high capacity to recycle nutrients</li> <li>- high storage of organic matter and CO<sub>2</sub> sink</li> <li>- net oxygen production</li> <li>- many biogeochemical cycles are closed by reducing N, C, S, Fe, etc., in anaerobic muds</li> <li>- heavy metals, radioactive isotopes, and other poisonous chemicals are sequestered in anaerobic muds</li> </ul>
Geomorphological	<ul style="list-style-type: none"> <li>- high potential for erosion control</li> <li>- protection of coastlines against storms, tides and winds</li> <li>- high potential to build land</li> </ul>
Biotic	<ul style="list-style-type: none"> <li>- serve as fisheries nurseries, bird rookeries, and refuges for terrestrial animals</li> <li>- gene banks for haline and euryhaline plant and animal species</li> </ul>
Other values	<ul style="list-style-type: none"> <li>- natural laboratories for teaching and research</li> <li>- location for recreation and relaxation</li> <li>- rich organic soils used in agriculture, aquaculture, or as fuels</li> <li>- location for solid waste disposal or construction activities</li> <li>- importance as natural heritage, particularly when they become scarce</li> <li>- representative of personal intangible values</li> </ul>

### **Mangrove floristics in the Great Barrier Reef World Heritage Area**

Mangroves are essentially a marine habitat, albeit a specialised one, but those all important intertidal plants which characterise mangroves have all evolved from terrestrial ancestors. The plants are important, since without them, there would be no mangrove ecosystem. As noted, they provide structure for the habitat, as well as a significant portion of the short and longer term net primary production on which the trophodynamics of the ecosystem are based.

Mangrove plants, furthermore, do not come from a single genetic source, and Avicenniaceae and Sonneratiaceae are the only plant families which are comprised exclusively of mangrove taxa. For the world, the total number of mangrove plants is 70 taxa of 21 families, ranging from a ground fern to a range of angiosperms, notably a palm, shrubs and trees (Duke 1992). In the GBRWHA, there are 37 taxa of 19 families (Table 3), representing a significant portion of the

worlds genetic variation in mangrove plants. Some species, like *Avicennia marina*, *Rhizophora stylosa* and *Bruguiera gymnorrhiza*, are widespread in the Indo West Pacific biogeographic region, while others, like *Ceriops australis*, *Bruguiera exaristata*, *Diospyros littoralis*, are more restricted to the Australasian region, and only *Lumnitzera X rosea* is more-or-less restricted to the GBRWHA. It is also of interest that *Avicennia marina* var. *eucalyptifolia* merges more with a south-eastern Australian variety, var. *australasica*, towards the southern boundary, south of the Tropic of Capricorn.

**Table 2.** Estimates of areas of mangrove vegetation in the Great Barrier Reef World Heritage Area

Coastal Regions	Area of mangrove in km <sup>2</sup> (plus saltpan area)			
	Galloway (1982)	Dowling and McDonald (1982)	Danaher (1995)	Ebert (1995)
1 Cape York to Evanson Point	354	395	240 (261)	—
2 Evanson Point to Bathurst Head (Princess Charlotte Bay)	93	10	99 (420)	—
3 Bathurst Head to Cardwell	243	230	>94 (>149)	—
4 Cardwell to Lucinda (Hinchinbrook Island and Channel)	216	120	—	>214
5 Lucinda to Clairview Bluff	645	365	—	—
6 Clairview Bluff to Bustard Head	498	935	—	—
7 Islands of the GBRWHA	20	—	—	—

**Factors influencing the distribution of mangroves**

The number of mangrove taxa in the GBRWHA generally decreases with increasing latitude south (Fig. 1) such that in some northern locations, like the Olive River, there are around 27 species, while in the south, a floristically diverse site at Port Clinton has only 13 species. This indicates the importance of temperature through the region, but species diversity is also correlated with a range of variables, including rainfall, river catchment size, estuary length and geological history (Duke 1992). In Fig. 1, the relationship between rainfall and species numbers is shown by the numbers of species reaching their southern distributional limits in the south of the three wetter regions (marked by the 1400 mm mean annual rainfall isohytes). In general, highest species diversity is found in sites where rainfall is higher, and in riverine estuaries with larger catchment areas.

Species occurrence is also characterised by their distribution upriver which may be described in terms of either, or both, downstream and upstream limits. These limits are essentially correlated with salinity, and as such, they are comparable between river systems, such as for example, Alligator Creek (a dry climate, smaller catchment system; Fig. 2), the Mulgrave River (a wet climate, larger catchment system; Fig. 3), and the Claudie River (a wet climate, medium catchment system; Fig. 4). Thus species might be described as upstream or downstream species, with overlapping ranges within an estuary. For the Claudie River (Fig. 4), the line through the centre of the figure serves not only to notionally divide upstream and downstream species, but it also marks the upstream limit of mangroves defined by Danaher (1995), based on satellite imagery. The Danaher study therefore missed four key upstream species, including *Nypa* the mangrove palm (found in only six other river systems in the GBRWHA), and *Sonneratia lanceolata* (found in only one other river system in the GBRWHA). Other upstream species missed in this report, in other river systems, include *Dolichandrone* (found in only one river system in Australia and in the GBRWHA) and *S. caseolaris* (found in eight river systems only in the GBRWHA). Satellite remote sensing is considered to be unsuitable for mapping riparian estuarine vegetation. Thus, although the mapping study by Danaher (1995) has considerable value, it is also important to understand its limitations and to make appropriate

adjustments when applying these results in the management of estuarine mangrove ecosystems, describing fish habitats, and so on, since these maps do not account for key mangrove species which characterise particular drainage systems. It is the current view that mangrove species distributions in the GBRWHA are essentially relict (Duke 1992), and they comprise distinct and genetically isolated populations, further emphasising their fragility and vulnerability to environmental change.

**Table 3.** Mangrove plant taxa in the Great Barrier Reef World Heritage Area

Family	Taxa
Acanthaceae	<i>Acanthus ebracteatus</i> <i>Acanthus ilicifolius</i>
Areaceae	<i>Nypa fruticans</i>
Avicenniaceae	<i>(Avicennia marina var. australasica)</i> <i>Avicennia marina var. eucalyptifolia</i>
Bignoniaceae	<i>Dolichandrone spathacea</i>
Bombacaceae	<i>Camptostemon schultzei</i>
Caesalpiniaceae	<i>Cynometra iripa</i>
Combretaceae	<i>Lumnitzera littorea</i> <i>Lumnitzera racemosa</i> <i>Lumnitzera X rosea</i>
Ebenaceae	<i>Diospyros littoralis</i>
Euphorbiaceae	<i>Excoecaria agallocha</i>
Lythraceae	<i>Pemphis acidula</i>
Meliaceae	<i>Xylocarpus granatum</i> <i>Xylocarpus mekongensis</i>
Myrsinaceae	<i>Aegiceras corniculatum</i>
Myrtaceae	<i>Osbornia octodonta</i>
Plumbaginaceae	<i>Aegialitis annulata</i>
Pteridaceae	<i>Acrostichum speciosum</i>
Sterculiaceae	<i>Heritiera littoralis</i>
Sonneratiaceae	<i>Sonneratia alba</i> <i>Sonneratia caseolaris</i> <i>Sonneratia X gulngai</i> <i>Sonneratia lanceolata</i>
Rhizophoraceae	<i>Bruguiera cylindrica</i> <i>Bruguiera exaristata</i> <i>Bruguiera gymnorrhiza</i> <i>Bruguiera parviflora</i> <i>Bruguiera sexangula</i> <i>Ceriops australis</i> <i>Ceriops decandra</i> <i>Ceriops tagal</i> <i>Rhizophora apiculata</i> <i>Rhizophora X lamarckii</i> <i>Rhizophora mucronata</i> <i>Rhizophora stylosa</i>
Rubiaceae	<i>Scyphiphora hydrophyllacea</i>

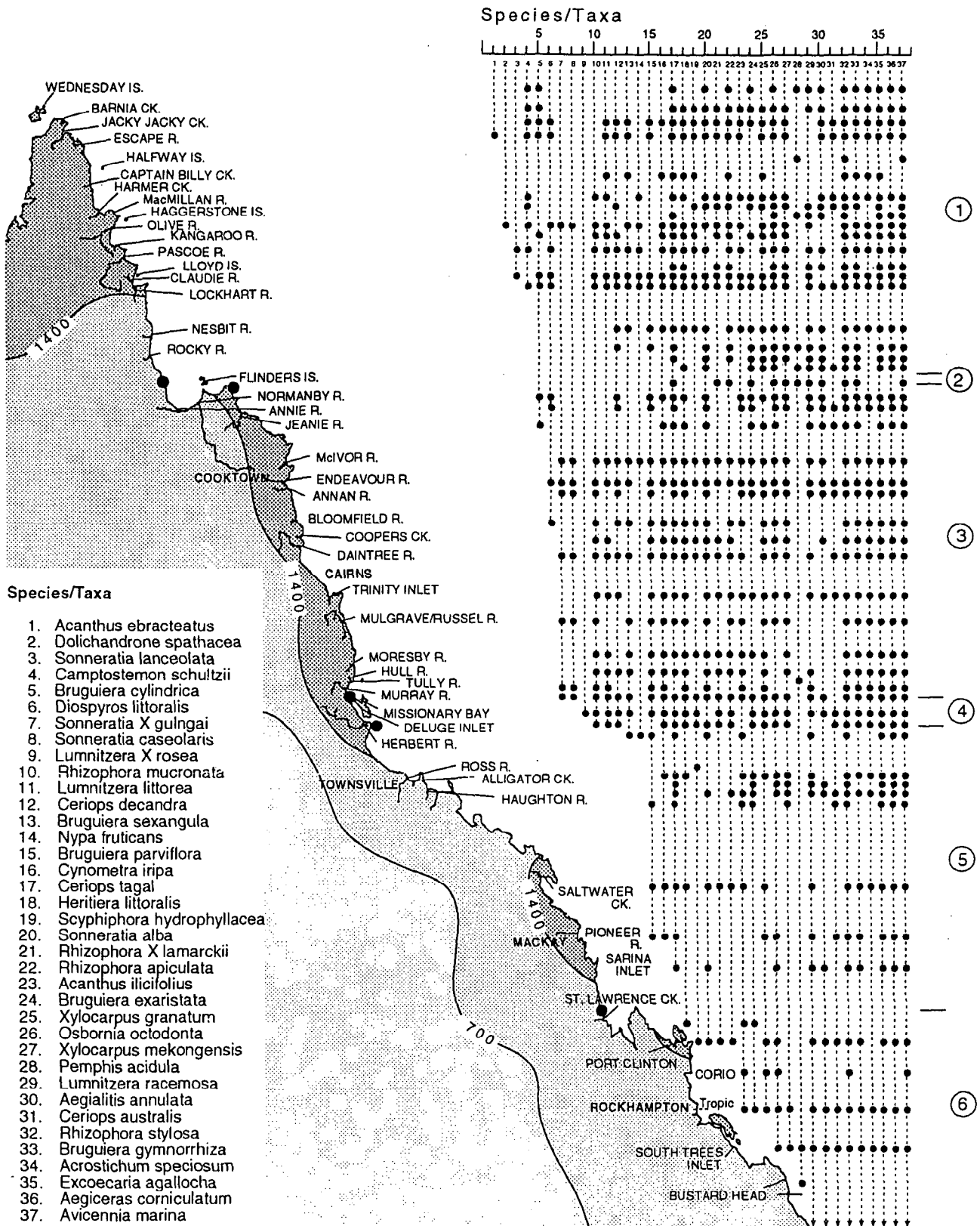


Figure 1. Distribution of mangroves in the GBRWHA. The six regions described in Table 2, are marked by filled circles on the coastline, and numbers in circles.

UpRiver - Alligator

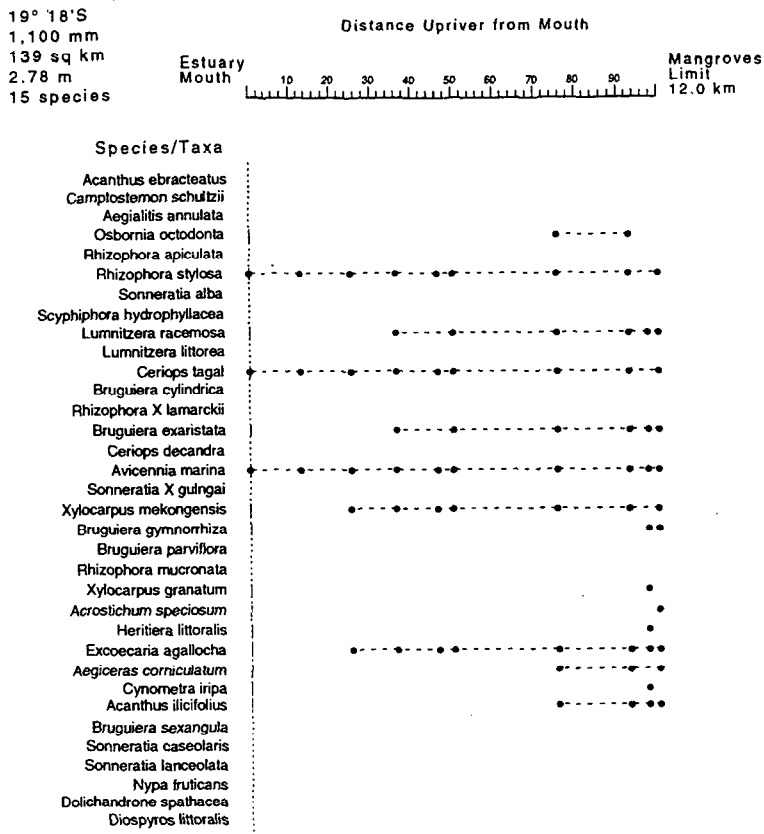


Figure 2. Upriver checklist of mangrove species in Alligator Creek

UpRiver - Mulgrave

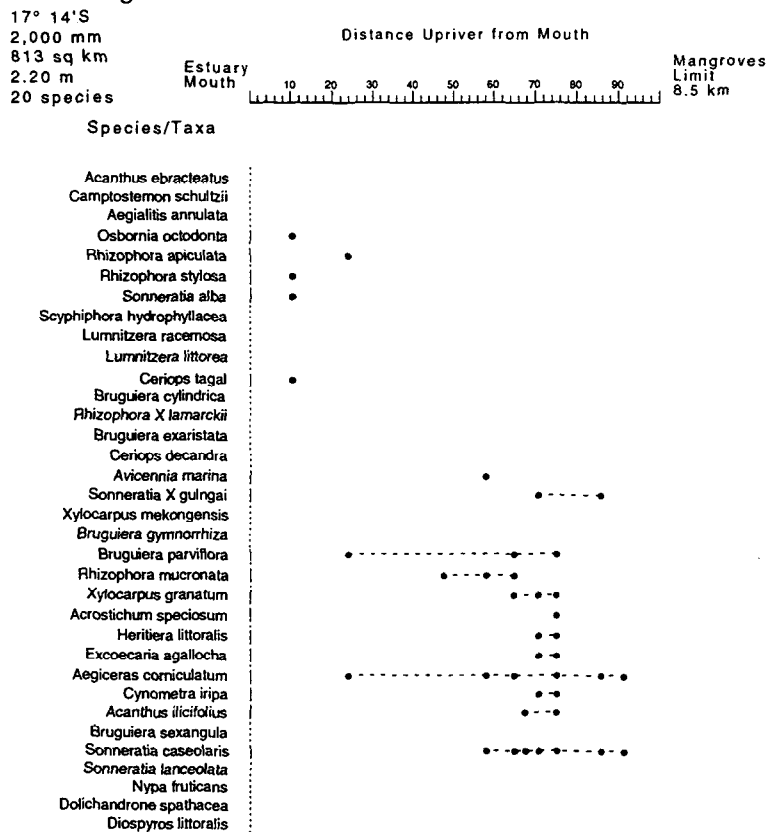


Figure 3. Upriver checklist of mangrove species in the Mulgrave River



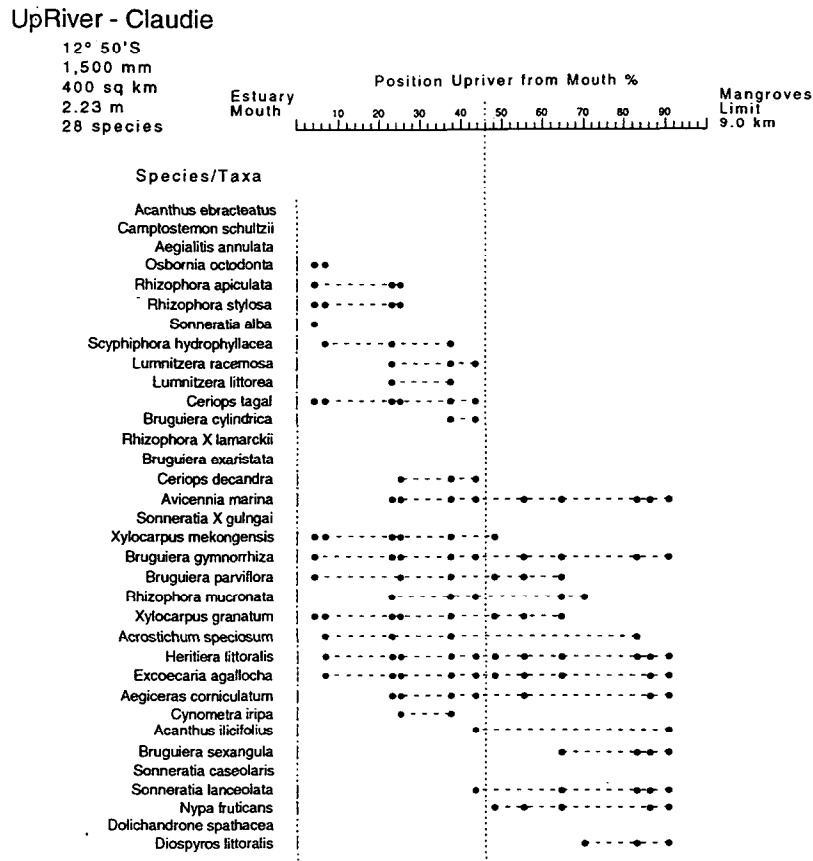


Figure 4. Upriver checklist of mangrove species in the Claudie River

Long-term trends affecting the extent of mangroves

Long-term change to the extent of mangrove forests was assessed recently in two locations in north Queensland, namely the Johnstone River estuary (Russell and Hales 1994), and the Hinchinbrook Channel islands and Missionary Bay (Ebert 1995).

The Johnstone River is a large river and estuarine system situated within the wet tropics region. Large parts of the catchment area are used in farming and agriculture, and few areas remain undisturbed from pre-settlement condition. Russell and Hales (1994) assessed vegetation cover of both freshwater and mangrove wetlands in this catchment, comparing aerial photographs from 1992 with those taken in 1951 (Table 4). They identified a very high loss of freshwater wetlands, around 65% being approximately 18 km<sup>2</sup>. By contrast, there was a net increase in mangrove area, around 15%, being approximately 0.3 km<sup>2</sup>. The gain in mangroves was chiefly observed in the lower estuary as expansion into tributaries of the estuary. An explanation for these changes may be that losses to terrestrial vegetation upstream have led to erosion of topsoil, and mangroves have colonised the resulting sediment deposition banks downstream.

Table 4. Changes in areas of vegetation cover for the Johnstone River, 1951 to 1992 (Russell and Hales 1994)

Wetland Ground Cover	Area in 1951 (ha)	Area in 1992 (ha)	Net Change (ha)	% Change
Mangrove	176	202	+ 26	+ 14.8%
Freshwater	2677	925	- 1752	- 65.4%

The Hinchinbrook Channel, with a mangrove area of around 164 km<sup>2</sup>, contains a group of mangrove islands with a combined total area of around 37 km<sup>2</sup>. The mangroves on these islands are mostly quite tall (around 10 m), and it is generally estimated that a large number of trees are older than 50 years. Based on accurately positioned aerial photographs (notably on data gathered by AUSLIG), Ebert (1995) compared vegetation cover in 1991 with that in 1943 (Table 5). He concluded that there was no appreciable net change in the total area of mangrove and saltpans (in fact around 1% gain, being 0.5 km<sup>2</sup>). However, there was a marked net change in the relative proportions of intertidal vegetation where saltpan area decreased by 78%, essentially replaced by tall mangrove forest which also replaced some short mangrove. In this context, it is of interest to compare the correlation between the ratio of mangrove to saltpan area with wet and dry climatic regions (Fosberg 1961), noting that saltpan area may be reduced to zero in wetter regions. An explanation for this occurrence therefore, may be that there was an increase in annual rainfall reducing ground water salinities over the period. However, the increased biomass of intertidal vegetation of the Hinchinbrook Channel islands may also be related to increased nutrient supply from the Herbert River outflow, and subtle changes in sediment deposition. A further assessment of the range of influencing factors is required.

**Table 5.** Changes in areas of vegetation cover for the Hinchinbrook Channel islands, 1943 to 1991 (Ebert 1995)

Ground Cover	Area in 1943 (ha)	Area in 1991 (ha)	Net Change (ha)	% Change
<b>Mangrove</b>				
- tall	3543.9	3779.0	+ 235.1	
- short	38.0	11.0	- 27.0	
- all trees	3581.9	3790.0	+ 208.1	+ 5.8%
- saltpan	207.0	46.0	- 161.0	- 77.8%
<b>All Mangrove</b>	3788.9	3836.0	+ 47.1	+ 1.2%
<b>Terrestrial</b>	22.0	21.9	- 0.1	- 0.1%

In an assessment of the geological history of the Hinchinbrook region (Ebert 1995), the mangrove islands were described as being of similar age, and composed of sediments derived from the Holocene post glacial marine transgression. Mangroves may have colonised these sediments as the sea level dropped after the Holocene period. The creeks draining the mangrove islands then evolved in response to tidal flushing to produce the current patterns. There is also some erosion on their northern edges, and it is suggested that mangrove growth may only occur after a large input of allochthonous sediments which has not occurred over the last fifty years. Current accumulation rates are insufficient to promote expansion of the mangrove islands.

This relative stability of mangroves was also observed in Missionary Bay (a mangrove area of 50 km<sup>2</sup>) on Hinchinbrook Island (Ebert 1995). And, the pattern where saltpans were replaced by mangrove forests was repeated over the same period from 1943 to 1991, while there was little or no expansion into surrounding waterways.

In view of these examples, it seems likely that many mangrove areas in the GBRWHA are quite old, and were changing slowly in the absence of human disturbance, responding to events over very long time-scales, except where they occupy the mouths of larger rivers in wetter regions.

### **Human effects**

It is unfortunate for mangroves that they are often mostly prevalent in sites preferred for coastal cities and industrial development. In tropical latitudes, estuaries are a major focus for commercial and recreational activities. For these reasons, urban developments, ports and

foreshore structures surround these estuarine habitats, often replacing mangroves, or large portions of them. It is apparent that the greatest long-term effect on mangroves in this region is in their removal and disturbance by people. This takes place in often small incidents, but each one adds to a total, larger accumulative impact. By comparison, natural trends are virtually unnoticed in human time scales, noting the examples described above. Therefore, there is an urgent need to quantify the loss of mangroves caused by humans in coastal areas of Queensland, since this information is needed most in any assessment of the impact and longer term trends in mangrove forests of the GBRWHA. The chief reason for the urgency is not only because of the significance of disturbance at any one site, but more importantly, to allow an assessment of accumulative damage throughout the region. Only after this information is available will it be possible to confidently manage mangrove ecosystems to preserve them and utilize them in a sustainable manner.

Over the last 30 years, there has been a rapid growth in public and scientific interest in mangroves prompted both by our increasing awareness of the fragility of similar natural environments, and by the greater demand for coastal land for development in tropical regions. This is chiefly due to population increases which have doubled in many north Queensland centres over this period. But, attitudes have changed also, and the language used by people to describe mangroves seems to have become less derogatory, marked by fewer references to 'scrub, swamps and bogs', to more about 'trees, forests and mudflats'. With such subtle changes in attitude, there is hope that there is a growing respect for these natural environments as places not only to be directly exploited and used, but as places which are important in preserving the well-being of our society, long into the future.

### **Management**

There are three major challenges for the conservation and management of mangrove areas in the GBRWHA. Firstly, to develop better linkages between responsible government departments, coastal research institutions and interested people, through jointly sponsored research projects, workshops and conferences. Secondly, to increase education on mangrove environments, describing mangroves, and identifying essential links with marine ecosystems and the continuum between terrestrial catchments and the sea. In this context, it would also be important to re-iterate the concept of cause and effect, such as, for example, that what happens in catchments upstream affects habitats downstream, including mangroves, and ultimately affecting coral communities along the Great Barrier Reef. Thirdly, to learn more about mangrove ecosystems and how they function, better defining environmental and ecological constraints, and in particular, focusing on management-orientated research, including their restoration. For day-to-day management, it would also be useful to compile information on existing mangrove interpretation centres around Australia, providing a base from which to improve public access and educational benefits for mangroves in the GBRWHA.

Wetland management strategies and objectives have been assessed by Bennett and Goulter (1989), and they described 12 specific goals which may be applied to mangroves in the GBRWHA:

1. maintain water quality;
2. reduce erosion;
3. protect from floods;
4. provide a natural system to process airborne pollutants;
5. provide a buffer between urban residential and industrial segments to ameliorate climate and physical impact, such as noise;
6. maintain a gene pool of wetland plants and provide examples of complete natural communities;
7. provide aesthetic and psychological support for humans - recreation

8. produce wildlife;
9. control insect populations;
10. provide habitats for fish spawning and other food organisms;
11. produce timber, food, fiber, and fodder;
12. expedite scientific enquiry.

### **Research Recommendations**

Mangrove research in this GBRWHA region had until recently concentrated on spatial variation and major trophodynamic processes. For example, botanical systematic studies by the Australian Institute of Marine Science from 1974-86 resulted in a progressive and rapid increase in the number of recognised mangrove taxa from 19 in 1968, to 28 in 1977, to 32 in 1982, to the 37 mangroves recognised today. That's three additional species every four years for the period up to 1992. I believe the number has now stabilised, and we now have an excellent understanding of mangrove floristics and distributions in this region. But, we still have some way to go before we know how the system functions and the links with terrestrial and nearshore marine systems. We also have little information on the range of management options and strategies available; a point of great concern as the pressure to remove or alter individual mangrove stands increases in the region.

To address the chief concerns, I identify a number of specific longer-term research projects on mangroves required in the GBRWHA; noting that some of these projects are already underway:

- map the current and past extent of mangrove and saltpan vegetation in all coastal and island regions;
- large-scale and long-term monitoring of forest plots along the coast - with an emphasis on changes in fringe areas, forest dynamics, demography, tree growth and gap restoration (this could be linked with long-term monitoring of estuarine water quality);
- dendrochronological assessment of comparable growth rings in mangrove trees and nearshore corals;
- genetic studies showing dispersal and distribution patterns of mangrove plants;
- ecological processes within mangrove forests, noting imports and exports;
- links between mangroves and nearshore fisheries/ecosystems (including coral reefs);
- dependence of fish and crustaceans on mangroves - food and/or shelter;
- long-term hydrodynamic and geomorphological processes in coastal areas;
- effects of human-induced disturbance and pollution on mangrove ecosystems;
- use of mangroves in water purification and as neutralisers of biotic effluents;
- restoration of disturbed mangrove areas.

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# Floristic analysis of the Great Barrier Reef continental islands, Queensland

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## Abstract

There are 552 continental islands recorded along the east coast of Queensland within the Great Barrier Reef Marine Park (GBRMP). The total area of these continental islands is about 1627 km<sup>2</sup> or 0.1% of Queensland's land mass. A total of 2195 plant species or about one quarter of Queensland's vascular flora occurs on these continental islands. At present 79 of these plant species are listed as rare or endangered. This is 6% of Queensland's known rare flora. Current knowledge indicates that there are only three endemic island plants found within the study area, i.e. *Albizia* sp. (South Percy Island G. N. Batianoff, 11444), *Berrya rotundifolia* and *Habenaria divaricata*.

The study identified a distinctive continental island flora dominated by rainforest species (48%), open-forest species (46%) and littoral plant species (6%). There appears to be no significant difference in species richness between northern and southern island floras. Species richness of island floras in northern tropical areas is more dependent on 'woody' and rainforest species, while in southern subtropical areas, it is more dependent on herbaceous species. There is a strong relationship between species richness and insular area up to 5000 ha size of islands.

This report focuses on botanical resource inventory, current status and trends for continental island flora. Spatial pattern analyses are carried out within and between the Far Northern, Cairns, Central and Mackay/Capricorn sections of the GBRMP. Pattern analyses provided five floristic regions within the Great Barrier Reef. Starting from north, these are 'Northern Region', 'Wet Tropics Region', 'Dry Tropics Region', 'Whitsunday Region' and 'Capricorn Region'.

Issues concerning maintenance of island species richness such as fire and exotic species management are highlighted. All rare and endangered species recognised in this study area listed in the appendix. Management implications for long term conservation are discussed.

## Introduction

This study included about 552 continental islands recorded within the GBRMP study area (Fig. 1) occurring from the tip of Cape York (10°41'S) to just north of Fraser Island (24°30'S). The total land area of these continental islands is an estimated 1627 km<sup>2</sup> or about 0.1% of Queensland terrestrial land, situated along more than 2000 km of the east coast.

The present day continental islands represent mountainous regions of the submerged continental shelf. According to Thom and Chapell (1975) between 12 000 and 10 000 years BP the sea level rose to 30 m below its present level. At this time some of the present day offshore islands were separated from the mainland. Some 6000 years BP the sea had risen to about its present level and during this period large amounts of sand moved inshore and along the shore to form most of the present day coastal dune systems (Capricorn Coast Beaches 1979). Some of these dunes occur on Curtis Island, Great Keppel Island, Percy Islands, Whitsunday Island, Hinchinbrook Island, Lizard Island, Turtle Head Island and Albany Island (near Cape York).

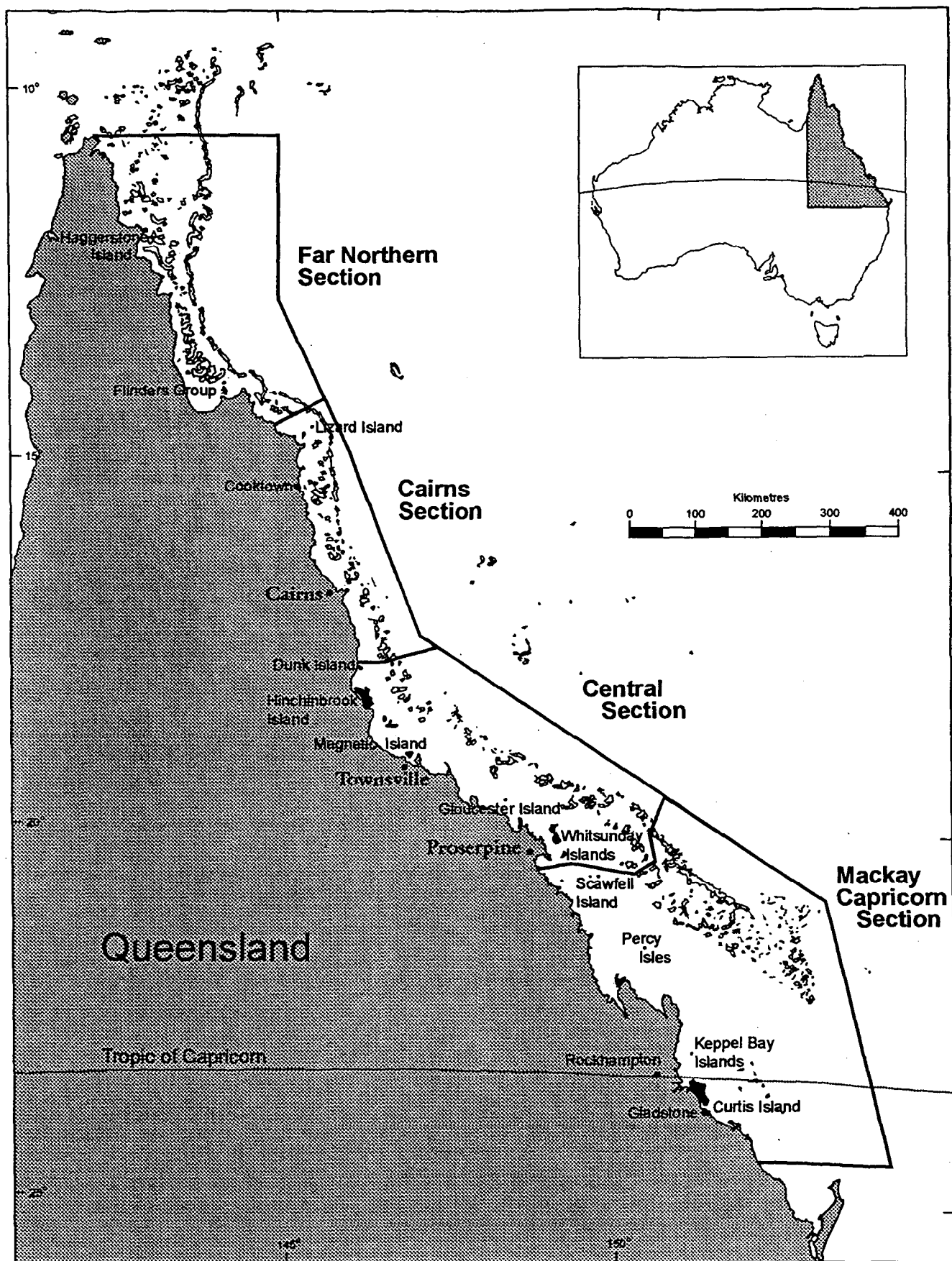


Figure 1. Locality map

As a result of the sea level rise during the Holocene period most of the mountainous areas between the present coast and continental shelf became the 552 continental islands within the area now known as the Great Barrier Reef.

Most of the major geological strata of the adjacent mainland are represented on these continental islands. Geological formations range from Devonian rocks to Quaternary deposits (Geological Survey of Queensland 1975). More common geological units include granites and Whitsunday volcanics. Also common are the Curtis Island Devonian-Carboniferous rocks from Shoalwater Bay to Gladstone (Geological Survey of Queensland 1975). A rare and unusual substrate is found on South Percy Island in the Mackay/Capricorn Section of the Great Barrier Reef Marine Park. About 70% of this island is ultramafic, largely serpentinite rock (Geological Survey of Queensland 1975). The most mountainous and rugged terrain occurs on Hinchinbrook Island, Palm Island, Magnetic island and Gloucester Island. Mt Bowen at 1121 m on Hinchinbrook Island is the highest mountain on any of the continental islands in Australia (with the exception of mountainous areas in Tasmania). The two largest islands are Curtis Island (46 000 ha) and Hinchinbrook Island (39 900 ha).

Mean rainfall in the area generally exceeds 1000 mm per annum (Anon 1971). On average, 10-14 cyclones occur each decade and bring torrential rain and destructive winds from December to April (Lourenz 1977). All areas have relatively mild winter days and hot wet summers. The climate ranges from humid tropical in the north to subtropical maritime in the south. Major maritime climatic elements affecting all islands are tides, waves, salt spray, windshear and south easterly prevailing winds. Vegetation formations are varied. Closed forests (including rainforest), open forests, woodland, scrubs (including semi-deciduous vine thickets), shrublands and grasslands are widespread. The most dominant vegetation is eucalypt forest, however most islands include rainforest, non-eucalypt open forest, littoral seashore vegetation and mangroves.

The Great Barrier Reef continental islands are covered by a variety of tenures, however most of the island areas are managed as National Parks.

We summarise botanical resource inventory data, identify trends and provide floristic spatial pattern analyses. Factors affecting species richness and issues concerning management of islands are discussed.

## **Methods**

### **Floristic analysis**

This paper uses floristic information collected from the 1770 to 1996 period and available to us (Batianoff and Dillewaard in prep.). Plant names used are currently accepted by the Queensland Herbarium and are on the Herbarium records database (HERBRECS) as of February 1996. 'Species-taxa' is used here to include not only the species but all other taxonomic entities such as subspecies, varieties, forms and the undescribed taxa recognised and recorded on HERBRECS.

In some spatial pattern analysis we used rainforest, open forest and littoral seashore species to divide entire continental island floras into three sections. In those analyses the rainforest species are defined as plants listed in the rainforest flora of Queensland and recorded on the database 'Queensland rainforest species identification key' (Jessup 1996, pers. comm.). The littoral seashore species are mostly sandy shore plants including mangroves and sea grasses. The remaining open forest species are the non-rainforest and non-littoral seashore species and include not only all the 'dry' land plants but also freshwater aquatic species.



## Spatial pattern analysis

Regional and island flora groups were analysed in order to determine relationships between the various groups located in the study area and are based on the floristic composition of these groups. Matrices of flora groups units and species were generated for all species found in the area. Data was then analysed using the PATN pattern analysis package (Belbin 1989). The association measure used for the presence/absence data generated was the Czekanowski coefficient which is a measure of dissimilarity. Data was classified using hierarchical agglomerative polythetic clustering method contained in the module FUSE which is based on a flexible unweighted pair group method using averages (UPGMA). The dilation value was set at -0.1. The ability of this particular method to accurately represent vegetation groups has been highlighted (Belbin and McDonald 1993). Dendrograms from the clustering are displayed using the module DEND.

## Overview of the flora

A total of 2195 species-taxa or about one quarter of Queensland's vascular flora are known to occur on continental islands in the GBRMP. Table 1 illustrates plant diversity using major taxonomic and lifeform groups found in the area. There are 2091 flowering plants species, 97 ferns, 5 conifers and 2 cycads belonging to 911 genera and 195 families. The dicotyledons comprise 71.3% of the continental island flora. The exotic introduced species account for 9.8% of the flora which is significantly lower than the Queensland mainland average of 13-14% (Johnson 1983, 1995).

There are 1018 herbs (46.4%), 664 trees (30.2%), 362 shrubs (16.5%) and 151 vine/lianas (6.9%) recorded for the area. It is important to note from the point of view of continental island species diversity that 46.4% of all plants are herbs. In Queensland's central coast flora 56% are herbaceous and 22% are tree species (Batianoff and Dillewaard 1988). On the Great Barrier Reef continental islands, the proportion of tree species is 8% higher, and herbaceous species is 10% lower, than the mainland central coast flora.

Table 2 shows the twelve largest families based on the number of native species of continental island flora compared with Queensland's twelve largest plant families. Note that overall flora diversity, for Queensland and continental islands depends largely on the speciation of the large families Myrtaceae, Poaceae, Fabaceae, Cyperaceae, Euphorbiaceae, Sapindaceae, Mimosaceae, Asteraceae, Rubiaceae and Orchidaceae. These families contribute significant proportions of plants on most continental islands and in Queensland as a whole. There are however, important differences. For example Chenopodiaceae ranks 12<sup>th</sup> in Queensland but is poorly represented on continental islands while relatively small Queensland plant families such as Convolvulaceae, Lauraceae and Verbenaceae are prominent. The relatively poor representation of Chenopodiaceae on continental islands could be explained in terms of this family's outstanding success in the semi-arid interior of Queensland and Australia. The high success rates of families Convolvulaceae and Verbenaceae colonising continental island habitats is difficult to explain. However, these families are cosmopolitan and exhibit great diversity in tropical climates. Finally the conditions of Great Barrier Reef continental islands favour tropical rainforest species. For example families contributing 1.5% or greater of species on the islands, include most of the large rainforest families in Queensland, i.e. Euphorbiaceae (5.0%), Rubiaceae (3.2%), Sapindaceae (2.4%), Orchidaceae (2.2%), Lauraceae (1.5%) and Rutaceae (1.5%).

**Table 1.** Major plant groups and life forms

Taxa	Totals	Dicotyledons	Monocotyledons	Gymnosperm	Pteridophytes
Families	195	129	36	5	25
Genera	911	657	197	5	52
*Species-taxa	2195	1566	525	7	97
(a) Native	1980	1413	464	7	96
(b) Exotic	215	153	61	0	1
* Species-taxa include species, subspecies, varieties etc. and undescribed taxa					
<b>Lifeforms</b>					
Trees > 5 m	379	354	20	5	0
Trees/shrubs					
2-5 m	285	285	0	0	0
Shrubs < 2 m	362	345	14	2	1
Herb (including creepers)	1018	453	470	0	95
Vines/lianas	151	129	21	0	1

**Table 2.** Twelve largest families of continental island plant families compared with Queensland's largest plants (based on the number of native taxa)

Continental Islands (spp. and % total flora)		Queensland (spp. and % of total flora)	
1. Poaceae	192/9.7%	1. Myrtaceae	758/8.2%
2. Fabaceae	121/6.1%	2. Poaceae	700/7.5%
3. Myrtaceae	111/5.6%	3. Fabaceae	526/5.7%
4. Cyperaceae	101/5.1%	4. Orchidaceae	448/4.8%
5. Euphorbiaceae	100/5.0%	5. Cyperaceae	385/4.2%
6. Rubiaceae	63/3.2%	6. Mimosaceae	382/4.1%
7. Mimosaceae	61/3.1%	7. Asteraceae	376/4.1%
8. Asteraceae	48/2.4%	8. Euphorbiaceae	303/3.3%
9. Sapindaceae	47/2.4%	9. Rutaceae	210/2.3%
10. Orchidaceae	43/2.2%	9. Rubiaceae	210/2.3%
11. Convolvulaceae	33/1.7%	11. Sapindaceae	16/2.1%
12. Lauraceae	30/1.5%	12. Chenopodiaceae	185/2.0%
12. Rutaceae	30/1.5%		
12. Verbenaceae	30/1.5%		
<b>Totals 1010: 51% of native continental island flora</b>		<b>Totals 4679:50% of native Queensland flora</b>	

The comparison between the larger families on the Great Barrier Reef continental islands and other Pacific Islands such as Fiji, New Caledonia, Samoa and Tonga demonstrate the similarity of many regional Pacific elements. According to Sohmer (1990) the families Cyperaceae, Euphorbiaceae, Myrtaceae, Orchidaceae, Poaceae, Rubiaceae and Sapindaceae are predominant on the Pacific islands. In addition, Fabaceae is listed as a large family on all islands except New Caledonia. Verbenaceae and Asteraceae are also listed in New Caledonia as large families of plants (Sohmer 1990). The diversity of Mimosaceae and Convolvulaceae on the Great Barrier Reef continental islands is not reflected by other floras in the Pacific region.

The five largest plant genera ranked by number of native species on continental islands are *Acacia* (49 spp.), *Eucalyptus* (35 spp.), *Cyperus* (33 spp.), *Ficus* (24 spp.) and *Ipomoea* (17 spp.). The visual similarity of most continental island vegetation to much of the Queensland and Australian landscape is characterised by significant presence of acacias and eucalypts. However, the number of species of acacias and eucalypts actually found on most individual islands is very low. The majority of the offshore islands have from 3-6 species of eucalypts and

acacias. Orchids are also poorly represented on continental offshore islands. *Dendrobium discolor* and *Geodorum densiflorum* are the only species of orchids which are widely distributed.

### **Species richness and the effects of island size**

According to MacArthur and Wilson (1967) the number of species present on an island represents an equilibrium between the rate of immigration of new species to the island and the rate of extinction of existing species that have been established previously. The essence of the equilibrium theory is that the number of species on an island is determined by island insular size and degree of remoteness. Heatwole (1991) analysed ten continental islands of the Great Barrier Reef and he concluded that species-richness is primarily related to island size. However, Heatwole (1991) also argues that on continental islands, size would also reflect habitat diversity. According to Kohn and Walsh (1994) the effect of island insular area is nearly twice that of habitat diversity.

Why insular distance has less of an effect on continental island species richness, than the emphasis given by the Equilibrium Theory of Island Biogeography, is not clear. Heatwole (1991) concluded that in his study area, the seawater gaps were not a major barrier to bird dispersed and ocean dispersed plants. Future studies are required to examine the relative importance of continental island size, degree of remoteness and habitat diversity for species richness in the Great Barrier Reef.

In our study a list of continental islands with a known number of native species is presented in Table 3. The data is also presented as a species richness area curve (Fig. 2). The effect of island insular size on species richness is most evident up to an island area of 5000 ha, while there is only a very moderate rise in the number of species on islands between 5000 and 10 000 ha in size. From 10 000 ha to 40 000 ha size islands there is only a small response in species number to area as size increases. The actual number of species recorded on continental islands in Table 3 is, in our opinion, designated as 'complete' by intensive surveys ranging from 2-3 person-days on small islands to 5-15 person-days on medium size islands and to several weeks on larger islands. Hinchinbrook Island may record extra number of species with more intensive sampling, but even if the number of species were increased to 700 the Fig. 2 curve shape would remain consistent.

Table 4 provides a summary of data for the four sections recognised by the Great Barrier Reef Marine Park (Fig. 1). It shows that the sections with the largest areas have the highest number of taxa. In particular the number of exclusive regional species (species found only in one region) seems to be strongly related to size of area (Table 4). However, the number of rare and endangered species is not related to size of area. The second lowest number (13) of rare and endangered taxa occurs in the Mackay/ Capricorn Section - the largest (788.19 km<sup>2</sup>) area.

We suggest that many factors such as insular area, habitat diversity, remoteness, palaeoclimates and fire are responsible for species richness on tropical continental islands of the Great Barrier Reef. Island area is the most important variable predicting species richness up to the critical island size (5000 ha). However, over 5000 ha island size the relationship becomes non linear indicating other factors interacting with number of species in complex ways (Fig. 2).

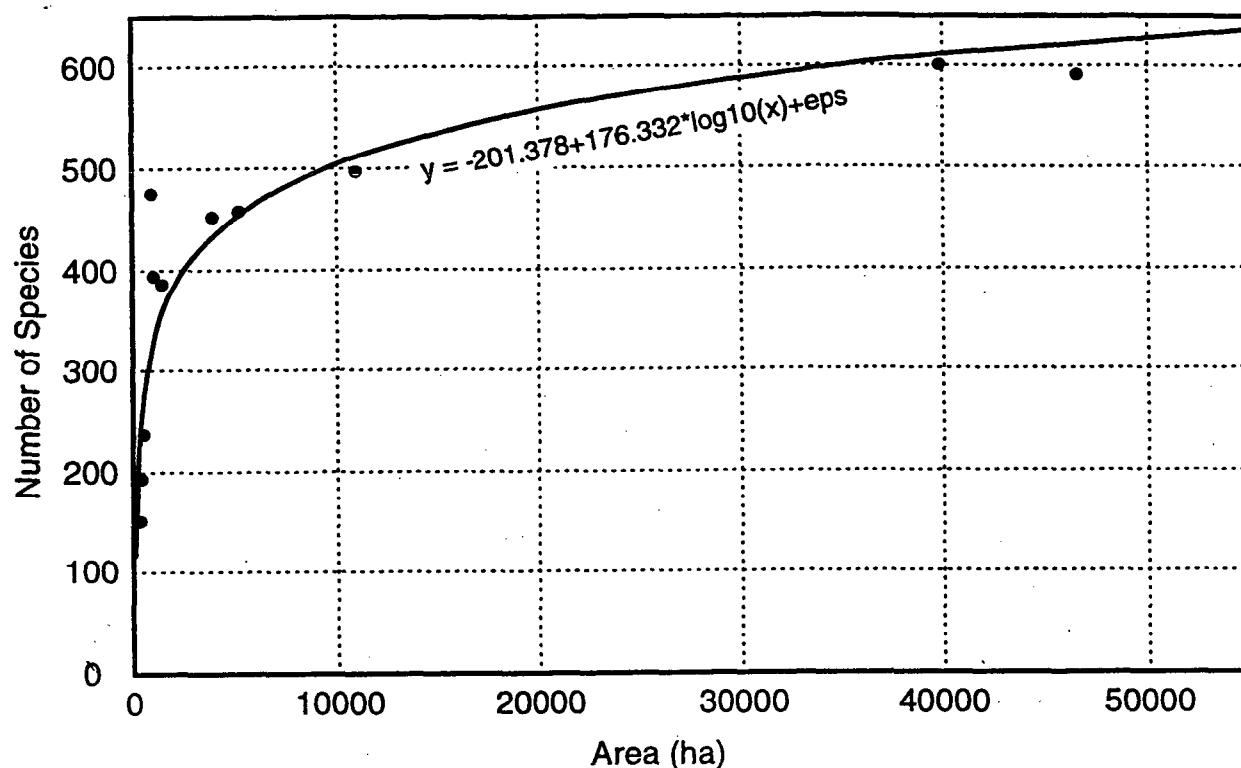


Figure 2. The relationship between species richness and island area

Table 3. List of islands with known number of native species and area

Island Names	Species Number	Area (ha)
Haggerstone Island	131	50
Calder Island	132	150
Penrith Island	150	162
Prudhoe Island	192	518
North Keppel Island	235	627
Lizard Island	475	1012
Scawfell Island	393	1090
Great Keppel Island	386	1454
Gloucester Island	450	3970
Magnetic Island	457	5164
Whitsunday Island (estimated)	495	10 935
Hinchinbrook Island	600	39 900
Curtis Island	590	46 600

Table 4. Botanical summary data for the four sections of the Great Barrier Reef Marine Park

	Far Northern	Cairns	Central	Mackay/Capricorn	Total GBRMP
Area km <sup>2</sup> +	75.57	14.99	748.23	788.19	1626.98
% of total area	4.6%	0.9%	46.0%	48.5%	100%
No of island	139	47	161	205	552
All species	856	700	1434	1252	2195
Exotic species	47	57	152	163	215
Rare/endangered species	24	9	47	13	79
Exclusive regional species	168	43	456	361	1028

## Floristic changes

A knowledge of flora responses to changes in palaeoclimates is an essential element in interpreting the composition and distribution of island vegetation. The evidence from Lynch's Crater (Kershaw 1985) indicated that Araucarian vine forest and rainforests in north Queensland were replaced by Eucalypt forests from 34 000 to 8 000 BP. Recent work using charcoal dating information suggest widespread Eucalypt forest expansion in North Queensland between 27 000 BP and 3500 BP (Hopkins et al. 1993). The process of recolonisation by rainforest species coincided with a wetter Holocene climate. According to Kershaw and Nix (1988) the climatic conditions in North Queensland between 5000 BP to 3600 BP were warmer and wetter than at present, favouring rainforest re-establishment on a large scale.

According to information provided by Thom and Chappell (1975) and Woodroffe and Mulrennan (1991) on sea level changes, we speculate that most of the Great Barrier Reef continental islands were separated from the mainland during the period 7500 - 6000 BP. Most certainly by the time of Keshaw and Nix's proposed large scale rainforest expansion began from 5000 BP to 3600 BP the sea had risen to its present level (Thom and Chappell 1975; Galloway 1978). We suggest that many of the present day island rainforest species have re-established from the mainland. Clearly, many areas of present day rainforests on continental island are comparatively simple and/or are dominated by 'pioneer' rainforest species, e.g. *Aidia racemosa*, *Celtis paniculata*, *Cryptocarya triplinervis*, *Diospyros geminata*, *Drypetes deplanchei*, *Mallotus claoxyloides*, *Micromelum minutum* and *Pongamia pinnata*. There are some exceptions, but most of the more complex rainforest occurs on the larger inshore islands, e.g. Hinchinbrook Island, Dunk Island and Turtle Head Island.

The area of present day rainforest may vary from 90% to 0.1% of individual islands, however the total area of island rainforest in the Great Barrier Reef is estimated to be between 5% and 10% only. At the same time the major components of the continental island flora are 48% rainforest species, 46% open-forest species and 6% littoral-seashore species. The small areas of rainforest on these islands contribute a relatively high proportion of species to the total number of plant species present.

In many areas on the continental islands the process of recolonisation by rainforest species is continuing today. For example according to Cumming (1995), on Hinchinbrook Island large areas of sclerophyll forest now have a well developed understorey of rainforest species. He speculates that without fire, the rainforest will continue to advance into sclerophyll forest under present day climatic conditions. Work undertaken in the Whitsunday Islands by the authors, also noted rainforest expansion on Long Island.

The role of Aboriginal peoples in the relationship between rainforest and sclerophyll forest is controversial. There were a number of good reasons for Aboriginal peoples to burn islands regularly, i.e. to facilitate travel and food gathering (Brennan 1986). Perhaps mainland tradition alone may well have been enough reason to burn (Haynes 1985). In our view there is a tendency to over-estimate the importance of Aboriginal fire regimes on islands. Not all of the 552 continental islands have good access for landing and many are too isolated, small and rocky to offer food or water. We speculate fewer Aboriginal induced fires occurred on islands than on the adjacent mainland. Burning by Aboriginal peoples may have led to changes in the floristic composition and structure but confined to larger islands with fresh water and possibly smaller islands with easy landing. After studying anthropogenic modifications of vegetation on continental islands in the Whitsunday region, Brennan (1986) suggested that much of the *Araucaria cunninghamii* (fire sensitive species) distribution may reflect extensive use of fire by Aboriginal peoples. He cites that most of the Araucarian forests occur on the steep rocky slopes and/or protected gullies of 'topographic refugia'. Brennan (1986) also found that most of the

islands supporting large areas of grassland in the Whitsunday region were remote, smaller, offshore islands. Brennan (1986) concluded that most of these grasslands occur on southeast sides of the islands and were natural formations maintained by windshear and salt spray.

We are intrigued by the vegetation of the relatively large islands of the Sir Charles Hardy Group of islands (11°55', 143°29'). According to Clarkson (pers. comm., 1995) the islands are covered entirely by grasslands which is very unusual for this area of north Queensland. Also according to Clarkson (pers. comm. 1995) these are the most species poor islands in the area. We speculate that deliberate frequent use of fire by Aboriginal peoples may have contributed to the loss and/or restricted colonisation of local 'woody' plant species on the Sir Charles Hardy Group of islands. The loss of arborescent species makes the island very unattractive for Torresian Imperial - Pigeon (*Ducula spilorrhoa*) visits Clarkson (pers. comm. 1996). As a result 'woody' species propagule recruitment from fruit eating birds is highly unlikely. Finally it is difficult to imagine that the Aboriginal peoples' use of fire promoted plant species richness on islands. The most likely effects of Aboriginal burning is the creation of mosaics of pyrophytic woodlands, shrublands, scrubs and grasslands in areas most frequently used by local tribes. Widespread occurrence of monospecific stands of some shrubs/trees and the dominance of genera such as *Eucalyptus*, *Acacia*, *Melaleuca*, *Xanthorrhoea* and the widespread and dominance of grasses may indicate some of the effects of Aboriginal people burning on larger islands.

Sandercoe (1989) studying Magnetic Island found that areas of eucalypt forest subjected to the most frequent fires showed the greatest increase in grass cover at the expense of trees (including eucalypts) and *Acacia* shrub species. Work in southeastern Australia indicates that repeated fires with an interval of less than 5-8 years can dramatically reduce the abundance of fire-sensitive plant species (Nieuwenhuis 1987 and Cary and Morrison 1995). Fox and Fox (1986) found a decrease in species richness with increasing frequency of burning and Noble and Slatyer (1981) emphasised that frequent fires in forests lead to species loss due to insufficient time given for propagule pools to be replenished. On continental islands, propagule replenishment is more difficult than on mainland areas. Sea water barriers combined with smaller insular populations may lead to local extinction of many species which are not fully adapted to island conditions. It is argued that frequent fires on islands may lead to local extinction of fire sensitive plants and consequently some decrease in species richness of native flora.

Other studies indicate in tropical savanna a total exclusion of fire for about 10 years in eucalypt forest decreases species richness (Fensham 1990). Fensham (pers. comm. 1996) argues that open forest species are most vulnerable to the island effects because of their inability to disperse. He also postulates that fire adapted open forest taxa are most at risk to local extinction without suitable fire regime.

Island flora changes due to historical events on Great Barrier Reef continental islands are underlined by the Holocene eucalypt expansion during the 'dry' periods and subsequent recolonisation by rainforest species in the 'wetter' periods. The consequence for species survival in island floras are not only the isolation and reduced plant species migration due to lack of seed dispersal, but the increased vulnerability of small populations to catastrophes such as cyclones, fires and pathogens. The evidence for species turnover on islands is best shown by the existence of 'island refugia' populations of some of the common mainland species.

Despite ample availability of suitable habitats the following are examples of local contraction of widely dispersed taxa.

1. Existence of remnant *Araucaria cunninghamii* vine forest (about 15 m wide and 50 m long with stunted araucaria trees 5-9 m tall) on the north west side of Cook Mountain on Lizard island.
2. Existence of remnant *Eucalyptus leptophleba* low open forest about 6-10m tall covering about 30 m wide and 100 m long also occurring on Lizard Island.
3. Existence of remnant *Eucalyptus robusta*, six or seven trees on Great Keppel Island.
4. Existence of remnant *Eucalyptus citriodora* open forest (5 ha) on North Keppel Island.
5. Possible local extinct eucalypts on Prudhoe Island (Whitsunday Region) and Pulfrey Island (near Lizard Island). There are no plants of *Eucalyptus* sp. recorded on these islands.

The above examples are just a few of many island species distribution anomalies present. One of the most widespread species of coastal trees is *Alphitonia excelsa*. However it is often absent from islands or found as one or two isolated trees, e.g. Lizard Island.

Some of the evidence for local extinction is best illustrated by the low species diversity of 'relic eucalyptus' communities on the more remote and/or smaller offshore islands. These islands usually support fewer open forest tree species than comparable areas on the mainland (Batianoff 1987, 1992; Halford 1995). The decline of tree diversity on small island (less than 1 ha) have been reported by Leigh et al. (1993). He and his colleagues working in Panama noted decline and change in tree species from six islands over the relatively short time of 70-80 years history of island separation.

Many areas of present-day island vegetation are probably not saturated with species. According to Heatwole (1991) there are 'vacancies' for species of plants on all islands. Heatwole (1991) gives examples of many weeds establishing on coral cays without displacement of native flora. Many of the island flora changes on continental islands are poorly understood. However, island biogeographic theories predict vacant niches on islands through random local extinction. These niches would be filled by a new well dispersed taxa such as exotic plants. In our view recolonisation by rainforest species is contributing to much of the present day island species richness, particularly in the tropical section of the Great Barrier Reef.

### **Biogeographical patterns and trends**

Interpreting present-day floristic changes across the latitudinal gradient does indicate regional differences occurring within the Great Barrier Reef area. Using data of all species, the relative percentages of 'woody' species (trees, shrubs and lianas) and herbaceous species are plotted in Fig. 3. The relative percentages of 'woody' species are much higher in the lower latitudes. For example at 10° latitude the proportions are about 70% of 'woody' plant species and about 30% of herbaceous species. The predominance of 'woody' species continues up to the level of Tropic of Capricorn (23°26'30") where the relative percentage of herbaceous and 'woody' species is about 50% each (Fig. 3).

The actual percentage of herbaceous species on the Keppel Bay islands is 61% showing that much of their species richness is dependant on the relative success of herbaceous flora. These continental island lifeform trends indicated across the latitudinal gradient reflect some of the complex relationships occurring between rainforest, and open forest vegetation and climatic pattern. Figure 4 indicates that at lower latitudes a high percentage of species belong to rainforest flora. This trend continues southwards until at about 21°S (Whitsunday-Mackay

area), where there are about equal numbers of rainforest and open forest species. Further south the Keppel Bay Islands flora contain about 65% of open forest species.

The rainforest flora is mostly comprised of trees, shrubs and liane species, i.e. a 'woody' lifeform, where as open forest communities include a majority of herbaceous species. As a result, trends shown in Figs. 3 and 4 are interrelated and similar. The dependence on rainforest flora for tropical continental island's species richness is to be expected, because of the proximity of the species rich, coastal mainland rainforests to these islands and the possible continuing process of recolonisation by rainforest species after the *Eucalyptus* expansion under present climatic conditions (Hopkins et al. 1993).

The distribution of the littoral margins flora across the latitudinal gradient is very similar from north to south (Fig. 4). This trend reflects the homogeneity of littoral margin conditions within the Great Barrier Reef area.

Continental island flora's from Curtis Island to Whitsunday Island contain higher proportions of herbaceous species and/or open forest species than 'woody' and/or rainforest species. The trends illustrated in Figs. 3 and 4 are the major floristic differences between tropical and subtropical continental islands. The predominance of open forest species on mainland islands in the Southern section of the Great Barrier Reef is difficult to explain at this stage. Perhaps a detailed floristic study of islands further south may indicate continuing latitudinal trends, similar to Figs. 3 and 4 and/or show unique regional features occurring only around Curtis and Keppel Bay Islands.

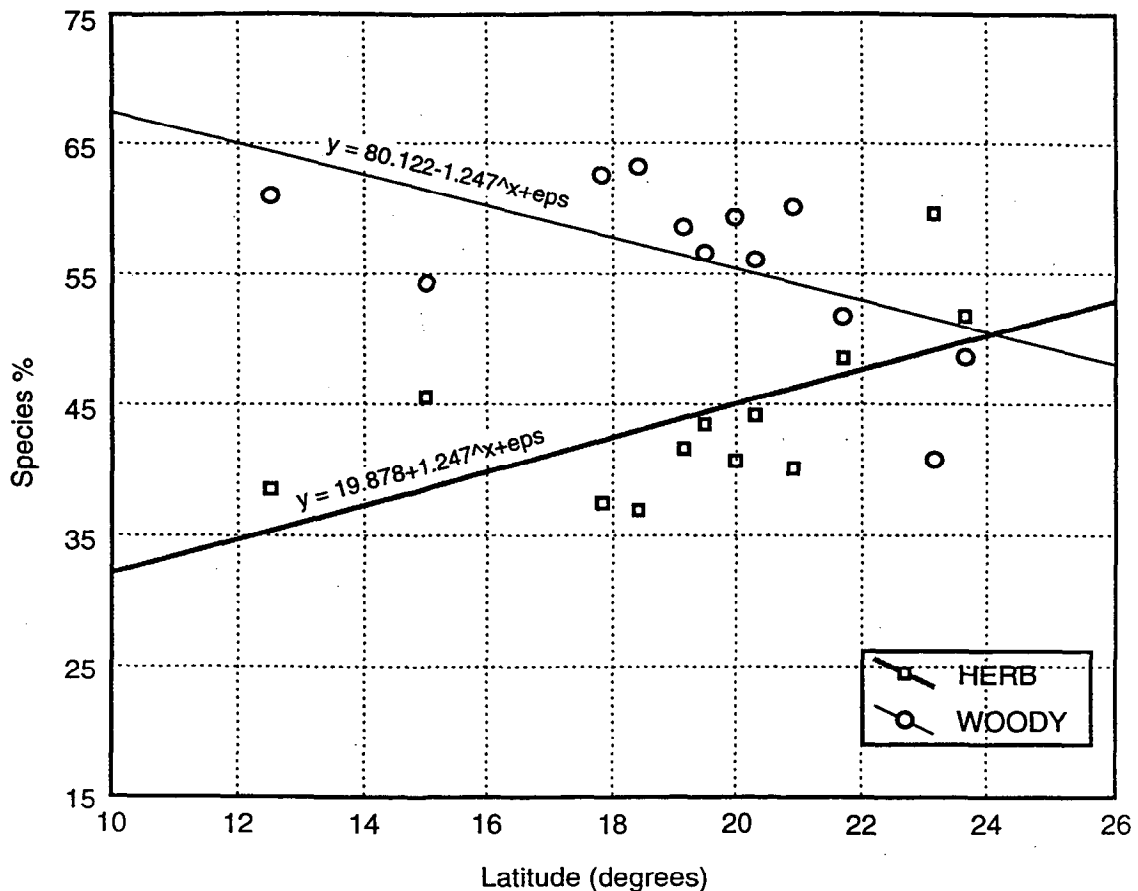
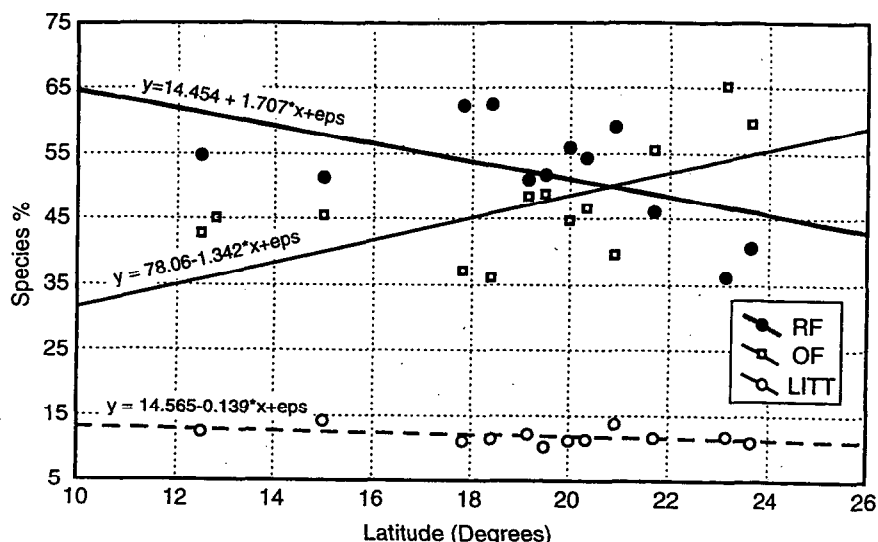


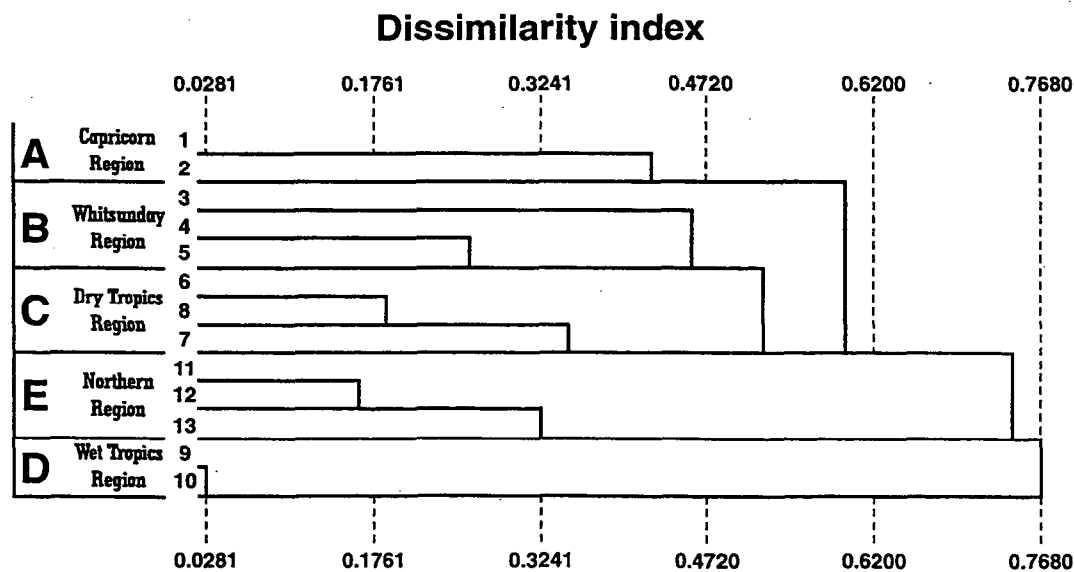
Figure 3. Percentage distribution of 'woody' and herbaceous species across the latitudinal gradient



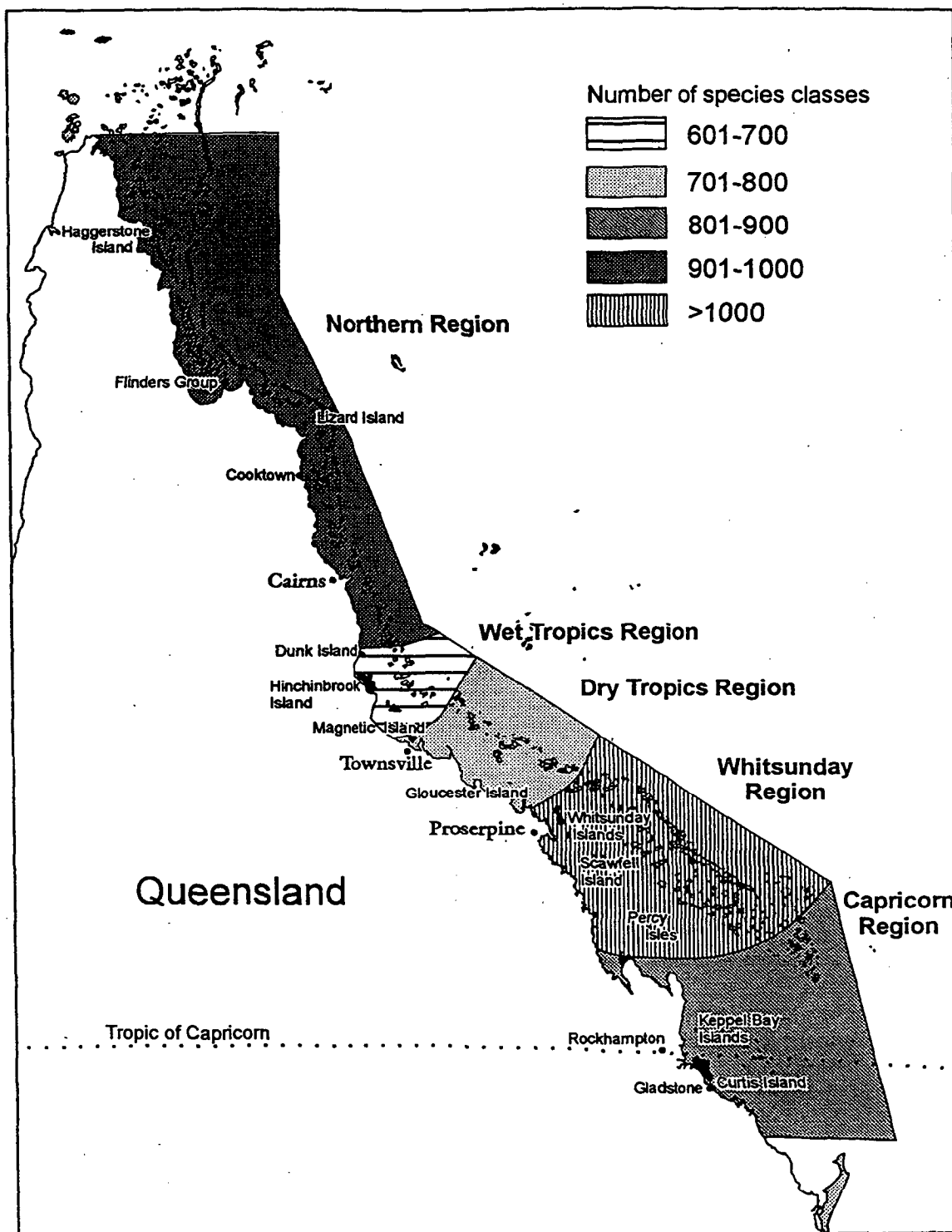


**Figure 4.** Percentage distribution of rainforest (RF), open forest (OF) and littoral (LITT) species across the latitudinal gradient

Thirteen regional and island flora groups were analysed using dissimilarity pattern analysis (Belbin 1989). The analysis is based on native species and is displayed as a dendrogram of five cluster groups which indicate 'natural' floristic regions of the Great Barrier Reef (Fig. 5). Group A is the 'Capricorn Region', it comprises floras of Keppel Bay Islands (1) and Curtis Island (2); group B is the 'Whitsunday Region' which includes floras of all the Whitsunday Islands (5), all of the Northumberland Islands (4) and Percy Islands (3); group C is the 'Dry Tropics Region', including Magnetic Island (8), Gloucester Island (7) and other granitic islands (6) flora located between Magnetic and Gloucester Islands; group D is the 'Wet Tropics Region', it includes floras of Hinchinbrook Island (9) and the wet tropics (10) area located from Dunk Island to north of Magnetic Island; group E belongs to 'Northern Region' it comprises floras of Lizard Island (12), Far Northern Section (13) and the Cairns Section (11) of the Great Barrier Reef Marine Park (Fig. 6).



**Figure 5.** Floristic region pattern analysis based on native species



**Figure 6.** Floristic regions of the Great Barrier Reef continental islands showing species richness

The dendrogram relationships shows that 'Wet Tropics Region' (D) and 'Northern Region' (E) are most dissimilar with other regions. The high degree of dissimilarity values occurring between all regions in this analysis provides a robust cluster of five groups. Three out of five groups shown in Fig. 5 display a strong latitudinal relationship similar to that shown between rainforest and open forest species Fig. 4 and Fig. 3 relationship between 'woody' and

herbaceous species. The trend reversal associated with group D and group E is most likely due to a high concentration of rainforest species occurring with the 'Wet Tropics Region' (D).

**Table 5.** Botanical summary data for the Floristic Region of the Great Barrier Reef Marine Park

Taxa	Northern Region	Wet Tropics Region	Dry Tropics Region	Whitsunday Region	Capricorn Region
All species	976	656	735	1141	846
Exotic species (% of total spp.)	66 (6.8%)	31 (4.7%)	70 (9.5%)	155 (13.6%)	122 (14.4%)
Rare/endangered species	27	24	18	20	1
Exclusive regional species (% of total spp.)	344 (35.2%)	217 (33.1%)	97 (13.2%)	255 (22.3%)	223 (26.4%)

There is no significant differences in species richness between northern and southern floristic regions. The 'Whitsunday Region' is shown as having the highest species diversity (Fig. 6 and Table 5). It includes 986 native species, 155 exotic species, 255 exclusive regional species and 20 rare and endangered species. The highest number of rare and endangered (27) and exclusive regional (344) species or 35.2% of the total flora occur in the 'Northern Region' (Table 5). The high percentage of exclusive regional species are found in the 'Northern Region' and 'Wet Tropics Region' due to much of the unique flora known to occur at Cape York and Wet Tropics area (Clarkson pers. comm. 1995). The 'Whitsunday Region' has the highest species richness and the second highest number of exclusive regional flora possibly due to its unique geology (Whitsunday volcanics) and high number of larger islands. The lowest percentage (13.2%) of exclusive regional flora occurs in 'Dry Tropics Region', indicating large overlap of species distribution between 'Whitsunday Region' and 'Wet Tropics Region'.

#### Rare, endangered and endemic flora

Current knowledge indicates that *Berrya rotundifolia*, *Albizia* sp. (South Percy Island G. N. Batianoff, 11444) and *Habenaria divaricata* are the only three endemic plant species found within the study area. *Berrya rotundifolia* is a small tree recorded from Calder Island and Middle Percy Island. In Australia *Berrya* is a two species genus. *Berrya javanica* is a native of Java and northern Australia and according to Halford (1993) it is not closely related to the island endemic *Berrya rotundifolia*. *Albizia* sp. nov. is known to occur on Penrith, Scawfell, Calder and South Percy Islands. Its close relative is thought to be *Albizia carrii* a tree found in New Guinea (Batianoff 1995). *Habenaria divaricata* is only known from its type locality Dunk Island. This orchid bears close resemblance to *Habenaria rumphii* and according to Dockrill (1992) may prove to be the same taxon. Altogether 79 rare and endangered species are found to occur on continental islands of the GBRMP (Appendix 1).

The pattern of distribution of most rare plants is very complex. The best known to the authors are *Acacia polyadenia*, *Cerbera dumicola*, *Omphalea celata* and *Stackhousia tryonii*. *Acacia polyadenia* was originally described from the Cumberland Islands (Shaw Island) and thought to be an endemic island species until recently. Small populations of this species have been discovered in Central Queensland.

The type specimen of *Cerbera dumicola* was collected from Middle Percy Island in September 1989. But this taxon was known since 1930s as an inland small tree from Dingo and Blackwater. According to Forster (1995) *Omphalea celata* originally was thought to be a species of *Aleurites* (candlenut). It was first found at Hazelwood Gorge west of Mackay and later from Gloucester Island. The known populations of this species are very small.

*Stackhousia tryonii* is a small herb discovered by Henry Tryon in 1904 on South Percy Island and in 1906 it was described by F. M. Bailey. In *Flora of Australia* vl. 22 (1984), *Stackhousia tryonii* was not recognised as a distinct taxa. In 1990 it was discovered that this taxa was not only a serpentinite endemic but also hyperaccumulator of nickel (Batianoff et al. 1990). Plants collected at South Percy Island recorded up to 4% of nickel in its oven dry leaves (Batianoff and Specht 1992). Closer examination has shown *Stackhousia tryonii* to be a distinct species (Batianoff et al. 1990).

Indications are that many of the rare and endangered species occur in the tropical parts of the Great Barrier Reef continental islands (Table 5). The occurrence of the highest number (27 of rare and endangered species) in the 'Northern Region' and the lowest (1 rare and endangered species) in the 'Capricorn Region' is puzzling. However the trend of declining numbers of rare and endangered species from north to south is similar to the rainforest species trend shown in Fig. 4. The rainforest vegetation types in the 'Northern Region' and the 'Wet Tropics Region' appear to be more complex compared to 'Whitsunday Region' and 'Capricorn Region' (Cumming 1995; Le Cussan 1995; Sandercoe 1990; Thomas and Sharpe 1989). However Fig. 7 shows that only 55% of the rare and endangered species occur in rainforest. The other 45% are the open forest species (including 5% in heath and scrub species).

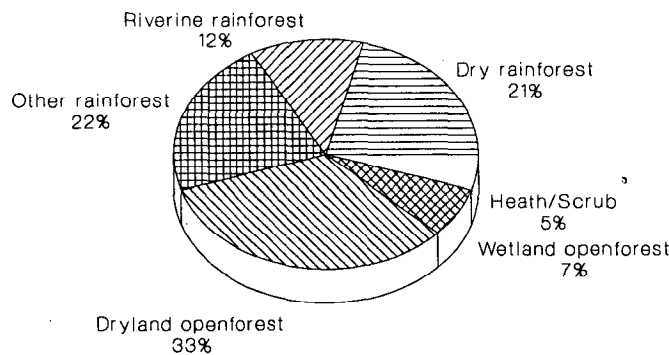


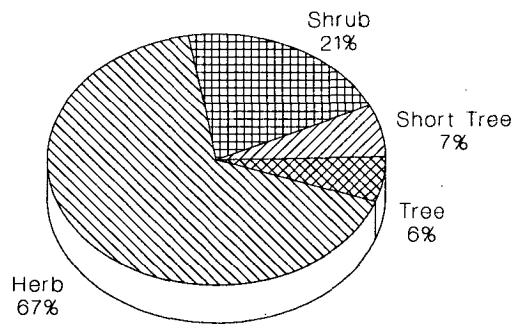
Figure 7. Percentage occurrence of rare and endangered species on continental island habitats

We have no explanation as to why *Actephila sessilifolia* (dry rainforest species) is the only rare and endangered species found in southern section of the Great Barrier Reef in 'Capricorn Region'. Another plausible explanation is that there are no north to south trends in distribution of rare and endangered species. For example Hinchinbrook Island (16 spp.), Gloucester Island (13 spp.) and Magnetic Island (11 spp.) are the islands with the greatest number of known rare vascular plant taxa. These islands are granitic inshore islands with a mountainous landscape situated in the tropical region.

### Exotic plants

It is generally reported that islands tend to have a higher concentration of non-native flora than comparable areas on the mainland (Crawley 1987; Humphries et al. 1991). According to Johnson (1995) 25% of Tasmania and 47% of the Hawaiian Island flowering plants are naturalised exotics. In the 'Whitsunday Region', Daydream Island records (1990) indicate 29% of the plants to be naturalised exotics. However on a regional basis this study reports a relatively low incidence of exotic flora. For example the highest incidence of exotic plants, i.e. 14.4% occur in 'Capricorn Region' followed by 13.6% of introduced plants recorded in the 'Whitsunday Region'. The 'Wet Tropics' records show the lowest percentage of 4.7% exotic species of plants (Table 5). The number of exotic species is most probably related to past history and general use of islands today.

Figure 8 shows that 67% of exotic flora on continental islands in the Great Barrier Reef are herbaceous plant species. This is not surprising because this study demonstrates that the proportion of total herbaceous species on these islands is much lower than on the adjacent mainland. We suggest that on continental islands, particularly in the northern areas, there are 'species vacancies' favouring the establishment of herbaceous plants (Fig. 3). Also herbaceous plants are well adapted to disturbed areas. Hobbs (1991) found that disturbance is a precursor to weed invasion in native vegetation. Heatwole and Walker (1989) studying coral cay flora concluded that human disturbances is an important factor influencing the proliferation of exotic plants on cays.



**Figure 8.** Lifeform percentage composition of exotic flora of continental islands

In this study species turnover caused by migration and local species extinction is seen as a natural and ongoing process on continental islands. We include exotic species as part of natural migration from mainland to adjacent islands. However, according to Chaloupka and Domm (1986) and Heatwole and Walker (1989), human activities and birds enhance the incidence of exotic plant introduction to the islands in the Great Barrier Reef. With an increasing number of human visits to islands, there will be more exotic plant species introduced by humans to the islands in the Great Barrier Reef (Chaloupka and Domm 1986).

These exotic species may in some areas out compete native species and not only seriously undermine the conservation and aesthetic values of individual island National Parks but also undermine natural values of the World Heritage Area and of the Great Barrier Reef as a whole.

A list of the more widespread troublesome and invasive exotic plants in this study are *Acacia nilotica* subsp. *indica*, *Agave* spp., *Annona squamosa*, *Bidens pilosa*, *Brachiaria mutica*, *Bryophyllum* spp., *Catharanthus roseus*, *Cenchrus echinatus*, *Cryptostegia grandiflora*, *Euphorbia cyathophora*, *Lantana camara*, *Leucaena leucocephala*, *Macroptilium atropurpureum*, *Melinis* spp., *Mimosa pudica*, *Opuntia stricta*, *Panicum maximum* var. *maximum*, *Passiflora* spp., *Psidium guajava* and *Stachytarpheta jamaicensis*.

This list does not include local infestations of *Yucca aloifolia* on Newry Islands north of Mackay, or infestations of *Tradescantia spathacea* from Shaw and Thomas Islands in the 'Whitsunday Region'.

The general attributes of the more troublesome weedy species are difficult to categorise. These littoral and open forest understorey species of plants are mainly herbs, shrubs and vines. Succulence is an attribute of some species well adapted for island conditions. For example *Opuntia stricta*, *Bryophyllum* spp., *Agave* spp., and *Yucca aloifolia* are all succulent plants. With the possible exception of *Bryophyllum* spp. all are successful in crossing sea water barriers and establishing on sandy shores using succulent vegetative propagules (Batianoff pers. obs.).

On the continental islands of the Great Barrier Reef possibly the most widespread invasive exotic plant is *Lantana camara*. It is highly flammable and its dense shrubbery carries a hot fire, which is a threat to native vegetation especially dry rainforest (Fensham et al. 1994). *Lantana camara* is recorded on most larger continental islands with the notable exception of Lizard Island. We suspect most of the *Lantana camara* seed is transported to the islands by birds, and as a result the *Lantana camara* absence from Lizard Island is puzzling. In our opinion, eradication of *Lantana camara* from most islands is not practical, therefore keeping Lizard Island free of *Lantana camara* should be a paramount management priority. Natural spread of rainforest species on islands may provide competition and check the spread of *Lantana camara*. Intact rainforest areas have fewer weeds (including *Lantana camara*) than open forest areas (Batianoff, Franks and Dillewaard, in prep.)

As a general management practice to reduce the establishment and spread of exotic plants, we recommend a 'minimum disturbance' policy for native island vegetation. Early detection and control of 'weedy' plants is also recommended, especially from islands where troublesome exotic weeds are absent. Early detection/recognition of exotic plants is relatively easy. Because most exotic plants at first appear near high concentrations of human activities such as roads, beaches, buildings etc. Finally frequent fires (disturbance) and increased travelling by humans may create conditions that allow increased establishment of exotic plants on burnt out natural areas of islands.

### **Conclusions and recommendations**

In conclusion it should be pointed out that the management of 552 continental islands spread over 2000 kilometres is a major challenge for the Australian and Queensland agencies. The study recognised this problem and has sought to provide summarised regional botanical information useful for conservation management of island floras. For example, the species richness concept is used as a fundamental unit of island flora biodiversity. The fragmented flora of the continental islands is analysed as one unit of the GBRMP. It is also analysed as part of four sections of the GBRMP (Fig. 1, Table 3). Closer examination of regional data revealed several patterns and trends.

We postulate that at the time of island formation some 6000 years BP most of the island flora consisted of dry open forest elements. The present 46% rainforest flora of the total flora is due to the process of recolonisation by rainforest species, which, in our view, is continuing. The process of island species extinction is seen only at local level, e.g. reduction of species numbers in large and widespread genera such as *Eucalyptus* and *Acacia*.

As predicted by MacArthur and Wilson (1967), species richness is highly related to island area. In this study however, the relationship was only linear up to island size of 5000 ha (Fig. 2). Current knowledge indicated only three endemic island plant species are found within the GBRMP. However 79 rare and endangered species or 6% of Queensland's known rare flora occurs on continental islands in this study.

Exotic flora of continental islands within Great Barrier Reef is low compared with other islands. This suggests there is the potential for many more exotic plants to enter into the study area. Management needs to be more vigilant to minimise the risk of weed infestation on Great Barrier Reef islands that undermine values of the World Heritage Area.

Weed control and early detection of exotic plants require detailed botanical information and training of management staff. Planning for wilderness walking tracks requires a policy of 'minimum disturbance' to native vegetation. Maintenance of 'weed free' resort areas may require special incentives given to resort management and/or education programs.

Fire management of continental islands should be directed towards maintenance of native species richness and not just habitat diversity. The current planned program of prescribed burning in our view is based on mainland management practices of frequent fires maintaining habitat diversity. This study indicates that island floras are different from the mainland, i.e. small population and species with restricted 'island' dispersal mechanisms such as acacias and eucalypts require special consideration. Fire benefit and consequences should be assessed region by region and island by island using more specific data on species richness, rare and endangered species and exotic plants. In our opinion, high incidence of fires may reduce species biodiversity within islands of the Great Barrier Reef.

We recognised five floristic regions (Fig. 6) and where possible defined differences between these biogeographic regions. However, more comprehensive botanical knowledge is required to determine where and when to use fire. Fire frequency for individual islands is a major concern for National Parks management.

More specific data on rare and endangered species and unique vegetation types are required for regional and local planning. Because in our view there are big gaps in our knowledge particularly in the 'Wet Tropics Region' and the 'Northern Region'. High use National Parks and islands resorts urgently need floristic base data for management and monitoring of changes in vegetation.

Finally, publication of 'Continental Island Flora Catalogue of the Great Barrier Reef Park' is seen by the authors as a major tool not only to improve floristic summary data but also to provide the general public, island managers and students with the knowledge to enjoy, study and conserve the unique island environments.

### **Acknowledgments**

1. The Great Barrier Reef Marine Park Authority provided funds for accommodation to attend the Technical Workshop in Townsville, and assisted with geographical data. Drs Jamie Oliver and David Wachenfeld were particularly helpful.
2. Queensland Department of Environment officers stationed at Rockhampton, Townsville, Mareeba and Cairns provided botanical data. Particularly helpful were Ms Jenni Le Cussan, Ms Joy Brushe, Mr Mick Godwin, Mr John Clarkson and Dr Bill Lavarack.
3. Mr Eddie Hegerl (Australian Marine Conservation Society) assisted with current island inventory data.
4. Queensland Herbarium staff: Drs G.P. Guymer and T.D. Stanley supported this project, Mr Andrew Franks assisted with plant catalogue compilation and analysis, Mr Paul Robins provided HERBRECS data, Mr Laurie Jessup provided rainforest key data, Mr Will Smith prepared illustrations, Mrs Yvonne Smith types the manuscript, Ms Megan Thomas and Dr Rod Fensham read the manuscript and provided constructive critiques.

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**Appendix 1.** Rare and endangered vascular plants of the Continental Islands in the Great Barrier Reef Marine Park (Australia). E= endangered, V = vulnerable, R = rare, as in the Schedules 2, 3 and 4 of the Nature Conservation Act 1992. P = species proposed for inclusion in the schedules, but not yet ratified by the Scientific Advisory Committee.

Taxa	Life form	Status	GBRMP Sections			
			Far Northern	Cairns	Central	Mackay/Capricorn
<i>Acacia homaloclada</i>	T	R			X	
<i>Acacia jackesiana</i>	S	R			X	
<i>Acacia polyadenia</i>	S	R			X	
<i>Acmenosperma pringlei</i>	T	R	X			
<i>Actephila sessilifolia</i>	S	R				X
<i>Albizia retusa</i> subsp. <i>retusa</i>	S	R	X			
<i>Albizia</i> sp. (South Percy Island G.N. Batianoff+ 1444)	ST	P				X
<i>Amaranthus pallidiflorus</i>	H	R	X			
<i>Aphyllorchis queenslandica</i>	H	P			X	
<i>Archidendron hirsutum</i>	ST	P	X			
<i>Arenga australasica</i>	T	R	X		X	
<i>Argyrodendron</i> sp. (Whitsunday McDonald+ 5831)	T	R			X	
<i>Aristolochia chalmersii</i>	V	R	X	X		
<i>Atalaya rigida</i>	ST	R			X	X
<i>Austromyrtus lucida</i>	ST	R			X	
<i>Austromyrtus pubiflora</i>	ST	R			X	
<i>Banksia plagiocarpa</i>	ST	R			X	
<i>Berrya rotundifolia</i>	ST	R				X
<i>Bonamia dietrichiana</i>	V	R			X	
<i>Brachychiton compactus</i>	T	R			X	
<i>Buchanania mangooides</i>	T	P		X	X	
<i>Canthium</i> sp. (Thornton Peak H.Flecker NQNC76110)	S	P			X	
<i>Capparis</i> sp. (Gloucester Island Batianoff 920912)	S	R			X	
<i>Cassia</i> sp. (Paluma Range G. Sankoswky+ 450)	ST	R			X	
<i>Cassia queenslandica</i>	ST	R			X	
<i>Cerbera dumicola</i>	ST	R				X
<i>Cerbera inflata</i>	ST	R	X			
<i>Cleistanthus myrtianthus</i>	T	R	X			
<i>Combretum trifoliatum</i>	V	R	X			
<i>Comesperma praeclsum</i>	S	R			X	
<i>Corchorus hygrophilus</i>	S	P			X	
<i>Croton magneticus</i>	ST	V			X	
<i>Ctenopteris blechnoides</i>	H	R			X	
<i>Dendrobium johannis</i>	H	V	X			
<i>Dendrobium phalaenopsis</i>	H	V	X	X		
<i>Dipodium ensifolium</i>	H	R			X	
<i>Dischidia littoralis</i>	V	V	X			
<i>Drosera adelae</i>	H	R			X	
<i>Didymoplexis pallens</i>	H	V			X	
<i>Ehretia grahamii</i>	S	R				X
<i>Elaeocarpus carolinae</i>	T	R			X	

Appendix 1 cont.

Taxa	Life form	Status	GBRMP Sections			
			Far northern	Cairns	Central	Mackay/Capricorn
<i>Eucalyptus xanthope</i>	T	V				X
<i>Gahnia insignis</i>	H	R			X	
<i>Grewia graniticola</i>	S	R			X	
<i>Gymnema brevifolium</i>	S	V			X	
<i>Gymnostoma australianum</i>	ST	R		X		
<i>Habenaria divaricata</i>	H	E			X	
<i>Habenaria xanthantha</i>	H	R			X	
<i>Homalium</i> sp. (South Molle Island J.A.Gresty AQ208995)	T	P			X	
<i>Huperzia phlegmaria</i>	H	R			X	
<i>Ipomoea saintronanensis</i>	V	R	X			
<i>Kunzea graniticola</i>	S	R			X	
<i>Larsenaikia jardinei</i>	ST	R			X	X
<i>Leucopogon cuspidatus</i>	S	V			X	X
<i>Livistona drudei</i>	T	V			X	
<i>Macaranga polydenia</i>	T	V	X			
<i>Macropteranthes fitzalanii</i>	S	R			X	X
<i>Muellerargia timorensis</i>	H	E	X	X		
<i>Myrmecodia beccarii</i>	S	V	X		X	
<i>Omphalea celata</i>	T	V			X	
<i>Ozothamnus eriocephalus</i>	H	V			X	
<i>Peripleura scabra</i>	H	R			X	
<i>Peristyles banfieldii</i>	H	R			X	
<i>Psychotria coelospermum</i>	S	R	X			
<i>Psychotria lorentzii</i>	ST	P	X	X		
<i>Quassia bidwillii</i>	S	R				X
<i>Rhodamnia pauciovulata</i>	ST	R			X	
<i>Solanum sporadotrichum</i>	S	R			X	
<i>Spathoglottis plicata</i>	H	V	X			
<i>Stackhousia tryonii</i>	H	R				X
<i>Stenocarpus cryptocarpus</i>	T	R		X		
<i>Syzygium alatoramulum</i>	T	R			X	
<i>Tephrosia savannicola</i>	S	R	X			
<i>Tetramolopium</i> sp. (Mt Bowen G.D.Fell 1224)	H	P			X	
<i>Tiliacora australiana</i>	V	R	X			
<i>Tinospora angusta</i>	V	R	X	X		
<i>Wrightia versicolor</i>	ST	R	X	X	X	
<i>Xylosma ovatum</i>	T	R				X
<i>Zanthoxylum rhetsa</i>	ST	R	X			

# Status of inter-reefal benthos in the Great Barrier Reef World Heritage Area

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## Abstract

The inter-reefal area of the Great Barrier Reef Marine Park accounts for about 95% of the region and comprises many different types of habitats that support a great diversity of seagrasses, algae, seabed animals and fishes, some of which are commercially important. The Great Barrier Reef lagoon also supports a valuable prawn fishery. However, in spite of the extent and importance of the inter-reefal area, few large scale studies have been conducted and there have been no long term studies.

Past studies with significant spatial coverage have yielded quite consistent results, showing that the habitats and the flora and fauna associated with them are closely related to the sediment type (i.e. a continuum of mud through sand, rubble and rock). Animals living in the sediment are known as infauna and have high species diversity. Animals living on the seabed are known as epifauna and also have high species diversity. The least diverse areas tend to be muddier sediments where the dominant animals generally feed on the deposits. Sandier and harder areas tend to be more diverse and the fauna are more abundant as well - the dominant animals generally filter food items suspended in the water column, or are scavengers or carnivores. Large epibenthos (i.e. corals, sponges, gorgonians, seawhips, soft corals), which form living structural habitat attached to the seabed, tend to be restricted to rubbly or rocky patches, or areas where the bedrock is exposed by fast tidal currents. Because of these habitat requirements, there is a distinct cross-shelf zonation of the inter-reefal fauna related to the change from terrigenous muddy sediments of the inshore lagoon through to coarse calcareous sediments of the offshore inter-reef. Typically, multivariate analyses discriminate the fauna into three main groups: inshore lagoon, offshore inter-reef and a mid-shelf transition area. This zonation appears common to all studies. Only one study compared samples from a range of latitudes (~12°S to ~18°S) and showed an overlapping continuum rather than discrete groupings of faunal variation.

Recent studies by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Queensland Department of Primary Industries (QDPI) have documented similar cross-shelf patterns in the cross-shelf closure of the far northern section - again with three main groupings of taxa, but within these several sub-groups each with slightly different cross-shelf patterns in abundance. Part of this study focussed on the sessile structural habitat fauna because of their contribution to biodiversity and importance as habitat for other organisms. These fauna are very patchily distributed on several scales. There were extensive areas of sand and silt almost devoid of megabenthos. Where megabenthos does occur, it tends to be limited to slightly raised harder substratum - and the occurrence of such substratum is often < 5% in transects. Typically, these patches are 5-6 m across and are separated by 100-150 m, but are highly variable.

The clear cross-shelf trends in inter-reefal communities should be considered in strategic planning for conservation of representative communities - current zoning plans are focussed on the reefs. Latitudinal trends in species assemblages are poorly known, but are likely to exist given the high diversity of the fauna and the high level of endemism in some of its components. To meet strategic planning objectives, mapping and inventories of the inter-reefal benthos are

required for regionalisation/ zonation studies - these should target large scale latitudinal trends but must also account for cross-shelf patterns. The long term dynamics of benthos populations and the ecological processes structuring them are virtually unknown -this knowledge is required to assess the sensitivity of the fauna to a range of pressures and establish expected time frames for recovery.

The inter-reefal benthos communities undoubtedly have World Heritage values in terms of their biodiversity (many thousands of species, most unnamed), high level of endemism (especially in sponges) and, contrarily, high level of conservatism in retaining some taxa since Tethyan times. Whether these values have been maintained or degraded is not possible to determine with the available data, but it is unlikely that they have been enhanced. There are significant pressures on the inter-reefal benthos, including runoff and sedimentation in nearshore areas and trawling in the Great Barrier Reef lagoon. Sedimentation can smother benthos and trawling can remove benthos, but the overall significance of these impacts is not yet clear, nor is what levels of impacts are sustainable or which management strategies will ensure sustainability and allow reasonable use. The dynamics of recovery from impact are unknown.

### **Introduction**

The inter-reefal area of the Great Barrier Reef Marine Park - which includes the inshore side often referred to as the main, or Great Barrier Reef (GBR) lagoon and the offshore side between the many coral reefs often referred to as the offshore inter-reef - accounts for about 95% of the region and comprises many different types of physical habitats from nearshore terrigenous muds, silts and sands through to offshore carbonate sands of various grades, all variably interspersed with rubble and rocky cracks and patches, deep reefs and shoals with hard corals, and exposed areas of bedrock. These habitats support a great diversity of benthic fauna, from the microscopic to megabenthic structural organisms, sessile and mobile invertebrates, seagrasses, algae, and many species of fishes, some of which are commercially important. However, despite the extent and importance of the inter-reefal area, there have been very few studies: four to five descriptive studies of inter-reefal seabed fauna and no long term studies of faunal dynamics.

In this paper, I have summarised the available data on inter-reefal benthos that covers as large a spatial scale and temporal scale as possible in the GBR region, to identify any large spatial and/or long-term trends. Further, to contribute to the requirements for World Heritage Area reporting, I have assessed the current status of the inter-reefal benthos in terms of the OECD 'Pressure-State-Response' model (DEST 1994); the capacity of our knowledge and understanding to be used to address the issues raised in the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area (GBRMPA 1994); and the degree to which the World Heritage Values (UNESCO 1972) of the area have been maintained. Finally, implications for management are discussed and information needs are identified.

### **Review of available information**

As noted in the introduction, there have been few studies of inter-reefal benthos, probably because they have been perceived to be less 'charismatic' than the coral reefs and certainly less obvious than the reefs, and partly because of some of the difficulties of working in the inter-reefal area. As a consequence, relatively little is known about the inter-reefal habitat and its faunal communities.

The few studies of inter-reefal benthos, to date, with significant spatial coverage have, nevertheless, yielded quite consistent results, showing that the physical habitats, and the flora

and fauna associated with them, are strongly influenced by sediment type (i.e. the continuum through mud, sand, rubble and rock). These patterns are quite typical of the ecology of the seabed (see reviews by Gray 1981 for soft seabed; also Longhurst and Pauly 1987). The inter-reefal faunas usually are classified broadly by their relationships with the substratum and their size: animals living in the sediment are known as infauna; animals living on the seabed are known as epifauna (or epibenthos); animals washed through a 1 mm sieve from a grab sample are meiofauna, whereas those retained are macrofauna (or macrobenthos); animals too large to be properly sampled by a 0.1 m<sup>2</sup> grab are megafauna (or megabenthos); and those firmly attached to the substratum are sessile.

#### Studies of inter-reefal benthos in the Great Barrier Reef

Birtles and Arnold (1983 and 1988) used an 1.6 m epibenthic dredge to sample inter-reefal epibenthos during a series of integrated studies at up to ~90 sites, on a roughly 8 n mile grid off Townsville, at various intensities between 1977 and 1983. Most sites were in the GBR lagoon area, between the coast and the reef-matrix, a few sites were sampled on the outer half of the shelf, amongst the reefs. Multivariate community analyses clearly showed cross-shelf zonation in fauna. There was a shallower (< 20 m) inshore zone, to about 30 n miles offshore characterised by resuspended terrigenous muddy deposits, with low species richness of carnivorous and deposit feeding echinoderms, molluscs, crustaceans, fishes, bryozoans and algae, and low species evenness - i.e. a relatively low number of species was dominated by even fewer. Further offshore, from ~30 n miles to the mid-shelf reef-matrix at ~80 n miles, the main lagoon zone was characterised by deeper water (20-50 m) and less muddy sediments dominated by coarse sand and rubble, primarily of biological origin, with higher species richness of all faunal groups. In part, this increased diversity was due to increased habitat heterogeneity in terms of patches of harder substratum that allow a wide variety of suspension feeders, such as sponges, ascidians, crinoids, holothurians, and bryozoans, to gain a foothold in addition to the deposit feeders in the sediments between the patches. On the outer half of the shelf (> ~80 n miles), in the offshore inter-reef zone the fauna changed again, with less fine sediment, more harder patches, and greater depth. A time series of six years was available for echinoderms at selected sites. For these fauna, patterns of distribution and abundance remained essentially stable over the period. Greatest variability was apparent in the nearshore sites, due to physical instability of the sediments caused by wind generated waves.

Cannon, Goeden and Campbell (1987) conducted classification and ordination analyses of trawl by-catch (fishes and macro and mega benthos) from two of a series of seven exploratory trawl surveys from three main areas of the GBR. Samples were collected primarily with 2 m try-shot nets at about 230 sites between 1979 and 1982. Although providing significant latitudinal coverage, most sampling was unstructured, with the objective of identifying new commercial prawning grounds. However, one survey in particular, provided replicated cross-shelf samples off Cairns. Trawl series I covered ~6° of latitude, from ~12°S to 18°S, but cross-shelf effects were not controlled for and data could only be analysed in binary form (presence or absence). Analysis of series I at several taxonomic levels generally separated the sites into three main groups, but the groupings did not correspond to any clear geographic pattern, except that sites from Princess Charlotte Bay usually were separated. There appeared to be no major latitudinal differences, the patterns were interpreted as weak cline, or continuum - however, the authors treated this result with caution given the uncontrolled nature of the sampling. Trawl series V was more rigorously conducted, with three replicate cross-shelf transects ~20 n miles apart with five representative and quantitatively sampled sites along each transect, from the inshore, lagoon and offshore inter-reef zones. The samples and the classification and ordination were dominated, not surprisingly given the sampling method, by fishes. Nevertheless, the results were qualitatively similar to Birtles and Arnold: the sites split in to three main groups, inshore and offshore inter-reef with a transition zone in the lagoon between. The inshore zone

was much less diverse than the offshore inter-reef zone; and these patterns were correlated with physical factors changing from inshore to offshore, i.e. increasing depth and from fine terrigenous to coarser carbonate sediments.

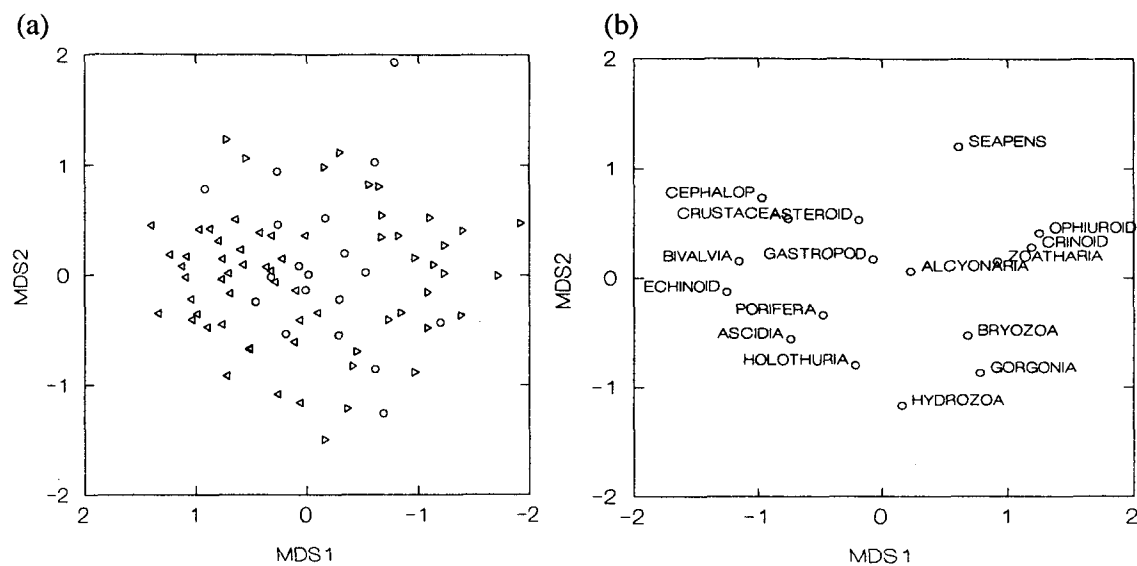
Watson and Goeden (1989) used commercial prawn trawl gear to sample fauna at monthly intervals in 20 sites distributed from the inshore, across the lagoon, into the offshore inter-reef matrix, over a  $\sim 1^\circ \times 1^\circ$  region off Townsville in 1985. Classification analysis showed very consistent group membership of sites, despite seasonal variation – the faunal composition of the samples consistently grouped the sites into inshore, lagoonal and offshore inter-reef zones similar to that of Birtles and Arnold. However, species richness appeared to be greater inshore than offshore, with 82% of the 200 species analysed present in the coastal zone, 80% in the inshore zone and 70% in the offshore. Interestingly, the coastal zone received  $\sim 5$ x less commercial trawling effort than the other zones. As with the other studies, these patterns were correlated with the physical factors depth, sediments and carbonate content.

Coles, Lee Long and co-workers (1996) conducted a video survey over  $\sim 4^\circ$  of latitude north of Cairns, primarily for broad scale mapping of seagrass, but sediment, algae and epibenthic megafauna were recorded also. The sampling strategy for the survey was to divide the region into 15-minute-of-latitude blocks and select a cross-shelf transect at random from each block; each transect was divided into 1 n mile segments and a randomly placed video transect  $\sim 100$ - $300$  m long was conducted in each segment. The patterns observed concurred with patterns documented by others: most megafauna were observed offshore on harder substratum, which were also areas trawled less. Algal beds (*Caulerpa* and *Halimeda*) and solitary corals were also more abundant offshore. Also sampled was a lagoonal area near the Turtle Group of islands, which was not trawled due to dense seagrass beds - large numbers of sponges were observed in this area.

Recently, in 1992-93, CSIRO and QDPI used commercial fish and prawn trawls, a 3 m epibenthic dredge, video sled and grab to sample fish, prawns and benthos at 166 stations distributed representatively, from the coast to the outer barrier, throughout the  $\sim 1^\circ \times 1^\circ$  area of the cross-shelf closure and adjacent open zones of the far northern section of the GBR (Blaber et al. 1993, 1994). Note that stations were restricted to trawlable, or semi-trawlable ground. The patterns documented for epibenthic dredge fauna were similar to those of previous studies - again cluster analyses of sites by taxa showed three main groupings in similar cross-shelf positions. These typical patterns are shown more concisely by a two-dimensional plot of the ordination of sites by taxa (Fig. 1a), which shows relatively close grouping of inshore sites ( $\triangleleft$ ), clearly separated from offshore sites ( $\triangleright$ ), and with midshelf sites ( $\circ$ ) scattered mostly between. Also clear is that offshore sites are much more heterogeneous in composition than inshore sites. Ordination of high-level taxa by sites (Fig. 1b), clearly showed different cross-shelf distributions at that level. The echinoids and bivalves were much more abundant inshore, whereas the ophiuroids, crinoids and zoanthids were much more abundant offshore - other taxa groups showed a range of patterns in between. Some species within each high-level taxa group had quite different cross-shelf patterns of abundance to the group as a whole and this is currently being analysed in more detail. As with other studies, these patterns were related to changes in the physical factors depth, sediments and carbonate content. Part of this study focussed on the large (mega) benthic epifauna (i.e. corals, sponges, gorgonians, seawhips, soft corals), because of their contribution to biodiversity and importance as structural habitat for other organisms. These megabenthos were very patchily distributed on several scales and tended to have many other organisms associated with them (e.g. fishes, holothurians, crinoids, urchins, seastars, molluscs etc.), in addition to the sessile fauna themselves. The megabenthic patches represented islands of high diversity surrounded by extensive areas of sand and silt almost devoid of megabenthos. Where megabenthos did occur, it tended to be limited to slightly raised harder substrata in offshore areas - and the occurrence of such substrata was



often < 5% in video transects. Typically, these patches were 1–10 m across and were separated by 10–100 m, but were highly variable.



**Figure 1.** Multidimensional scaling plots of (a) dissimilarities of sites, by taxa, inshore sites (◄), midshelf sites (○) offshore sites (▷), and (b) dissimilarities of high-level taxa, by stations. Note, the MDS1 axis corresponds primarily with inshore to offshore orientation, left to right.

#### Common patterns and relationships

Most studies focussed on the larger animals living on the seabed, i.e. the macrobenthos, and in many cases just the subset of species sampled as by-catch by prawn trawls. This epifauna has high species richness - typically 700+ species would be found in a representative set of samples from the GBR. The infauna was not included in these studies, but similar work in adjacent regions (e.g. Gulf of Carpentaria, Long and Poiner 1994) has showed that tropical infauna also has high species richness - again, typically 700+ species larger than ~1 mm, and at least as many < 1 mm - and probably similar richness would be found in any representative series of samples from the inter-reef from any section of the GBR.

The studies showed that the least diverse areas tended to be muddier sediments where the dominant animals generally were deposit feeders. Sandier and harder areas tended to be more diverse, at least partly because of the greater range of physical habitats, and the fauna were more abundant as well - the dominant animals generally filter food items suspended in the water column, or are scavengers or carnivores. The megabenthic epifauna, which form living structural habitat attached to the seabed, tended to be restricted to rubble or rocky patches, or areas where the bedrock or coarse substrata are exposed by fast currents. Such patterns are also typical in other regions (e.g. Gulf of Carpentaria, Long and Poiner 1994; Long et al. 1995).

Because of these habitat requirements, there is a distinct cross-shelf zonation of the benthic fauna, related to the change from terrigenous muddy sediments of the inshore lagoon through to coarse calcareous sediments of the offshore inter-reef. Typically, multivariate analyses discriminated the fauna into three main groups: inshore lagoon, offshore inter-reef and a mid-shelf lagoon transition area. This zonation appears common to all studies to date, although the membership of the species groups among the different studies has not been examined for consistency. Only one of the studies (Cannon et al. 1987) compared samples from a range of latitudes (~12°S to ~18°S) and showed an overlapping continuum rather than discrete

groupings of (trawl by-catch) faunal variation, though the authors treated this result with caution.

### **Implications for World Heritage Area reporting**

The Great Barrier Reef Marine Park Authority (GBRMPA) has obligations to UNESCO and to the stakeholders of the region to report on the status and values of the GBRWHA. The 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area (GBRMPA 1994) is the GBRMPAs and stakeholders' response to developing guidelines for integrated management of the Region to preserve its heritage values for the future. In order to contribute to the requirements for World Heritage Area reporting, I have commented on the current status and values of the inter-reefal benthos, given the available information, with reference to the objectives of the 25 Year Strategic Plan.

#### **Current status of inter-reefal benthos**

Australia has adopted the OECD 'Pressure-State-Response' model for environmental reporting (DEST 1994), where 'pressures' are the result of human activities, 'state' is the condition of the environment which may be altered, and 'response' is the development and implementation of policies to abate the pressure. Here, the current status of the inter-reefal benthos is examined in terms of the 'Pressure-State-Response' model. There are at least two identifiable pressures on the inter-reefal benthos, sedimentation and trawling, though the magnitude of these pressures is highly dependent on location.

#### *Sedimentation*

Erosion of agricultural land and other developments has lead to increased sediment output from rivers flowing into the GBR lagoon, especially the Burdekin and Fitzroy Rivers (Moss et al. 1992) - this has the potential to increase sedimentation and nutrient loads in some nearshore areas. The possible impacts of sedimentation are to directly smother some epibenthos, the most vulnerable being the epibenthic suspension feeders, to alter the sediment composition by addition of terrestrial fines, which may alter the benthos community further in the direction of the less diverse soft-sediment composition, and to indirectly affect the benthos through elevated nutrient levels.

While some studies have addressed the state of nearshore reef corals with respect to the impact of sedimentation and nutrients (see references in Larcombe and Woolfe 1995), these issues have not been specifically addressed for nearshore lagoon benthos. Consequently, the significance of these pressures on the state of nearshore benthos is not known. However, despite the increased sediment outflow, many rivers flowing into the GBR region would have had high sediment loads naturally and data from sediment cores give some indication (Johnson 1995), but no clear evidence of increased sedimentation or increased proportion of terrestrial fines (McIntyre 1995) over that deposited in recent geological history, except for a few limited dredge sites (Woolfe pers. comm.). Most of the river outflow sediments are deposited within a few km of the coast, due to the SE Trade Winds, rather than carried out into the GBR Lagoon (Johnson 1995). Over the past several thousand years, the terrestrial sediments have slowly prograded up to 10-15 km offshore, but are often narrower - this zone is disturbed regularly by wind induced wave action. Therefore, it is possible that the composition and stability of the inshore sediments, and thus the benthos community composition, has not changed greatly with development of the region. However, currently there is no data available to test this and further, the possible impacts of excessive nutrient loads are unknown.

In terms of response, it is not clear whether there are any impacts on nearshore benthos due to current levels of sedimentation, or whether the potential impacts are sustainable. Geological research would suggest that the thick wedge of terrestrial sediments, nearshore, has not been changed significantly by development of the region. Thus, in the context of nearshore benthos, it is not clear that any management strategies should be developed and implemented to respond to increased sediment outflow from rivers in the region. The required response may be different to ensure sustainability and allow reasonable use of other nearshore resources.

### *Trawling*

The GBR lagoon supports a valuable otter trawl fishery, with about 900 boats, and trawlers operate in extensive areas of the lagoon and inter-reef within the GBR region, though high levels of effort are concentrated in Princess Charlotte Bay and the Townsville region. Penaeid prawns are the primary target species group (with ~7000 t per annum landed), but scallops (~1000 t), sand crabs, scyllarid lobster, squid, and a few fin-fish species are also landed. Trawl nets clearly can remove benthos, as many anecdotal reports and a few scientific studies have demonstrated; however, the overall significance of this pressure is not yet fully clear. The impacts of trawling have been documented most comprehensively by a recent 5-year study of the effects of prawn trawling, conducted in the far northern section of the GBR by CSIRO and QDPI. One aspect of this study was to measure the impact of prawn trawling on seabed communities - this was examined in three ways:

1. by surveying the cross-shelf closure and comparing the species composition and abundance with that in adjacent areas north and south that are open to trawling;
2. by conducting a Before-After-Control-Impact (BACI) experiment in the mid-shelf section of the area closed to trawling, to determine the impact of a single-prawn-trawl per unit area; and
3. by conducting a repeated trawl depletion experiment on selected tracks in the mid-shelf section of the area closed to trawling.

The surveys of the cross-shelf closure and adjacent open areas showed that at this scale and resolution, there appeared to be few significant differences between the benthic communities in open and closed areas (Blaber et al. 1993, 1994). However, this should NOT be interpreted as a comparison of trawled v. untrawled areas and does not indicate that trawling has no impact, because it is known that the inshore area of the closure was heavily trawled before the closure declaration and some trawling has continued in this area. Also, much of the area open to trawling is not trawled.

The BACI experiment was designed to simulate the situation where trawlers may move into new mid-shelf inter-reefal areas to target red-spot prawns and for grounds that are not trawled intensively. During the impact phase, between 1-7 t of benthic material was removed from each treatment plot - equivalent to 3-20 kg/ha. Despite this obvious indication of some impact, and the fact that the power of the experiment was as designed, there were few significant differences between the benthic communities in trawled and control plots (Burrige et al. 1996). Direct observations of structural habitat also showed little change - clearly, the impact of a single trawl per unit area was less than order-of-magnitude.

The repeated trawl depletion experiment was conducted to determine the intensity of trawling that would cause a substantial impact on the sessile benthos, to place the BACI experiment in perspective and to document the rate of impact of intensive trawling on seabed benthos. The repeated trawls were conducted on six 2.7 km tracks for which there was detailed information about their 'before' status. Each track was trawled 12-13 times over, with highly accurate vessel navigation - the overall width of the trawled area in each track was ~35 m compared with the width of the trawl gear at ~17 m. A central area of 10-15 m wide in all tracks was trawled at

least 10 times over. Overall, ~2.25 t of sessile benthos was removed, corresponding to ~54 kg/ha. Each trawl removed ~8–20% of the available sessile benthos and 12–13 trawls removed 70–90% of the initial biomass, although the rate was dependent on the type of organism (e.g. large sponges appear to be removed more rapidly than gorgonians - CSIRO/QDPI unpubl.).

Clearly, trawling can alter the state of the inter-reefal benthos and in spite of the absence of long term data sets to confirm trends, circumstantial evidence and anecdotal reports suggest that there have indeed been changes. However, the overall significance of trawling pressure is not yet fully clear. The CSIRO/QDPI experiments show that the cumulative effect of high intensity trawling is likely to be substantial on epibenthos in species rich offshore areas, but the impacts may not be detectable in areas that are trawled infrequently or sparsely. Further, the experiments could not be designed to answer questions about past impacts in previously trawled grounds on soft sediments of the GBR lagoon, especially smaller infauna. These lagoonal soft sediment fauna may, however, be less vulnerable to trawling. Whether or not these levels of impacts are sustainable requires more information on the spatial distribution and intensity of trawl effort, at much finer scales than presently collected, in both the lagoon and inter-reefal areas, as well as information on the vulnerability of lagoonal soft sediment fauna.

While it has been important to determine the impact of trawling on the sessile seabed communities, it is now perhaps even more important to monitor their recovery after trawling. This is because large areas of the GBR have already been trawled and for future management of the region it is necessary to understand if and how these areas may recover if they were closed to trawling or if different strategies for trawling were implemented.

The response to trawling pressures will include management strategies which ensure ecological sustainability, whilst allowing reasonable use. Certainly, inter-reefal epibenthos can be impacted substantially and thus zoning plans should aim to preserve representative areas of such habitat and its biodiversity. Impacts on lagoonal soft-bottom benthos are suspected, based on by-catch composition, but have not yet been formally documented - in the absence of rigorous information, the precautionary principle should be adopted and representative areas of this habitat and its biodiversity should also be preserved in zoning plans. The biological information needs should be addressed and, in addition, the introduction of systems to provide much more reliable information on the fine scale distribution and intensity of trawling. Such information could be obtained with the introduction of a vessel monitoring system and will be essential for assessing and managing the environmental impacts and ecological sustainability of prawn trawling.

#### Maintenance of World Heritage values

The nomination of the GBR as a World Heritage Area carries with it an obligation to maintain or enhance the World Heritage values of the region. These values include: significant stage of earth's evolution; significant geological or biological evolutionary process; unique, rare or superlative natural phenomena or formations; and support biological diversity, rare or endangered species (UNESCO 1972).

The inter-reefal benthos communities contribute to these World Heritage values by virtue of their biodiversity (thousands of species, many or most unnamed), high level of endemism (especially in sponges, where the GBR supports ~10% of the world's species and 30–70% of these are endemic - Hooper and Lévi 1994) and, contrarily, high level of conservatism in retaining some taxa of Tethyan origin. Whether these values have been maintained or degraded - i.e. Has biodiversity been lost? Have any endemic species been lost? Have any rare, endangered or ancient species been lost? Have any natural phenomena or formations been degraded? - since the listing in 1981, is not possible to determine with the available data. This

indecisive situation arises because the inter-reefal area has not been well documented and there is no baseline and no data to examine long terms trends. However, it is highly unlikely that these values have been enhanced – in all probability there has been some degree of incremental degradation, the ecological significance and sustainability of which is unknown.

#### 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area

The goals and issues raised in the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area relevant to inter-reefal benthos include, but are not limited to: sustainable multiple use, maintenance/enhancement of values, integrated planning, knowledge based decision making, effects of fishing, incremental degradation, management techniques (e.g. closures), region wide monitoring, runoff, ecologically sustainable development.

Our knowledge and understanding of inter-reefal benthos is very limited, especially compared with that for the coral reefs. Consequently, our capacity to address the goals and issues raised in the 25 Year Strategic Plan is also very limited. Nevertheless, a few aspects of these goals and issues can be addressed, with suggestions for further work needed.

The pressure most clearly identified as having the potential for significant impact on inter-reefal benthos is trawling; consequently, most of the issues for inter-reefal benthos are related to the effects of trawling. It is clear by extension of research results, and from anecdotal reports, that trawling has caused incremental degradation - what is not known is whether the impacts are ecologically sustainable or whether values have been maintained or lost. It is also clear that the effects of trawling depend on the benthic community type, which changes across the shelf, and on the distribution and intensity of trawling, which is very patchy. The available information does not suggest that trawling cannot be a sustainable multiple use of lagoonal or inter-reefal habitat - with appropriate planning and management techniques, trawling for prawns can very likely be a sustainable activity. Nevertheless, in the absence of complete knowledge, the precautionary principle should influence decision making and a range of representative areas of inter-reefal and lagoonal habitat should be preserved in closures. Planning, in terms of the zoning system, should be more integrated, i.e. the zoning of reefal and non-reefal areas should be consistent and appropriate. To date, there has been emphasis on the reefs, this should be matched with complementary zoning of the inter-reef and lagoon.

To achieve the objectives stated in the Strategic Plan, the following information is needed:

- Maps and inventories of inter-reefal and lagoonal habitats are required for planning of representative areas, the zoning system, and closed areas. These should include cross-shelf and latitudinal trends, and infauna as well as epifauna.
- Maps of the fine scale distribution and intensity of trawling, in both the lagoon and inter-reefal areas, are essential for assessing and managing the environmental impacts and ecological sustainability of prawn trawling. The introduction of a satellite-based vessel monitoring system would greatly facilitate this need.
- The vulnerability, and effects, of trawling on lagoonal soft-bottom benthos should be formally documented.
- The natural dynamics and processes structuring inter-reefal and lagoonal habitats are almost completely unknown and should be documented to provide information on the sensitivity of benthos to pressures and their resilience/recovery from impact, to assess sustainability of multiple uses, such as trawling.
- The taxonomic diversity of the inter-reefal and lagoonal habitats should be documented. Presently many, or even most, species are unnamed and their evolutionary relationships are unknown. This is essential for assessing changes in World Heritage Area values.
- Region wide monitoring of the state of inter-reefal and lagoonal habitat should be initiated following the inventory mapping, and be consistent and complementary with the current

monitoring of coral reefs. This monitoring will provide baseline and temporal information for long term trend analysis. Again, this is essential for assessing changes in World Heritage Area values.

- The results of nearshore sedimentology research should be reviewed specifically to address whether there have been any significant changes in nearshore lagoonal sediments that may have consequences for the state of nearshore benthos.

### **Implications For Management**

The management issues revolve around the following facts: (1) there is so little known about the distribution and composition of the lagoonal and inter-reefal habitats, (2) there is a large trawl fishery and, (3) the best available evidence indicates that there have been, and continue to be, impacts on the inter-reefal habitat due to trawling, as well as changes to other components of the ecosystem. In the GBR, seabed habitats outside trawled grounds are not considered to be pressured, so are not at great issue - but habitats inside trawled areas are.

The management questions include: what have been the impacts due to trawling on the lagoon-bed habitats? What are the ongoing impacts? Is biodiversity being lost? Are the impacts in soft ground different from those in structured ground? What is the distribution and intensity of trawl effort? How should the lagoonal and inter-reefal areas be classified for representative areas? How should the zoning system be reviewed to manage inter-reefal areas to maintain biodiversity? - currently inter-reefal areas are not well represented in protected areas of the GBR. Should some currently trawled areas be set aside in reserves? If so, how should they be selected? and What kind of recovery can be expected, over what time period?

Even though these questions are currently unanswered, the available knowledge does have several important implications for management:

- The inter-reefal benthos communities are valuable in terms of their biodiversity, high level of endemism (e.g. sponges), and in terms of evolutionary history, due to retention of some fauna since Tethyan times. In total, there are many thousands of species of benthos organisms, most of which are as yet unnamed. Thus, these resources must be managed.
- The clear cross-shelf trends in inter-reefal communities should be considered in strategic planning for conservation of representative communities - lagoonal and inter-reefal areas are under-represented in current zoning plans, which are focussed on the reefs.
- There are pressures on the inter-reefal benthos, the most clearly identifiable being runoff and sedimentation in nearshore areas and trawling in the GBR lagoon. Sedimentation has the potential to smother benthos and trawling can remove benthos.
- The impact of trawling may not be detectable in areas that are trawled infrequently or sparsely. However, the cumulative effect of frequent trawls in intensively trawled grounds will be substantial both in terms of organisms directly affected by trawling and indirectly due to attracting scavengers and removing refuge habitat for fish and other mobile organisms. The CSIRO/QDPI results for a once-over-trawl impact and for intensive repeated-trawl impact are both highly relevant to understanding the overall impact of trawling as it is clear that trawl grounds are not subjected to a uniform intensity of trawling. Large areas may never be trawled or perhaps only once every few years, but other areas can be trawled quite intensively (many times per year).

Finally, the underlying implication for management is that there is insufficient scientific knowledge available to address the multitude of management questions, or manage the issues, or meet requirements for state of the environment reporting, or obligations for maintaining World Heritage Area values, or to achieve the objectives of the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area. To address these shortcomings, processes must be initiated to provide the information needs outlined in the previous section.

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# Fishing club activities on the Great Barrier Reef

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## Introduction

Recreational fishing is a pastime enjoyed by many Australians. The combined nation wide harvest by recreational fishers was estimated to be 30 943 tonnes of seafood for the year ending April 1992 (Australian Bureau of Statistics 1994). State by state, Queenslanders accounted for the highest proportion (23.5%) of the national recreational catch, with total landings of 7284 tonnes (Australian Bureau of Statistics 1994). Just over one third (34.5%) of the catch was landed by residents in Brisbane, the State's capital city. Although recreational line fishing is by far the most important extractive recreational activity within the Great Barrier Reef World Heritage Area (GBRWHA), there have been relatively limited attempts at quantifying the importance of the activities (Blamey and Hundloe 1993; Hundloe 1985), and their associated impacts. The GBRWHA recreational fisheries have traditionally been classified by the way anglers access the marine resource. Fishing access is provided by: 1) privately owned and operated vessels, 2) the charter boat fleet, 3) the club boat fleet; and 4) shore based fishing activities from island resorts operating within the GBRWHA. By far the most significant potential increase in recreational fishing effort exists in the recreational small boat fleet, with the number of registered vessels adjacent to the GBRWHA increasing 5 fold from 1968 to 1994. Even with this rapid increase in potential fishing effort, research into this section of the recreational fisheries has been limited to two GBRWHA wide surveys (Blamey and Hundloe 1993; Hundloe 1985) that utilised different sampling methodologies to estimate recreational fishing effort and fish catch. Higgs (1996) provides a critical review of the sampling methodologies utilised in these two surveys, and suggests that a precautionary approach should be used before the results are compared between the two surveys.

Although anglers associated with fishing clubs only represent a small fraction of the fishing community, historically, the activities of these anglers are well documented through the records fishing clubs maintain for competition purposes. Analysis of recreational fishing club catch records have been used to monitor trends in many of Queensland's inshore recreational fisheries. In southern Queensland, club catch records have been used to monitor the recreational fisheries for bream from 1923 to 1991 (Thwaites and Williams, in prep.) and whiting from 1959 to 1991 (Pollock and Williams 1983; Thwaites and Williams 1993). Club records have also been used to monitor the tropical shore based line fishery in the Mackay region over the period 1952 to 1984 (Quinn and Pollock 1992). Fishing clubs have generally accessed the Great Barrier Reef using either commercial charter vessels, or one of four vessels owned and operated by individual fishing clubs. The analysis of catch records maintained by fishing clubs that operate in the GBRWHA therefore provides a history of the activities of clubs that operate from the charter and club boat fleet.

The Great Barrier Reef Marine Park Authority (GBRMPA) has collected club competition records on a number of occasions from the fishing clubs that access the GBRWHA. This information was used to create a relational database, the REEF FISH database. The fishing club information has been used in a number of publications (Craik 1989; Craik 1981; Craik 1979; Zann Schuster 1991) and forms the only long term history of recreational fishing activities from club and charter boats operating in the GBRWHA. This paper summarises the research results presented in the most recent detailed analysis of the database by Higgs (1993). The aim of this paper is to present catch trends depicted in the REEF FISH database system. Trends in

catch rates, species composition and average weights of landed fish are presented for each of the four regions of the GBRWHA.

## Methods

Competition records were collected from the recreational fishing community on four separate occasions. On the first two occasions information spanning the years 1957 to 1979 was collected by Craik from clubs from Cairns to Maryborough (Zann Schuster 1990). Zann Schuster made a third collection in 1989 to update most of the original sources first collected by Craik. The final collection of data was initiated by the author in 1992 using an augmentative grant funded by the GBRMPA. The extent of the REEF FISH database is shown in Table 1. The majority of information collected recorded amateur angling club competitive fishing activities, with some information provided by charter boat operators and individual recreational anglers. Quality and type of information varied with each source of information. A total of 1807 trips had sufficient information to calculate average fish weight and catch per unit effort information. Catch per unit effort (CPUE) was calculated as mean catch rate per trip on an annual basis, with units measured in number or kilograms of fish caught per angler day.

**Table 1.** Summary of the REEF FISH database records used by Higgs (1993)

Region	Annual coverage	Number of fishing trips*	Effort in angler days	Total weight of fish (kg)	Total number of fish
Cairns	1971-1992	349	8879	57303	21029
Townsville	1961-1992	715	18463	233894	140940
Mackay	1971-1989	172	4184	64117	42903
Rockhampton	1956-1989	571	10358	126291	130896
TOTAL		1807	41884	481605	335768

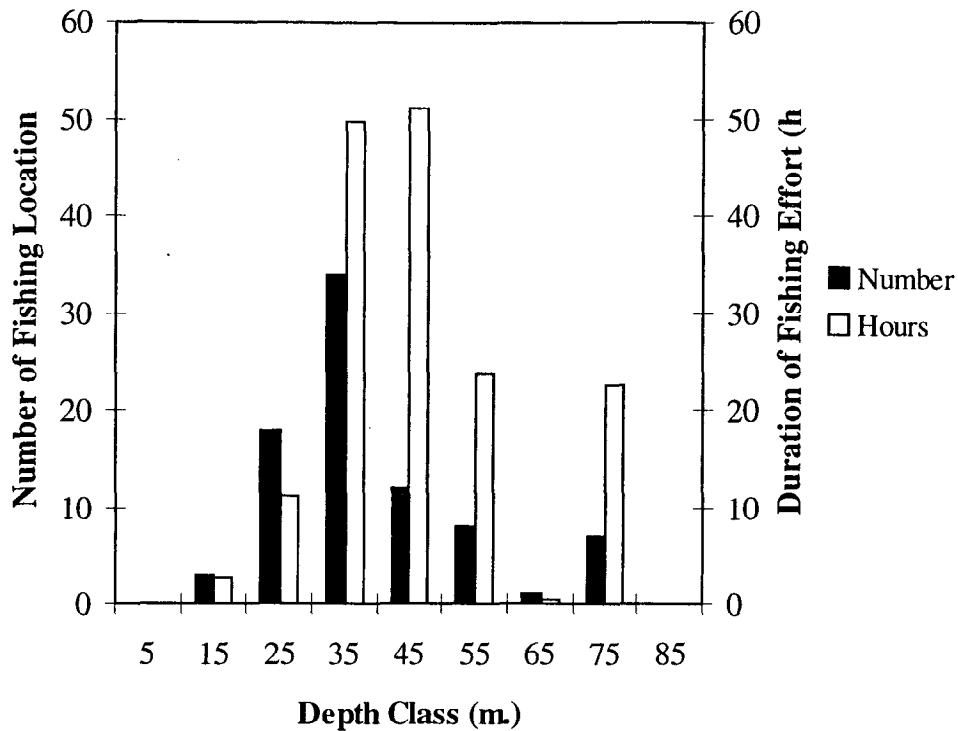
\* Number of trips that recorded effort in number of people on board, trip duration in days, and recorded the fish catch in number and weight of fish.

To facilitate analysis and to comply with previous publications of this work, the GBRWHA region was divided into four regions similar to the economic zones used by Hundloe (1985). The regions were Cairns in the north, Townsville, Mackay, and Rockhampton in the south.

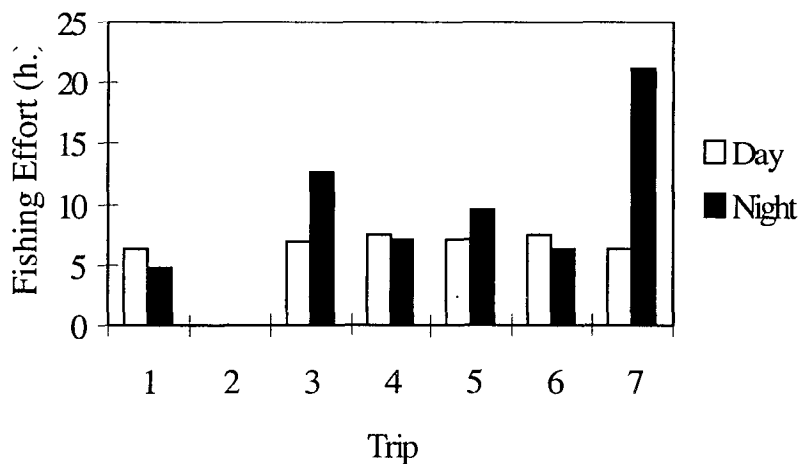
In 1992 on board observations were made during seven amateur fishing club trips in the Townsville region in an attempt to estimate the accuracy of the clubs records provided to the REEF FISH and to document the contemporary fishing activities of the clubs. The author recorded spatial and temporal distributions in fish catch and fishing effort, and compared the actual total catch with the landings recorded in the fishing club competition records.

## Results

Results from on board observation of fishing club competition activities suggest that major suppliers of information in the Townsville region recorded 75.4% of their fish catch into the club records. A further 13.7% of the total catch was released alive and 8.2% was used for bait. The remaining fish were retained for scientific samples. Fishing activity occurred predominantly in water deeper than 30 m (Fig. 1) with 52% of the total fishing effort occurring at night (6 p.m. to 6 a.m.) (Fig. 2).

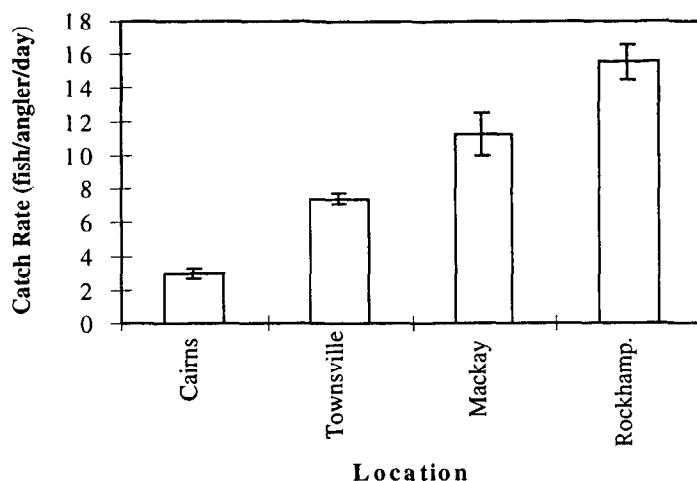


**Figure 1.** Depth distribution of fishing effort in terms of number of fishing locations and actual fishing time during observed fishing club activities

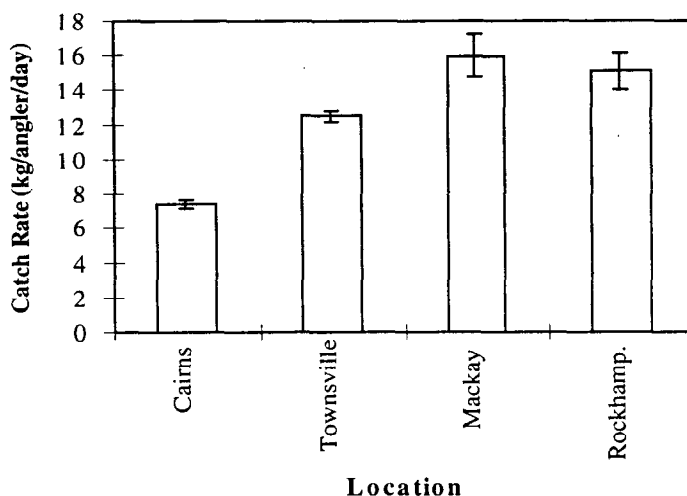


**Figure 2.** Temporal distribution of fishing effort between 'Day' (6 a.m. to 6 p.m.) and 'Night' (6 p.m. to 6 a.m.) fishing activities during observed fishing club activities

Clear latitudinal changes in fish weight and catch rates can be seen in the regional summaries of information. Cairns, Townsville, Mackay and Rockhampton recorded average catch rates of 2.9, 7.4, 11.3, 15.6 fish per angler day (Fig. 3), or 7.4, 12.5, 16.0 and 15.0 kg per angler day (Fig. 4), and average fish weights of 2.7, 1.7, 1.5, and 1.0 kilograms clean weight respectively (Fig. 5). Differences in catch rate and average size of landed fish are related to the species composition of the catch (Fig. 6) which largely reflects targeting of certain species by anglers and the demographic characteristics of the target species. Average catch rate had remained constant in the Rockhampton region (1956-1989) and Townsville regions (1961-1992), increased in the Cairns region (1975-1992) and decreased in the Mackay region (1971-1989) (Fig. 7).



**Figure 3.** Regional summaries of mean total catch rate measured in number of fish caught per angler day (mean +/- 95 % confidence intervals)



**Figure 4.** Regional summaries of mean total catch rate measured in kilograms of fish caught per angler day (mean +/- 95 % confidence intervals)

Average weight of landed fish had remained constant in the Rockhampton region (1956-1989) and increased in the Cairns and Mackay regions for the periods 1971-1992 and 1971-1988 respectively (Fig. 8). After an initial rapid decline from 2.3 kg in 1961, the average size of fish captured in the Townsville region declined gradually from 1.6 kg CW in 1967 to 1.4 kg CW in 1985. Average weight of captured fish increased progressively after 1986 for the Townsville region (Fig. 8), presumably as effort was directed towards the night fishery, targeting lutjanids which has a heavier average weight than coral trout (*Plectropomus* spp.) and red throat sweetlip (*Lethrinus miniatus*) that were traditionally targeted. Catch rates for coral trout and red throat sweetlip remained consistent in the Townsville region during the period 1961-1986. A shift in angler motivation to target lutjanids (mainly red emperor - *Lutjanus sebae*, large mouthed nannygai - *L. malabaricus*, small mouthed nannygai - *L. erythropterus*) was suggested by anglers to be responsible for the reduction in coral trout and red throat sweetlip catch rates in the last three years of records for the Townsville region. Catch rates for lutjanids increased substantially during this period (Fig. 9).

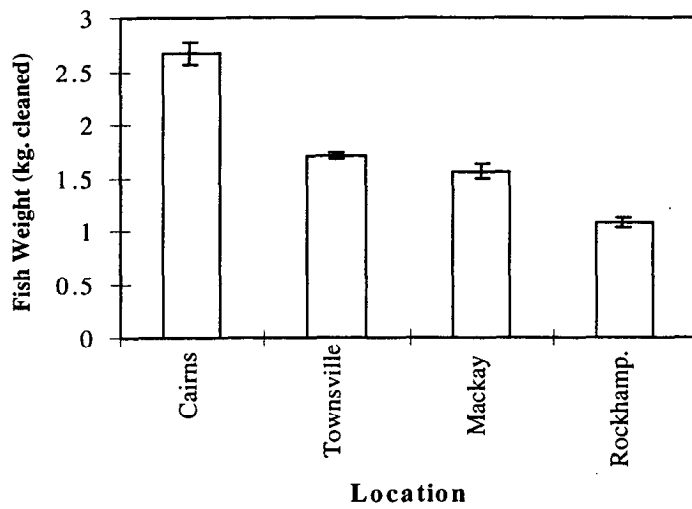


Figure 5. Regional summaries of mean cleaned weight of landed fish in kilograms (mean +/- 95 % confidence intervals)

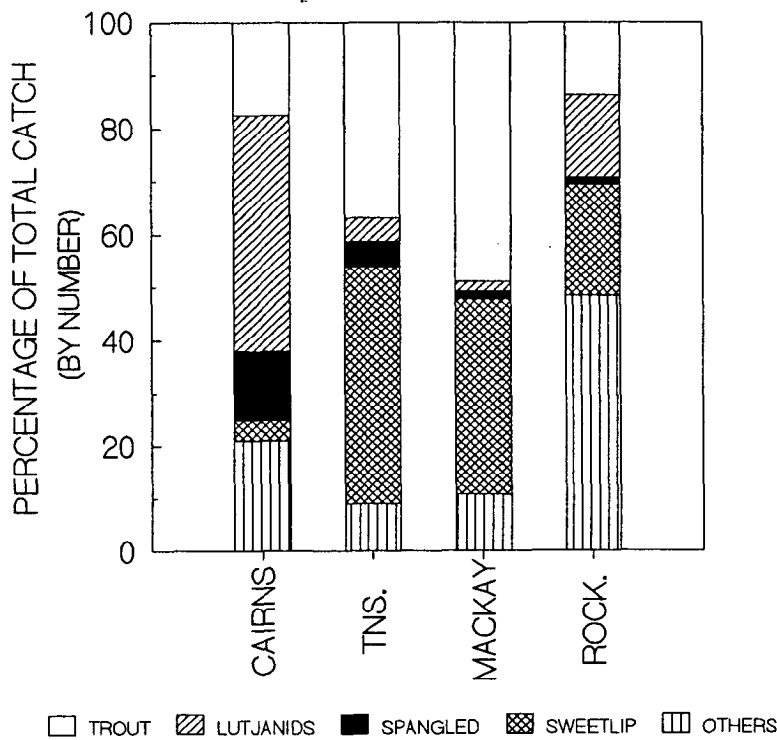


Figure 6. Regional species composition of catch calculated over the history of available records for each region

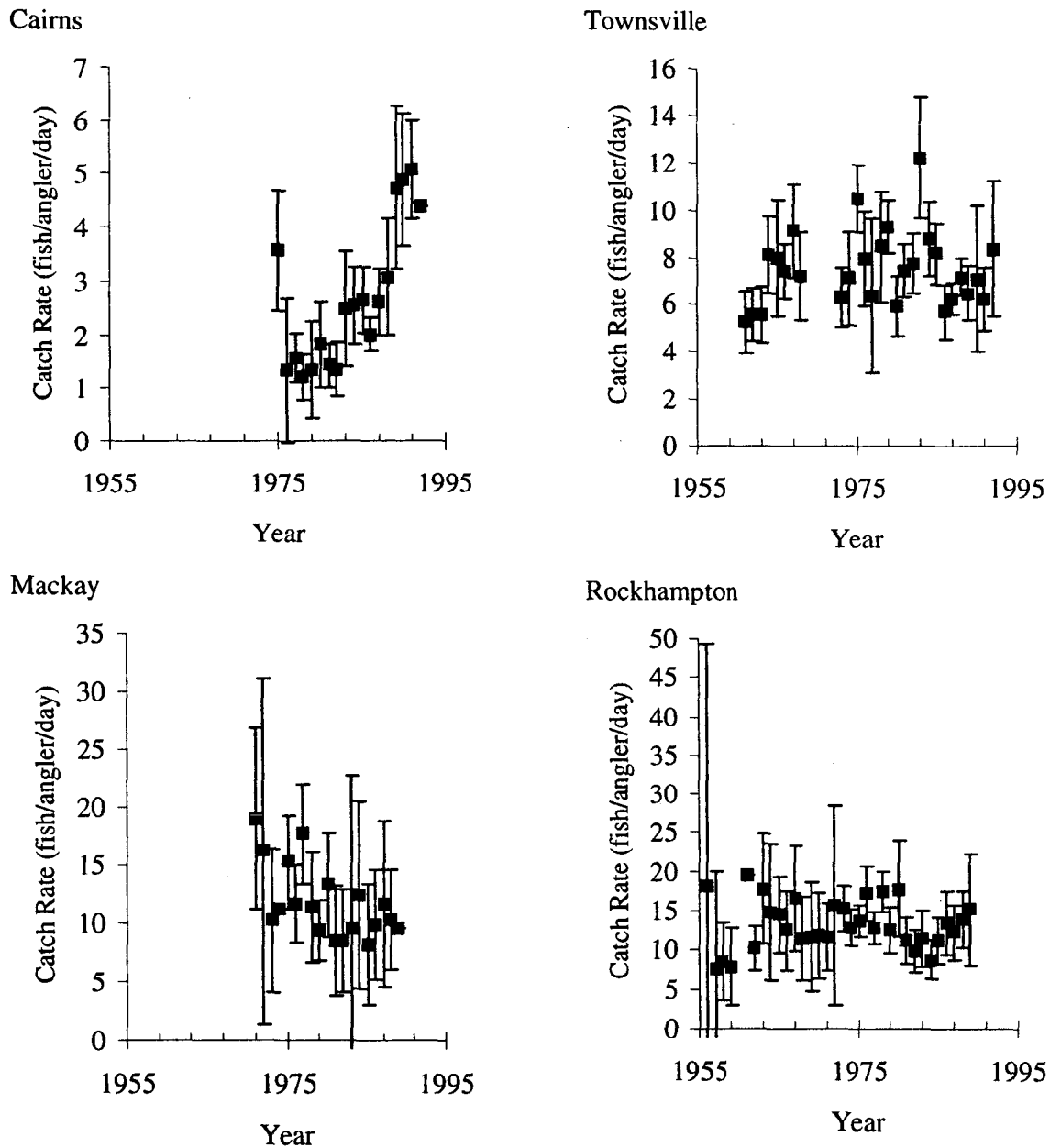


Figure 7. Annual summaries of mean total catch rate (fish/angler/day +/- 95% CI)

## Discussion

### Pressure

A state wide survey conducted by the Australian Bureau of Statistics showed that for the 12 months ended October 1985, an estimated 572 000 persons, or 30% of the Queensland population aged 15 years and over, engaged in some form of recreational fishing activity. State wide, an estimated 561 000 people were involved in rod or line fishing, 125 000 in crabbing, 16 000 in spear fishing, and 57 000 in netting in Queensland waters (Australian Bureau of Statistics 1986). Of the 561 000 people involved in rod and line fishing state wide, almost 34 000 people fished

using rod or line in the offshore waters, north of Baffle Creek (approximately the southern extremity of the Great Barrier Reef Marine Park) to the tip of Cape York Peninsula<sup>1</sup> (Australian Bureau of Statistics 1986). An estimated 29 000 people fished 'open reef waters' in the same region. Forty three percent (14 500) of this figure had used the offshore waters 1-2 times, 19% 3-4 times, 22% 5-9 times, 9% 10-19 times and 6% 20 times or more during the preceding 12 months (Australian Bureau of Statistics 1986).

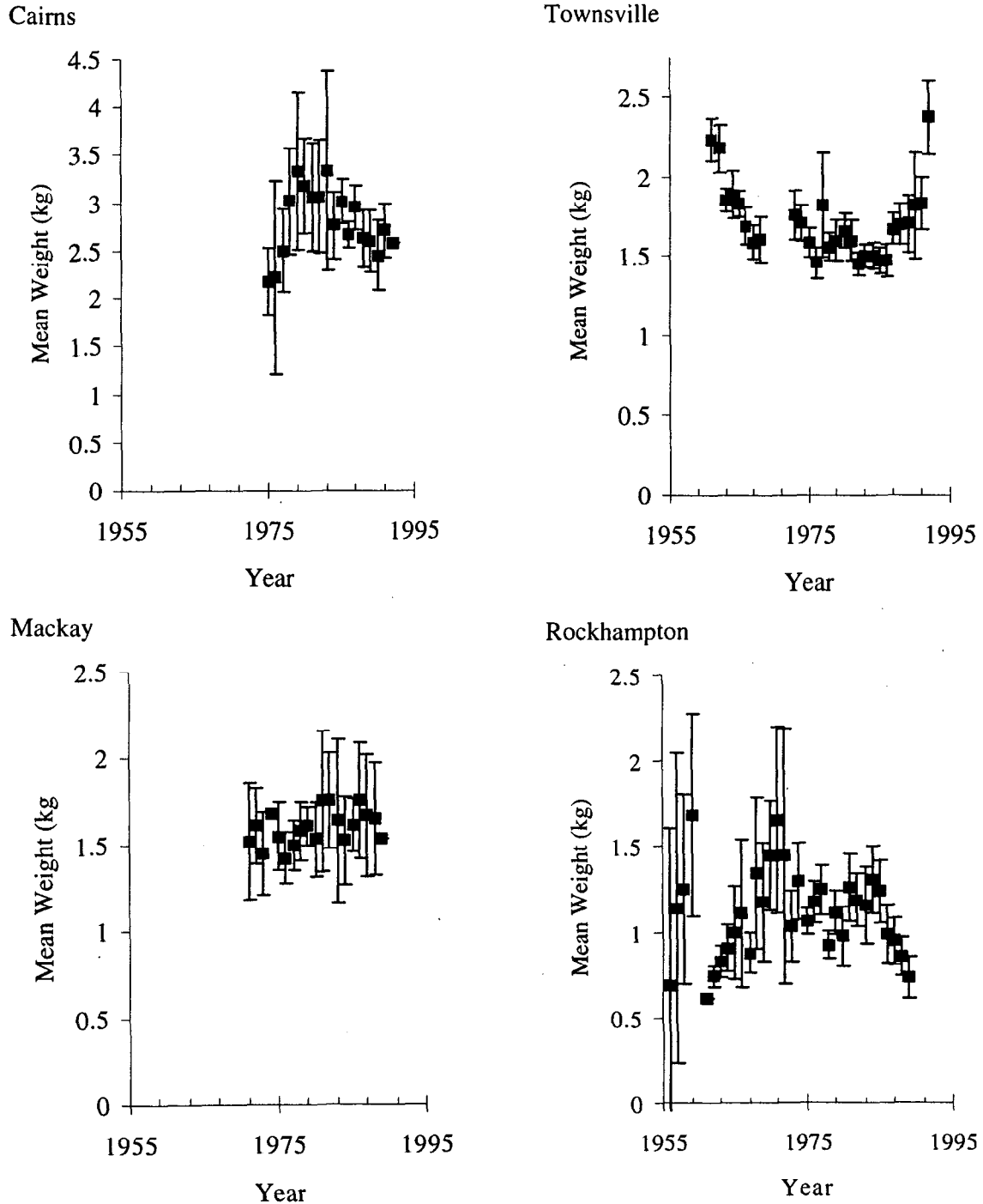
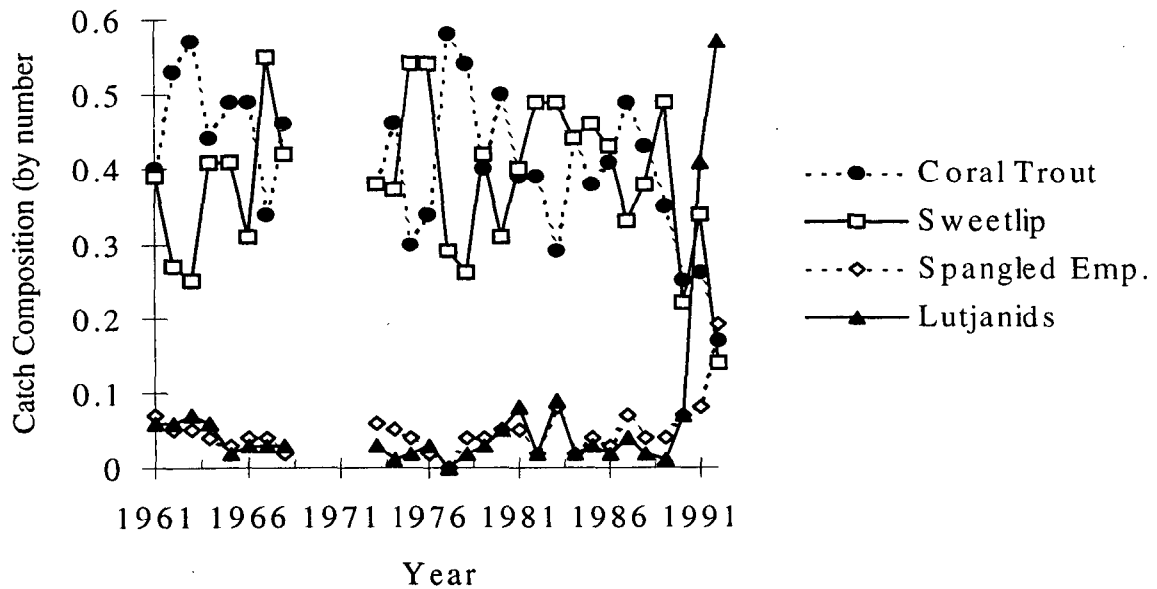


Figure 8. Annual summaries of mean weight of landed fish (cleaned weight in kg +/- 95% CI)

<sup>1</sup> Fishing areas 18, 15, 13 and 11 (Australian Bureau of Statistics 1986)



**Figure 9.** Annual species composition of the fish catch recorded by clubs operating in the Townsville region

There is clear evidence that the *potential* for increasing recreational fishing effort in the GBRWHA exists with the number of privately owned and registered vessels in Queensland increasing 5 fold from 1968 to 1994. It has been widely assumed that the recreational reef line fishing effort has been increasing in proportion to the number of private boat registrations within coastal areas adjacent to the GBRWHA. Craik (1989), for example, suggested that 'on the best figures available the combined fishing effort of recreational fishermen is estimated to be increasing at a rate of about 7% a year. If catch continues to increase at the present rate, it will be about 12 000 tonnes by 1990'. Driml et al. (1982) estimated that the number of boat owners that used their vessels to fish at sea was in the vicinity of 14 800 and they accounted for a landing of between 6572 and 8770 tonnes of fish. Blamey and Hundloe (1993) estimate that the number of motor boats used for fishing or crabbing within the GBRWHA was approximately 24 300 and they accounted for between 3500 and 4300 tonnes of fish. Apart from the information from Hundloe (1985) and Blamey and Hundloe (1993) there is no accurate information that details the true magnitude at which the fishing effort has been increasing, or what the current catch levels are within the GBRWHA.

Information collected during boat ramp surveys implies that the majority of fishing effort in the GBRWHA was focused on the coastal and inshore areas (Blamey and Hundloe 1993). This means that localised areas of high fishing pressure are likely to occur in the coastal areas of the GBRWHA, and not in the mid- and outer shelf reef areas. Although there is no documented evidence to support it, fishing pressure on the mid- and outer shelf reefs may have in fact decreased in recent years with increased vessel operational expenses, competing recreational activities (SCUBA diving, snorkelling, and shore based activities such as supporting national rugby league and basketball teams) and increased environmental awareness of the general community.

#### State

Research by Blamey and Hundloe (1993) clearly indicated that anglers perceived that the GBRWHA line fishery was in demise with 58.5% and 40.8%, of interviewed anglers replying



that they believed catch rates and average weight of fish had decreased in the past five years respectively. Results from the analysis of the REEF FISH database did not, however, support this perceived decline in catch rates. Catch rates had remained consistent for regions where constant sources of information had been available for analysis in the REEF FISH database (over 25 years in some cases). This suggested that club fishers, who are often assumed to be more competent fishers, were still capable of obtaining catch rates similar to those reported in the 1960s and 1970s. Average fish weight for the traditional coral trout/sweetlip emperor fishery in the Townsville region had decreased by approximately 1 kg from the high levels recorded in the early sixties. However, there was only a relatively small decrease in average weight of captured fish (0.24 kg) from the late sixties to the mid eighties. Higgs (1993) suggested the decrease in average weight in the early to mid eighties may have been related to an increase in the catch rate of sweetlip emperor since the early eighties in the Townsville region. Average weight of captured fish in the Townsville region had increased rapidly since 1988 and this corresponds to an increase in the percentage of lutjanids in the catch as suppliers of information changed their fishing styles to include fishing deeper water and/or at night, often targeting lutjanids.

Higgs (1993) suggested that significant declines in average fish weights provided evidence that growth overfishing had occurred in the Townsville day fishery for coral trout and red throat sweetlip. He also pointed out that the absence of a significant decline in catch rate on a regional scale suggested that 'recruitment overfishing' had not occurred throughout the Townsville region. Higgs (1993) reported that significant declines in catch rates were observed for a number of individual reefs in the Townsville region, but the 'reliability' of the trends was not always clear because of low sample sizes and high variability in catch rates from year to year.

Higgs (1996) suggested that 'results of the research conducted to date suggest, contrary to public opinion, that there is little evidence of decline in catch rates of the recreational reef line fisheries over a 30 year period. This perception is based on historical catch records dating from the late 1950s, provided by amateur fishing clubs, and the comparison of catch information collected at boat ramps during surveys from the early 1980s and 1990.'

#### Response

Response of the management agencies over recent years to the assumed increases in fishing effort has been to introduce a number of controls such as bag and size limits for frequently targeted reef fish species. In addition, the ability for recreational anglers to legally sell part of their catch, up until 22 May 1990, under Section 35 of the *Fishing Industry Organisation and Marketing Act* was abolished. The ability for recreational anglers to sell part of their catch up until 1990 does, however, create problems for managers who have traditionally relied on historical trends in angler catch rates to monitor fisheries. The ability to sell fish prior to 22 May 1990 means that catch rates, and volume of catch, prior to this time may have been inflated because of the presence of a 'semi-commercial' attitude in segments of the recreational fishery. As Gwynne (1990) noted, 'the mere existence of Section 35 did infer a right to all unlicensed fishermen to sell product' and this 'semi-commercial' attitude of being able to take large quantities of fish is still retained in some sectors of the recreational fishery. This has enormous implications for analysis of records systems such as the REEF FISH database, where catch rates and average size of fish recorded are modified by management practices.

In response to the lack of a coordinated recreational fishing sampling program the Queensland Fisheries Management Authority (QFMA) and the Queensland Department of Primary Industries have together been developing a state wide data collection system (RFISH) for the Queensland recreational fisheries. The system is designed to 'describe the nature and extent of recreational fishing in Queensland, conditions and trends in fisheries resources targeted by recreational

anglers, and be consistent with national standards for data collection of this type'(QFMA 1995). The RFISH program, as it stands, has six components:

- a comprehensive contact survey to establish participation in recreational fishing in Queensland to be conducted by a reputable agency;
- an individual diary system to be completed voluntarily by recreational fishers identified in a random selection process to obtain sample catch and effort data for key species of recreational interest;
- a data collection system to cover tourist fishers who are not Queensland residents (and consequently not accounted for in the above survey and diary system);
- constant surveys conducted by field officers;
- occasional surveys such as creel surveys; and
- a facility for interested parties to record historical data such as club records, tag and release data, research data and the like (QFMA 1995).

### **Acknowledgments**

The majority of this work was undertaken as part of a MSc degree at the James Cook University of North Queensland. Funding for the collection of data from the clubs operating within the Great Barrier Reef World Heritage Area was provided by the Great Barrier Reef Marine Park Authority. This summary of the historical trends in the amateur reef line fishery would not of been possible without the ongoing logistical support and intellectual input from amateur angling clubs and charter boat operators.

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# Reef fish fisheries in the Great Barrier Reef World Heritage Area

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## Description of the fishery

Principal reef fish species occurring in the Great Barrier Reef World Heritage Area are fish from the demersal tropical coral reef group and reef pelagics.

Tropical coral reef fish species targeted by fishers include many species of the families of *Lethrinidae*, *Lutjanidae* and *Serranidae*, amongst others. Coral trout (*Plectropomus sp.*), red throat sweetlip emperor (*Lethrinus miniatus*) and red emperor (*Lutjanus sebae*) form a significant proportion of catches.

Reef pelagics comprise a further range of species taken. Most commonly targeted as food fish are spanish mackerel (*Scomberomorus commerson*), other mackerels, shark of the family *Carcharhinidae*, and tunas (*Scomberidae*). Billfish are sought after by sports fishers for tag and release fishing.

The above fish species occur elsewhere in Queensland but are most commonly landed from the waters of the Great Barrier Reef.

## Participants and their catches

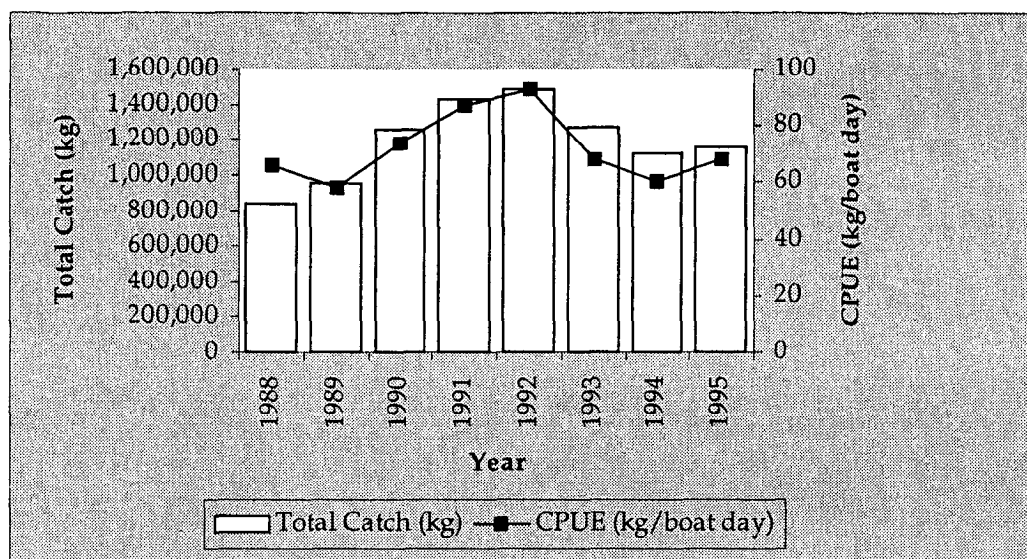
Many people use reef fish stocks of the Great Barrier Reef; commercial, recreational and indigenous fishers, clients of charter and guided fishing tours, divers, underwater photographers and others simply viewing those stocks.

Commercial fishers participate extensively in the harvesting of tropical coral reef and reef pelagic fish stocks of the Great Barrier Reef. There are 251 licensed operators in the principal Great Barrier Reef Line Fishery with a further 1563 licence holders with more limited commercial access to those stocks.

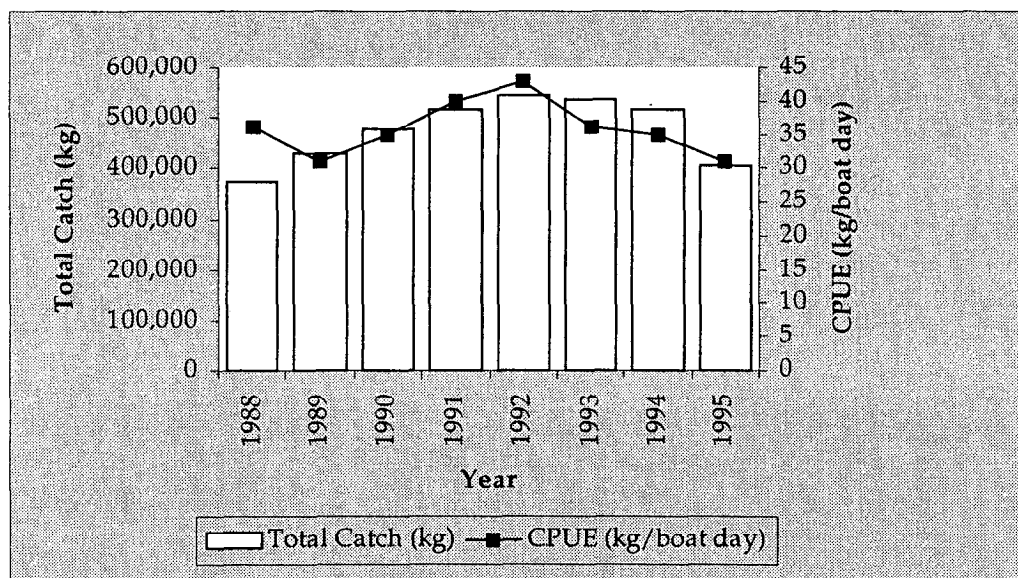
Time series data about catches are limited to log book records kept by commercial fishers. Summary records of commercial landings of the principal fish species in the Great Barrier Reef Region are contained in Figs. 1, 2 and 3. A more comprehensive analysis of these data can be found in an independent review of the commercial log book data undertaken by the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef (Mapstone et al. 1996).

They observed that effort in the tropical commercial demersal reef line fishery appeared fairly stable over the period 1989-94. The notable exception was effort that resulted in landings of red emperor, which has consistently declined. This may be the result of a shift in targeting by the fishery, especially since red emperor are caught mostly at night in deeper waters rather than in daylight hours on the shallower reefs where most reef line effort is currently directed. There are few conspicuous signals in the logbook data of incipient problems with the reef line fishery, although the slight downward trends in catch rates of red throat emperor and of miscellaneous

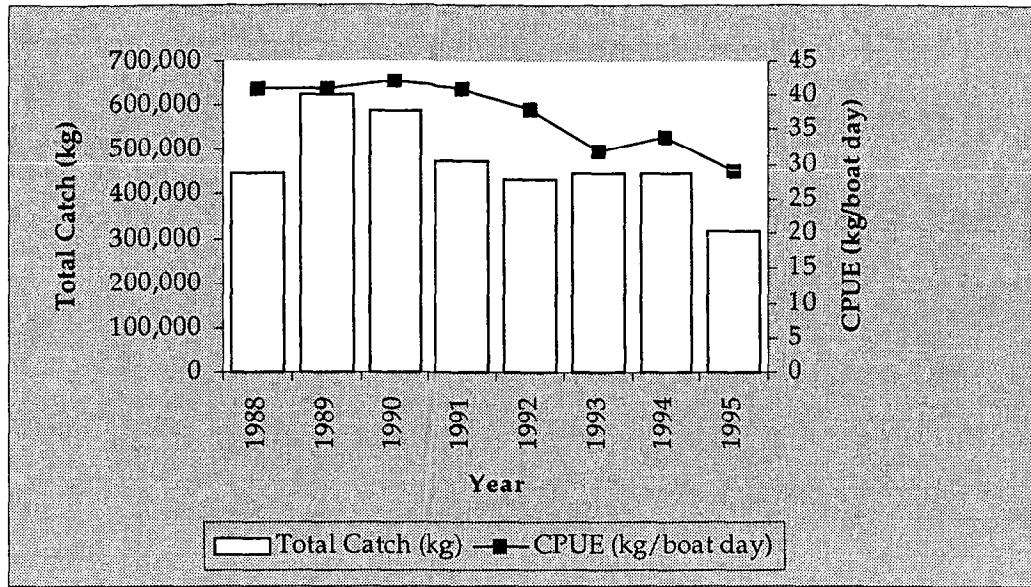
reef species should be monitored carefully in future years. The recent drop in total catch of coral trout in the face of increased effort is also noteworthy, and should be monitored carefully.



**Figure 1.** Total catch and catch per unit effort (CPUE) in the commercial coral trout (*Plectropomus* spp.) fishery in the Great Barrier Reef World Heritage Area from 1988 to 1995. Source: QFISH logbook system, QFMA.



**Figure 2.** Total catch and catch per unit effort (CPUE) in the commercial red throat emperor (*Lethrinus miniatus*) fishery in the Great Barrier Reef World Heritage Area from 1988 to 1995. Source: QFISH logbook system, QFMA.



**Figure 3.** Total catch and catch per unit effort (CPUE) in the commercial spanish mackerel (*Scomberomorus commerson*) fishery in the Great Barrier Reef World Heritage Area from 1988 to 1995. Source: QFISH logbook system, QFMA.

Recreational fishing for stocks on the Great Barrier Reef is also a popular pastime. Limited information is available on the levels of recreational fishing on reef fish stocks. Comparisons drawn from two studies 10 years apart yield the following information on the levels of participation by recreational anglers.

**Table 1.** Use of pleasure craft for fishing in the Great Barrier Reef Region (source: Hundloe 1985; Blamey and Hundloe 1993)

Economic region	Number used for fishing in reef region 1980	Number used for fishing in reef region 1990	Percentage increase over ten years	Estimated number used in open waters 1990
Rockhampton	4440	6911	56%	442
Mackay	2597	4898	89%	264
Townsville	4320	6370	47%	535
Cairns	3530	6122	73%	826
<b>Total</b>	14 887	24 301	65%	2067

Blamey and Hundloe (1993) estimated the total annual catch from the 24 300 boats (in 1990 above) at between 2.6 and 3.2 million fish, with a total weight of between 3500 and 4300 tonnes. (Note: this estimated catch includes tropical coral reef fish, reef pelagics and other species).

Blamey and Hundloe (1993) made comparisons with catch characteristics of an earlier study in 1980-81. The authors note that the validity of these comparisons is questionable, given that the 1980-81 survey figures were based on fishers' recall (in mail surveys) of previous trips, whereas the 1990-91 boat-ramp survey documented catches of the trip from which fishers had just returned. Tentative calculations estimate that the total weight of fish caught in 1990-91 was

40% lower than the 1980-81 figure, even though the number of people fishing has increased by about 50% in many regions.

Higgs (1993 and this volume) has assessed historical records provided by recreational fishing clubs in areas adjacent to the Great Barrier Reef.

### **Current management arrangements**

Current management arrangements for reef fish stocks can be divided into four main categories: those that apply to all fishers, and those that apply only to the commercial fishery, only to the recreational fishery and only to the charter fishing vessel industry.

Minimum and maximum legal size limits for 36 reef fish species apply to all fishers. Most of those species fall within the tropical coral reef fish species group.

Commercial harvesting of tropical coral reef fish is controlled by existing regulatory requirements, which limit access to licence holders whose primary fishing-boat licences are endorsed for that purpose. Access for operations within the tropical coral reef fishery is divided into several main categories endorsed on the licence as set out below.

- L1        Line fishery (other than Great Barrier Reef region)  
Permits the holder to fish using a rod and line or handline with a maximum of six hooks and no more than three lines a person from a boat in waters outside the Great Barrier Reef Region on the east coast of Queensland.
  
- L2        Line fishery (reef)  
Permits the holder to fish using a rod and line or handline with a maximum of six hooks and no more than three lines a person from a boat and use more than one tender vessel to operate in the Great Barrier Reef Region, but (in effect) only if such tender vessels were licensed before June 1993.
  
- L3        Line fishery (reef)  
Permits the holder to fish using a rod and line or handline with a maximum of six hooks and no more than three lines a person from a boat and permits the use of a maximum of one tender (if currently licensed) in conjunction with the primary commercial fishing boat in the line fishery in the Great Barrier Reef Region.
  
- L6/L7    Line fishery (south Queensland)  
Permits the holder to fish using a rod and line or handline with a maximum of six hooks and no more than three lines a person from a boat within all tidal waters east of the territorial sea baseline and south of latitude 25° S.
  
- L8        Line fishery (multiple hook - east coast)  
Permits fishers to operate within tidal waters deeper than 200 metres that are east of longitude 142° 31'49"E. However, these operators are not permitted to take coral trout, red emperor (and snapper).

For each of the fishery symbols, requirements on apparatus available for use and conditions of use of tender vessels also apply.

The Fisheries Regulation 1995 sets maximum size limits on boats used in line fisheries:

- primary fishing boats - 20 metres; and
- tender fishing boats - 7 metres.

(Larger boats licensed before the new regulation are exempt from this 20-metre limit.)

The size of vessels is further limited by the Queensland Fisheries Management Authority (QFMA) policy on boat replacement in commercial fisheries. Persons in charge of licensed fishing operations for tropical coral reef fish species must also be licensed as commercial fishers. Other persons are required to hold Assistant Fishers licences. The Fisheries Regulation 1995 allows for a crew licence to be issued in certain circumstances.

Recreational fishers are limited to a total of 30 fish in their possession. This applies to 26 popular reef fish species. Within this overall total of 30 fish, certain species have sub-limits (for example, 10 coral trout). Recreational fishers are not permitted to sell their catch.

Recreational fishers may fillet their catch at sea, but must retain all the skin on each fillet until the fish is brought ashore. This is to help identify the species of fish.

Recreational fishers can use a rod and line or handline with up to six hooks attached. Each person may use up to three sets of such apparatus. Recreational fishers may also use spears or spearguns, but not while using or wearing underwater breathing apparatus (for example, SCUBA).

Charter boats, when engaged in fishing charters in excess of 48 hours duration (extended commercial fishing tours), may possess double the normal recreational bag limit (that is, 60 fish in possession). Charter boat clients on extended tours may remove most of the skin other than a 3 cm<sup>2</sup> area for identification purposes.

Under the new Fisheries Regulation 1995, all charter fishing boat operators (commercial fishing tours) require a commercial fishing-tour permit if they take a fee-for-service.

### **Purpose of management arrangements**

Current management arrangements were introduced primarily to cap fishing effort in tropical coral reef fish and reef pelagic fisheries. Minimum legal sizes were introduced based on the principle of allowing each individual of a species to spawn on average at least once before being legally available for capture.

Maximum legal sizes have been applied to some tropical coral reef fish species, such as estuary cod and potato cod. These size limits were introduced in response to public opinion about poor eating quality of those large specimens and the perceived desirability of protecting large fish for viewing purposes.

Bag limits now in use for reef fishes have essential roles in fisheries management, including:

- conserving heavily exploited species;
- encouraging anglers to be more conservative in their fishing practices;
- spreading the catch more equitably amongst anglers; and
- reducing the potential for illegal marketing of excess catches by some fishers.

Limited licensing of the commercial sector is used to contain levels of fishing effort, in this case to those that applied when the limited licensing regime was introduced in 1993.



## **Current issues**

Current issues in management of reef fish stocks include:

- concerns about catch and fishing effort trends for popular reef fish species;
  - localised depletion of coral reef fish;
  - the value of using spawning area and seasonal closures;
  - the appropriateness of existing minimum and maximum size limits and bag limits;
  - the adequacy of current data collection;
  - disputes about resource allocation;
  - the adequacy of surveillance and compliance resources;
  - the impacts of habitat modification and pollution on stocks;
  - the emergence of the live fish trade;
- amongst others.

## **Present actions**

Major conservation initiatives were taken in 1993 with the introduction of a package of measures which applied restraints on all users of reef fish stocks. Generally those measures set out to place a limit on further growth in fishing effort across all sectors. Whilst it is difficult to measure the performance of those measures towards the stated goal after only two years, reviews of both commercial and recreational catch data show some consistency in catch/effort relationships over time. This however is neither evidence for nor guarantee of current effort levels being within the limits of sustainable use of reef fish stocks. Nor do they confirm that those stocks are overfished.

In the absence of conclusive information about reef fish stocks, management arrangements are kept under close scrutiny. Over the 1996-1997 period, management arrangements for tropical coral reef fish stocks are being publicly reviewed with the purpose of forming a statutory fisheries management plan for those stocks consistent with ecologically sustainable use principles provided under the new *Fisheries Act 1994*. Current issues identified above are to be addressed in that process. Reef pelagic fish stocks are scheduled for similar review on completion of the plan for the demersal fishes.

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# Queensland east coast trawl fisheries

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## **Description of the fishery**

The Queensland East Coast Trawl Fishery is a multi-species fishery in which participants target several species of prawns, saucer scallops and fin fish (stout whiting) with a range of other species taken incidentally. It involves the use of several types of trawl apparatus and occurs in a range of marine environments throughout Queensland jurisdictional waters.

There are four main elements to the fishery. These are:

- East Coast Trawl
- River Beam Trawl
- Concessional Zone Trawl
- Fin Fish Trawl

A description of the area of management for those elements of the fishery are attached (Attachment 1-3).

The fishery produces on average 8000 tonnes of seafood per year viz:

- 5000 tonnes of prawns
- 1000 tonnes of saucer scallops
- 1500 tonnes of stout whiting
- 500 tonnes of bugs

(Approximately 300 tonnes of blue swimmer crabs are also taken predominantly in Moreton and Hervey Bays.)

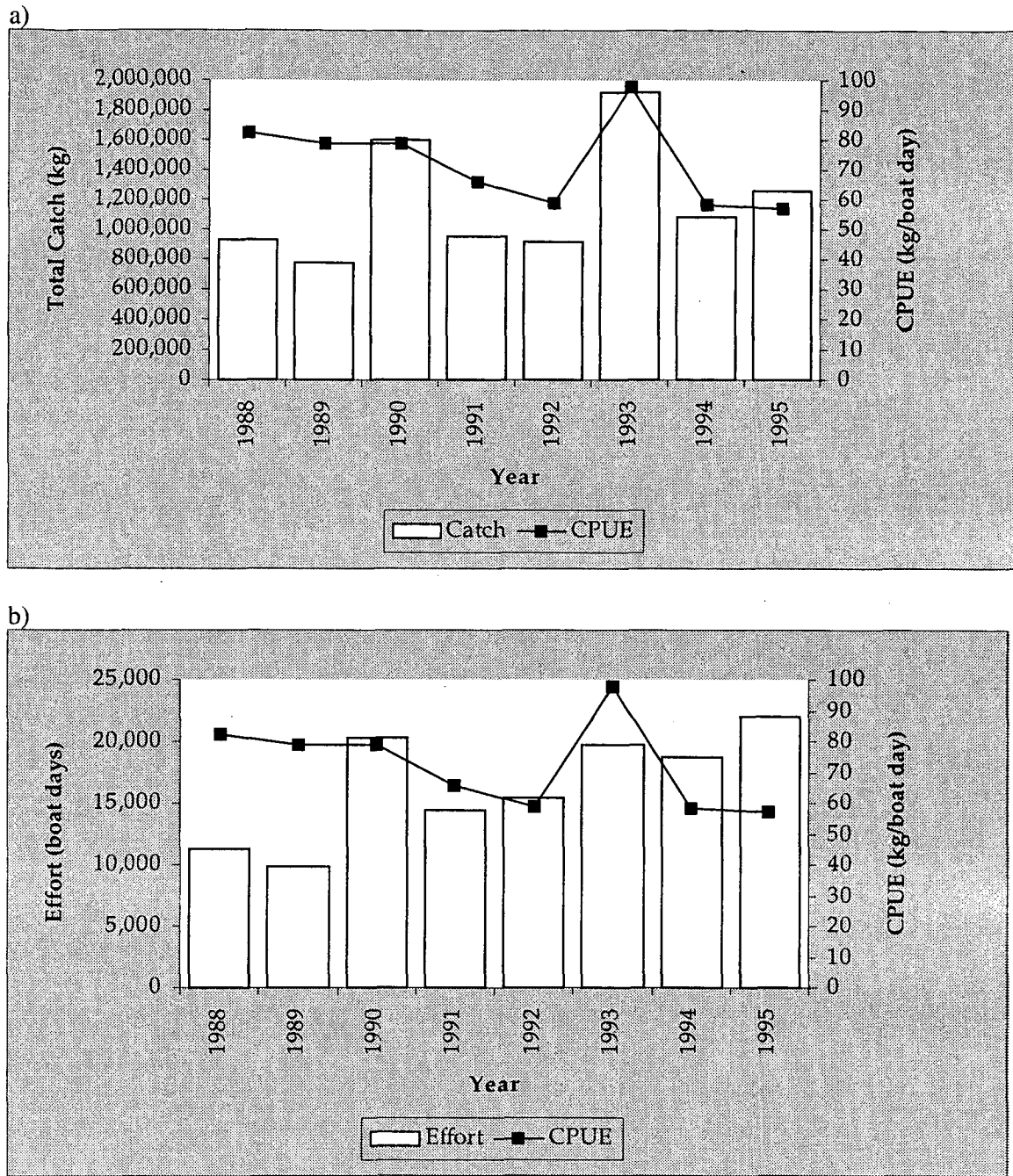
Date on catch, effort and catch per unit effort for most of these fisheries are presented in other papers in these proceedings (see papers by Brown and Gribble). However, no data for the scallop fishery are presented elsewhere in these proceedings, therefore, these data are presented in Fig. 1.

The principal prawn species taken are:

- banana
- tiger
- endeavour
- king
- bay

This product is distributed to export, domestic and bait markets. Queensland seafood received premium prices on overseas markets. Queensland saucer scallops have for several years received highest world prices for the species.

Fishing operations occur throughout the area of management, however the major proportion of the catch is taken from within the Great Barrier Reef World Heritage Area.



**Figure 1.** a) Total catch and catch per unit effort (CPUE) and b) effort and catch per unit effort data for the scallop fishery in the Great Barrier Reef World Heritage Area

In excess of 50% of the catch is taken from areas adjacent to less than 30% of the coastline. Three areas in particular are regarded as 'hot spots' within the fishery. These are:

- Moreton Bay
- Townsville Region
- Princess Charlotte Bay

Over the 1993 and 1994 seasons the area north of Princess Charlotte Bay accounted for 30% and 20% respectively of prawn landings.

## **Management**

Management of the fishery is characterised by constraints on inputs in the form of vessel and gear restrictions, optimisation of value through seasonal closures and the protection of nursery habitat through permanent closures.

The Queensland East Coast Trawl Fishery has been a limited entry fishery since 1979. Details of the current number of licences endorsed for operation in the fishery are set out below.

East Coast Trawl Fishery	851
River Beam Trawl Fishery	223
Concessional Zone Trawl Fishery	34
Fin Fish Trawl Fishery	5

Vessel length restrictions applying to vessels operating in the fishery are:

East Coast Trawl	20 metres
Moreton Bay	14 metres
River Beam Trawl	9 metres

Since the introduction of limited entry arrangements the trawl fleet has been reduced from approximately 1400 to 850.

A restrictive vessel upgrade and replacement policy has operated since 1988. This policy causes the forfeiture of fishing capacity units on a two for one basis. Under the policy, an operator wishing to introduce a replacement vessel must hold one licence entailing units equal to or greater than the units of the incoming vessel and also acquire and surrender one or more other licences whose total units are equal to the incoming vessel. Hull units are a measurement of the internal capacity of the vessel by multiplying length by breadth by depth. The policy also applies a maximum of 70 hull units on the replacement vessel.

Over the last five years the application of this policy has been responsible for the removal of approximately 50 licences.

Apparatus used in the fishery must conform to prescribed limitations both in length and mesh size. Length in relation to trawl nets is described as follows:

- otter trawl: combined length of head rope and bottom rope
- beam trawl: distance between points of attachment of the net to the beam

Mesh size in relation to all nets is measured from the inside of knots. The specifications of all nets used in the fishery are outlined below.

### **Otter Trawl**

Inshore Otter Trawl	Length 32.5 metres Mesh 38-60 millimetres (Moreton Bay, Hervey Bay, Fitzroy River Mouth, Cleveland Bay)
Offshore Otter Trawl	Length 88 metres Mesh 38-60 millimetres
Deepwater Otter Trawl	Length 184 metres Mesh 38-60 millimetres

Scallop Otter Trawl	Length 109 metres Mesh 75 millimetres minimum
Fin Fish Trawl	Length 88 metres Mesh 38-60 millimetres * sweeps 128 metres maximum (* including any wire, chain, rope, shackle and other fitting by which otter boards are attached to the net)

Management arrangements seek to protect spawning stocks and optimise value from the fishery through seasonal closures and size and reproduction limits. These are:

- seasonal prohibition on the taking and possession of prawns between Cape Tribulation and Cape York from 15 December to 1 March;
- variable minimum shell size for saucer scallops of 95 mm from 1 May to 1 November and 90 mm for the remainder of the year;
- a three month closure to the taking of stout whiting from 1 January to 31 March; and
- all year round daylight trawl closure for the taking of saucer scallops except for designated banana prawn areas from 22°S (Broadsound) to 25°S (Hervey Bay).

Management of the fishery also provides for the protection of critical habitats and juvenile prawn nursery areas by maintaining year round 'strip' closures along the Queensland coastline and applying spatial and temporal closures in other critical areas, e.g. Wide Bay Bar, off Fraser Island, within Moreton Bay and off North Stradbroke Island to the Queensland/New South Wales border.

### Production

Production in the fishery can be highly variable and is generally related to fluctuations in climatic and other environmental fluctuations in addition to fishing pressures. Over recent years there has been a general reduction in prawn production with an increase in fin fish production.

The Queensland scallop fishery is remarkably stable in terms of landings. During the past 20 years, annual landings have remained in the range 700-1800 tonnes, which is a low variation by comparison with other scallop fisheries around the world.

Whilst fisheries scientists have expressed some concern over catch per unit effort in the eastern king prawn fishery (the majority of fishing activity occurring prior to the northward migration of the species) as well as concern over the rapidly increasing catches in the fin fish trawl fishery, the east coast otter trawl fishery is regarded as being fully utilised but relatively stable.

### Management planning

The major management issue facing the fishery at this time is the development of a fisheries management plan having regard to the principles of ecologically sustainable development.

The *Fisheries Act 1994* provided the framework for the development of management plans for all fisheries. The Act defines ecologically sustainable development as development:

- (a) carried out in a way that maintains biodiversity and the ecological processes on which fisheries resources depend; and
- (b) that maintains and improves the total quality of present and future life.

The Act outlines the basic structure for management plans. Management plans must contain the following elements:

- a description of the fishery;
- a known status of the fishery statement;
- objectives of the management plan;
- the means by which the objectives are to be put in place and
- the mechanism for amendment of the management plan.

## **TRAWLMAC**

In March 1995 the Authority established a Trawl Fishery Management Advisory Committee (TRAWLMAC). Membership of the Committee is:

Independent Chair  
Queensland Fisheries Management Authority  
Queensland Commercial Fishermen's Organisation (4)  
SUNFISH  
Queensland Seafood Marketers Assn.  
Conservation Representative (Cairns and Far North Environment Centre)  
Queensland Boating and Fisheries Patrol  
Queensland Department of Primary Industries Fisheries Scientist  
Great Barrier Reef Marine Park Authority

The principal task of TRAWLMAC is to provide advice to the Queensland Fisheries Management Authority on the development of the management plan. The MAC met on three occasions throughout 1995. Discussion to this point has concentrated on the initial elements of management planning, i.e. on description of the fishery and the known status of the fishery statement.

### **Strategic Issues**

In addition to the prescribed elements of management planning, discussion papers and draft management plans must also identify and address a range of strategic issues the resolution of which may have implications for the implementation of the management plan. Some of the more prominent strategic issues to be addressed in the development of a trawl fishery management plan are outlined below.

#### *Threats to estuarine and inshore habitat*

Threats to estuarine and inshore habitat important to prawns are a cause for concern. Along with many species of fin fish, the majority of prawns are highly dependent, for at least part of their life cycle, on estuarine and inshore areas.

Mangrove lined creeks, marine muds, salt marsh wetlands and sea grass meadows have all been demonstrated to have significance to prawn species. Degradation of prawn nursery areas through coastal development for urban and agricultural use, soil erosion and agricultural chemical run off all pose threats to the continued viability of particular species. Many species of prawn are rapidly growing and capable of tolerating high levels of exploitation. Whilst maintaining a self regulatory level of stock, however, reduction in habitat area may cause a rapid decline in stock abundance.

Destruction of prawn nursery areas through commercial fishing practices has been largely eliminated through an extensive program of permanent nursery closures and seasonal fishing closures. Any impacts from fishing on sensitive habitat areas has generally been temporary,

since regrowth has allowed resources to re-establish. It is the systematic degradation and total destruction of habitat which compromises the renewable capacity of our coastal marine resources.

### *Effects of trawling*

Over recent years concern has been expressed from a number of quarters including industry, fisheries scientists and managers over the effects of fishing, particularly trawling on the marine ecosystem. The State of the Marine Environment Report summarised this concern as follows:

'The effects of trawling on the marine environment are of major concern in fisheries and environmental management around Australia. Very little is known of the environmental impacts of trawling. Possible effects include the reduction of fished and non-fished species, removal of organisms attached to the sea floor, and changes in food webs, including increased population of scavengers such as seabirds, fish and crabs. Management strategies include better use of the by-catch, development of more selective fishing gear to reduce the by-catch, and spatial and seasonal closures to trawling to maintain biodiversity. However, compared with some other fishing nations, Australia has lagged in developing selective fishing gear.

The effects of trawling are one of the major issues in the Great Barrier Reef Marine Park. Zoning prohibits trawling on about 20% of the sea floor and a major research program is underway to assess its impacts on bottom communities.'

An understanding of the direct and indirect ecological effects of trawling is central to the development of long term management measures. Research into the effects of trawling on inter reef communities is now one of the priority areas of research activity supported by the Great Barrier Reef Marine Park Authority.

The project, known as 'The Environmental Effects of Prawn Trawling in the Far Northern Section of the Great Barrier Reef' is being undertaken by the Commonwealth Scientific Industrial Research Organisation and the Queensland Department of Primary Industries. The project began in April 1992 and is being carried out in and adjacent to the Marine National Park 'B' cross shelf transect of Shelburne Bay in the Far Northern Section of the Marine Park.

The project has a number of components:

- (i) descriptive survey of the biota and sediments of the cross shelf closure area and adjacent areas to the north and south;
- (ii) comparison of fish and prawn trawls to determine the proportion of demersal fish fauna which is extracted by prawn trawling;
- (iii) comparisons of benthic and demersal communities between open and closed areas;
- (iv) environmental manipulation experiments to determine the real effects of trawling on benthic communities and habitat structure and their rates of recovery after trawling ceases; and
- (v) fate of discards to determine the survival and fate of by-catch species including their impact on local seabird populations.

A summary of the results of the first two years of the project is included in the following section of this document dealing with by-catch.

In addition to providing information about the direct and secondary effects of trawling on the seabed, the study will provide detailed information about the time needed for trawled areas to

recover to their original condition as well as the effectiveness of spatial fishing closures in conserving prawn stocks and associated benthic communities.

#### *By-catch*

In most trawl fisheries a large number of non target species, or 'by-catch' are taken. Often by-catch is of non commercial value and is discarded. The proportion of by-catch to target species can be as high as 8 or 10 to 1.

Australia's tropical fisheries are normally characterised by a large number of species of which commercial interest is shown in only a small proportion.

The Commonwealth Scientific Industrial Research Organisation is currently engaged in research focussed on the problem of how to reduce by-catch from trawling in the NPF. Additionally a variety of by-catch reduction devices are being trialed in other fisheries around the country. The results of the first years' descriptive survey of the Great Barrier Reef Marine Park Authority project on the effects of trawling showed that fish comprised the largest component of by-catch (70-80%). Results emerging from these projects will be utilised by TRAWLMAC in seeking solutions to by-catch problems in Queensland fisheries.

The Queensland Fisheries Management Authority presented a paper on by-catch to the Third National Fisheries Management Conference held in Perth in August 1995. The issues covered included:

- FAO global assessment of fisheries by-catch and discards;
- by-catch - definitions;
- by-catch and Queensland fisheries;
- responses to by-catch in Queensland.

#### *Access considerations*

Over recent years, the trawl fishery along with other methods of commercial fishing has come under increased scrutiny from other resource users as the potential for overlapping use of resources increases. This trend is a factor of increasing population size coupled with increased leisure time and recreational opportunities. Competition in relation to sharing of resources has led to demands for exclusive use of areas, species and the imposition of gear and other restrictions. The State of the Marine Environment Report found that the concerns of recreational fishers centred on commercial netting which they felt was responsible for declining fish stocks, the effects of trawling, the need to protect fish habitats, growing fishing pressure from both sectors and perceptions of unequal regulations which favour the commercial sector.

Conversely the concerns of commercial fishers centred on their own strict regulation as opposed to limited regulation of the recreational sector, the individually small but cumulatively large effects of recreational fishing and illegal sales of fish by some recreational fishers.

#### *Indigenous fishing*

The Authority has recognised the need for improved consultation with aboriginal interests. Membership of all Management Advisory Committees and Zonal Advisory Committees includes indigenous fishing representatives. Additionally, Native Title considerations will be directly taken into account in the formulation of the management plan. Fishing activities undertaken by aboriginal communities have been largely confined to net, line and crabbing activities. It should be anticipated that aboriginal communities will express a desire in participating in the east coast trawl fishery.



These and other issues will be further developed in the discussion paper phase of the management planning process. TRAWLMAC will be seeking the views of other resource managers and interested organisations and individuals as to how these issues can best be addressed or resolved.

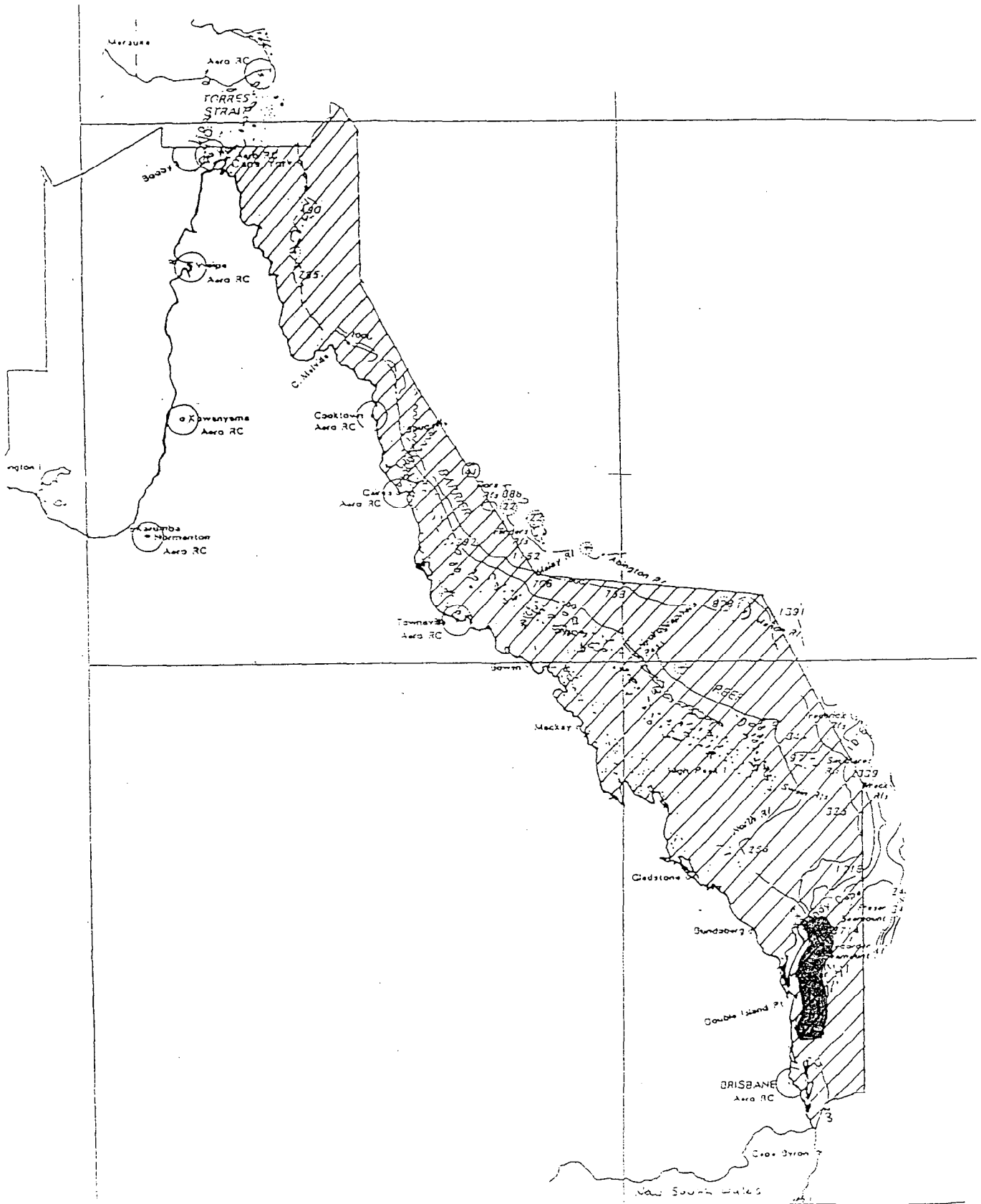
**State Government inquiry into recreational fishing (SGIRF)**

The following issues relevant to the trawl fishery were raised by the SGIRF: Moreton Bay Zone, fish trawling, recreational fishing areas, commercial catch quotas, river and inshore beam trawling, offshore otter trawl boundaries and seasonal closures and commercial catch quota on winter whiting. These issues are being considered in the fisheries management plans currently being developed.

Attachment 1

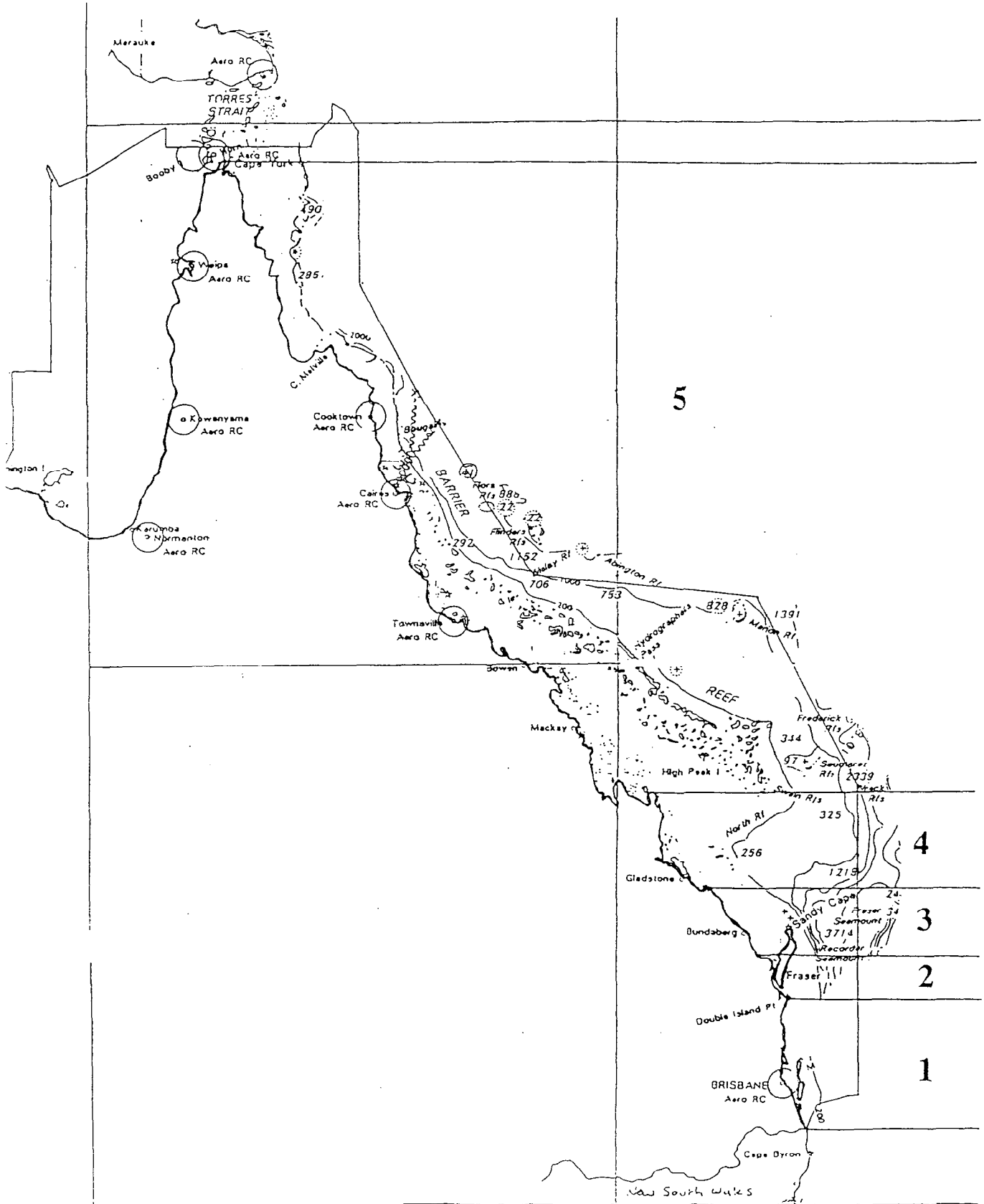
Shaded area describes the area of management for the Fin Fish Trawl Fishery

EAST COAST TRAWL FISHERY



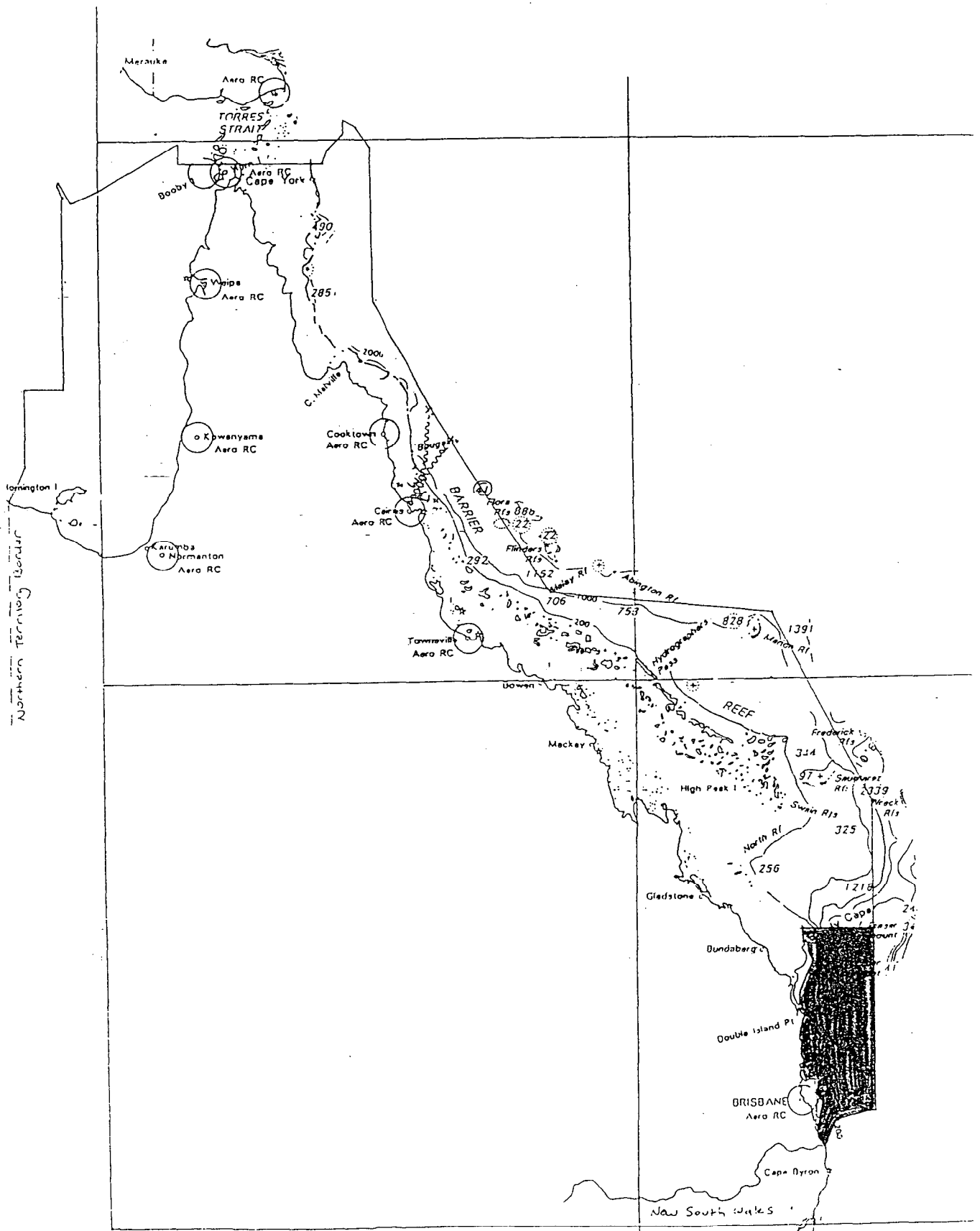
Attachment 2

RIVER BEAM TRAWL AREAS



Attachment 3

CONCESSIONAL ZONE TRAWL



## Status of the Great Barrier Reef World Heritage Area: estuarine and inshore fisheries

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Estuarine and inshore fisheries resources within the Great Barrier Reef World Heritage Area are multiple use fisheries accessed by commercial and recreational fishers, charter boat and fishing guides and traditional indigenous fishers.

The predominant species include mullet, bream, whiting, lesser mackerel, salmon, barramundi, shark and mud and spanner crabs.

Total catch in the Great Barrier Reef World Heritage Area of inshore fin fish is approximately 3000 tonnes with an estimated value of \$15 million. Additionally, approximately 300 tonnes of mud crabs and 1500 tonnes of spanner crabs are taken in the area for a total value to fishers of approximately \$12 million.

Fin fish species and mud crabs are widely distributed throughout the inshore area of the Great Barrier Reef World Heritage Area with some variation in distribution dependent on geographical location.

The spanner crab fishery in the Great Barrier Reef World Heritage Area is limited to south of 23° at present, however, new fishing grounds are being explored with a consequent increase in fishing area annually.

Increasing human populations based in the littoral zone are increasing pressure on fisheries resources through increased recreational fishing activity and increased demand for local fresh seafood. Detrimental impacts on local habitats and degradation of water quality resulting from population pressures also have major effects on dwindling stocks.

Sectors involved in harvesting or using inshore fish and crab stocks include:

- Commercial fishers
- Recreational fishers
- Charter boat operators and fishing guides
- Traditional fishers

The actual number of commercial net and inshore fishers accessing inshore stocks within the Great Barrier Reef World Heritage Area is difficult to determine as commercial operators are not confined to any regional locality. However, there are 1029 commercial net endorsements issued to east coast operators and an estimated 40% to 50% are believed to operate in the Great Barrier Reef World Heritage Area.

The corner stone of fisheries management in Queensland is the limited licensing program. This has been in effect since 1984. Each licence holder is further constrained in their fishing activities through limitations on length, drop, mesh size, and line strength of commercial nets. Vessels upgrade and replacement policies have been implemented to assist in constraining effort at present levels. Additionally, there is an extensive range of spatial and temporal closures aimed at protecting juvenile and breeding stocks and reducing conflict among fishing sectors.

Minimum and maximum legal sizes of fish are considered an important management intervention to ensure sustainable catches. Minimum sizes have been established for many species to ensure at least one spawning prior to capture. Maximum sizes are implemented to protect large breeding female fish, for example, barramundi.

Similar to the net fishery, the mud crab fishery allows access to the entire Queensland coast by 1064 fishers, the present number of crab fishery entitlements on issue in Queensland. Commercial mud crab fishers must not use more than 50 pots or dillies under each entitlement. A minimum legal size of 150 mm applies to mud crabs with a total prohibition on the taking of female crabs.

The spanner crab fishery is seen as a developing fishery. It has increased dramatically in area and catch over the past five years. Recent management interventions have included a zoning arrangement to reflect the developed and developing fisheries, a total allowable catch of 2000 kg in the developed zone and a daily catch quota of 300 kg throughout the fishery. These arrangements are aimed at reducing fishing pressure and are additional to the traditional management measures such as restrictions on apparatus, minimum legal sizes and seasonal closures.

Apparatus used to take spanner crabs is limited to 30 dillies (flat frames) not greater than 1 m<sup>2</sup> with a mesh drop of not more than 10 cm and a mesh size of 25 mm when hung singly or 51 mm when hung doubly. Recreational anglers accessing inshore fin fish species and crab species require no authority but are constrained in their activities by output and apparatus controls.

Bag limits have been established for significant species, for example, barramundi and mud crabs, and the State Government Inquiry into Recreational Fishing has also identified other species it believed should be subject to bag limits. The proposed bag limits on whiting, bream, grunter, flathead and mangrove jack are expected to be implemented through the management planning process. Recreational fishers are permitted to use a bait net not exceeding 16 mm in length, 3 m in depth with a maximum mesh size of 28 mm to take bait for their own use. They may also use a cast net with a diameter less than 6 m and a maximum mesh size of 28 mm. Recreational fishers may only use hand lines or rod and reels with not more than six hooks on each line. When used from a boat not more than three lines may be used by each angler.

Recreational crab fishers may not use more than four dillies or crab pots and the prohibitions on taking female mud crabs and crabs less than 150 mm across the carapace apply.

Clients of charter boat operators and fishing guides are subject to the same provisions as all recreational fishers. The Queensland Government has introduced a licensing scheme for charter boats and fishing guides to enable management of the sector.

The number of fishing guides and charter vessel operators is presently unknown and their effort adjacent to population centres and tourist destinations is considered significant.

Traditional fishers have access to inshore fin fish and crab resources and may use nets, hand lines, stone traps, spears and hand gathering techniques to take fish for traditional uses.

Commercial inshore fin fish catch levels in the Great Barrier Reef World Heritage Area have remained constant over the past seven years (the period during which catch records are available).

Some localised declines have occurred but are considered to be either seasonal or resulting from poor climatic seasons.

The present levels of commercial harvest are considered to be sustainable and the resource to be fully utilised. Concerns have been expressed in relation to the extent of latent effort and the issue of zoning of operators will need to be addressed under the proposed Management Plans.

The commercial mud crab fishery catches have remained stable since the early 1980s.

Whilst the commercial landings of spanner crab have increased annually since the late 1980s recent indications of declining catch rates have occurred. Pressure from the demand for export of spanner crabs has driven the fishery with 80% of product exported. These declines are expected to be arrested under the management arrangements that have been implemented.

While recreational catch rates of fish and crabs are unknown it is believed that catch rates are declining, in particular adjacent to population centres. This trend can be expected to continue with increasing human populations.

The major knowledge gaps in the fisheries are the lack of recreational catch data and data relating to stock assessment of all species.

The *Fisheries Act 1994* has highlighted the development of species based management plans to ensure sustainable fisheries.

The precautionary principle is being invoked where gaps in knowledge of the resource occur. Advisory Committees have been established involving all sectors of the community in the decision-making process to ensure sustainable fishing practices are adopted. Attention is being given to practices which inadvertently take endangered species. These measures may include variations to apparatus or ultimately areas closed to fishing to protect endangered species.

Advisory Committees are providing advice on relevant research programs required to enable managers to make decisions based on the biological needs of fish stocks. The Advisory Committees also provide a forum for advised debate and a conduit for dissemination of information to the public including the rationale for management decisions aimed at ensuring sustainable use of all inshore fisheries resources.

# Pelagic fishes

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## Abstract

Fisheries for pelagic species within the Great Barrier Reef World Heritage Area exist over a wide range of habitat areas from coastal headlands, across the continental shelf into oceanic waters. Pelagic species inhabit various levels of the water column and some species may be found adjacent to reef crests.

While a number of smaller species spend their entire life cycle within the Great Barrier Reef World Heritage Area (for example, the smaller pelagics that function as prey for larger pelagics such as Spanish mackerel and juvenile billfish, and reef associated species such as trevallies and double lined mackerels), the dominant species of commercial and recreational importance such as Spanish mackerel, shark, and billfish species migrate in or out of the Great Barrier Reef World Heritage Area on a seasonal or life history basis. As a result of this migratory movement, management of stocks of pelagic fishes can fall to a wide range of State and Commonwealth agencies.

Major issues to affect the long term status of these fisheries include El Nino episodes, fisheries development in adjacent regions to the Great Barrier Reef World Heritage Area, and a lack of consistent catch data for commercial and recreational fishing sectors. Significant fishery interaction issues currently being investigated include by-catch of marlin species taken by the tuna longline fishery that operates on the fringes of the remote waters of the Great Barrier Reef World Heritage Area, while by-catch of cetacean species taken by the shark and barramundi gill net fisheries over the continental shelf could become an issue in the future.

## Overview

Pelagic fin fish resources of the Great Barrier Reef World Heritage Area (GBRWHA) include a wide variety of fish families that inhabit various, but usually the upper, levels of the water column. They may range from coastal headlands and nearshore areas, across the continental shelf (sometimes associated with coral reefs) and into oceanic waters.

The term 'small pelagic fishes' usually refers to a diverse group of planktivorous herring or trevally-like species which generally attain a maximum weight of less than 500 g and have attained prominence throughout coral reef areas of the Pacific, at least, as 'baitfish' for industrial tuna pole-and-line fisheries, or as a subsistence food source. There has often been controversial interaction between these fisheries and domestic fisheries. This controversy usually centres around whether or not the industrial fisheries capture juveniles of 'commercially' important species.

Inshore baitfish are small pelagic species normally found close to shore or in close proximity to coral reef crests. While no fisheries currently exist for this group of pelagics within the GBRWHA, potential for industrial fisheries of tuna pole-and-line baitfish species such as anchovies (*Stolephorus*) and sprats (*Spratelloides*) has been shown to exist in substantial localised quantities often close to coral reefs (McPherson unpubl. data 1986, 1992a; Glaister and Diplock 1993).



Open water baitfish are small pelagic species such as garfish (Hemiramphidae, *Hemiramphus* and *Hyporamphus*), various scads (Carangidae, *Decapterus*, *Selar*, *Atule* and *Selaroides*), pilchards, sardines and herrings (Clupeidae, *Amblygaster*, *Sardinella* and *Herklotsichthytes*). In GBRWHA waters they are either fished commercially as baitfish (especially garfish), or have considerable potential as baitfish for commercial longlinefishing in the Coral Sea (Imai 1972), for recreational marlin or sailfish fishing activities (Williams and Cappo 1990), and perhaps for cat food, mariculture or human consumption (Glaister and Diplock 1993).

Large coastal pelagic species are encountered over continental shelf areas, sometimes associated with coral reefs. They include the narrow-barred Spanish (simply Spanish mackerel) and double-lined mackerels (Scombridae, *Scomberomorus commerson* and *Grammatorcynus* spp. respectively), neritic tunas (Scombridae, *Thunnus tonggol* and *Euthynnus affinis*), trevallies (Carangidae, primarily *Caranx*, *Carangoides* and *Scomberoides*), barracudas (Sphyrnidae) and semi-pelagic reef fish (Lutjanidae, *Caesio* and *Pterocaesio*). Commercial and recreational fishing for all but the semi-pelagic Lutjanidae species is usually line based on trolling methods which depends on the highly mobile and carnivorous behaviour of the species. Fishing technology is available to utilise drift gill net commercial fishing activities for most of these species. These gear are currently utilised to take a number of shark species of the Family Carcharhinidae which inhabit continental shelf waters, and the more inshore *Scomberomorus* species (grey 'Spanish' mackerel *S. semifasciatus*, Australian spotted 'Spanish' mackerel *S. munroi* and school 'Spanish' mackerel *S. queenslandicus*).

Oceanic pelagic species of tuna (Scombridae), billfish (Istiophoridae), wahoo (Scombridae, *Acanthocybium solandri*) and dolphinfish (Coryphaenidae, *Coryphaena hippurus*) usually occur in oceanic or continental slope waters with juveniles of some tuna (yellowfin *Thunnus albacares*) and marlin (black marlin *Makaira indica*) species occurring for a short period in continental shelf waters. Other oceanic billfish such as sailfish (*Istiophorus platypterus*) may be found as either juveniles or adults in both oceanic and continental shelf waters.

### Existing zoning

In the General Use 'A' and 'B' Zones within the Great Barrier Reef Marine Park offshore from the outer Barrier Reef, pelagic fishing operations are limited to line gear of no more than six hooks. Commercial pelagic activities are therefore restricted to trolling, pole-and-line, handline, and very short horizontal or vertical longlines. Commercial netting activities for larger pelagics is permitted for specific large mesh nets of specified length depending on whether the gear is deployed offshore or inshore. Some limited length and smaller mesh nets are permitted in surround net fisheries for bait species such as garfish.

Great Barrier Reef Marine Park Authority (GBRMPA) Marine Park Buffer Zones exist around a number of reefs which restrict pelagic fishing operations for large pelagics within set distances of the reef crests. 'Seasonal' closures of waters adjacent to specific reefs are available if required, to afford seasonal protection to spawning stocks. Both of these closure types were primarily developed to protect demersal reef fish stocks. McPherson (1987) demonstrated that open water small pelagic species were more important in the diet of Spanish mackerel than reef associated semi-pelagic lutjanids that are usually restricted to within the Buffer Zones.

The gamefishing sector has expressed concern at the closure of Hilder Reef near Lizard Island through GBRMPA rezoning. The area was a prime location for baitfish capture intended for use in the heavy tackle marlin fishery.

When high incidences of ciguatera fish poisonings have been reported from pelagic fish (primarily Spanish mackerel), the Queensland Fisheries Management Authority (QFMA) has restricted fishing operations within these areas.

### **Management**

Management of many of the larger coastal pelagic species is often complicated by the migratory behaviour of adults, or variable habitat requirements throughout the life cycle of some species, which means individual fish may spend only a part of their life history within the GBRWHA.

Management of stocks of large pelagics in the GBRWHA is the responsibility of a range of State and Commonwealth agencies. The Offshore Constitutional Settlement (Anon. 1987) established that tuna and some tuna-like species (and billfish species) fall under the responsibility of the Commonwealth, now the Australian Fisheries Management Authority (AFMA) through its East Coast Tuna Management Advisory Committee (ECTUNAMAC). Tuna fishing by longline of more than six hooks occurs outside of the GBRWHA. In waters to the north of latitude 19°S there is a restricted zone where effort is restricted to 13 domestic longline vessels each limited to sets of 500 hooks, and Japanese effort restricted to handline gear. Management of tuna stocks within the restricted zone and GBRWHA has primarily been cautious, awaiting research information on the stock structure of yellowfin and bigeye (*Thunnus obesus*).

While management of billfish stocks is generally an issue for consideration by the Commonwealth, which adjacent to the GBRWHA in the Australian Fishing Zone involves the commercial non-retention of black and blue marlin and sailfish, through a voluntary ban (since 1 March 1996), there are no specific regulations relating to the troll gamefishery for billfish species. The recreational sector has a voluntary code of practice of non-retention of black marlin, except first marlin in some cases or potential record weight fish. The majority of marlin taken are released, some are tagged.

The tuna-like species such as the continental shelf *S. commerson* are considered to be a component of the Reef Line Fishery and as such fall within the responsibility of the QFMA and its Reef Management Advisory Committee (REEFMAC) as are the more reef associated pelagics such as carangid species and double-lined mackerels (*Grammatorcynus* spp.). Wahoo appear to be landed in higher quantities by longline gear outside the GBRWHA although responsibility for management of the species is with REEFMAC.

Shaklee (1990) and McPherson (1992b) have demonstrated that two stocks of *S. commerson* occur in Queensland waters, a northern Australian stock and an east coast stock. The latter east coast stock is present in waters south of Torres Strait within the GBRWHA, and seasonally into waters of southern Queensland and into northern New South Wales waters.

For east coast stock fish within GBRWHA a minimum legal size holds for *S. commerson*, while a bag limit exists for the recreational sector. A ban on 'target' gill netting of the species east of Cape York was established to prevent any gill netting on major identified spawning areas for this species off Cairns and Townsville. This ban was partly established following problems with Taiwanese gill net vessels operating illegally in the Torres Strait Protected Zone (TSPZ) waters in 1983. Taiwanese vessels operating in the vicinity of the only defined spawning location of the northern Australian stock in Torres Strait waters apparently affected troll catch rates within the TSPZ, and generated clear evidence of fish 'dropout' from the gill nets (McPherson 1986). Interpretation of 'target' gill netting is left to the discretion of Queensland

Boating and Fisheries Patrol (QB&FP) officers. 'Target' netting is permitted for the northern Australian stock.

Other large pelagics of the continental shelf such as 'edible' shark species and other *Scomberomorus* species (notably *S. semifasciatus*, *S. munroi* and *S. queenslandicus*) are managed by the QFMA's Tropical and Subtropical FINFISHMAC's as the species' are taken for commercial purposes primarily by gill nets. Specific gill net and surround net length and mesh size regulations exist for these fisheries. Minimum legal size provisions hold for these *Scomberomorus* species, with a bag limit for the recreational fishery.

Apart from regulations pertaining to small mesh surround nets deployed for garfish species, there are currently no specific management practices for small pelagics within the GBRWHA that have baitfish or fishmeal potential other than QFMA gear restrictions that presently do not permit purse seine or liftnet type gear. Although initially rejected by QFMA, a commercial operator has achieved a license through the courts to conduct purse seine operations for small pelagic species in waters immediately adjacent to the southern GBRWHA boundary. The possible effect of this operation on larger pelagic species is not known.

## Issues

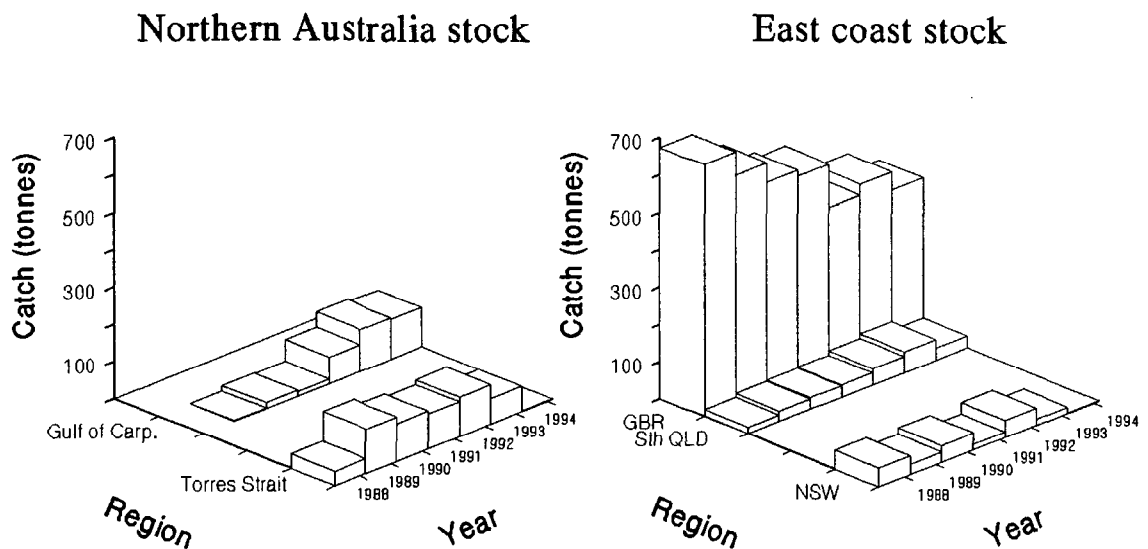
### Effect of 'El Nino' episodes on pelagic fisheries

A relationship appears to exist between recruitment of young-of-year spanish mackerel to the offshore troll fishery and high rainfall during the preceding summer months (McPherson, unpubl. data). During the mid to late 1970s Queensland spanish mackerel landings averaged 1018 tonnes until a decline to around 700 tonnes after 1977 (McPherson 1989). Official figures are unavailable from 1980 to 1985. Landings have remained low from then, up to more recent landing figures for Queensland waters of 710 tonnes in 1993 (QFMA Logbook Data for east coast and Gulf; AFMA Logbook Data for Torres Strait).

As two stocks have been demonstrated to occur in Australian waters, the commercial landings by stock are given in Fig. 1. Landings of the east coast stock occur primarily within the GBRWHA where catches have substantially declined over recent years from 675 to 407 tonnes. Approximately 60 to 70% of total east coast landings are reported from the Cairns to Townsville region, notably during the October to November spawning period for the species (McPherson 1994).

Landings data for east coast stock in 1995 exhibit a continued downward trend in catch and catch per unit effort (QFMA CFISH Database). A preliminary examination of the available biological data collected by the Queensland Department of Primary Industries (QDPI) since the mid-1970s suggests that the fishery is fully exploited and stocks are in decline with a relative spawning stock biomass levels at seriously low levels.

Over recent years the Australian east coast has been influenced by a sustained negative index of the Southern Oscillation Index caused by 'El Nino' episodes in the eastern Pacific. Whether recent declines in catches can be attributed to the effects of 'El Nino' events is not clear.



**Figure 1.** Landings of *Scomberomus commerson* from the northern Australian and east coast stocks

#### Cetacean by-catch in gill nets

Catches of offshore and nearshore set gill nets often include marine mammals. These catches are undesirable as they could have the potential to deplete a mammal population and may cost commercial operators substantial downtime and gear replacement. The management plans for marine animals under the Queensland Department of Environment Nature Conservation Plan requires that cetaceans and turtles be released if taken incidentally by any fishing gear.

There has been a variety of approaches to reduce mammal by-catch in gill nets involving net redesign, closures, and passive and active alarms. The International Whaling Commission (International Whaling Commission 1991, published 1994) reviewed early research to 1990 into these approaches (Lien, pers. comm.). A general consensus was that those early developmental active acoustic alarms did not provide conclusive solutions to the problems of cetacean entrapment in gill nets. Alarms were also considered to be costly, difficult to maintain and hard to deploy which would render them unattractive to deployment by commercial gill net operators (Dawson 1991).

Since the collation of acoustic alarm data up to 1990 for the International Whaling Commission review, Professor Jon Lien (Memorial University, Newfoundland) who chaired and drafted the report on 'Causes and Solutions' of gill net entrapment, has developed an acoustic alarm to reduce collisions between humpback whales (*Megaptera novaeangliae*) and floating cod traps off Newfoundland resulting in a progressive reduction from 150 per year at the worst to 21 in 1995, although fishing levels were reduced from previous years. Nonetheless the reductions in entrapments coincided with an increase in the north Atlantic population of humpbacks from approximately 600 to 1000 in 1970 to 4-5000 at present (Lien, pers. comm.).

The Queensland Shark Control Program of QDPI established the same alarms on half of the shark nets off the Gold Coast during 1993. The low incidence of collision between humpbacks and Queensland Shark Control Program nets prior to the installation of the alarms made comparison between alarmed and non-alarmed nets extremely difficult. The only humpback entrapped during the 1993 season was in a non-alarmed net.

Present conclusions are that the installation of alarms on all nets has reduced the accidental collisions of whales. These observations have coincided with an increase of approximately 11.7% per year in the numbers of northward migrating adult whales, and southward moving adult and calf whales over the past three years (Paterson et al. 1993). There has been an increase in the incidence of entrapments of whales in non-alarmed fishing gear throughout south-east Queensland, especially during 1996.

Highly successful pilot studies on the use of acoustic alarms to reduce harbour porpoise (*Phocoena phocoena*) by-catch in gill nets off Maine in 1992 and 1993 (Lien et al. 1995) resulted in the United States National Marine Fisheries Service recommending that more exploration of the use of acoustic alarms for harbour porpoise was warranted. These experiments have been concluded with the clear result that acoustic alarms significantly reduced harbour porpoise by-catch (Kraus et al. in press). Further studies concluded by the Protected Species Branch of the National Marine Fisheries Service in the Gulf of Maine (Potter unpubl. report) and northern Washington State (Gearin et al. unpubl. report) also provided significant reduction in harbour porpoise by-catch.

The Queensland Shark Control Program will continue to develop low frequency acoustic alarms suitable for humpback whales, and continue to liaise with providers of higher frequency alarms and fisheries organisations currently trialing these devices suitable for smaller cetacean species with the ultimate objective of deployment of alarms on shark control, and commercial fishery, gill nets in Queensland waters. While alarms provide a potential for reducing entrapment, the low probability of entrapment in any gill net would make clear demonstration of their effectiveness a long term objective.

The draft report of the Acoustic Deterrents Workshop sponsored by the National Marine Fisheries Service (March 1996) accepted that by-catch in some fisheries would always be low and sample sizes required to demonstrate alarm effectiveness would not be feasible. For these instances a series of component projects were suggested where the results of small studies of several similar fisheries could be combined to make an overall inference about significance.

The by-catch in all forms of gill nets within the GBRWHA will be an issue for the future. Some United States of America States have legislated for compulsory involvement of acoustic alarms on gill nets, while Canada is considering such an approach (Jon Lien, pers. comm.). The United States Marine Mammal Commission draft report on active acoustic alarms urged restraint on the unrestrained use of acoustic devices to reduce cetacean by-catch, particularly in the absence of monitoring of cetacean responses. However the report is positive about the potential of active acoustic devices to reduce cetacean by-catch.

#### Marlin by-catch on tuna longlines

Yellowfin and bigeye tuna are primarily targeted by domestic longliners within the Coral Sea of the Australian Fishing Zone. The potential by-catch of billfish species important to the recreational gamefishery (particularly black marlin) by the longline fishery is of considerable importance to the well established Australian east coast gamefishery. Little information exists to evaluate the interaction between the fisheries. There is currently a Commonwealth Scientific and Industrial Research Organisation/QDPI study funded by ECTUNAMAC to investigate the interaction effects, with an ultimate objective to define a window of longline operation that would minimise the level of interaction between the fisheries.

This issue has been identified by all stakeholders, including those with areas of management responsibility well beyond the boundaries of the GBRWHA, as being highly emotional but of uncertain biological risk.

### Baitfisheries

Determining the potential, or advisability, of baitfisheries for small coastal pelagic species within the GBRWHA will always be a major issue. Glaister and Diplock (1993) identified two major issues of concern to pelagic fisheries baitfish requirements:

- rights of access to bait stocks for commercial tuna operations; and
- concerns of the recreational sector of the potential impact of commercial operations on baitfish stocks, particularly those identified by Williams and Cappo (1990). Issues identified included dispersal of aggregations, and the significance of the aggregations to juvenile marlin.

While no data are available on landings, there has been an apparent decline in the catch, or availability, of 'scad' (*Grammatorcynus bilineatus*) by the gamefishing sector. The species is attractive as a marlin bait for its moderate size (namely 3-5 kg) and long 'life' as a towed marlin bait. The species is taken around bommies on the western side of outer barrier ribbon reefs north of Cairns (McPherson 1984). To reduce pressure on scad stocks an alternate bait source for marlin fishing could well come from small yellowfin, bigeye or skipjack (*Katsuwonus pelamis*) taken by longline gear. Glaister and Diplock (1993) noted a requirement for 15-20 (maximum of 50) marlin baits per day.

Although an application to conduct purse seine operations for small pelagic species immediately south of the GBRWHA was rejected by the QFMA, subsequent legal action has resulted the QFMA not being in a position to prevent the development of this fishery. The long term effect of this fishery on larger pelagic species that migrate to and from the GBRWHA through the area of operation of this new fishery is not known.

### Shark fisheries

Landings of shark on the east coast varied from 320 to 450 tonnes between 1988 and 1993. Between 60 and 95% of these landings were reported from within the GBRWHA (Fig. 2).

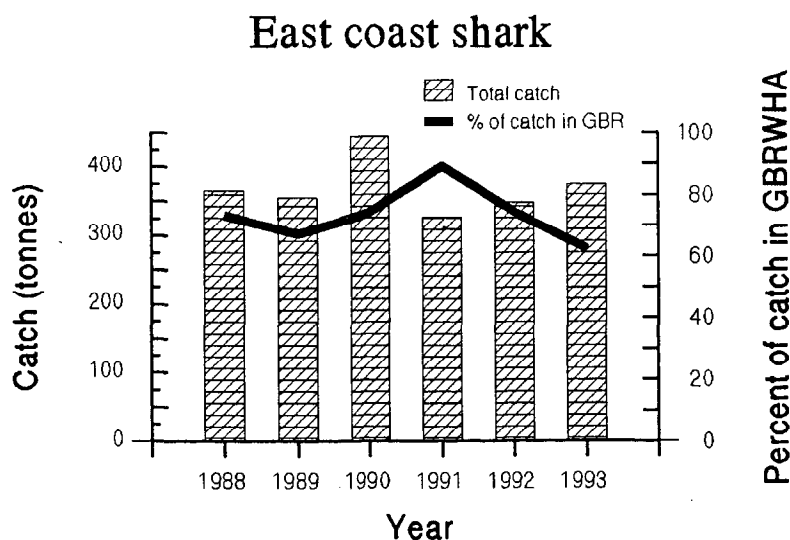


Figure 2. East coast shark landings

Despite the size of the shark fishery, little has been documented about the species composition within the fishery (McPherson 1985a, 1985b), and the mercury levels of the landed product (Queensland Health Department Report 1993).

### **Research and monitoring**

While a number of issues have been flagged as potential areas of concern or resource conflict there are a number of areas that require long term attention. These include:

- Monitoring of the relative catch and effort of the commercial and recreational fishing sectors for spanish mackerel, and the age composition and relative reproductive contribution of spanish mackerel during the spawning season off Cairns to Townsville.
- Monitoring of catch and effort rates of the heavy tackle marlin, and light tackle billfish and spanish mackerel gamefisheries, and the scad baitfishery.
- Assessing the stock structure of various billfish species in relation to other Pacific localities.

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# Crustacean resources (other than prawns) in the Great Barrier Reef World Heritage Area

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## Abstract

Crustacean species other than prawns represent a significant component of the State's marine fishery landings. The main commercial species are spanner crabs (*Ranina ranina*), Moreton Bay bugs (*Thenus indicus* and *T. orientalis*), blue swimmer crabs (*Portunus pelagicus*), and mud crabs (*Scylla serrata*). Minor catches of other species including reef crayfish (*Panulirus* spp.), mantis shrimps (*Squilla* spp.), three-spot crabs (*Portunus sanguinolentus*) and coral crabs (*Charybdis cruciata*) are also taken.

Blue swimmer crabs are taken in recreational and commercial pot fisheries from estuarine and nearshore areas, usually in crab pots. The recreational crab fishery is considered very important, particularly in southern Queensland, but no reliable estimate is available of the size of the catch from this sector. In addition to their capture in the commercial pot fishery, incidentally-caught crabs are frequently retained by trawler operators. While the bulk of the State's annual blue swimmer crab catch comes from Moreton Bay and Hervey Bay, about 18% is derived from the Great Barrier Reef World Heritage Area (GBRWHA), primarily in the vicinity of Mackay and the Keppel Islands.

Mud crabs (*Scylla serrata*) are fished commercially and recreationally in mangrove estuaries and tidal reaches of rivers and streams around the entire coastline of Queensland. About 68% of the State's annual commercial catch is taken from the GBRWHA.

The Australian fishery for spanner crabs is of relatively recent origin. Since its inception in the early 1980s, most of the catch of this crab species has been taken outside the boundaries of the GBRWHA. However, with the recent northward expansion of the fishery into the Bundaberg and Gladstone areas inside the Capricorn-Bunker Group, an increasing proportion of the total landings is derived from the GBRWHA.

Scyllarid bugs represent an important byproduct of the East Coast Trawl Fishery, with the majority of the catch sourced from the GBRWHA, largely from between Ingham and Mackay, and from Rockhampton to Hervey Bay.

Stocks of mud crabs, spanner crabs and bugs in the GBRWHA appear (from analysis of trends in catch rate) to be in no obvious danger, either from recruitment overfishing or environmental causes. Inshore blue swimmer crab catches, however, should be monitored in conjunction with the trawl catch of this species to determine the cause of an apparent decrease in both catch and catch rate or catch per unit effort (CPUE).

## Introduction

Commercial fisheries in Queensland for crustacean species other than prawns are currently worth around \$30 million to the industry, even before any value-adding or multiplier effects are considered. In 1994 the total commercial catch of all marine species amounted to approximately 21 672 t, which comprised 10 726 t of crustaceans, 9824 t of fish, and 1122 t of molluscs.

The reported crustacean catch in 1994 was made up of 5883 t of prawns, 4277 t of crabs (*Ranina ranina*, *Portunus pelagicus*, *Scylla serrata*, *Portunus sanguinolentus* and *Charybdis cruciata*), 537 t of bugs or shovel-nosed lobsters (*Thenus indicus* and *T. orientalis*), and 29 t of tropical lobsters (*Panulirus* spp). Over the eight-year period from which commercial fisheries statistics are available, the average annual catch of crustaceans other than prawns amounted to about 2800 t. Spanner crabs, mud crabs, blue swimmer crabs, and bugs made up most of this catch (2765 t), with species such as lobsters, other crabs, and mantis shrimp making up the remaining 30 t (Table 1).

**Table 1.** Mean annual Queensland catch of non-prawn crustacean species over the period 1988-95, listed in descending order

Species	Mean annual catch (tonnes)
Spanner crabs	1538.1
Bugs	484.9
Blue swimmer crabs	384.3
Mud crabs	360.0
Lobsters	19.1
Three-spot crabs	7.7
Coral crabs	0.4
Mantis shrimps	0.3

This paper briefly outlines the state of knowledge about the biology of the major species and their fisheries, and presents a basic assessment of the state of the stocks from analysis of trends in commercial fishery statistics.

## **Resources in the Great Barrier Reef World Heritage Area**

### **Spatial distribution**

The various crustacean stocks harvested by the commercial (and to a much lesser extent the recreational) fisheries in Queensland are not distributed uniformly along the coastline. The bulk of the State's catch of mud crabs (*Scylla serrata*) is taken from the GBRWHA, with smaller amounts taken from southern Queensland and the Gulf of Carpentaria (Table 2). The fishery for blue swimmer crabs (*Portunus pelagicus*) is centred almost entirely in the southern part of the State, while most of the catch of bugs (*Thenus indicus* and *T. orientalis*) and lobsters (*Panulirus* spp.) is derived from the GBRWHA (Table 2). Spanner crabs are taken both in south Queensland and the southernmost latitudes of the GBRWHA. The distributional patterns reflect mainly the distribution of suitable habitat (e.g. mangrove forests in the case of mud crabs, and a clean oceanic sand environment in the case of spanner crabs).

### **Catch by species and fishery in the Great Barrier Reef World Heritage Area**

The commercial catch statistics are maintained in two major databases, corresponding to the trawl fishery and the 'mixed' fishery, which includes all non-trawling commercial fishing activities including crab potting, line fishing and netting. While the exploitation of most crustacean stocks is fishery-specific, there is some overlap where one fishery takes as by-catch certain species targeted by the other. In southern Queensland the bulk of the blue swimmer crab catch, for example, comes from the pot fishery, but a very significant component is also taken as by-catch by prawn trawlers, particularly in Moreton Bay. In the GBRWHA the blue swimmer crab catch is much smaller than in southern Queensland (Table 2) and is taken primarily by the trawl fleet (Table 3).

**Table 2.** Mean annual catch (tonnes) over the period 1988-1995 of major crustacean species other than prawns in three major geographic sectors of the Queensland commercial fishery

Species	Gulf of Carpentaria	Great Barrier Reef World Heritage Area	Southern Queensland
Spanner crabs	0.0	576.7	961.4
Bugs	0.1	435.6	49.2
Blue swimmer crabs	0.0	43.5	340.7
Mud crabs	26.2	249.5	84.3
Lobsters	0.0	19.1	0.1
Three-spot crabs	0.0	0.3	7.4
Coral crabs	0.0	0.0	0.4
Mantis shrimps	0.0	0.0	0.3

**Table 3.** Mean annual catch of the major crustacean species other than prawns in the Great Barrier Reef World Heritage Area (1988-1995) by fishery

Species	Mixed Fishery	Trawl Fishery	Total
Bugs	0.0	435.6	435.6
Crabs - mud	249.4	0.0	249.5
Crabs - sand	7.0	36.5	43.5
Crabs - spanner	575.9	0.8	576.7
Crabs - three-spot	0.0	0.3	0.3
Lobsters	0.5	18.5	19.1
TOTAL	833.0	491.8	1324.8

#### *Blue swimmer crabs*

Known throughout Queensland traditionally as the sand crab, *Portunus pelagicus* (Linnaeus) (Fam. Portunidae) has recently been ascribed the Australia-wide recommended marketing name 'blue swimmer crab'. In some areas it is also referred to as the blue manna crab. It ranges through the Indo-West Pacific from East Africa to Japan, Tahiti and northern New Zealand. In Australia, *P. pelagicus* occurs in northern coastal waters from Cape Naturaliste (Western Australia) to southern NSW, and also at Lord Howe Island and in the South Australian Gulfs (Kailola et al. 1993).

Blue swimmer crabs are able to mate throughout the year, but only when the female crab is in the early post-moult (soft shell) condition. Female crabs carrying eggs occur throughout the year, but the proportion of ovigerous females is greatest during early spring (August-October) (Potter and Sumpton 1987). Eggs are extruded and attached to the pleopods beneath the female's tail flap. Such egg masses can contain up to two million eggs, and females may produce several batches of eggs in one season, all fertilised by sperm from the one mating (Kailola 1993). Embryonic development takes about two weeks, after which time the larvae hatch and enter a 4-stage pelagic phase. The final stage settle out as megalopae in shallow estuarine waters where they metamorphose into juveniles at 15 mm carapace width (CW), the distance measured across the shell between the tips of the lateral spines. In summer the juveniles begin to move out of the coastal shallows and at the age of 12 months (about 80 mm CW) females can become sexually mature. Males mature at a greater size (95-150 mm CL) probably because of slightly faster growth. Maximum longevity is around 3 year, although the bulk of the recruited sector of the population comprises the 1+ age-class (Sumpton et al. 1994). Growth occurs through the process of moulting, which involves the shedding of the hard exoskeleton and the swelling of soft body tissues before the new carapace calcifies. Settlement-stage juveniles measure about 15 mm CW, and through a series of moults reach sexual maturity at 80-120 mm (females) and 95-150 mm (males) after 10-12 months (Sumpton et al. 1994). As

the crabs grow the frequency of moulting decreases. Males can reach a size of 195 mm CW by their maximum age of 3 year (Sumpton et al. 1994). Movement is localised and associated with changes in salinity and temperature (Potter et al. 1983).

Because of the species' very high fecundity, recruitment is more likely to be a function of environmental and hydrological conditions than stock size, except at extremely low levels of spawner biomass.

Blue swimmer crabs are benthic carnivores and scavengers, feeding on animal material such as shellfish, other crustaceans, worms, brittle-stars and discarded trawl trash on the bottom. Feeding activity is greatest at dusk (Williams 1982). The main predators on adult crabs are probably turtles, sharks, rays, and large fish. A wide variety of fish and possibly other crustaceans probably prey on small juveniles.

The preferred habitats of juveniles include shallow seagrass meadows, sand banks and mud banks around the periphery of estuaries and embayments. Adults are also found in the vicinity of shallow sandbanks, but tend to occur generally in deeper waters of the bays and estuaries (Potter et al. 1983) and outside in the coastal marine environment.

Blue swimmer crabs attract a range of parasites, the most conspicuous of which is the parasitic barnacle *Sacculina granifera* (Bishop and Cannon 1979), which is visible as an external egg sac beneath the tail flap of a proportion of mature crabs. In areas such as Moreton Bay infestation rates may be as high as 17% in males and 50% in females (Potter and Sumpton 1987). This parasite ultimately destroys the infected crab's reproductive organs, and causes a reversion of some of the male's external sexual characteristics toward those of the female. A parasitic microsporidian can affect flesh quality in some crabs, turning the normally translucent muscle tissue and blood milky white. This is a factor contributing to the problem of 'mushiness' in cooked blue swimmer crabs, but appears only to occur in a small proportion (< 1%) of the population (Slattery et al. 1989).

#### The fishery

Blue swimmer crabs are taken by recreational fishers using inverted dillies and wire or collapsible mesh-covered pots, typically in nearshore or estuarine areas. The recreational crab fishery is considered very important, particularly in the southern part of the State, but there is no reliable estimate available on the size of the catch from this sector.

Commercial crabbers traditionally take blue swimmer crabs with pots and dillies. There is an increasing tendency for trawlers to retain by-caught crabs for sale, and indeed to target the species; during 1994 trawlers accounted for 88% of the commercial *P. pelagicus* catch in the GBRWHA.

Regulations controlling the Queensland blue swimmer crab fishery include a maximum limit on the number of commercial pots (50) and recreational pots or dillies (4) per fisher, a total prohibition on the taking of female crabs, and a minimum legal size for male crabs of 150 mm CW.

#### Trends in catch, effort and catch rate

In the GBRWHA during 1994 the trawled catch of blue swimmer crabs exceeded the mixed fishery pot catch by a factor of seven (Table 4). The data in Table 4 have been augmented to include the trawl catch of crabs which were not specifically identified. Trawlers rarely capture mud crabs or spanner crabs, so it is assumed that the records of unspecified 'crabs' refer to blue swimmer crabs. They may, however, also include some three-spot and coral crabs. Of the 50 t caught in the GBRWHA by trawlers in 1994, most originated from south of Mackay (Table 4).

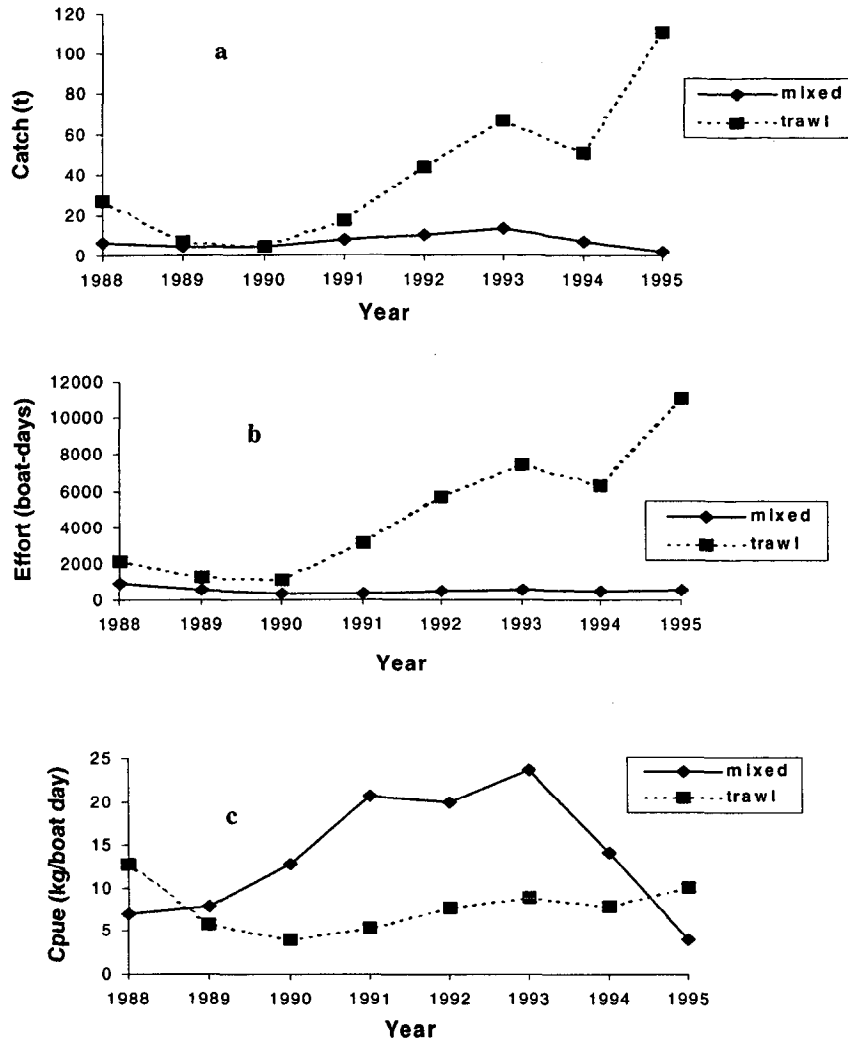
Although blue swimmer crab catches were reported consistently along all parts of the coastline, no catch in any of the 30-minute latitude bands north of Bowen exceeded 0.5 t.

**Table 4.** Geographical distribution of the 1994 catch (in kg) of blue swimmer crabs (*Portunus pelagicus*) from the trawl and mixed fisheries within the Great Barrier Reef World Heritage Area

Latitude (°S)	Locality	Trawl	Mixed
10.5	Cape York	13	0
11	Cairncross Is (Cape York)	212	5
11.5	Hunter Pt-Round Pt	65	0
12	Cape Grenville-Fair Cape	3	0
12.5	Cape Weymouth	32	0
13	Cape Direction-Friendly Pt	56	0
13.5	Claremont Is	11	0
14	Princess Charlotte Bay	273	0
14.5	Lizard Is	64	0
15	Cape Flattery-Cooktown	70	0
15.5	Cooktown-Cape Trib	17	0
16	Cape Trib - Port Douglas	40	0
16.5	Cairns	39	0
17	Babinda	114	143
17.5	Innisfail	76	105
18	Cardwell-Hinchinbrook	123	310
18.5	Ingham	479	3
19	Townsville	478	965
19.5	Ayr-Home Hill	366	0
20	Bowen-Whitsundays	102	0
20.5	North Mackay	4 274	0
21	Mackay	6 694	0
21.5	Cape Palmerston south	22	0
22	St Lawrence	537	0
22.5	Cape Manifold	4 614	101
23	Yeppoon	11 794	811
23.5	Gladstone	9 038	1 740
24	Round Hill Head	10 815	2 623
<b>TOTAL</b>		<b>50 420</b>	<b>6 806</b>

The major catches taken in the pot fishery during the same period came from the southernmost part of the GBRWHA - in the vicinity of Gladstone and Round Hill Head (Table 4). These catches were relatively small, and the only other part of the State where blue swimmer crabs were reported in the mixed fishery catch was between Cairns and Townsville.

Over the eight-year period for which commercial logbook data area available, the annual catch of blue swimmer crabs from the GBRWHA pot fishery has remained small (at around 8-10 t) and relatively stable, while the reported trawl catch increased by a factor of four, from 27 t in 1988 to 110 t in 1995 (Fig. 1a). Effort in the pot fishery was also relatively constant, averaging about 540 boat days annually (Fig. 1b). The pot-catch rate increased from about 8 kg/boat day in 1989 to 24 in 1993 (Fig. 1c), but declined just as rapidly in the following two years, to less than 5 kg/boat day in 1995. This trend in CPUE might suggest a strong recruitment pulse in the period 1991-93, but the trawl catch rate showed quite a different temporal pattern. The change in trawl fishing effort appeared to follow the trend in catch very closely, from around 2000 boat days in 1988 to over 11 000 in 1995 (Fig. 1b), which resulted in a relatively flat catch rate trajectory, averaging around 8 kg/boat day.



**Figure 1.** Temporal changes in the commercial catch (a), effort (b) and catch rate or CPUE (c) of blue swimmer crabs (*Portunus pelagicus*), taken by the trawl and mixed (pot) fisheries separately, within the Great Barrier Reef World Heritage Area

Interpretation of fishing effort with respect to by-catch species needs to be approached with great caution, as variation in the degree of targetting can have a profound impact upon the catch and hence CPUE data. In interpreting these trends, the (weak) assumption is that catches of blue swimmer crabs are consistently reported, regardless of the size of the catch, by all trawl vessels. At face value the data suggest that the inshore pot fishery in the GBRWHA is subject to inter-annual recruitment cycles which may cause local stock abundance to vary considerably. The present downward slope of the CPUE trajectory in the pot fishery (Fig. 1c) needs further investigation. Although the trawl catch rates in the more offshore parts of the fishery (Fig. 1c) suggest an apparent stability, there is a need to monitor the apparently rise in trawl effort directed towards blue swimmer crabs to determine whether increasing exploitation of the offshore component of the stock could be having an impact upon recruitment to the inshore pot fishery. Changes in the blue swimmer crab population within the GBRWHA must also be interpreted in the broader context of the state-wide distribution of the crab stock.

## Mud crabs

The mud crab *Scylla serrata* (Forsskål) (Fam. Portunidae), elsewhere known as the mangrove or black crab, occurs throughout the Indo-West Pacific from the east coast of South Africa to northern Australia, and across the western Pacific to Tahiti, including Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia, and Fiji (Brown 1993). The species was introduced into Hawaii during 1940s. In Australia *S. serrata* occurs in tropical to warm temperate regions from Exmouth Gulf (Western Australia) across the Northern Territory coast and down the east coast of Queensland and New South Wales as far as the Bega River (Kailola et al. 1993).

A taxonomic revision is under way as a result of genetic resolution of the genus into three species (Keenan 1996). The 'green' mud crab (*S. serrata*) is by far the most abundant species on the Queensland east coast, but populations of 'brown' mud crabs also occur in the northern tropics, in the estuarine reaches of some of the Cape York rivers. A comprehensive review of mud crabs and their exploitation in the South Pacific is provided in Brown (1993).

Mature crabs mate when the female is in the soft shell condition, within 48 hours after moulting (Fielder and Heasman 1978). The female may remain in the protection of the male for several days until her new shell has become hard, frequently in the shelter of a burrow. Sperm is stored until the eggs are extruded, and can remain viable for up to seven months (DuPlessis 1971). Multiple spawnings in the one season may follow a single mating, and each egg mass may contain from 1 to 8 million eggs, depending upon the size of the female (Fielder and Heasman 1978). Egg-bearing females migrate to deep waters offshore to hatch their eggs, and are rarely seen (Arriola 1940; Ong 1966; LePeste et al. 1976; Hyland et al. 1984). Embryonic development in the egg takes from 10 to 17 days depending on ambient water temperature. After hatching, the larvae progress during a 2-3 week period through four pelagic zoeal stages, to the semi-pelagic megalopa phase. If a suitable substrate is found in shallow water the megalopae settle, and after a period of 5-12 days metamorphose into juvenile crabs (Delathière 1990; Ong 1964).

Sexual maturity is reached in 18 months in tropical areas to two or three years in warm-temperate areas (Fielder and Heasman 1978). In Moreton Bay this period is between 18 and 27 months (Heasman 1980). Mud crabs live for up to 3 years and can reach a maximum carapace width of 240 mm.

Mud crabs appear to be omnivorous scavengers and predatorial, eating other crabs, barnacles, bivalve molluscs and moribund or dead fish. The larger claw is often used for crushing shellfish such as mussels, while the other is used for biting, cutting, and manipulating the food (Williams 1978).

Mud crabs usually remain in the protection of burrows during the day and feed at night, in the early evening and just before dawn (Hill 1976; Fielder and Heasman 1978). Juveniles and adults inhabit sheltered estuaries, the tidal reaches of mangrove-lined rivers and streams, mud flats and mangrove forests where they are natural prey to sharks, turtles, rays, herons, crocodiles and large fish such as barramundi and rock cods.

The parasitic barnacles *Octolasmis*, *Loxothylacus* and *Sacculina* have been reported in *S. serrata* from various localities (Hashmi and Zaida 1964; Quinn and Kojis 1987; Mounsey 1990). The former grow on the crab's gills but the latter two affect the flesh and, as in the blue swimmer crab *P. pelagicus*, cause parasitic castration (Hill 1982). Little is known about the incidence of infestation of mud crabs in the GBRWHA by any of these parasitic species, but it is not likely to be significant, and certainly nowhere near the level found in estuarine blue swimmer crabs.

As in other crustacean species, growth occurs through the process of moulting. In the latitude of Moreton Bay, mud crabs grow to 80-100 mm CW in their first year, 130-160 mm CW in their second year, and (potentially) 180-200 mm CW in their third year (Fielder and Heasman 1978). Growth is seasonal, with moulting activity being most prevalent in spring to mid-summer (September-January).

No estimates of mortality rate are available for populations of *S. serrata* in Queensland. However Hill (1975) calculated that an unfished population in a South African estuary was subject to natural mortality rates of 41% (age 2 years;  $M = 0.53$ ) and 60% (age 3 years;  $M=0.92$ ).

Apart from the poorly-documented and understood seaward migration of mated female mud crabs, there is little evidence that adult crabs undergo any significant movement. The fact that they inhabit burrows indicates that they are relatively site-associated, although there is a certain amount of longshore movement within contiguous habitat (Hyland et al. 1984).

#### The fishery

Fisheries for mud crabs (*Scylla serrata*) occur in mangrove estuaries and tidal reaches of rivers and streams around the entire coastline of Queensland, including the Gulf of Carpentaria. Some 69% of the annual commercial catch, which has remained relatively stable at around 400 t over the past seven years, is taken from the GBRWHA. Of the remainder, about 7% comes from the Gulf of Carpentaria and 23% from the southern coast between Bundaberg and the New South Wales border.

The standard apparatus for the commercial or recreational capture of crabs (mud crabs, blue swimmer crabs and spanner crabs) is the crab pot or dilly. The inverted dilly is a long cone of fine-thread mesh suspended apex-up by means of a small net float attached to the peak. The bait is attached to a wire or cord running across the diameter of the (typically circular) frame, and is enclosed by the mesh cone when the net is set on the bottom. Crabs attempt to reach the bait through the wall of mesh and become entangled. Inverted dillies continue to be used in the recreational fishery for mud crabs and blue swimmer crabs, and to some extent also in the commercial fishery.

Crab pots or traps come in a variety of shapes and sizes, but generally consist of a mesh-covered box with two horizontal entry funnels. The recreational crab pot is typically circular, about 100 cm in diameter and 30 cm high, made of chicken mesh wired onto a light galvanised steel rod frame. Short conical entry funnels are incorporated into the wall diametrically opposite one another, and a simple trapdoor is built into the wall or top to allow access for baiting and removal of the catch. Several proprietary lines of metal and plastic pots with the usual two side entrances are also available. Some of these are collapsible (covered in synthetic mesh) for ease of stowage on small recreational boats.

Commercial crabbers also use a variety of pots, but for mud crabbing perhaps the most common configuration is a rectangular box about 100 cm x 40 x 40 cm covered in 7.5 x 5.0 cm weldmesh, with two horizontally-opposed but staggered plastic entrance funnels. Other variants include dome shaped 'beehive' pots with a single top entrance.

#### Trends in catch, effort and catch rate

Unlike blue swimmer crabs, mud crabs are effectively taken only in the 'mixed' fishery, mainly by pots but occasionally as a by-catch in estuarine netting operations (Table 5). There is essentially no trawl catch of this species.

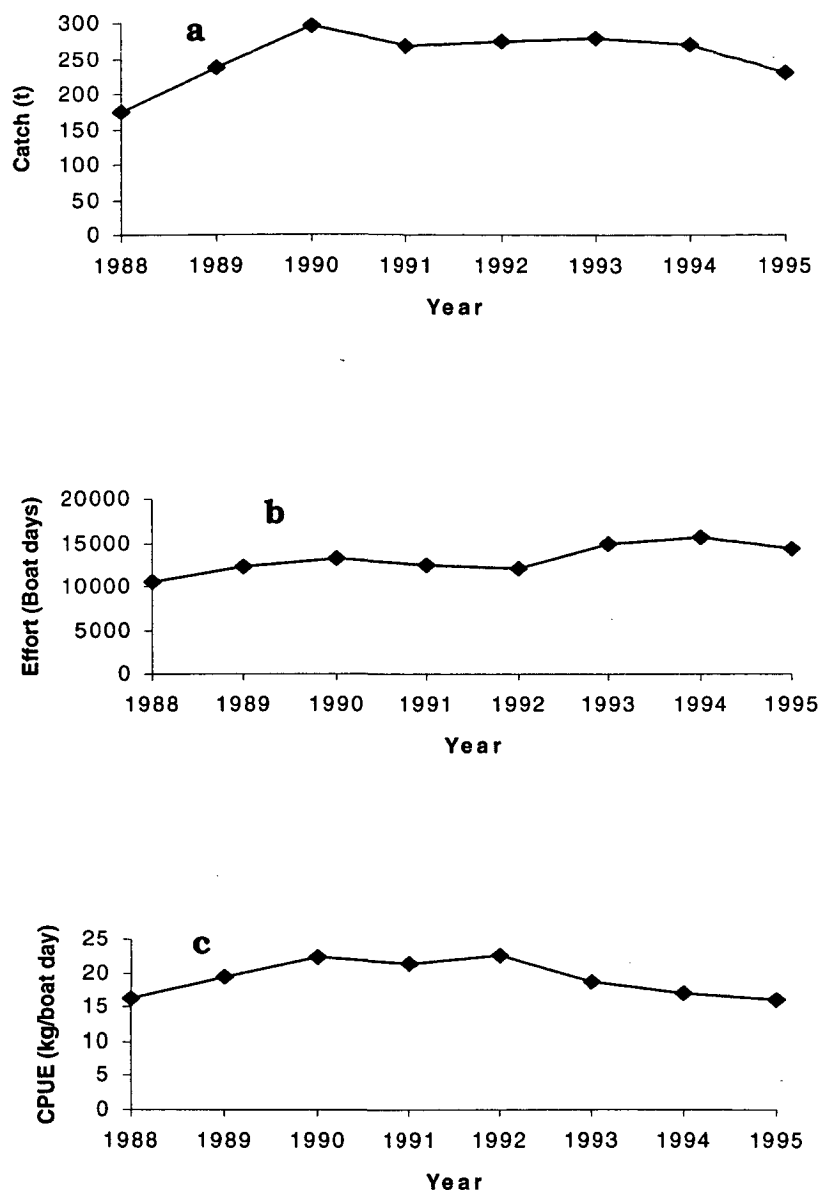


There are few parts of the Queensland coastline within the boundary of the GBRWHA where mud crabs are not caught, either commercially or recreationally (Table 5). The bulk of the 1994 mud crab catch in the GBRWHA (264 t) came from south of St Lawrence-Broad Sound (188 t), but significant catches were also reported from Princess Charlotte Bay (12 t) and Cardwell-Hinchinbrook (22 t).

**Table 5.** Geographical distribution of the 1994 catch (in kg) of mud crabs (*Scylla serrata*) from the trawl and mixed fisheries within the Great Barrier Reef World Heritage Area

Latitude (°S)	Locality	Trawl	Mixed
10.5	Cape York	0	15
11	Cairncross Is (Cape York)	0	39
11.5	Hunter Pt-Round Pt	0	1
12	Cape Grenville-Fair Cape	0	212
12.5	Cape Weymouth	0	5
13	Cape Direction-Friendly Pt	0	0
13.5	Claremont Is	0	0
14	Princess Charlotte Bay	3.9	11 692
14.5	Lizard Is	0	13 290
15	Cape Flattery-Cooktown	0	50
15.5	Cooktown-Cape Trib	0	36
16	Cape Trib - Port Douglas	0.3	156
16.5	Cairns	0	1 232
17	Babinda	0	289
17.5	Innisfail	0	1 989
18	Cardwell - Hinchinbrook	0	21 951
18.5	Ingham	0	447
19	Townsville	0.3	9 887
19.5	Ayr-Home Hill	72	5 074
20	Bowen-Whitsundays	0	2 345
20.5	North Mackay	4	2 885
21	Mackay	0	2 222
21.5	Cape Palmerston south	0	2 295
22	St Lawrence	0	39 232
22.5	Cape Manifold	0	14 664
23	Yeppoon	0	4 397
23.5	Gladstone	1.2	106 795
24	Round Hill Head	0	23 129
<b>TOTAL</b>		<b>82</b>	<b>264 329</b>

The annual statistics for the GBRWHA mud crab pot fishery show a surprising lack of variation (Fig. 2). Catches increased initially from about 170 t in 1988 to 300 t in 1990, possibly as a result of incomplete reporting in the early stages of the logbook program, but remained relatively stable at around 270 t over the remaining period (Fig. 2a). Fishing effort was also consistent over the eight year period, averaging around 13 000 boat days per year (Fig. 2b). As a result there was little temporal change in the CPUE trajectory, with annual catch rates averaging 19 kg of crabs per boat day (Fig. 2c). These data suggest a fishery that is not undergoing any significant change, with respect either to fishing effort or to apparent stock density.



**Figure 2.** Temporal changes in the commercial catch (a), effort (b) and catch rate or CPUE (c) of mud crabs (*Scylla serrata*) within the Great Barrier Reef World Heritage Area

*Spanner crabs*

In 1994, for the first time, spanner crabs represented the greatest catch (by weight) of any of Queensland's fished species. The exceptional increases in landings over the past four years have resulted from a significant rise in fishing effort, driven in turn by the development of a profitable Asian export market for live crabs.

The spanner, red frog, or kona crab *Ranina ranina* (Linnaeus) (Fam. Raninidae) ranges throughout the Indo-Pacific, from the east coast of southern Africa to Hawaii, the Philippines and southern Japan (Brown 1986). In Australia they occur from the Great Barrier Reef area south to Nowra (New South Wales), but the bulk of the stock is concentrated between Yeppoon

(southern Queensland) and Ballina (northern New South Wales). On the west coast the species has been reported between Quinn's Rocks (north of Perth, Western Australia) and the Houtman Abrolhos Islands (Kailola et al. 1993)

Spanner crabs aggregate to spawn during the warmer months of the year (between October and February). Unlike the portunid crabs, spanner crabs can probably mate at any stage of the moult cycle. There is a distinct spawning period, but female crabs can produce several batches of eggs each season, depending on their size (Onizuka 1972; Brown 1986). *R. ranina* is less fecund than the portunids, producing between 60 000 and 160 000 eggs per batch (Brown 1986; Kennelly and Watkins 1994). The incubation period lasts from four to five weeks, after which the eggs hatch into the first of an 8-stage pelagic zoeal larval period spanning between five and eight weeks (Brown 1986). The final megalopa stage settles on a suitable substrate (if available) and metamorphoses into a juvenile spanner crab. Most female crabs mature at 70-75 mm CL although egg-bearing females as small as 64 mm CL have been recorded (Brown 1986). Ovary development seems to occur earlier in the northern part of the species' range.

Spanner crabs remain buried beneath the sand except when feeding or engaging in reproductive activity. They are opportunistic feeders, their diet under natural conditions probably comprising heart urchins, brittle-stars, shellfish, small crustaceans and polychaete worms.

Juvenile and adult crabs prefer a clean, well-sorted sand habitat in an oceanic environment with little fluctuation in salinity (Brown 1986, 1994). For this reason they tend not to occur in truly estuarine conditions or on reef or very coarse rubble bottom. The fishery does not extend much further north than Yeppoon, as the sea floor in the deep 'lagoon' between the Swains Reefs and the mainland comprises a high proportion of unsuitable soft, silty sediments (Brown 1994). There are almost certainly areas of suitable habitat capable of supporting spanner crab populations, but these areas are believed to be isolated and quite small.

Turtles, sharks, rays, and large benthic predatory fish are believed to be the major natural predators of adult spanner crabs. There is ample evidence of crabs being eaten out of tangle nets both by sharks and turtles. Newly-settled juvenile crabs are almost certainly vulnerable to a wide range of predators such as fish and rays, but the colour of their carapace is well camouflaged against the sand, and, like the adults, they spend much of the time almost completely buried in the substrate (J. Kirkwood, pers. comm.).

No obvious parasites or diseases have been reported in this species of crab. It does not appear to be susceptible to the parasitic barnacles which infest a significant proportion of the blue swimmer crab population in Moreton Bay.

Newly settled spanner crabs grow quickly, reaching 30 mm CL in perhaps three or four weeks. Moulting increments may be as much as 12 to 16 mm in males and 5 to 9 mm in females, with an average of one moult per year (S. Kennelly, pers. comm.). Preliminary estimates based on New South Wales tagging data suggest a longevity of 7-8 yr, with males reaching a maximum size of around 150 mm CL and a weight of 1 kg. Females are significantly smaller (presumably because of slower growth rates), reaching a maximum size of 120 mm CL and an equivalent weight of 400 g (Brown 1986).

Some localised movement occurs as the crabs appear to aggregate in certain localities prior to spawning, but there is no evidence of any significant migration patterns. No estimates of stock-recruitment relationships are available. However spanner crab recruitment patterns are almost certainly driven largely by environmental factors, particularly the timing and direction of oceanic water currents during and for the weeks following spawning, and the spawning

biomass would have to be depleted significantly in order to appreciably affect recruitment rates.

#### The fishery

The commercial Queensland spanner crab fishery is based on a fleet of high-speed vessels each deploying around 30 flat tangle-nets in 'strings' of 10 in coastal waters to a depth of 60-80 m. By far the bulk of the catch, since the inception of the fishery in the early 1980s, has been taken from the area south of the southern limit of the GBRWHA. However, recent expansion of the fishery has seen an increasing proportion coming from the southern part of the GBRWHA south of the latitude of Yeppoon, from inshore waters east to the seaward edge of the Capricorn-Bunker Group. There has been a marked tendency for new, larger vessels to enter the fishery in the more northern areas (from Bundaberg to Gladstone), as well as for existing vessels to move northward in response to the discovery of new fishing grounds and the development of appropriate marketing and transportational infrastructure. Concerns about the ultimate sustainability of such increases in fishing effort have led to the imposition of limits both on vessel numbers and total catches. These measures are to be incorporated in the Spanner Crab Management Plan currently in preparation. Compared to the commercial fishery, the recreational fishery for spanner crabs is insignificant.

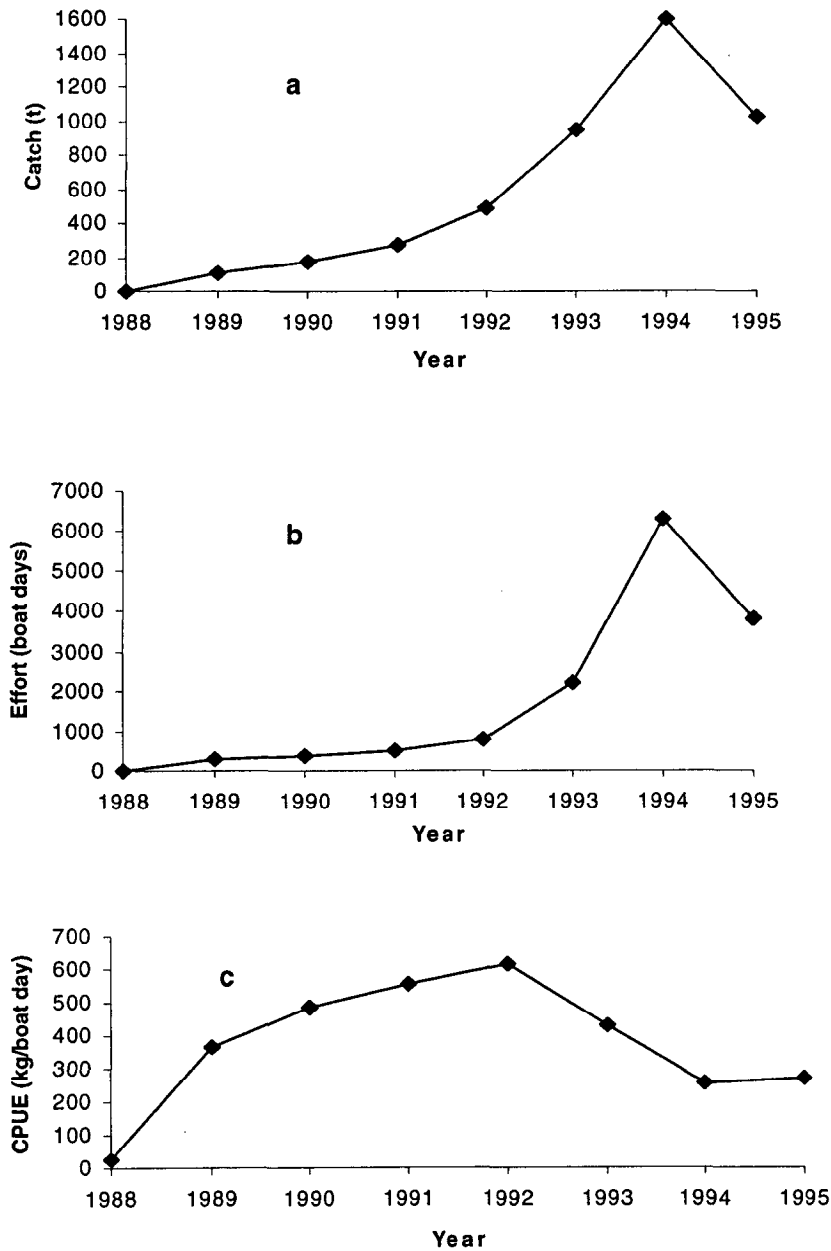
Inverted dillies were used during the early years of the spanner crab fishery (Brown 1986), but problems of clearance time and gear damage led to the development of a more cost-effective flat net, which has subsequently become the industry standard. This net is still referred to as a dilly, but unlike previous versions the mesh is stretched quite tightly across the frame, and should more accurately and simply be called a tangle net. Frame size is limited by legislation to an area of not more than one square metre, and the amount of 'drop' (or slack in the net) is limited to a maximum of 10 cm beneath the plane of the frame. Additionally stretched mesh sizes must not be less than 25 mm if a single layer of mesh is used, or 51 mm if a double layer is used.

#### Trends in catch, effort and catch rate

Temporal changes in the spanner crab fishery within the GBRWHA are shown in Fig. 3. Prior to 1988 there was very little serious spanner crab fishing activity in the GBRWHA, but from that point onward fleet size and fishing power grew rapidly until 1994 when effort peaked at about 6 300 boat-days (Fig. 3b). In that period the fleet grew from five vessels to 147.

The pattern of change in mean annual catch followed a very similar trajectory to that of effort, growing from almost nothing in 1988 to nearly 1600 t in 1994 (Fig. 3a). The catch rate or CPUE pattern showed the classic characteristics of a fishery in its initial expansion phase (Fig. 3c). Catch rates peaked in 1992 at about 612 kg/day when the fishery was beginning to expand into new grounds north of Bundaberg, inside the Capricorn-Bunker Group, and later between Gladstone and Yeppoon. At this time the fishery was harvesting the accumulated stock. Subsequently there was an expected decline in catch rates, until by 1995 CPUE had dropped to 280 kg/day. This does not necessarily mean that the stock is being overfished; merely that, as occurs in any new developing fishery, the initial high catch rates cannot be sustained (Hilborn and Walters 1992).

About 6 t of spanner crabs was reported from the trawl fishery catch in the WHA during 1994, compared with nearly 1600 t from the specialised crab fleet (Table 6). In neither fishery, however, were any catches registered from latitudes further north than Townsville. By far the bulk of the year's catch was taken south of the Yeppoon area, and almost half from the southernmost half-degree latitude band in the GBRWHA, just south of Lady Musgrave Island in the Bunker Group.



**Figure 3.** Temporal changes in the commercial catch (a), effort (b) and catch rate or CPUE (c) of spanner crabs (*Ranina ranina*) within the Great Barrier Reef World Heritage Area

*Bugs or bay lobsters*

Several species of 'bay', 'shovel-nosed' and 'slipper' lobsters (Family Scyllaridae) occur in Australian waters between Shark Bay (Western Australia) and Coffs Harbour (northern New South Wales), and more generally throughout the tropical Indo-West Pacific Ocean between 20°N, 40°E and 30°S, 155°E (Kailola et al. 1993). Two species are susceptible to capture by trawl nets in Queensland waters. They are the mud or tiger bug *T. indicus* and the reef or sand bug *T. orientalis*, both of which constitute an important byproduct of the east coast trawl fishery. Most of the State's catch of bugs is derived from the GBRWHA, largely from the vicinity of Townsville and from between Rockhampton and Hervey Bay.

**Table 6.** Geographical distribution of the 1994 catch (in kg) of spanner crabs (*Ranina ranina*) from the trawl and mixed fisheries within the Great Barrier Reef World Heritage Area

Latitude (°S)	Locality	Trawl	Mixed
10.5	Cape York	0	0
11	Cairncross Is (Cape York)	0	0
11.5	Hunter Pt-Round Pt	0	0
12	Cape Grenville-Fair Cape	0	0
12.5	Cape Weymouth	0	0
13	Cape Direction-Friendly Pt	0	0
13.5	Claremont Is	0	0
14	Princess Charlotte Bay	0	0
14.5	Lizard Is	0	0
15	Cape Flattery-Cooktown	0	0
15.5	Cooktown-Cape Trib	0	0
16	Cape Trib - Port Douglas	0	0
16.5	Cairns	0	0
17	Babinda	0	0
17.5	Innisfail	0	0
18	Cardwell-Hinchinbrook	0	0
18.5	Ingham	0	0
19	Townsville	0	0
19.5	Ayr-Home Hill	0	175
20	Bowen-Whitsundays	0	0
20.5	North Mackay	11	0
21	Mackay	0	309
21.5	Cape Palmerston south	0	10 318
22	St Lawrence	890	12 166
22.5	Cape Manifold	0	50 188
23	Yeppoon	3 351	264 057
23.5	Gladstone	0	452 493
24	Round Hill Head	2 054	809 219
TOTAL		6 306	1598 925

Like most other marine crustaceans, bugs have a planktonic larval stage which aids in the dispersal of the species. This stage, the *phyllosoma*, lasts for 2-3 months, during which time it drifts around largely at the mercy of prevailing water currents. Subsequently the *phyllosoma* moults into a *nisto*, which settles to the sea-floor and, after about one week moults into a juvenile bug (Jones 1991). Juveniles and adults prefer the flat open sea-floor and so are frequently found in the same geographic locations as prawns. The mud or tiger bug *Therinus indicus* occurs on silty inshore substrates to a depth of about 30 m, while its larger congener *T. orientalis* (the reef or sand bug) is found more in sandy inter-reef habitats between 30 and 60 m (Jones 1991).

Growth is reasonably rapid for the first two years, after which time under natural conditions they will have attained a total length of 160-180 mm (Jones 1991). In hatchery conditions growth is considerably faster (S. Mikami, pers. comm.). Although most of the commercial catch constitutes animals three or four years old, it appears that they may survive up to or even beyond 10 years.

Bugs can swim very effectively, and tagging studies have shown that they can move quite considerable distances (up to 50 n miles). However there does not seem to be any consistent migratory pattern to these movements (Jones 1991). Animals held in tanks and offered a variety of food showed a strong preference for small bivalve molluscs including clams, scallops and cockles, but they are also capable of active predation on prawns and small fish (Jones 1991). The animals are nocturnal, remaining buried in the substrate with only their eyes and antennules visible during daylight hours (Jones 1988).

Sexual maturity is reached during the animals' first year at a length of 125-135 mm (mud bugs) or 155-165 mm (reef bugs). They spawn during the summer months. Spawning may involve multiple ovulations, each resulting in an egg mass containing between 5000 and 50 000 ova, which are retained under the female's tail for a period between four and ten weeks prior to hatching (Jones 1991).

#### The fishery

Virtually all commercially caught bugs are taken as by-catch in prawn or scallop trawling operations. Sometimes bugs are sufficiently abundant to make it economically viable for trawlers to target them rather than prawns. The proportions by weight in the annual central Queensland commercial trawl catch are approximately 10% (sand bugs) and 4% (mud bugs). The average density of the population has been estimated to be about two animals per hectare (Jones 1991).

#### Trends in catch, effort and catch rate

Between 400 and 500 trawlers reported catches of bugs each year during the period 1988-1995, and the associated annual effort ranged from 24 000 to 35 000 boat-days, resulting in annual catches between 350 and 580 t. Logged fishing effort remained at about 25 000 boat-days between 1988 and 1992, then increased progressively to 35 000 boat-days during the next three years (Fig. 4b). Catches followed a similar trajectory, increasing from around 350 t in the period 1988-91 to nearly 600 t in 1995 (Fig. 4a). Apart from a modest rise in 1992-93, catch rates have been generally flat at around 15 kg/boat-day throughout the eight-year period (Fig. 4c). As there was relatively little year-to-year variation in the number of trawlers reporting catches of bugs, the increase in catch after 1992 appears to have been due either to increased targeting (because of improved price incentives) or to a greater consistency in by-catch reporting.

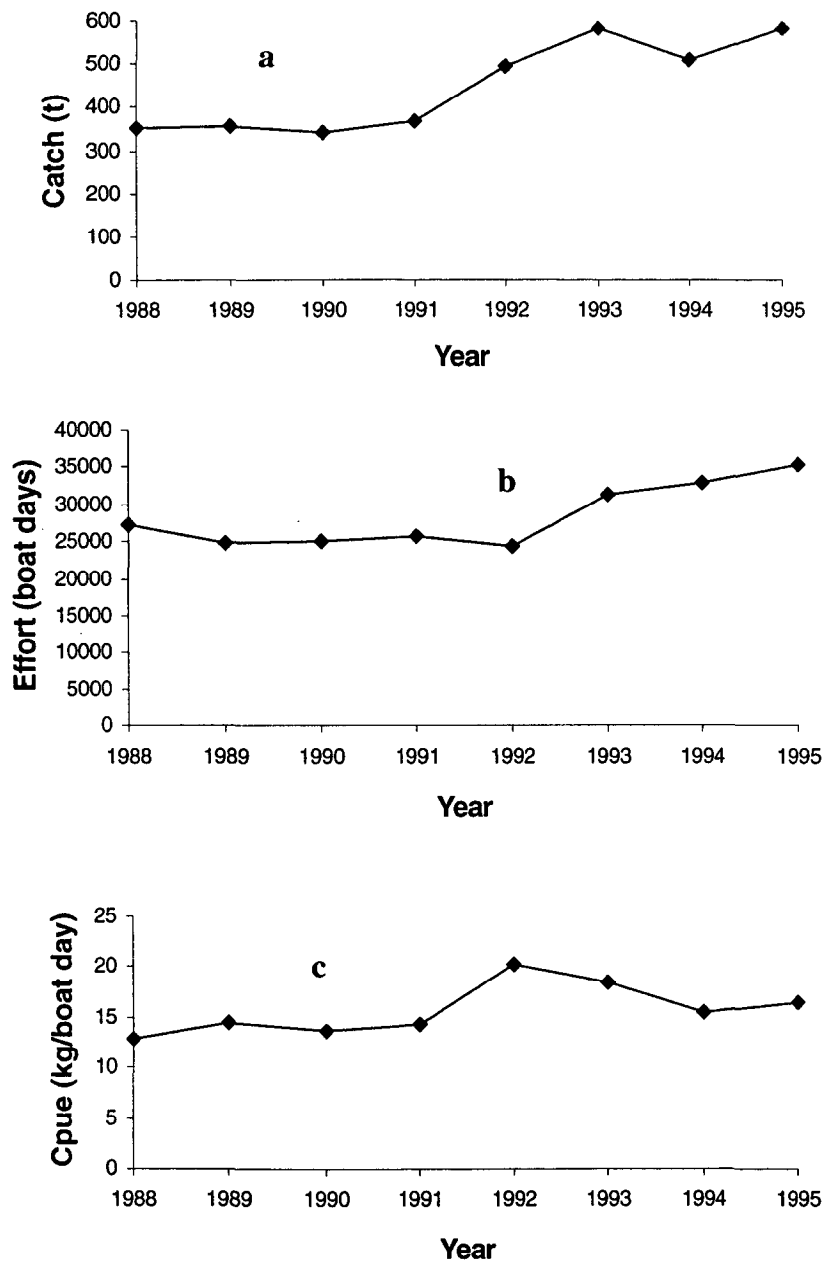
Catches of bugs were reported in 1994 from all the 30-minute latitude bands within the GBRWHA (Table 7). While modest catches (generally less than 4 t per 30-minute band) were reported from the coastline north of Innisfail, between Cardwell and Mackay the catches were quite substantial, with a peak of over 100 t in the Townsville area. A second area (in the vicinity of Gladstone) also produced significant catches (Table 7).

#### Conclusions

The main source of information on the State's fished crustacean stocks is the commercial fishery itself, as there are virtually no recreational fisheries for prawns, bugs or spanner crabs, and few statistics are available on the recreational catch of blue swimmer crabs or mud crabs. Therefore the only avenue for routinely monitoring the status of these stocks at present is through analysis of data from the compulsory QFish logbook system. In the absence of any information to the contrary, catch rates are assumed to provide an index of stock abundance. Within the GBRWHA stocks of crustaceans (other than penaeid prawns) appear generally from the catch rate data not to be under immediate threat from overexploitation or environmental stress.

Catch rates of mud crabs and bugs in the GBRWHA are stable, although in the latter case CPUE may not be a reliable indicator of population density for reasons related to changing fishing practices. The spanner crab fishery has recently experienced an expansionary phase and the index of stock abundance, while less than it was in the early part of the decade, appears to have flattened out with an anticipated drop in total catch. A recent decline in the catch and catch rate of blue swimmer crabs in the GBRWHA pot fishery needs to be examined closely, and in the context of the entire stock, most of which occurs outside the GBRWHA. This change may have resulted from natural cycles in recruitment success, alienation of inshore habitat, or the transfer of

dedicated fishing effort into the spanner crab fishery. In contrast, the 'offshore' component of the blue swimmer crab fishery, exploited by the trawl fleet as either a by-catch or target species, appears not to be undergoing any significant change despite substantial increases in landings and effort. However, as in the case of the bug fishery, these changes are particularly difficult to interpret with any degree of confidence because of the fact that the species is sometimes taken incidentally to the prawn catch, and at other times is targeted specifically.



**Figure 4.** Temporal changes in the commercial catch (a), effort (b) and catch rate or CPUE (c) of bugs or bay lobsters (*Thenus indicus* and *T. orientalis*) within the Great Barrier Reef World Heritage Area



**Table 7.** Geographical distribution of total catch (kg) of bugs during 1994 in the Great Barrier Reef World Heritage Area

Latitude (°S)	Location	Catch (kg)
11	Cairncross Is (Cape York)	4 126
11.5	Hunter Pt-Round Pt	2 436
12	Cape Grenville-Fair Cape	502
12.5	Cape Weymouth	2 038
13	Cape Direction-Friendly Pt	1 770
13.5	Claremont Is	3 457
14	Princess Charlotte Bay	16 793
14.5	Lizard Is	1 985
15	Cape Flattery-Cooktown	1 593
15.5	Cooktown-Cape Trib	685
16	Cape Trib - Port Douglas	2 607
16.5	Cairns	3 695
17	Babinda	4 182
17.5	Innisfail	9 313
18	Cardwell-Hinchinbrook	22 323
18.5	Ingham	57 634
19	Townsville	102 528
19.5	Ayr-Home Hill	72 248
20	Bowen-Whitsundays	16 719
20.5	North Mackay	48 227
21	Mackay	29 968
21.5	Cape Palmerston south	1 414
22	St Lawrence	1 461
22.5	Cape Manifold	13 136
23	Yeppoon	29 649
23.5	Gladstone	41 107
24	Round Hill Head	10 970
TOTAL		502 566

Pressure on the State's resources of crustaceans other than prawns is likely to increase during the time-frame of the GBRWHA Management Plan, particularly in fisheries with a major recreational component, purely as a result of population growth (Table 8). Rising market prices and the development of overseas live export markets is already making it more profitable for prawn and scallop trawler operators to retain incidentally-captured bugs and indeed to target bugs specifically. In inshore areas water quality and habitat destruction or modification may become issues by virtue of their potential impact upon the survival of the early stages of portunid crabs. One of the major challenges for managing the exploitation of all these species is to identify mechanisms sensitive enough to detect changes in the stocks against a particularly noisy background of natural variability in recruitment success.

### **Acknowledgments**

Thanks are due to staff members at the Southern Fisheries Centre for their comments on the manuscript, and particularly to Mr StJohn Kettle (Queensland Fisheries Management Authority) for his support in facilitating a number of data retrievals from the QFish database.

**Table 8.** Pressure-state-response analysis of Queensland's four most important crustacean resources other than prawns

Resource	Pressure	State	Response
Blue Swimmer Crab	<p>Increasing exploitation by trawl fleet and probably recreational pot fishery</p> <p>Continuing exploitation by commercial pot fishery</p> <p>Possible alienation of juvenile habitat</p>	<p>Most of GBRWHA catch is taken by trawlers. Trawl catch rates stable despite large increases in effort.</p> <p>Pot fishery catches and catch rates declining despite apparently stable effort.</p> <p>Poor species definition in commercial logs; no information available on size of recreational fishery.</p>	<p>Management plan under development by CrabMAC.</p> <p>Through public consultation process existing management measures to be refined and strengthened.</p> <p>Careful monitoring of interactions between trawl and pot fisheries required.</p> <p>Improvement in trawl by-catch species definition required.</p> <p>Estimation of size of recreational fishery required through QFMA Recreational Fishery Program.</p>
Mud Crab	<p>Commercial fishing pressure likely to continue at current level</p> <p>Probable increase in recreational fishing pressure</p> <p>Possible alienation of juvenile habitat</p>	<p>Catch, effort and catch rate trajectories show no significant trend.</p> <p>Stock widely distributed along Qld coast and not presently exhibiting signs of overfishing within the GBRWHA.</p>	<p>Management plan under development by CrabMAC</p> <p>Through public consultation process existing management measures to be refined and strengthened</p> <p>Estimation of size of recreational fishery required through QFMA Recreational Fishery Program.</p>
Spanner Crab	<p>Increasing commercial fishing pressure on the non-TAC regulated sector.</p>	<p>Stock status uncertain, but fishing effort stabilised through tight management controls.</p> <p>Probability of discovering significant new virgin sub-stocks is remote.</p> <p>Very small recreational fishery.</p>	<p>Interim management plan incorporating output controls (TACs) already in place</p> <p>Final management plan under priority development by CrabMAC</p> <p>Through public consultation process existing management measures to be refined and strengthened</p>
Bug	<p>Increased targetting by trawlers likely as market opportunities and product value improve</p>	<p>Catch rates do not signify stock problems, but considerable uncertainty surrounds interpretation of by-catch CPUEs.</p>	<p>Introduce minimum legal size restrictions</p> <p>Ensure accurate and complete reporting of by-catch</p>

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# The management of fisheries in the Great Barrier Reef Marine Park

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## Introduction

Fishing, both commercial and recreational, is the major extractive activity in the Great Barrier Reef World Heritage Area (GBRWHA). The commercial fishery consists of about 3700 professional fishers and 1400 vessels involved in a wide range of commercial activities, including about 800 prawn trawlers, 200-300 reef fishing operations and about 300 inshore (net and crab) operations. The direct economic value of the commercial fishery in the Great Barrier Reef region is between AUD\$150 to AUD\$200 million annually (Driml 1995).

Under the offshore constitutional settlement between the Australian States and the Australian Government the management of fisheries within the Great Barrier Reef Marine Park (GBRMP) is the responsibility of the Queensland Government through the Queensland Fisheries Management Authority (QFMA) and the Queensland Department of Primary Industries (QDPI).

The Great Barrier Reef Marine Park Authority (GBRMPA) in its aim to protect the natural qualities of the Great Barrier Reef whilst providing for reasonable use of the reef region, does have control over fishing by virtue of the use of management zones which restrict certain fishing activities in specific areas. GBRMPA well recognises that the harvesting of fish, prawns and other living resources as an established reasonable use of the GBRMP, yet GBRMPA acknowledges that fishing effects target species, non-target species and the habitat and hence has the potential for producing ecological effects in both the fished areas and the reef system as a whole.

Because of the potential overlap between the activities of the GBRMPA and fisheries management agencies, a Memorandum of Understanding (MOU) was established between the agencies to clarify roles and responsibilities. As outlined in this MOU, GBRMPA's responsibilities are primarily for the care and development of the Marine Park and are not responsible for fisheries management except for this purpose. The fisheries agencies responsibilities are defined as primarily responsible for the management of fishing and collecting operations and optimisation of the use of available fisheries resources.

Common to the charter of all resource management agencies are the principles of conservation, ecologically sustainable use, the protection of critical areas, equitable resource use, and an integrated management approach which involves the preparation of management plans in consultation with the major users and interest groups. These principles are applied as effectively as possible but for most of the fisheries within the GBRMP, the issues are extremely complex. Such issues include declining catch or a decreased average size of fish caught in some areas, increased fishing effort or a large excessive capacity in the fishery (termed 'latent effort'), potential environmental impacts of fishing activities on incidentally caught species some of which are endangered, the impacts of fishing on the marine habitat, the increase and emerging significance of the recreational fishery in resource allocation, indigenous use and rights to the resource, and issues associated with compliance of fisheries and marine park management regulations.

### **Management arrangements of the Queensland Fisheries Management Authority**

The *Fisheries Act 1994* details the legislative arrangements and regulations that apply to fisheries in Queensland. Under the Act there are also legislative arrangements for developing, implementing and repealing fisheries management plans. Management plans can be applied to specific fisheries and can be much more flexible and prescriptive than the fisheries regulations. In general for commercial fisheries, effort and catch regulations are achieved through limited entry licences, gear type and size restrictions, species size restrictions, and areas and seasonal closures. The recreational fisheries are managed by gear type and size restrictions, species size restrictions, area and seasonal closures, and bag limits on most popular species.

The QFMA has established a system of Management Advisory Committees (MAC) for all the major fisheries in Queensland. The MACs contain representation from all major stakeholder groups including recreational and commercial fishing, marine park managers, enforcement officers, research scientists, conservation and Aboriginal and Torres Strait Islanders. The MAC system works well in ensuring all interests are considered in the management of a fishery. On a more regional scale the QFMA has developed Zonal Advisory Committees (ZAC) which consider more local fisheries related matters. The ZACs have representation from local commercial and recreational, conservation, local council, local Aboriginal and Torres Strait Islander interests, and local representatives of relevant state government agencies. The MACs and the ZACs meet on a roughly quarterly basis and report directly to the QFMA Board. Currently a review of the management of all the major fisheries in Queensland is being undertaken by the MACs.

### **Management arrangements of the Great Barrier Reef Marine Park Authority**

The *Great Barrier Reef Marine Park Act 1975* provides for the establishment, control, care and development of the GBRMP. The Act has significant influence on the management and accessing of fish stocks as GBRMPA's framework for planning and management the Marine Park is provided principally by zoning plans which regulate activities such as fishing. The purpose for which areas of the Marine Park are zoned is in accordance with the following objectives:

- (i) the conservation of the Great Barrier Reef;
- (ii) the regulation of use of the Marine Park so as to protect the Great Barrier Reef, while allowing the reasonable use of the Great Barrier Reef region;
- (iii) the regulation of activities that exploit the resources of the Great Barrier Reef region so as to minimise the effect of those activities on the Great Barrier Reef;
- (iv) the preservation of some areas of the Great Barrier Reef in their natural state undisturbed except for the purposes of scientific research.

The GBRMPA has significant responsibilities for ensuring the conservation of fish stocks, within the wider context of its responsibilities. Similar complementary legislation for Queensland's marine parks is contained in the *Marine Park Act 1982* administered by the Queensland Department of Environment.

The zoning plans for each section of the GBRMP have traditionally been reviewed every five years although in recent years this period has been more protracted due to the greater activity in many areas of the GBRMP leading to a greater complexity in rezoning procedures. There is now a tendency to change from section by section reviews to reef wide amendments to zoning plans based on a particular theme or issue. It is hoped that such an approach will lead to greater consistency in zoning arrangements than currently exists between the different sections of the GBRMP.

The QFMA and GBRMPA consult regularly to ensure that fisheries and Marine Park management planning arrangements are complementary and compatible. The GBRMPA also

maintains its practice of consulting representatives of the commercial and recreational fishing organisations and individuals in the development and review of zoning plans. In practice, there is some overlap, but a good working arrangement has been established, with close involvement of the fisheries agencies when zoning plans are being developed and reciprocal consultation by the QFMA.

### **Effectiveness of the management arrangements in relation to the major Great Barrier Reef fisheries**

The degree to which the fisheries and marine park management schemes protects fished and non-fished species and their habitats is difficult to assess but could be evaluated in relation to three of the major fisheries.

#### **Trawl fishery**

The trawl fishery in the GBRWHA occurs predominantly within the Great Barrier Reef lagoon, the area between the Queensland coastline and the western margin of the mid-shelf reef complex. The fishery has two main components: (i) The inshore tiger prawn (*Penaeus semisulcatus* and *Penaeus esculentus*) and banana prawn (*Penaeus merguensis*) fisheries which occur to a maximum depth of 40 m; and (ii) the offshore fisheries, which target king prawns (*Penaeus longistylus* and *Penaeus latisulcatus*) in the central and northern sections of the park (30-50 m) and scallops (*Amusium japonicum balloti*) in the southern sections of the park. In addition, endeavour prawns (*Metapenaeus endeavouri* and *Metapenaeus ensis*) and Moreton Bay Bugs (*Thenus orientalis*) make up valuable by-catch in some areas.

The trawl fishery is a limited entry fishery. Licensed operators fish both components of the fishery and are free to fish anywhere within the GBRWHA where trawl fishing is permitted. Restrictions are placed on the size and number of nets used and also their mesh size. A logbook program has been established since 1988 and indicates that the total catch for the whole GBRWHA has fluctuated for both the tiger and king prawn fishery while catch per unit effort (CPUE) has remained relatively stable and actually increased in 1995. From the logbook data the fishery seems in sound condition although a number of issues currently face the trawl fishery including the excessive level of by-catch, the incidental capture of vulnerable turtle species, and the damage to sessile epibenthic communities. Most of these issues will be addressed in the development of the new management plan.

Both spatial and seasonal closures under fisheries management regime and the zonal management system for the GBRMP apply to the trawl fishery. Spatial closures are intended to protect fisheries habitat such as inshore seagrass beds or reserve areas free from extractive use. The area of the Great Barrier Reef lagoon that is protected from trawling is approximately 10% of which 40% is in the Far Northern Section of the GBRMP. Apart from nearshore areas much of the Great Barrier Reef lagoon south of Princess Charlotte Bay is not protected from trawling. This is a problem which GBRMPA is planning to evaluate and address in future major rezoning exercises for the entire Great Barrier Reef. Seasonal closures also apply in some areas and are designed to protect young adolescent prawns recruiting to the fishery and reaching a commercial size before fishing commences.

#### **Reef fish line fishery**

The commercial reef line fishery is also a limited entry fishery. Restrictions apply on the number of hooks used, and minimum size limits on the major species (*Plectropomus* sp, *Lutjanus* sp, and *Lethrinus* sp). The total catch of the principal species, the common coral

trout *Plectropomus leopardus* has fluctuated slightly since 1988 yet the CPUE has remained quite consistent. A number of issues currently face the fishery however, including the effectiveness of minimum sizes for hermaphroditic fish, the increasing interest in the live fish fishery, the latent effort in the fishery and what levels of fishing are ecologically sustainable in the different regions of the Great Barrier Reef.

Under the zoning plan, the GBRMPA makes no distinction between commercial and recreational operations in this fishery. The reef area that is protected is 12% of the total reef area yet approximately 65% of this protected area is in the Far Northern Section of the GBRMP. Clearly in the sections other than the Far Northern Section, very little protection is offered from fishing. Reef closures under the GBRMP zoning plan are for conservation purposes only and are not intended to be a fisheries management tool. Under the GBRMP a provision also exists, however, to nominate reefs as replenishment areas which enables suspected over-fished reefs to be closed for several years until fish stocks recover. The potential for reef closures to act as harvest refugia for fisheries management has been often speculated and attempts have been made to incorporate reef closures into the management of fish stocks in the Great Barrier Reef (QFMA 1996). Several studies of the status of fish stocks on open and closed reefs and on reefs opened to fish following years of protection suggest that fishing can significantly alter the number and size of targeted reef fish populations (Ayling and Ayling 1985, 1986). Preliminary studies at Bramble Reef which received a very high amount of fishing effort once the reef was reopened to fishing after 3.5 year closure, indicated that fishing may reduce the total coral trout population by 25% in the first two months (Sea Research 1996). How this scale of fishing affects the age and size structure of fish populations remains to be determined. However, not all studies have provided conclusive evidence that reef closures support more numerous and larger fish than their fished counterparts (Ayling and Ayling 1992) and may relate to the amount of fishing pressure, the strength of the age cohorts that are supporting the fishery and the amount of illegal fishing on protected areas.

#### Inshore gill net fishery

Two types of netting are associated with this fishery: i) beach seining and mesh netting; and ii) set net fisheries. Both components of the fishery are generally undertaken in coastal rivers and creeks, estuaries and foreshores extending to less than 0.5 km from low water mark. Beach seining targets Mullet, Whiting, Flathead, Bream and Tailor. Set netting targets fish which do not travel so much in schools such as barramundi, salmon and grunter.

The restrictions placed on the net fishery by the fisheries management agencies are limited entry plus a maximum length on net and minimum mesh size. There is a minimum size on the major fish species taken and also a maximum size limit on some species. A closed season exists for Barramundi from November to February. Spawning zones also exist at the mouths of some rivers and some estuaries are closed to commercial netting.

In the GBRWHA certain areas cannot be net fished under Great Barrier Reef and State Marine Park regulations. Gill netting impacts considerably on the exploited fish stocks and threatens vulnerable species such as dugong in a number of localities in the GBRWHA. Current zoning arrangements are potentially inadequate to counteract the decline in dugong numbers at the most significant areas in the animal's distribution.



## **A strategic approach to managing fishing impacts by the Great Barrier Reef Marine Park Authority**

To ensure that the nature conservation and world heritage values of the GBRWHA are maintained, the GBRMPA is adopting a strategic approach to managing fishing impacts which contains the following components:

### **1. Improving knowledge of fishing and its impacts**

To achieve this objective a four stage process is considered which includes:

#### *(i) Research into the environmental impacts of fishing*

Research began in 1992 into the impacts of trawling on marine ecosystems including the effects on the target species, the by-catch and the sea-bed communities, recovery of benthos after trawling, and the effectiveness of closing large areas as a management tool to conserve the prawn stocks and associated sea bottom communities. Additionally, research has been proposed to investigate the effects of reef based fishing on targeted reef fish stocks, the recovery of fished populations following protection, the gross secondary effects on non-target species and indications of sustainable levels of fishing.

#### *(ii) Spatial and temporal distribution of fishing*

The commercial fishing logbook records provide the best information of the coarse distribution of fishing effort and catch. QFMA are currently developing a database to record recreational catch and effort data. The resulting maps of fishing distributions provide indications of high fishing areas and hence potential areas of major fishing impacts. The fishing distribution maps can be refined with time as other data comes to hand and the accuracy and definition of the fishing records improve.

#### *(iii) Description of ecological communities in the Great Barrier Reef Marine Park*

Little is known about many communities in the GBRMP particularly in the inter-reefal areas and the Great Barrier Reef lagoon. Such areas have been largely overlooked by scientific research in the last two decades. The paucity of data for inter reefal areas and the Great Barrier Reef lagoon makes the mapping of these areas extremely difficult and requires the compilation of existing data to identify proxies, e.g. sediment type, that could be used to provide a coarse map of biotypes. It is expected that the limitations in the data will highlight regions where additional information needs to be collected.

#### *(iv) Spatial modelling of fishing impacts over the Great Barrier Reef Marine Park*

The spatial modelling is the culmination of the synthesis of information on where fishing occurs, what ecological communities occur in fished areas and their sensitivity and resilience to fishing impacts. With a spatial model of fishing impacts it is then possible to assess whether the current zoning regime for the GBRWHA is adequate in protecting representative habitat types, critical areas and rare and endangered species.

### **2. Adequate protection of habitats**

By compiling as much information as is available on the species and habitats in the Great Barrier Reef, the major and critical habitats in the Marine Park are identified. The aim of this work is to establish a system of ecologically representative areas, and ensure adequate protection is afforded to these habitats.

### 3. Integrated ecosystem and fisheries management

The integration of fisheries and ecosystem management in the GBRMP is being achieved through continual collaboration with fisheries management agencies and the fishing industry. It is the intent of GBRMPA to ensure effective representation is maintained on Fisheries Management Advisory Committees and by ensuring fisheries management complements the Marine Park management planning. The GBRMPA also actively supports new/improved technology to reduce by-catch and capture of vulnerable and endangered species, in association with management agencies and industry.

### 4. Protection of endangered species

By zoning and other species-specific management strategies, rare, threatened and endangered species, together with their critical habitats, are protected from the effects of fishing.

### 5. Involvement of indigenous peoples

The GBRMP continues to support traditional fisheries of Aboriginal and Torres Strait Islander peoples. The GBRMPA's strategy is to recognise and involve indigenous peoples in Marine Park management to develop management strategies for the ecologically sustainable use of the area.

### 6. Compliance

The Marine Park is used by recreational and commercial fishers, tourist operators, pleasure craft, divers and shipping. Surveillance is carried out using vessels and aircraft that regularly patrol the Great Barrier Reef, to obtain activity data and to ensure compliance with Marine Park legislation. The most prevalent offence occurring in the Marine Park is illegal fishing in the Marine National Park 'B' Zone, a 'look but don't take area'. In addition to prosecution, education is a key to reducing this activity. By informing the users about the values and attributes of the Great Barrier Reef, they will have a greater understanding and a commitment to conservation and ecologically sustainable use of the world's largest and most complex Marine Park.

### Conclusion

Fishing is an important use of the GBRMP but has the potential to impact significantly on the Great Barrier Reef. It is the objective of both the QFMA and GBRMPA to ensure that fish stocks are conserved and that fishing is ecologically sustainable. The QFMA has established a consultative management framework to allow all major interests to be incorporated into the management of Queensland fisheries. This system appears to be achieving its objective in the current review and development of all fisheries management plans. The zoning plans used in the management of the GBRMP are intended to protect the resources of the Marine Park while providing a reasonable opportunity for fishing to continue. The extent to which they do that is open to debate. A greater understanding of the environmental effects of fishing and the application of broad-scale habitat protection measures are required to be sure that the zoning plans adequately address the GBRMPA's conservation objectives.

The GBRMPA is taking a strategic approach to dealing with the impacts of fishing. The components of the strategy will serve to improve our understanding of fishing and its ecological impacts in the GBRWHA and to ensure that representative ecological communities and vulnerable species are adequately protected from extractive use. The

approach will hopefully ensure that in fished areas, fishing is undertaken in a equitable and ecologically sustainable way.

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# Penaeid prawn stocks

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## Abstract

An on-going series of research projects on the reproductive biology, population dynamics, and spatial distribution of prawn stocks of the Great Barrier Reef region have been carried out by the Queensland Department of Primary Industries Fisheries Division from the early 1980s till the present. Sites for these studies stretched from the southern Great Barrier Reef to the border of the Torres Strait and have included Bowen/ Mackay (21°S), Townsville (19°S), Cairns (17°S), Princess Charlotte Bay (14°S), and the cross-shelf closure (Green Zone) from Shelburne Bay to Raine Island (11°S).

Based on this research 22 species of penaeid prawns have been identified from the Great Barrier Reef region, with seven of these being commercially exploited by the Queensland East Coast Trawl fleet. The stocks of the commercial prawns are genetically continuous although tagging studies suggest that there are local populations with a low level of cross-migration which maintains the genetic homogeneity. The movement by a small percentage of the population also provides 'pioneers' for new areas of suitable habitat or areas that have been depopulated due to storms or heavy trawling. Commercial species tend to inhabit the inshore reefal lagoon with the exception of *Penaeus longistylus* (the red spot king prawn) which is associated with the reef and inter-reef habitats. Strong spatial trends have been found in the distribution of the penaeid prawns in the Great Barrier Reef region with each species occupying a preferred zone or habitat type as part of a complex cross-shelf mosaic. Spatially auto-correlated phenomena are also apparent due to 'schooling' or contagious distribution of adults. Juvenile prawns are associated with inshore seagrass and algal beds, or with the reef-top seagrass beds in the case of *Penaeus longistylus*. Recently discovered deep water seagrass beds appear to have a suite of non-commercial 'coral prawn' species associated with them.

Stocks currently appear to be stable but fully exploited with the prawn trawl fleet subject to input controls, limited entry, and a two-for-one boat upgrade condition. There are three to four major commercial categories of prawn caught for both export and domestic markets; these are the tiger, king, banana, and endeavour prawns. Each commercial category represents at least two species which can raise problems for management. In particular it is difficult to optimise the timing of seasonal closures to protect against growth overfishing with juveniles arising from multiple species with asynchronous spawning. The multi-species nature of the fishery also has the potential danger of over-fishing a less common but commercially valuable species while maintaining economic viability by catching the lower value but more common species.

## Introduction

It is the intention of this paper to review the current management strategies, trends in catch/effort, and the available knowledge on the biology and population dynamics of penaeid prawn stocks of the Great Barrier Reef World Heritage Area (GBRWHA). The basis of the analysis is the results from an on-going series of research projects on the reproductive biology, population dynamics, and spatial distribution of prawn stocks of the Great Barrier Reef region carried out by Queensland Department of Primary Industries Fisheries Division from the early 1980s till the present. Sites for these studies stretched from the southern Great Barrier Reef to

the border of the Torres Strait and have included Bowen/Mackay (21°S), Townsville (19°S), Cairns (17°S), Princess Charlotte Bay (14°S), and the cross-shelf closure (Green Zone) from Shelburne Bay to Raine Island (11°S). These studies include the full latitudinal extent of the GBRWHA but particular emphasis will be given to the northern section of the Great Barrier Reef where long-term datasets are available.

### Queensland East Coast Prawn Trawl fishery

The Queensland East Coast Prawn Trawl fishery is 'limited entry' requiring a Queensland Fisheries Management Authority (QFMA) license and endorsements but there are currently 870 boats licensed, with the right to fish in any fishing zone along the 2000 km of coast. Within the Great Barrier Reef section fishing is restricted to certain areas according to the Great Barrier Reef Marine Park Authority (GBRMPA) zoning plan. The fishery in the northern section of the Great Barrier Reef is also subject to a two and half month seasonal closure from mid-December till March. The central and southern sections have been subject to seasonal closures in the past but are currently subject only to selective inshore area closures to protect juvenile prawns. Nets are restricted to 50 mm diagonal stretch multi-filament mesh with a maximum of 20 fathoms (36.6 m) headline length; usually configured as four, five fathom nets (Quad-gear). Otter trawl (bottom trawl) gear using ground chain is standard. The average size of trawlers in the fleet is relatively small at 17 m waterline length, with a size limit of 20 m. Most of the trawl grounds are located in the inshore reefal lagoon of the Great Barrier Reef, within 30 km of the coast. The commercial catch is separated according to buyers categories which may contain more than one species, see Table 1. The majority of commercial prawn species are caught at night however there is a small daylight inshore fishery for banana prawns. Total number of kilograms of prawns caught (all species), and days fished are given in Fig. 1 for each half degree band between 11°00' to 24°00'S.

**Table 1.** Commercial categories and scientific names of prawn (shrimp) species targeted by the Queensland East Coast Prawn Trawl fishery

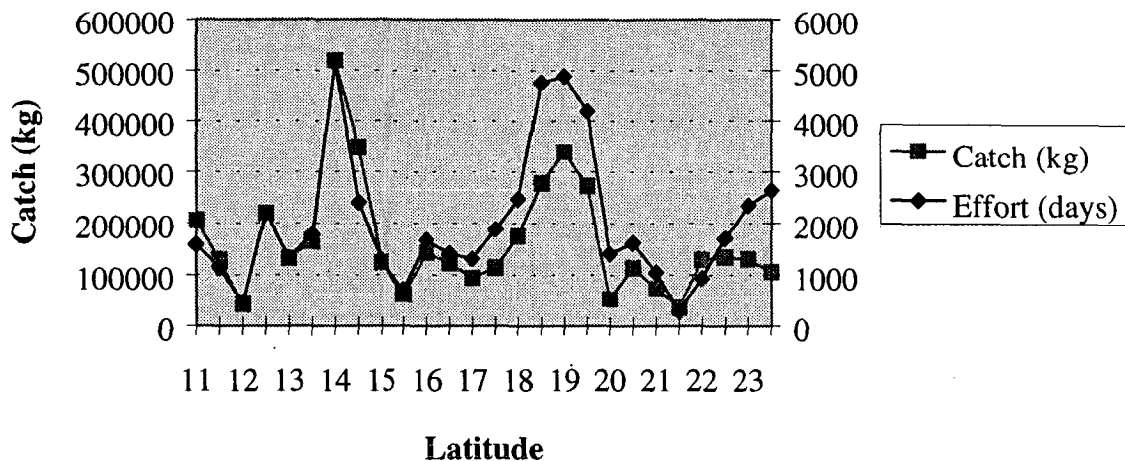
Category	Common name	Species
Tiger	Brown tiger prawn	<i>Penaeus esculentus</i>
	Grooved tiger prawn	<i>Penaeus semisulcatus</i>
King	Red spot king prawn	<i>Penaeus longistylus</i>
	Blue leg king prawn	<i>Penaeus latisulcatus</i>
Dev's or Endeavours	True endeavour prawn	<i>Metapenaeus endeavouri</i>
	False endeavour prawn	<i>Metapenaeus ensis</i>
Banana	Banana prawn	<i>Penaeus merguensis</i>

There were two major peaks in catch and trawling activity, one in Princess Charlotte Bay (14°S) and a second off Townsville (19°S). Highest catches were made in Princess Charlotte Bay while most effort, for less return, was put into Townsville. This pattern of catch and effort has been relatively stable for a number of years.

### Commercially exploited prawn stocks

Twenty-two species of penaeid prawns have been identified from the Great Barrier Reef region, with seven of these being commercially exploited by the Queensland East Coast Trawl fleet (Table 1). The stocks of the commercial prawns are genetically continuous although tagging studies suggest that they consist of local populations with a low level of cross-migration which maintains the genetic homogeneity (Clive Keenan, Southern Fisheries Centre, pers. comm.). The movement by a small percentage of the population also provides 'pioneers' for new areas

of suitable habitat or areas that have been depopulated due to storms or heavy trawling. Through the latitudinal range of the GBRWHA commercial prawn species tend to inhabit the inshore reefal lagoon with the exception of *Penaeus longistylus* (the red spot king prawn) which is associated with the reef and inter-reef habitats (Dredge 1989). Strong spatial trends have been found in the distribution of the penaeid prawns in the Great Barrier Reef region with each species occupying a preferred zone or habitat type as part of a complex cross-shelf mosaic. Spatially auto-correlated phenomena are also apparent due to 'schooling' or contagious distribution of adults. Juvenile prawns are associated with inshore seagrass and algal beds, or with the reef-top seagrass beds in the case of *Penaeus longistylus*. Recently discovered deep water seagrass beds appear to have a suite of non-commercial 'coral prawn' species associated with them (W. Lee Long, Northern Fisheries Centre, pers. comm.).



**Figure 1.** 1994 profile of catch/effort in the prawn trawl fishery for each half degree of latitude in the Great Barrier Reef World Heritage Area

Industry does not distinguish between the brown and grooved tiger prawns but these are distinct species with different spawning times. The ratio between brown tiger prawns and grooved tiger prawns varies geographically and appears largely dependent on the distribution of high mud content sediments. Similarly the ratio of the two endeavour prawns is variable but in most studies cited the blue endeavour prawn dominated the commercial catch, particularly in the northern section.

The population structure changes from predominantly small prawns early in the year, due mainly to the influx of tiger prawn juveniles, to larger export-grade prawns mid-year as the recruits grow and move into deeper water. Recruitment from endeavour and king prawn species and a second pulse of grooved tiger prawn recruits in April to June make the picture more complex. Both species of endeavour prawns tend to recruit throughout the year but with a summer maximum, hence there will be small prawns from a number of species on the trawl grounds all year. For all species, spawning and recruitment take place over a number of months and can be affected by climatic variables such as rainfall and cyclones. The current timing of the seasonal closure in the northern Great Barrier Reef protects the majority of juvenile brown tiger prawns up to 21/30 commercial size category (sub-adults). In both the northern and southern sections inshore area-closures provide protection for both recruits and juvenile nursery habitats (e.g. Derbyshire et al. 1995) of all species.

### **Spatial distribution of prawn stocks**

A study of the cross-shelf spatial distribution of penaeid species on the far northern Great Barrier Reef was part of an integrated project investigating the environmental effects of commercial trawling on the Great Barrier Reef, carried out by the fisheries divisions of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Queensland Department of Primary Industries (Gribble et al. in press). The project provided a unique opportunity to study the spatial distribution of relatively undisturbed coral reef communities in heterogeneous cross-shelf habitats over an area of 3 429 900 hectares (10 000 square nautical miles) of the northern Great Barrier Reef.

The basic sampling design was a matrix of five cross shelf strata and four north-south strata comprising two north-south divisions of the Far Northern cross-shelf closure area (Green Zone) and the open areas to the north and south of the closure. The mid-shelf reef/shoal area was subdivided into two east-west strata to balance the relative areas sampled and to reflect the importance of this habitat. Power analysis based on the variation in prawn abundance in preliminary surveys suggested that five stations per matrix cell would allow statistically valid comparisons to be made. This gave a total of 100 possible stations to be sampled for prawn, fish, benthos and sediments.

Multi-dimensional scaling (MDS) analysis showed a definite gradient in abundance and biomass in prawn species from the inshore lagoon through onto the mid-shelf reef-shoal zone; with a relatively low number of large-bodied species in the inshore lagoon and a larger number of smaller bodied species offshore in the reef-shoal zone. Isopleth plots of species abundance and biomass, when overlaid onto a map of the study area, showed a mosaic or 'jig-saw' of interlocking distributions with each species occupying 'preferred' areas or regions on the cross-shelf. The spatial distributions of individual species showed both large scale gradients across the reef shelf and smaller scale autocorrelated concentrations within these distinct regions of the cross-shelf habitat. Canonical correspondence analysis (CCA) was used to explore and partition the variance in the abundance into spatial and environment components (Gribble et al. in press). Approximately 9% of the variance was attributed to intrinsic spatial effects, 9% to purely environmental effects, and 29% of the total variance to spatially structured environmental effects.

In the southern Great Barrier Reef, between Townsville and Bowen, a study on prawn distribution and reproductive biology showed a distinct segregation between the inshore tiger prawns and the reef associated red spot king prawns (Dredge 1989). The study did not include surveys of the full cross shelf habitat but did indicate that similar spatial partitioning between prawn species occurred in the inshore lagoon and inner shoal reef area.

### **Management**

Ian Somers (CSIRO) reviewed the options for manipulation of fishing effort and the benefits of seasonal closures in Australia's prawn fisheries, mainly from the perspective of the Gulf of Carpentaria prawn trawl fishery (Somers 1990). He stated that 'limited entry in conjunction with restrictions on vessel and gear characteristics has become the standard means of controlling total fishing capacity (such as in the Great Barrier Reef World Heritage Area). Closures are now the most popular, administratively simple, equitable, and socially acceptable means of manipulating fishing effort patterns to optimise catch size composition.' He also pointed out that seasonal closures can reduce operating costs without reducing annual revenue and will make seasonal peaks in catch rates more regular. Seasonal closures have been in place as a management strategy for the past 10 years in the Queensland East Coast Prawn fishery,

which includes the GBRWHA, principally to protect juvenile *Penaeus esculentus* (brown tiger prawn) from growth overfishing (Glaister 1989; Watson and Mellors 1990).

In his stock analysis Somers (1990) used a simplified model for a single species fishery with tiger prawns and banana prawns modelled separately. Watson and Restrepo (1995) used a more sophisticated model to explore the effects of multiple recruitment pulses on the yield of prawn fisheries and the effect of an increase in fishing effort that can occur in anticipation of valuable catches immediately following a closure (i.e. a 'pulse' of effort). They found when a species had a single tight cohort of recruits then an appropriately timed closure could improve the yield-per-recruit to the fishery by 30% to 40%. If however recruitment was spread out in a multi-cohort pattern then the best a closure could improve yield-per-recruit was 7%. A multi-species yield-per-recruit analysis (Gribble and Dredge 1993) found that the seasonal closure on the Queensland central coast only improved the yield by 5%. Similarly a multi-species assessment of the closure in Princes Charlotte Bay, on the Queensland northern coast, showed at best a 5-10% improvement in yield and value (Derbyshire et al. 1993). The direct benefit of seasonal closures in multi-species prawn fisheries in the Great Barrier Reef region would appear to be relatively low but as noted by Somers (1990) there are operational cost savings to fishers by not fishing during the closure. There also may be environmental benefits from 'resting' the trawl grounds for three months each year.

Socio-bioeconomic models describing the interaction of fleet dynamics (the behaviour of fishers), the population dynamics of prawns, and market forces are rare (e.g. Krauthamer et al. 1987). Cobb and Caddy (1989) noted a byproduct of seasonal closures protecting juvenile prawns on the Gulf coast of Texas was a strong pulse of fishing effort as fishers congregated in anticipation of large catches at the opening of the season. The economic implication of the pulse was an increase in overall revenue due to the increase in product although the revenue per boat did not necessarily increase because of the larger number of boats fishing. The biological implication was increased pressure on the stock which actually went against the original management aims of the seasonal closure. On a much smaller scale a similar 'pulse' of effort occurred at the start of the fishing season on the Queensland central coast prawn trawl grounds (Gribble and Dredge 1993), and on the Queensland northern prawn trawl grounds (Gribble and Turnbull 1996). Again there was an increased yield in proportion to the increased effort at the beginning of the season, but with an unknown long-term effect on the prawn stocks.

The most comprehensive research project(s) into prawn stocks and the effects of the seasonal closure in the GBRWHA have been carried out in the northern section of the Great Barrier Reef centred on Princess Charlotte Bay (Coles et al. 1985, 1987; Derbyshire et al. 1993; Gribble and Turnbull 1996). The general conclusions from this work were that the prawn stocks had remained relatively stable over time and that the current seasonal closure over the December to March period was effective in protecting juvenile recruitment of a number of commercially important prawn species. There was a direct gain of 5% to 9% in dollar value to the fishery by having the seasonal closure, the commercial prawn stocks were fully exploited, and a reduction in effort was considered prudent (in line with the QFMA's two-for-one boat replacement policy).

#### **Fishing effort in the northern Great Barrier Reef (10° to 15°S latitude)**

Over the five years from 1990 to 1995 an average of 274 boats per year fished within the northern section of the GBRWHA although not necessarily over the full year nor in every year. Boats that fished in the section every year made up only 25% of the fleet (see Table 2). The maximum number of days spent in the fishery by a single boat in any year ranged from 216 to 266 days, the minimum was one day (see Table 3). To put this in perspective, given the annual seasonal closure of approximately 90 days then the absolute maximum that could be fished



would be around 275 days in any one year. Total fishing effort over the five years was 95 884 boat-days at an average of 19 177 boat-days per year.

**Table 2.** Number of boats that fished the northern section of the Queensland East Coast Prawn Trawl grounds in one or more years over the five years analysed

Years Fished	Number of boats
5 out of 5 years	117
4 out of 5 years	74
3 out of 5 years	67
2 out of 5 years	83
1 out of 5 years	123
TOTAL	464

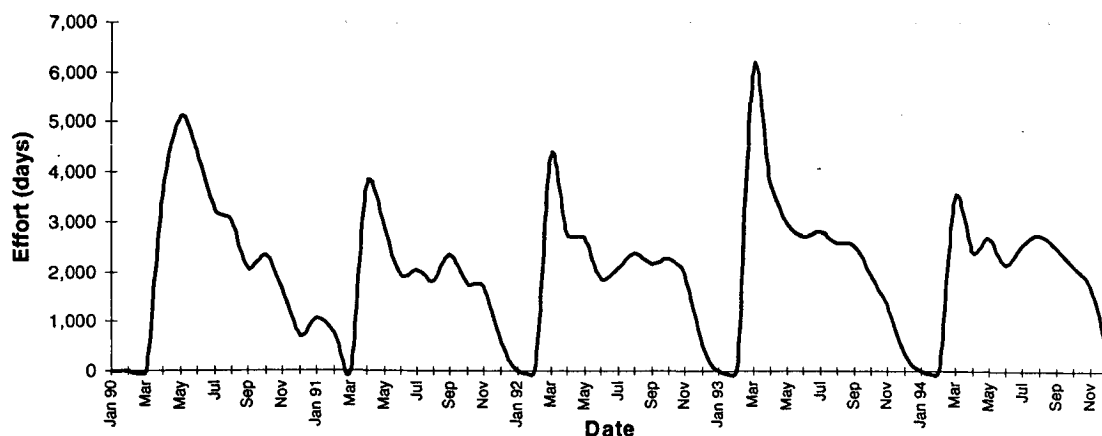
Analysis of the summary logbook data highlights the highly mobile character of the Queensland East Coast Prawn fleet, particularly in the north. Only 41% of the fleet fished in the northern section for more than four out of the five years analysed. The remainder of the fleet either fished elsewhere on the coast (or in the Gulf of Carpentaria or Torres Strait) or were out of the fishery for other reasons for at least one full year. Within any year less than 20% of the fleet fished in the northern section for more than 150 out of a possible 275 days. The remaining 80% of the fleet fished in other fisheries as well as the northern section for a large proportion of the year. This mobility makes defining a 'local boat' very difficult. Boats that are registered at ports within the section may not fish there consistently, as is the case with dual endorsed boats that work a large proportion of the season in the Torres Strait. Less than 6% of the boats fishing the northern section were registered locally (QFMA data) and spent more than 150 days in the fishery for more than four out of the five years studied.

**Table 3.** Fishing effort in the northern section of the Queensland East Coast Prawn Trawl grounds (southern edge of Torres Strait to Cape Tribulation)

	1990	1991	1992	1993	1994
Total days	20652	16661	18145	21756	18670
No. boats	312	281	252	266	260
Avg boat day	66.2	59.3	72.0	81.8	71.8
Min. boat day	1	1	1	1	1
Max. boat day	231	216	253	266	247
Boats spending >150 boat days in section	27	31	51	58	47
Boats spending < 50 boat days in section	149	158	143	126	129

#### Profile of fishing effort in the northern Great Barrier Reef (10° to 15°S latitude)

A monthly breakdown of fishing effort in the northern section of the Queensland East Coast Prawn Trawl grounds is summarised and presented as a time-series in Fig. 2. The annual seasonal closure extended from early December till early April during 1990-91 and till early March in 1992-93-94. A pulse of effort at the beginning of the fishing season was pronounced in each year, the effort then diminished throughout the rest of the year.



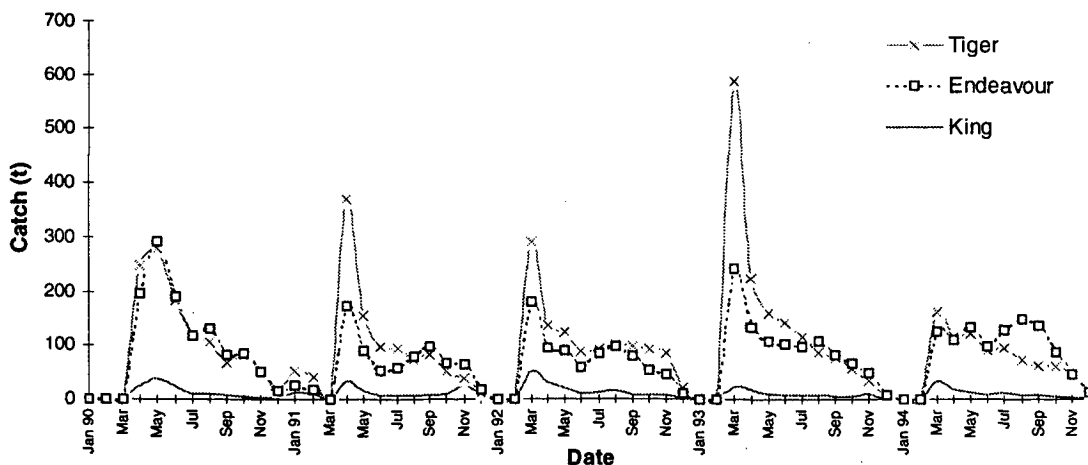
**Figure 2.** Time plot of monthly fishing effort in the Northern Section of the Queensland East Coast Prawn Trawl grounds for each year from 1990 to 1994 (source QFISH Logbook database)

**Profile of catch and catch per unit effort (CPUE) in the northern Great Barrier Reef (10° to 15°S latitude)**

During the five years between 1990 and 1994 the annual prawn catch from the northern section of the Queensland east coast prawn trawl grounds remained reasonably stable at around 2266 tonnes but ranged from 2005 to 2627 tonnes (Table 4). The yearly catch profile mimicked the effort with a pulse of at the beginning of each fishing season then a diminishing return throughout the rest of the year (Fig. 3).

**Table 4.** Prawn catch in tonnes from the northern section of the Queensland east coast prawn trawl grounds (taken from the southern edge of Torres Strait to Cape Tribulation)

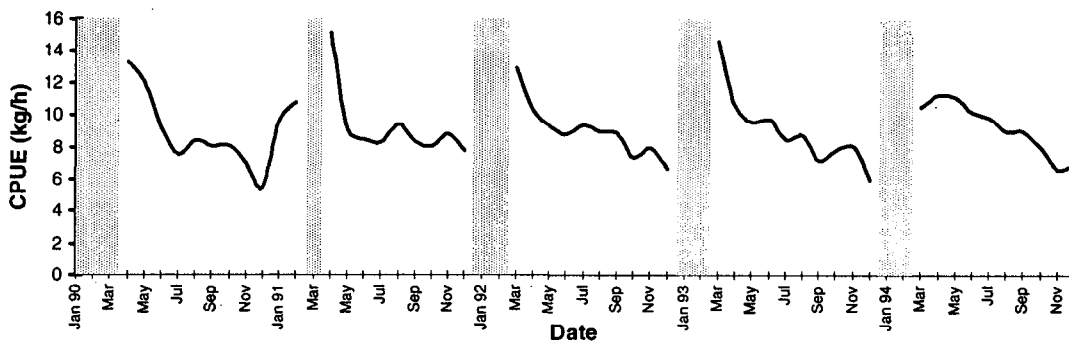
	1990	1991	1992	1993	1994
Total	2516	2032	2147	2627	2005



**Figure 3.** Time plot of monthly prawn catch for the major species groups, from the Northern Section of the Queensland East Coast Prawn Trawl grounds for each year from 1990 to 1994

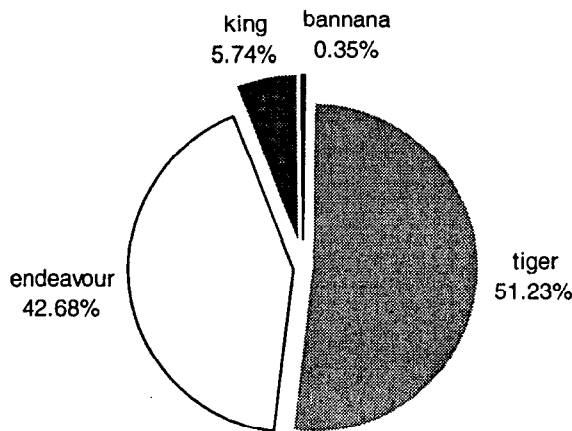
Catches of endeavour prawns tend to mirror the catches of tiger prawns at the start of the season (Fig. 3). Although tiger prawns are the primary target species the two species groups generally occur in similar areas and this is reflected in the catch. In the later half of the year however, catches of endeavour prawns often increase while tiger prawn catches continue to drop. A similar pattern has been observed in the catches of the Torres Strait Prawn Fishery (Turnbull, Queensland Department of Primary Industries data).

The resultant CPUE (Fig. 4) has an initial sharp decline then remains reasonably constant dropping again late in the season, as seen in similar studies within the section in the past (Derbyshire et al. 1993). Catch and CPUE in the northern section of the East Coast Trawl grounds have been relatively stable over the last five years, given a high inter-annual variability typical of tropical penaeid fisheries. There are no major detrimental trends evident, although a slight decline in tiger prawn catch may be present.



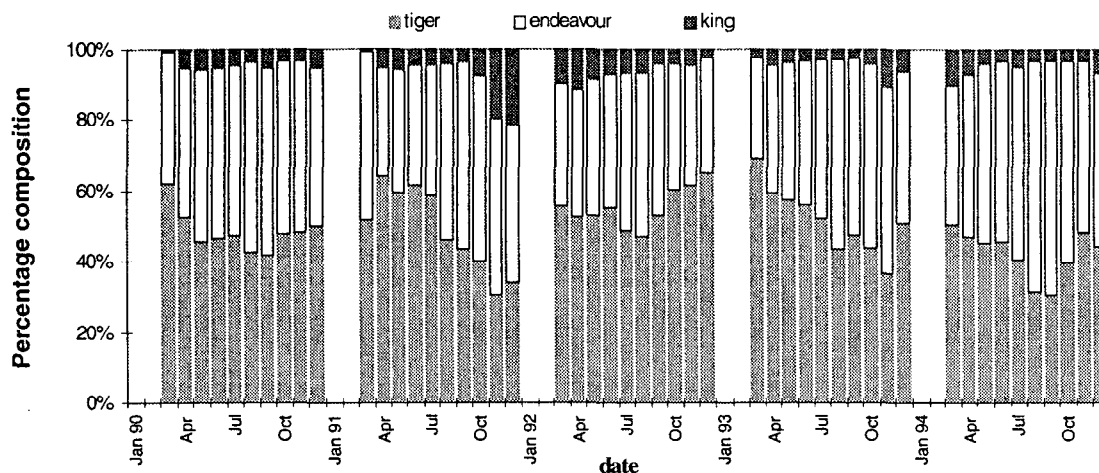
**Figure 4.** Time plot of monthly prawn CPUE in kg/boat hour from the Northern Section of the Queensland East Coast Prawn Trawl grounds for each year from 1990 to 1994. Note shaded bars represent seasonal closure.

A breakdown by commercial species category is shown in Figs. 5 and 6. Minor species made up less than 2% of the catch, the major components were tiger prawns, endeavour prawns, and king prawns (both red spot and blue leg kings). In terms of export earnings the tiger prawn catch is the most important, however the catch of endeavour prawns represents a substantial proportion of the value on both the local market and as a relatively low value export.



**Figure 5.** Catch composition by weight of the prawn trawl catch from the Northern Section of the Queensland East Coast Prawn Trawl grounds from 1990 to 1994

The percentage of tiger prawns in the monthly catch appears to have two peaks, one at the beginning of the fishing season and a second smaller peak in the second half of the year. These peaks may simply reflect the mix of brown tiger and grooved tiger prawns that are caught in the northern section. The brown tiger has a single spawning and pulse of recruits in the summer while the grooved tiger has two spawnings one in summer and a second in autumn.



**Figure 6.** Percentage species composition by weight of the prawn trawl catch from the Northern Section of the Queensland East Coast Prawn Trawl grounds for each year from 1990 to 1994

**Profile of price per species in the northern Great Barrier Reef (10° to 15°S latitude)**

Gribble and Dredge (1993) showed that the export price structure is as important as population dynamics of prawn species when considering dollar value per recruit to the fishing fleet. The elastic 'supply-demand curve' describes the normal situation where if large quantities of prawns are available to the market then the price drops and if the supply of prawns is limited then the price rises. This normal situation can be distorted by factors outside the market affecting the demand for prawns. Two such events, the death of the Japanese Emperor and wide scale failure in Asia of aquaculture prawn crops due to disease, caused the price of prawns exported to Japan to fall in the first case, and in the second example caused the price of Australian prawns to rise due to a lack of low-cost competition. These events have shown that the export prawn price structure can be 'demand driven' and is not determined simply by the quantity of prawns caught.

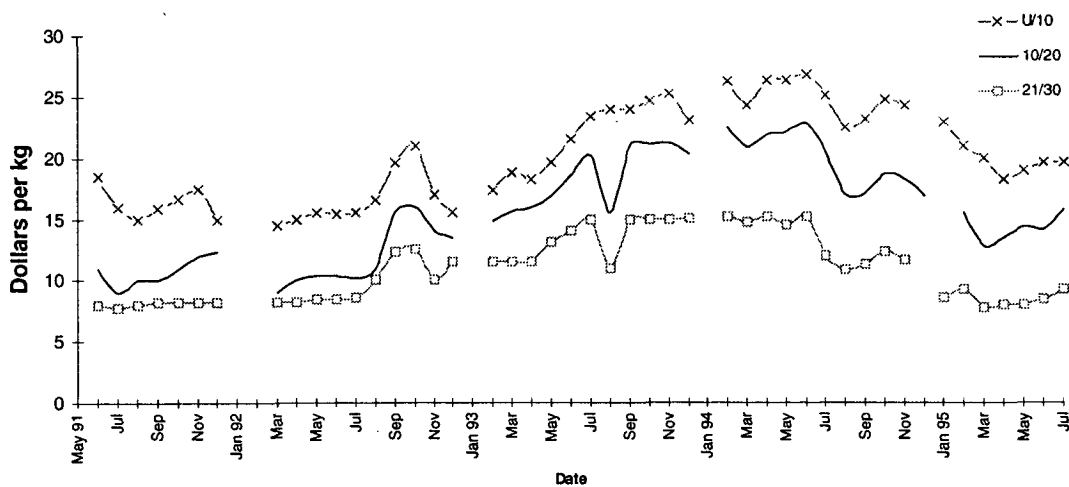
In normal circumstances the pulse of effort at the start of the season would supply large quantities of prawns to the market hence the price should be relatively low. In the northern section boats only fishing during the first few weeks of the season would tend to exploit the large quantities of relatively low value prawns. Boats fishing over the full year would exploit the lower quantities of higher value prawns on a more sustained basis. Reinforcing this pattern is the occurrence of brown tiger prawn recruits (small prawns) early in the season, with the high-value export grades not normally caught till later in the year. As seen above however, a volatile export price structure can modify this simple scenario.

The yearly variation in price of commercial categories of tiger prawns (Fig. 7) shows this volatility clearly. In 1992 and 1993 the price of all size categories started low then increased as the season progressed, following the normal supply-demand relationship. Comparing the catch in kilograms in 1993 (Fig. 3) with the price structure in that year (Fig. 7) is a good example of

the law of supply and demand; when catches were good the price was low. In 1994 and 1995 however the prices began on a high then dropped which is the reverse of what could have been expected based on the previous two years. In 1994 the catch was not large in the early part of the season (Fig. 3) which partially explains the high prices early in that year. The price differential between U/10, 10/20, and 21/30s appears to have widened in each year from 1992, with an increasing premium being paid for U/10. The price paid for 21/30s was the same in 1995 as in 1992 although it had increased then decreased in the two intervening years.

The prawn price information reflects the complex system of commodity economics where a large number of domestic and overseas influences can affect the price gained by the producer. There can be variation within and between years in both the price for a species and in the price per size category. The dollar value or financial benefit of the seasonal closure will depend largely on the price paid in a particular month rather than on the generalised price profile of a typical or 'normal' year. In the best case scenario, where high prices are paid at the start of the season, the current closure will increase revenue by maximising the number of export-size prawns in the catch. In the case where prices are initially low, the benefit of the closure will be reduced because of an over supply of low-value product too early in the season.

The major implication of this volatile price structure is that the differential prices paid for both species and size classes has the potential for altering the fishing effort of the fleet. Price as well as prawn abundance can determine the fishing pressure hence fishing induced mortality. The multi-species nature of the fishery also carries the danger of over-fishing a less common but commercially valuable species while maintaining economic viability by catching the lower value but more common species.



**Figure 7.** Yearly price structure for tiger prawn from the northern section of the Queensland East Coast prawn trawl grounds, over the period from 1991 to 1995

### General discussion

The consensus of industry and fisheries research organisations is that the Queensland East Coast Trawl Prawn fishery is fully exploited at the moment, with a gradual reduction in participating boats planned. A series of short-term research projects within the GBRWHA over the last sixteen years, when taken as a series of snapshots, have shown no evidence of a major stock decline in commercial prawn species. Anecdotal and historic logbook information provide some evidence of a gradual change in species composition from predominantly tiger prawn to a mixture of tiger and endeavour prawn. This is far from conclusive as the market

acceptance of endeavour prawn has increased through the years and now the fleet may be deliberately targeting and retaining these prawns. Given the proviso that tropical fisheries in general tend to be highly variable and may be subject to long-term climatic variability (e.g. El Niño), the current status of the commercially exploited prawn stocks would suggest that the current level of fishing is sustainable.

Estimation and prediction of future trends in prawn stock status are complex tasks. Changes in the market, both domestic and overseas, can affect the targeting behaviour of the trawl fleet which directly affects fishing mortality. Technological change, particularly in fishing gear and navigation aids will increase fishing efficiency of individual boats which may increase the effective effort of the fleet even though the number of participating boats is being reduced. For example the general adoption of Global Positioning Systems (GPS) by the fleet means that boats can now locate a prawn aggregation (or 'school') with a 100 m accuracy. This ability creates a distortion in the CPUE calculations as these no longer give an index of the underlying abundance of the prawns but rather gives the abundance of prawns within the aggregations. It is possible that the CPUE may remain stable until the last school is fished out, as with the cod fishery off Canada. A second consideration with GPS is that computer disk charts that are produced by experienced operators can be transferred to a boat operated by a novice instantly up-grading the novice's efficiency. Local knowledge and expertise that may have taken years to acquire can be transferred electronically, potentially turning the whole fleet into 'instant experts'.

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# Tourism impacts

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## Abstract

Tourism is the principal commercial use of the Great Barrier Reef Marine Park and World Heritage Area. The Reef tourism industry is estimated to be worth well over \$1 billion per annum, well in excess of the commercial fishing industry in the area. Assessment and management of the impacts of tourism are necessary to adequately provide for the protection of the ecological, social and cultural values of the Great Barrier Reef World Heritage Area.

In general, it is considered that the ecological impacts of specific Marine Park tourist developments and works are localised, and have to date been well predicted and managed. With such development projects, detailed assessment and monitoring of impacts have provided a reasonably good information base on which to base this conclusion. Procedures for the assessment and management of impacts of structures and developments within the Marine Park are discussed in this paper, with emphasis on ecological impacts and with reference to some specific case studies. The procedures for monitoring the impacts of approved developments involve scientifically rigorous monitoring programs conducted by independent consultants, and these procedures are considered a good model for effective and impartial monitoring.

Much less information is available on the impacts of tourism and recreation activities where detailed assessment and monitoring have not been possible or required but where cumulative impacts of use at heavily used locations may be a cause for concern. For example, there has been concern regarding anchor damage to coral caused by tourist and private vessels. However, apart from some limited information from the Whitsunday region and the 'Cod Hole' (Cairns Section), few data are available at this stage on the extent of anchor damage or recovery of affected corals. Indeed, in some areas of the Cairns Section, the effectiveness of policy which has required tourist operators to use moorings at certain reefs in order to prevent anchor damage has not been scientifically verified, although casual observations suggest the measures have been successful.

Within the Great Barrier Reef Marine Park and on the adjacent islands, there has been increasing concern regarding the impacts of tourism on social or amenity values, and on the cultural and traditional values of such areas for indigenous people. Great Barrier Reef Marine Park Authority policy has given first priority to the minimisation of impacts of an ecological nature. However, as tourism use of the Marine Park continues to grow steadily, especially off Cairns and Port Douglas, social and cultural issues are receiving much greater attention in Marine Park zoning, management planning and permit assessment.

Finally, as noted in previous reviews of Marine Park tourism impacts, the greatest threats to the Great Barrier Reef Marine Park and World Heritage Area are considered to be the use and development of adjacent mainland areas. Thus coastal development, loss of mangroves and seagrass areas, and increasing input of effluent associated with urban expansion including tourism infrastructure, may result in equal or greater impacts on the Great Barrier Reef area, than impacts arising from tourism infrastructure and activities located within the Marine Park. Limited data are available on the impacts of such development, but the Marine Park Authority's concerns regarding coastal development and land use are receiving increased attention, for



example in the context of evaluating World Heritage values and development of strategic policy on coastal development.

In conclusion, some good data sets exist regarding specific tourist developments within the Marine Park, where ecological impacts appear to be localised and insignificant. In contrast, comparatively little quantitative information is available about the social and cultural impacts, or the cumulative ecological effects of tourism operations conducted within the Marine Park and World Heritage Area. Similarly, little information is available regarding the impacts on the Great Barrier Reef of coastal and tourism development on the adjacent mainland. The cumulative ecological impacts of present and future development on the Great Barrier Reef could prove to be greater than those of tourist operations and structures located within the Marine Park.

## **Introduction**

Tourism is the principal and most rapidly growing industry in the Great Barrier Reef province, and its management is a major task for the Great Barrier Reef Marine Park Authority and other agencies, such as the Queensland Department of Environment, involved in managing the World Heritage Area. The principal objective of the Authority in managing use, including tourism, is to protect the natural values and ecological processes of the Great Barrier Reef province. In addition, the Authority has responsibilities to provide for a range of uses consistent with conservation of natural features and processes. With growth in use, greater attention is now being paid to maintenance of social and cultural values which may be impacted upon by, for example, increasing tourism activity (see, for example, Honchin 1996; Williams in press and other reports in this publication.) The Authority is not responsible for managing commercial aspects of the tourism industry, but management for Marine Park and World Heritage objectives may have economic implications for industry and other stakeholders.

This paper will outline the key characteristics of the tourism industry on the Great Barrier Reef; briefly discuss past and new approaches to managing the impacts of tourism in the World Heritage Area; and indicate what data are available and what measures are being taken to control and minimise specific types of impacts. A good deal of the information on management tools has been derived from Dinesen (1996), with some of the text from that paper being incorporated, in abridged form, into this review.

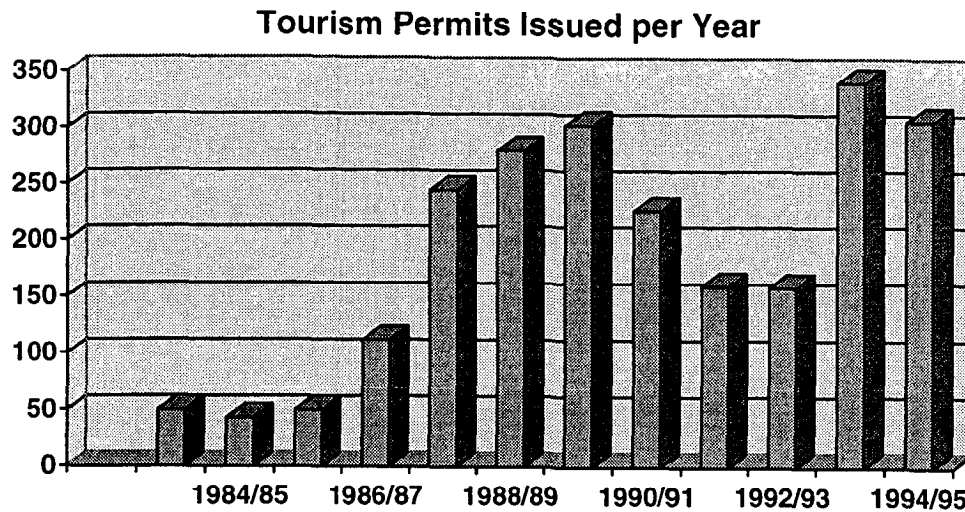
## **The Great Barrier Reef tourism industry**

Tourism is now the largest industry in the Great Barrier Reef, worth well over \$1 billion per annum (adjusted for 1994-95 after Driml (1994)). In the last ten years there has been a steady increase, by an order of magnitude, of the number of permitted tourist operations in the Marine Park (Dinesen 1995). Most tourist operations visiting the Marine Park also visit or pass through parts of the World Heritage Area lying outside the boundaries of the Great Barrier Reef Marine Park, i.e. Queensland tidal lands and waters (including Queensland Marine Parks) and islands. At this stage, the most comprehensive information on tourism use of the Great Barrier Reef comes from Marine Park logbook data returns submitted by permittees in connection with the Environmental Management Charge (Honchin 1996; Williams in press).

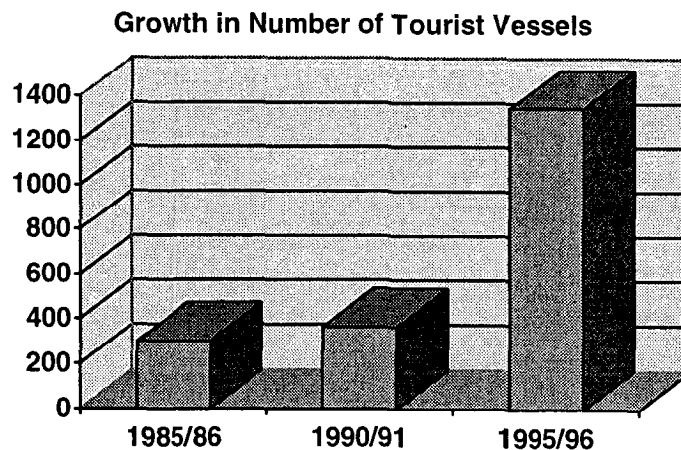
Although Marine Park tourist program permits are now generally issued for six year periods, the number of permits issued annually continues to rise (Fig. 1), and the industry is expected to continue to grow at around 10% per year (Honchin 1996). Another indicator of tourism growth is the four fold increase in the number of permitted tourist vessels within the Marine Park over the last decade (Fig. 2). A total of 864 tourist program permits allowed for the carriage of up to

10 million tourists (Honchin 1996) in 1994-95, although much of this permitted capacity is at present unused (see below). These operations are primarily vessel-based and included:

- 751 separate tourism operators;
- 1348 tourist vessels; 36 aircraft operations;
- 23 structures and facilities such as pontoons; and
- miscellaneous activities such as glass-bottom boats, semi-submersibles and kayaks.



**Figure 1.** Changes in numbers of permits issued for tourist activities in the Marine Park. Low numbers in the period 1983-1988 are due in part to an increase in the percentage of the marine park which had been zoned. No permits were required for unzoned sections.



**Figure 2.** Growth in number of tourist vessels operating in the Great Barrier Reef Marine Park over the last decade

Reef tourism activities typically include (partly after Kelleher and Dinesen 1993):

- Snorkelling
- SCUBA diving
- Reef walking
- Scenic cruises and flights
- Viewing marine life from glass bottom boats, semi-submersibles, underwater observatories
- Whale watching
- Sailing and windsurfing
- Motorised watersports such as water skiing and parafling

- Other activities such as boom-netting and sausage-riding
- Visits to adjacent islands for viewing wildlife or for recreation

Marine Park tourist operations may be broadly divided into two categories (Williams in press): site specific operations running to particular sites usually with moorings or a tourist pontoon installed; and roving operations which are permitted to visit a wide range of locations throughout much of the Marine Park. While some roving operations are genuinely roving charter operations at least within a reasonable range of the vessel's home port, many roving operations tend to regularly visit a handful of localities. Permit conditions restrict roving operations to a maximum of two days' visitation to a particular locality per seven day period (Williams in press), although this is not regularly monitored or enforced.

Most of the tourism activity in the Great Barrier Reef is concentrated in two areas - Cairns (north Queensland) and the Whitsunday Islands (north of Mackay) - which represent less than 5% of the total area of the Marine Park. The Cairns and Airlie Beach areas are the principal nodes from which tourist programs, catering for both international and domestic tourists, operate to the Great Barrier Reef. According to log book returns from operators, almost half (47%) of permitted vessels did not operate at all in 1994-95, while nearly 80% operated at less than the nominal financial viability threshold of 60% capacity (Honchin 1996). However, some 75% of tourists are carried by only a handful of large operators generally running with vessels filled to near capacity.

'Latent' or unused permit capacity has been identified as a significant potential problem inherent in the current permitting arrangements for tourism (Honchin 1996; Williams in press). Currently only about 1.5 million of the 10 million visitor-days allowed through the permit system are actually used. While tourism use appears to be relatively manageable given present use patterns, a five- or six-fold increase in use (which currently permitted) could present serious challenges for conservation and orderly management. This is a genuine management concern given that permits are now transferable, that most tourism activities are focused in prime, accessible areas, and that permit assessment procedures do not take adequate account of the cumulative impacts of use.

#### Nature of impacts of tourism

The impacts of tourism use of the Great Barrier Reef have been discussed and reviewed in a number of recent papers (Carey 1993; Kelleher and Dinesen 1993, 1994; Dinesen 1995; Honchin 1996). In general, tourism impacts may be divided into three broad categories:

- ecological - impacts on features and processes of the natural environment (primarily biophysical);
- social - particularly in relation to amenity or historical use of other user groups; and
- cultural - impacts affecting cultural values associated with the Great Barrier Reef region. For the purposes of this paper, cultural values will be those that are particularly associated with traditional and historical use of the World Heritage Area by Aboriginal and Torres Strait Islander peoples.

This paper will focus particularly on the ecological impacts of tourism activities and developments, and will review current information available on the impacts of activities and structures and constructions. However, as management of the World Heritage Area is now recognising and addressing the significance of social and cultural values, a brief discussion will also be included of the impacts of tourism on social and cultural values. Specific impacts and management responses will be considered later in this paper, following a discussion of past and new approaches to management of tourism on the Great Barrier Reef. It is also important to point out that tourism can also have positive effects (as well as being of major economic value).

By enhancing people's understanding and enjoyment of the Great Barrier Reef, tourism can ensure continued public support for its conservation and management (Kelleher and Dinesen 1993, 1994).

### **Past approaches to tourism management on the Great Barrier Reef**

Almost a quarter of the Authority's budget is spent on Marine Park tourism management (internal estimate), and at present only a small proportion of these costs are recovered through permit assessment fees and the Environmental Management Charge which tourist operators are required to pay.

#### **Tools used in tourism management**

Although Zoning Plans have been a major and integral component of management of the Great Barrier Reef Marine Park, the primary effect of Zoning Plans has, to date, been to define where extractive activities, such as trawling, line fishing and collecting are allowed, restricted or prohibited. This was because, in the early years of the Marine Park, tourism use was very low and a permits-based approach to management was the best option at that time. Tourism is allowed, subject to permit requirements, in all zones except Scientific Research Zone and Preservation Zone - that is, in over 99% of the Marine Park. During a recent rezoning of the Cairns Section, a No Structures Sub-zone was introduced to, inter alia, place some limitations on the location of permanently located or moored facilities such as pontoons. Aside from this limitation on structures, the Zoning Plans have provided no overall framework for the management of Marine Park tourism.

Until recently, the principal tool used to manage tourism on the Great Barrier Reef has been the permit system. Applications for tourist program permits and facilities are individually assessed against a series of criteria in the legislation (Great Barrier Reef Marine Park Regulations, Reg. 13AC(4)), broadly dealing with likely impacts on ecological features, and to some extent on social and cultural values although these values have not been easy to define without stakeholder input. Major infrastructure projects occasionally trigger additional legislation concerning environmental impact assessment of major proposals.

Permits have been supplemented by management plans for some intensively used areas, but until recently these plans had no statutory basis. They have therefore been regarded only as policy guidelines, have not been consistently implemented, and have been subject to appeals by tourist permit applicants. A few Special Management Areas have been applied to individual reefs or bays on a very localised basis to deal with impacts of use. Education of park users has always been considered an important ingredient of management, particularly considering the size of the Marine Park and the huge enforcement difficulties this presents. However, education programs and products have tended, historically, to focus on providing information regarding the reef environment. They have not in the past been sufficiently integrated with other management tools such as permits and plans, and it has been difficult to ensure that educational materials reach the growing number of tourist operators and their staff and visitors.

#### **Problems with over-reliance on permits**

A management approach based largely on a discretionary permit system was appropriate in the early 1980s, when there were few tourist operators and programs, and a flexible approach to tourism management was called for at a time when the impacts of marine tourism were poorly understood.

However, numerous problems have arisen because of over-reliance on permits to manage the burgeoning marine tourism industry. Briefly, these include (after Dinesen 1995) an escalation in the number and complexity of permits; increased demands on park management resources; administrative delays and duplication as most Marine Park permits are issued jointly with the Queensland Department of Environment; case-by-case assessment without adequate consideration of cumulative impacts; and the fact that permit decisions, and even permit conditions, may be appealed. Other significant problems have also been identified (Honchin 1996; Williams in press), such as those associated with 'latent' or unused permit capacity (as indicated above, currently only about 1.5 million of the 10 million visitor-days allowed through the permit system are actually used), and the present site allocation system based on 'first come, first served' processing of applications.

#### Review of the Marine Park permit system

A review of the Marine Park tourist permit system in 1993-94 concluded that there could be no 'quick fix' to the permit system, but rather a combination of other tools and strategies would need to be applied, in an integrated way, to reduce reliance on permits in managing tourism. The review recommendations which have been reported by Dinesen (1995), include: reducing most tourist program permits to simple licences but retaining proper impact assessment procedures for proposals likely to cause significant impacts; greater emphasis on site management and control of use impacts (rather than regulation of user groups targeted through permits); and better use of plans, education, training and Codes of Practice in managing tourism use impacts. A subsequent report by Claridge (1994) identified ways in which management of roving tourist operations and the associated permits could be streamlined.

#### New approaches to tourism management

##### Management planning and policy

Major steps have now been taken to implement the recommendations of the Permits Review Working Group. The *Great Barrier Reef Marine Park Act 1975* has been amended to provide a statutory basis for management plans and to allow for moratoria on new permit applications to be declared while planning is in progress. Planning for the Cairns and Whitsunday regions under this new legislative framework has been progressing well. These key management plans have adopted an issues-based approach, addressing impacts on the natural environment such as anchor damage to coral, and social and cultural issues (previously not adequately addressed) through the provision of settings to better cater for different types and intensity of tourism and other uses (see Honchin 1996; Williams in press). Many tourist permit conditions are to be replaced with Regulations applying broadly to all user groups (including 'as of right' users as well as those requiring permits), which should help to reduce the impacts of use in a more equitable way. At the same time, solutions are being developed through planning processes to problems such as 'latent' or unused permit capacity (Honchin 1996).

The 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area (GBRMPA 1994a) provides a general strategic framework for the conservation and ecologically sustainable use of the reef region. But effective management of tourism use into the twenty-first century also requires a Tourism Strategy and overall policy to address current issues and future growth of the industry on a reef-wide basis. This is expected to be developed during 1996-97 with the participation of the industry and other stakeholders (Vanderzee, in press). Other policy issues, particularly in terms of arrangements for use of public and private moorings, and mechanisms for allocating sites to tourist operators, are being tackled by the Authority in consultation with stakeholders and other government agencies.

### Monitoring and research

The move away from permits as the primary management tool to a more strategic, plan-based approach has also highlighted the need for a better understanding of the cumulative impacts of tourism. Both the ecological and social impacts of Marine Park tourism are being investigated by a number of researchers and institutions, for example through the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef (CRC Reef Research Centre), James Cook University of North Queensland, the Australian Institute of Marine Science and the Great Barrier Reef Marine Park Authority. Cultural issues are also being explored through joint studies with Aboriginal communities, so that the impacts of tourism use on the cultural values and use patterns of indigenous peoples can be more appropriately managed. In addition, monitoring of levels and impacts of tourism use need to be conducted at a wide range of sites, not just at locations where major facilities such as pontoons are located.

### Education, Best Environmental Practices and Codes of Practice

Better use is also being made of other tools for managing tourism. More comprehensive education and training for tourist operators, their staff and visitors, are being provided through a recently completed users' manual (Great Barrier Reef Marine Park Manual, GBRMPA 1996) and training videos, in addition to operator training courses which can reach only a small percentage of staff involved. Best Environmental Practices for various activities, targeting all relevant user groups, have been developed to help Marine Park users understand and reduce the impacts of their activities. These encompass both statutory requirements (e.g. Regulations regarding waste disposal) as well as voluntary 'good practice' procedures. In due course, these practices may be formally adopted by industry and user group associations into Codes of Practice. Thus, a shift towards more environmentally aware tourism and ecotourism is being actively encouraged.

### Community involvement

The need for wider community involvement in management of the Marine Park and World Heritage Area has emerged, both in relation to identification of issues affecting stakeholders, long-term planning, and management decision-making concerning tourism and other issues. Accordingly, various stakeholder liaison groups have been established to facilitate communication and participation. These include: Councils of Elders of Aboriginal communities concerning indigenous involvement in planning and management generally, as well as traditional hunting matters; Regional Marine Resource Advisory Committees consisting of a cross-section of local stakeholders including local tourism industry associations.

### Management of impacts on the Marine Park from adjacent development

While the impacts of many activities taking place within the Marine Park can be managed and regulated directly by the Authority, the situation with respect to adjacent areas is more complex. Activities (including tourism development, urban development and agriculture) located on the adjacent mainland, coast and islands may impact directly or indirectly on the Great Barrier Reef. Although these mainland areas come under the jurisdiction of the Queensland government, a holistic approach is required to ensure the continued health of the Reef ecosystem. (The impacts of such developments are considered in a later section of this paper.)

The Authority, through Memoranda of Understanding with other Federal and State Government agencies, is generally assuming lead responsibility for assessment and management of impacts

arising from developments located within the World Heritage Area but outside the Marine Park boundaries. The Authority is also working cooperatively with other Federal departments, the Queensland State Government, and Local Government authorities regarding better integrated planning and management of developments, agriculture and industry on the Queensland mainland.

### **Impacts associated with activities and facilities located within the Marine Park**

In this section, we will deal with impacts of tourist activities and facilities located within the Great Barrier Reef Marine Park since these require permits from the Authority, and procedures for controlling impacts are generally more straightforward. In the same section we will also include impacts arising on islands visited as part of tourist programs conducted to the Marine Park. Impacts of tourism, particularly resort developments, located outside the Marine Park (whether within the World Heritage Area or on the adjacent mainland) will be considered in a later section.

#### **Ecological impacts**

As stated above, tourism activities in the Marine Park tend to be concentrated in heavily used marine and island locations, particularly in the Cairns - Port Douglas and Whitsunday areas. Actual and potential impacts relate to use of vessels and structures, and direct impacts of visitors, and include:

- Anchor damage to coral from vessels;
- Localised damage to coral from intensive diving, snorkelling and reef walking;
- Effects of fixed and moored structures on corals, fish communities;
- Effects of recreational fishing and collecting;
- Effects of fish feeding on fish communities;
- Reduced water quality and aesthetic impacts from waste discharge and littering by vessels;
- Interference with nesting seabirds and turtles on coral cays which are significant rookeries;
- Damage to littoral vegetation on islands;
- Social and cultural impacts.

#### *Anchor damage and other vessel-induced damage*

Of the impacts of tourist operations on the natural environment, damage to coral has been of principal concern. Although at present there is no evidence to suggest that it is a major problem of ecological significance on a broad regional scale, anchor damage to coral from tourist and recreational vessels has been particularly evident on some fringing reefs in the Whitsunday Islands (Harriott and Fisk 1990; DeVantier and Turak 1995), and is certainly an important aesthetic impact. Site inspections by Marine Park staff, surveys by Harriott and Fisk (1990), and reports from experienced divers in the Whitsunday Islands suggest that some popular anchorages have suffered very high levels of coral damage. High levels of anchor damage have also been identified at a number of reefs offshore from Cairns and Port Douglas (anecdotal reports from management staff, tourists and operators). This evidence, and growing public concern, have been sufficient to trigger management strategies (refer below) to prohibit or limit anchoring at popular tourist destinations. Nevertheless, additional fixed moorings are required to cover all sites of concern within the Marine Park.

Anchor damage from tourist vessels, plus private recreational boats and fishing vessels, is being addressed through a combination of management tools. These are primarily: controls on anchoring designation of 'no anchoring areas' or 'limited anchoring' for smaller vessels only (implemented through Management Plans and Special Management Areas); regulations which prohibit removing or damaging coral; Best Environment Practices (contained in the Great

Barrier Reef Marine Park Manual, GBRMPA 1996); training videos and courses for tourist operators.

Glass-bottom boats and semi-submersibles could potentially cause damage due to collisions with the reef during viewing tours. However a study by Ayling and Ayling (1994b) at one heavily used site (Norman Reef) could find no overt damage caused by semi-sub operation over a five-year interval.

*Damage to coral from intensive diving, snorkelling and reef walking*

Damage to coral by SCUBA divers and snorkellers has also been reported by park managers and Marine Park users. Recent studies (e.g. Roush and Inglis 1995) have indicated that damage by qualified SCUBA divers is generally slight. Most damage is caused by a small proportion of divers and further work is being conducted to determine whether these divers form a specific group (e.g. photographers) which could be targeted for further attention. Diver damage occurs predominantly in areas with branching or other susceptible growth forms. Thus in intensively dived sites, damage can be reduced by directing divers away from the most sensitive areas. Monitoring studies at tourist pontoons indicate that both snorkelling and resort diving may have a small effect on coral height and coral damage levels, although the trends detected were generally not significant due possibly to the low power of the monitoring programs to detect change (Nelson and Mapstone, in press).

Damage by 'resort' divers remains a matter for concern among Marine Park management staff. Resort divers have no SCUBA qualifications or experience and are given an introductory lecture and dive accompanied by an instructor. Reports from tourist dive masters and casual observations by Marine Park staff, indicate that these inexperienced divers can cause substantial damage to susceptible corals. Further studies on this source of damage are required. In the mean time, the main management tools used to minimise these impacts are Best Environment Practices, training videos and courses, and on-site advice from tourist program staff to visitors to raise awareness (e.g. regarding buoyancy control). In some operations, dives for novices are carried out over sand or less fragile coral, while reef walking by groups of visitors in popular sites is generally supervised by interpretive staff.

Reef walking is only conducted intensively at a few locations (e.g. Heron Island Reef, Hardy Reef, Low Isles) where tides and reef structure allow. Kay and Liddle (1984a) found that the impacts are likely to be localised with damage occurring chiefly in areas dominated by upright branching corals. In a study of one heavily used area at Hardy reef, Kay and Liddle (1984b) found no obvious signs of trampling damage except at the point where boats landed to disembark tourists. At Heron Island, Kay and Liddle could find no evidence that reef walking tours were causing any damage, although they stressed the need for longer term monitoring before any conclusions could be reached.

*Effects of fixed and moored structures on corals, fish communities*

During the last ten years or so, pontoons have become standard facilities for larger tourist operations. The more recently installed pontoons are sophisticated two-storey structures incorporating theatrettes, underwater observatories and dining areas, catering for several hundred visitors. The designs of the pontoons and associated moorings must be able to withstand severe cyclone conditions (cyclone category 4). While localised damage may occur during installation, mooring designs (currently under review by the CRC Reef Research Centre) are formulated to minimise the likelihood and impacts of environmental damage which would be caused if pontoons breaking free during storm conditions. Tourist operators installing



facilities such as pontoons are often required to fund environmental monitoring programs, approved by the Authority and conducted by independent experts.

In the early days of Marine Park tourism, there were justified concerns that shading resulted in decline or death of corals situated beneath the pontoons. While small changes in coral cover and damage have been documented as part of various monitoring programs, no major irreversible ecological damage appears to be caused by pontoons (Ayling and Ayling 1994a, b). Early problems such as shading of coral and damage from mooring equipment have been largely overcome by ensuring pontoons are installed in areas of sand rather than living coral. A full review of data relating to the impacts of pontoons has been carried out by the CRC Reef Research Centre. This study (Nelson and Mapstone, in press) found some evidence that pontoons had a small effect on adjacent biota through shading and the activities of snorkellers and resort divers. However, problems associated with the design of these programs and subsequent statistical analysis, resulted in poor statistical power.

There have also been concerns that pontoons might impact on local reef fish communities by attracting larger predatory fish. Aggregations at pontoons have been censused during monitoring programs and these results have been reviewed by Nelson and Mapstone (in press). The aggregations vary substantially in size and composition between pontoons. The number of predatory fish in an aggregation is closely related to the level of fish feeding which occurs at each pontoon. Cessation of feeding and removal of a pontoon both result in the dispersal of an aggregation. Although there were originally some concerns that large aggregations of predatory fish might result in impacts on fish and invertebrate prey species near the pontoon, a recent study by Sweatman (1996) of spangled emperor and red bass at two tourist pontoons failed to detect major predatory effects. Based on the evidence from pontoons with different levels of fish feeding activity, it would appear that the size of any predator aggregation is determined primarily by the level of fish feeding rather than the size or presence of the pontoon itself (Berkelmans, unpublished data).

#### *Recreational fishing and collecting*

Impacts of recreational fishing are being addressed in another section of this publication. The main concern here is the depletion of target stocks by recreational fishing and collecting (although this involves only a small minority of tourist operations and tourists).

Most recreational shell-collecting apparently occurs through specific recreational clubs (Barnett 1989) and there have been concerns about the status of target species in key areas such as Dingo Beach. While little is known of amount or impacts of shell collecting by participants in tourist programs, this is considered relatively minor as many tourist operators strongly discourage shell-collecting even where zoning would permit limited collecting.

#### *Effects of fish feeding on fish communities*

The Authority has developed fish feeding guidelines, to ensure that only appropriate items and quantities are fed to fish at tourist destinations. These guidelines were developed in response to concerns that inappropriate types of food could adversely affect the health of fish, and that frequent feeding of large volumes of food could promote unduly large and aggressive fish aggregations. Compliance with the guidelines is a requirement on tourist program permits. Current guidelines specify (among other things) that: a) fish food must consist of fresh marine products or commercial fish pellets; b) no more than one feeding station should be operated at each tourist site; and c) no more than 1 kg of food may be used per site per day. Operators are no longer allowed to throw miscellaneous food scraps overboard as part of fish feeding.

*Waste discharge and littering from vessels*

Complaints have been received sporadically from visitors to the Great Barrier Reef of unpleasant waste discharge from those vessels not fitted with holding tanks, for example in areas where snorkelling is being conducted. From 1998, new vessels over 10 m will be required to fit holding tanks under Queensland legislation. Great Barrier Reef Marine Park Authority regulations and permits require that vessels not empty holding tanks within 1 km of the edge of a reef.

Waste discharge from tourist vessels is not considered to be of ecological significance, but may be problematic on a very local scale, such as adjacent to marinas and in bays (e.g. in enclosed Queensland waters in the Whitsundays), however at this stage, no data appear to be available to confirm this view.

Littering of any kind is totally prohibited within the Marine Park under MARPOL Annex and Australian legislation. Since plastic and other debris in the water and on beaches are perceived by the public as evidence of marine pollution, tourist operations generally strive to minimise such litter and consequently this is rarely raised as problem in respect of tourism operations. No data appear to be available on the illegal dumping from tourist operations.

*Interference with nesting seabirds and turtles on coral cays which are significant rookeries*

Some of the Great Barrier Reef islands which are important nesting or roosting sites for seabirds and other significant avifauna, are also popular tourist destinations. Certain areas, particularly in the Capricorn-Bunker group, are also important nesting areas for sea turtles. In many instances, tourists are excluded from sensitive nesting areas. Zoning provisions, Management Plans, Queensland national parks legislation and permit conditions are being used to prohibit access to some of the most sensitive rookeries (e.g. Raine Island for turtles, and Wreck Island and part of Michaelmas Cay for seabirds). Guidelines for visiting seabird islands have been developed jointly with the Australian Nature Conservation Agency, and are in the process of being refined for use in the context of relevant Great Barrier Reef islands. Specific Management Plans, Best Environment Practices, videos and courses are also important management tools, along with signage, extension and interpretation, in the context of island rookeries which are more heavily used for tourism purposes.

Further details on turtle and seabird status and management issues can be found in the relevant papers in this workshop proceedings.

*Vegetation damage*

Tourist trampling of vegetation on offshore islands and cays is a potential problem at some heavily used locations. In general these areas, once identified, are managed through the use of marked trails, restrictions on visitor numbers.

*Social and cultural impacts*

Major and rapid growth in the tourism industry has led to displacement of traditional and historical use, notably private recreation and traditional hunting and fishing. While little research has been undertaken on social and cultural impacts of marine-based tourism, increasing concern from both affected stakeholders and park managers has led, during the past couple of years, to social and cultural issues having a much higher profile in park management permit assessment and planning (e.g. Great Barrier Reef Marine Park Authority 1994a; Williams in press). Some data on the social and cultural impacts are available from recent

surveys and research, and from public submissions as part of the development of Marine Park zoning and management plans. These are covered in other sections of this publication.

### **Impacts associated with tourist developments located adjacent to the Marine Park**

While the impacts of many activities taking place within the Marine Park can be managed and regulated directly by the Authority, the situation with respect to adjacent areas is more complex. Activities (including tourism development, urban development and agriculture) located on the adjacent mainland, coast and islands may impact directly or indirectly on the Great Barrier Reef Marine Park and World Heritage Area.

Briefly, the impacts of major tourist developments sited on the adjacent coastline and islands include (partly after Kelleher and Dinesen 1993):

- loss of habitat such as mangroves and seagrass beds resulting from dredging and reclamation for marinas and resorts;
- dumping of dredge spoil;
- increased effluent discharge from resorts which may cause reduced water quality (only those outfalls discharging directly into the Marine Park are required to have tertiary treatment);
- effluent, fuel and antifouling preparations from marinas and/or from vessels in marinas; and
- effects on social and cultural values arising from such development, including impairment of aesthetic values and displacement of traditional and historical use.

Although the cumulative impacts of coastal development for tourism and other purposes are not well documented, the impacts of such developments on the adjacent marine environment may be as greater or more significant than those associated with tourist activities taking place within the Marine Park (Kelleher and Dinesen 1993). From overseas experience, the cumulative effects of increasing development and progressive loss of natural coastal habitat, e.g. mangrove systems, may be very substantial and should not be underestimated.

A recent paper by Cook (1996) discusses relevant problems using case studies affecting mangrove systems, and highlights the need for integrated planning and management of areas adjacent to the World Heritage Area. Cook (1996) considered mechanisms such as Memoranda of Understanding which are being developed between government agencies to try to heighten awareness and improve management of the impacts of development. A recently commissioned report to the Authority on the World Heritage Values of the Great Barrier Reef will be used *inter alia* as a basis for clarifying and enhancing consideration of these values in planning and development approval processes. The Authority (Great Barrier Reef Marine Park Authority 1994b) has also developed guidelines for marinas which are relevant to components of such infrastructure located respectively within or adjacent to the Marine Park. Any new developments will be subject to assessment under the new Queensland Coastal Protection and Management Act, which provides for integrated planning and management.

### **Conclusions**

Overall, the impacts of individual tourist operations on natural values of the Marine Park and World Heritage Area are probably localised, in comparison with other marine-based activities such as fishing, and the downstream effects of agriculture and coastal development (Kelleher and Dinesen 1993). Some reasonably good data sets exist regarding the impacts on the natural environment of specific tourist developments within the Marine Park, where ecological impacts appear to be localised and relatively insignificant, and reasonable management measures have been taken to mitigate such impacts. In contrast, comparatively little information is available

about the social and cultural impacts, or the cumulative ecological effects of tourism operations conducted within the Marine Park and World Heritage Area. Similarly, little information is available regarding the impacts of coastal and tourism development on the adjacent mainland but their cumulative ecological impacts on the Great Barrier Reef could be very significant. While a cautious management approach adopting the precautionary principle is the most prudent interim measure, in the longer term the fruits of research and monitoring will be crucial to enable managers to make better informed decisions regarding tourism activities and facilities in and adjacent to the World Heritage Area.

Continuing evaluation of effectiveness of tools and strategies to manage use such as tourism is an essential ingredient of management. This needs to include compliance monitoring and assessment of the effectiveness of training and education products. While such evaluation will also require the allocation of some resources, in the long run it will help to ensure that management is on track as well as responding better to new issues, problems and patterns of use as they emerge. The effectiveness of new strategies and combinations of tools for tourism management, including management planning, site allocation mechanisms, education and training materials, and Codes of Practice must be regularly evaluated, so that these approaches and tools can be modified or new ones introduced before any major problems have escalated.

### **Acknowledgments**

We thank Bryony Barnett, Ray Berkelmans and Peter McGinnity for providing constrictive comments on the manuscript of this paper.

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## Quality reef tourism: building a web of strategic knowledge

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According to the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area 'tourism is the major and most rapidly growing economic activity' (Great Barrier Reef Marine Park Authority 1994, p. 2). In accordance with this statement it should be apparent that the successful management of tourism will play a critical role in achieving the goals of the 25 year vision. The Plan recognises the importance of understanding the impact of tourism as part of the maintenance of a healthy environment, and tourism is seen as a major activity which must be considered as a part of sustainable multiple use. The visions of integrated management and cautious knowledge-based decision making also include explicit recognition of the need to develop management plans for tourism and the necessity to base these plans on information about the nature and extent of tourism to the Great Barrier Reef (GBR) region and the characteristics and experiences of tourists. What is not explicitly recognised is the importance of tourism in the other two parts of the vision, the maintenance and enhancement of values and an informed, involved, committed community. Tourism has the potential to make a major contribution by encouraging individuals to understand the values, attributes and sustainable use of the reef. There are also important links to be made between tourism and Aboriginal and Torres Strait Island communities. Overall, the challenge is to both recognise the potential that exists and to develop it. This challenge requires reliable, valid and relevant data on tourism.

This paper will examine the status of knowledge on the nature of tourism to the Great Barrier Reef World Heritage Area (GBRWHA) and its adjacent regions. This examination will consist of four major parts. The first section will provide an overview of concepts and models from tourism literature and practice which are relevant to the management of tourism in the GBRWHA. The rationale for this section is to establish a framework for the kinds of tourism research necessary to support management of the GBRWHA. This framework can then be used to identify gaps in the current state of knowledge about tourism and the GBRWHA. The second and major section of the paper will present a summary of the tourism data currently available which are relevant to the management of the GBRWHA. There are several levels or types of data which will be reviewed and summarised. The paper will describe both the patterns which can be identified from these data sets and the limits or gaps in the knowledge provided by the data sets. While there are some major gaps in these data sets, there are some important patterns which can be identified and directly linked to management. In particular, multivariate analyses of various data sets have identified several clusters or types of visitors to the regions adjacent to the GBRWHA who exhibit very different characteristics and behaviours and who have very different attitudes towards the GBR.

The third part of the paper will consist of an overview of the market survey and interpretation evaluation projects which are part of the Cooperative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef (CRC Reef Research Centre). These projects have been specifically designed to address some of the major gaps in the knowledge of reef tourism. The conclusion of the paper will outline some issues that need to be considered in any discussion of the status of reef tourism knowledge.

### **Research needs for strategic tourism planning**

Currently in the field of tourism two concepts are seen as essential for the successful management of tourism. They are the principles of ecologically sustainable development and strategic planning. These two interrelated concepts are focused on the quality of both the tourism experience and the setting for tourism, and are critical to the successful management of tourism in world heritage areas. In establishing a framework for research needs to support the management of tourism and the GBRWHA it is important to review the major components of these two concepts.

It is appropriate to begin with the principles of ecologically sustainable development as these provide the broad framework within which strategic tourism planning operates. In Australia we have had the benefit of a federal government sponsored process of examining what ecologically sustainable development means for tourism. The ESD Working Group concerned with tourism (1991) suggested that an ecologically sustainable tourism industry would be one which:

1. considers carefully the quality of experiences offered;
2. does not diminish the range of educational, recreational and environmental activities available to present or future generations;
3. protects biological diversity and maintains ecological processes and systems;
4. ensures the cultural integrity and social cohesion of communities;
5. is based upon activities or designs which reflect the character of a region;
6. allows the guest to gain an understanding of the region visited and encourages visitors to be concerned about, and protective of, the host community and environment; and
7. is integrated into local, regional and national plans.

To achieve such a tourism industry as described above requires regional strategic planning. What then are the core elements of strategic planning in tourism? Figure 1 summarises these core elements or stages. The stages of most direct relevance to the present discussion are those of research, synthesis and evaluation. These are the elements most often missing from the process of planning and management of heritage resources. Many authors have suggested that there has been too much emphasis, often as the result of political pressure, on development or implementation rather than research and evaluation (Dowling 1993; McArthur and Hall 1993; Gunn 1994). 'The long-standing reliance on "gut feeling" is being overdone and cannot be seen as reliable in the dynamic world of the visitor' (McArthur and Hall 1993, p. 267). Indeed in the area of heritage resource management it has been proposed 'that the visitor experience should be placed at the centre of any heritage management process' and that traditional management which has focused on the physical resource is 'deficient because it generally takes inadequate account of the human element in heritage management and especially the significance of visitors' (Hall and McArthur 1993, p. 13).

Table 1 provides a summary of the tourism features to be examined in the research stage of the strategic planning process. This summary is subdivided into categories which reflect the major components of the tourism system. Five important points need to be made about this summary of tourism features. Firstly tourism must be seen as a dynamic system in which various components interact (Gunn 1994). There is a relationship, for example, between information available and the type of tourists who are attracted to a region. Secondly, tourists should not be seen as a single homogeneous group. What is necessary is to develop a market segmentation approach to understanding tourism in any region. It is possible to adapt the business definitions of market segmentation to a management context. Such an adaptation would result in the following description of this approach.

The underlying premise for a segmentation approach in understanding tourism is that the facilities, access and experience offered or supported by management for one type or segment of tourist may not be appropriate for tourists from another segment. Although the conference delegate and the scuba diving enthusiast can be both classified as tourists, their needs and impacts differ in many ways (adapted from Heath and Wall 1993: 92).

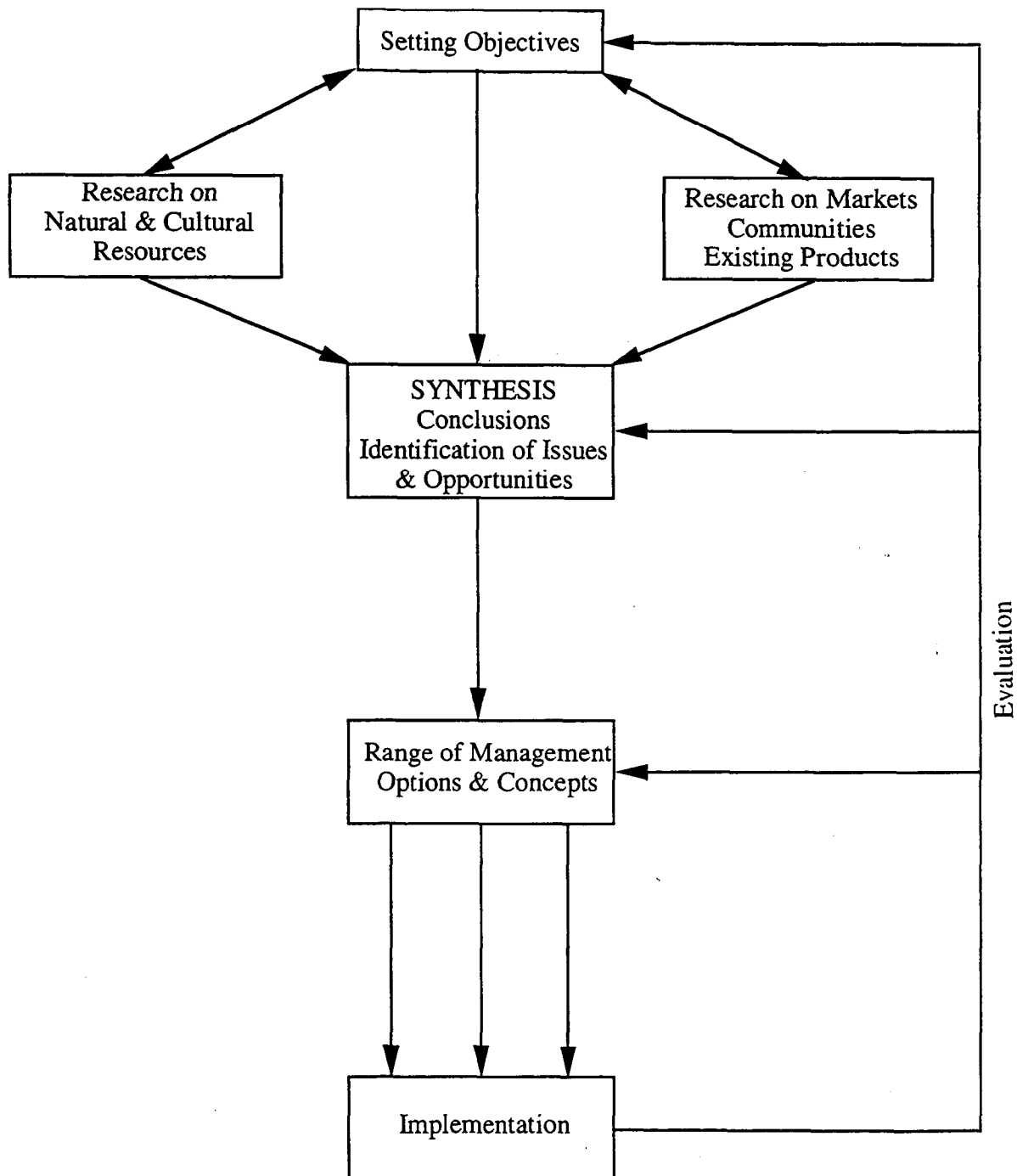


Figure 1. Core elements of strategic tourism planning (Derived from Gunn 1994; Dowling 1991)



**Table 1.** Tourism features to be considered in research for strategic tourism planning

<p><b>1. Markets</b></p> <p>Who are the tourists? What socio-demographic or psychographic segments exist? What are they seeking? How many tourists are there? What do they do? Where do they come from? Where do they go? Who does not come to the destination? How do the tourists move around the area? What images do they have? How satisfied are they with their experiences?</p> <p><b>2. Attractions/Activities</b></p> <p>What are the attractions/activities offered by the destination? Where are they located? What sorts of experiences do they provide? What impacts do they have?</p> <p><b>3. Services/Facilities</b> (Includes transport, accommodation, shopping, eating facilities, infrastructure)</p> <p>What facilities are available? What facilities will be required? Where are facilities located? What impacts do they have?</p> <p><b>4. Information/Promotion</b></p> <p>What images are portrayed in promotion? What information is available for tourists? Where is information provided? How effective is the provision of information?</p>
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A third point to be made about the summary contained in Table 1 is that it emphasises the human aspects of tourism. All strategic tourism planning models, however, recognise explicitly the need to understand the natural and cultural resources which serve as the attractions or settings for tourism. Further, it is important that these two sets of research are integrated and a dominant theme in the tourism planning literature is the integration of the two sets of information through spatial analyses (Dowling 1993; Gunn 1994). In other words it is important for many of the features listed in Table 1 that the information be organised spatially. For example, the research question, 'What are the major market segments for the GBRWHA?' must be accompanied by the question, 'Where do these different market segments go when they visit the GBRWHA?'. Finally it is also important that research into these various components of tourism moves beyond the level of describing the current situation into the realm of exploring relationships and identifying factors which influence tourism. This is necessary if management is to be future oriented.

In summary, we must understand and research the following aspects of tourism in order to effectively plan for, develop and manage quality sustainable tourism to the GBRWHA.

#### The spatial distribution of tourism

This first research area refers to generating a detailed description of tourist use of the GBRWHA. Such a description is necessary if managers are to be able to identify such things as sites of potential impact or use conflicts, or locations for interpretive activities. Such a description also requires an understanding of patterns of tourism in adjacent regions as it is these areas which support and supply tourism to the GBRWHA.

#### The nature of the market

Another area of major management activity is that of decisions about access and the provision of facilities. It has long been recognised in the recreation and protected area management literature that managers have a major influence on visitor experiences through the way in which they provide settings for activities (Manning 1986). In order to make sound decisions on these matters managers must understand the factors which influence the experiences sought by visitors. Decisions of access and facility provision must be guided by information on the motivations and expectations which guide tourist decisions. Specifically, it must be recognised that there are different types of tourists, or market segments, each with a different profile in terms of activities sought, and motivations and expectations.

#### Visitor evaluation of their experiences

The sustainability of tourism to the GBRWHA requires both that tourists are satisfied with their experiences and that strategies to minimise any impacts of tourism are effective. This indicates two areas for research. It is important that research identifies components of success and failure both for interpretive activities and tourist experiences.

#### The nature of community perspectives

Tourist activity takes place in, or adjacent to, the local communities which border the GBRWHA. It is vital that these communities support tourism since negative community reactions can result in reduced support for promotion, hostile responses to development proposals and anti-tourist behaviour. Management agencies must rely in part on the informal communication links between hosts and guests and attempts to encourage sustainable tourist behaviour will be undermined if host community perspectives on tourism are ignored. Aboriginal and Torres Strait Island communities' perspectives on tourism development should be of particular concern to the management of the GBRWHA.

#### The factors which explain each of the above

In each of the previous sections the dominant theme has been to describe the existing situation. As previously noted, it is also necessary for managers to be able to predict future trends and requirements. Such a prediction requires both an understanding of larger forces in tourism such as changing patterns of travel opportunity, and the processes which create existing patterns of tourist activity.

## **Summary of currently available tourism research relevant to the Great Barrier Reef World Heritage Area**

As noted in the introduction research relevant to understanding tourism and the GBRWHA has been conducted at several levels of analysis. The first level is data on international tourism trends which includes information on changing technology, changing patterns of international travel and changing expectations of tourists. The second level of data is that collected at a national level on both international visitors to Australia and domestic travel within Australia. A third level is data collected at the state and regional level by the Queensland Tourist and Travel Corporation (QTTC). The fourth level is data collected at a regional level by various organisations. This section will review each of these levels concentrating on results and patterns of data that are of significance for the management of tourism to the GBRWHA.

### **International tourism trends**

The World Tourist Organisation (WTO) is the international body charged with the responsibility for compiling statistics on international tourism and predicting future tourism trends. In order to fulfill these responsibilities the WTO works to identify factors which are related to and influence patterns of tourism. This section will review both current and predicted international tourism trends drawing out the implications for the management of tourism to the GBRWHA.

#### *Summary of data and information*

The WTO predicts that international tourism arrivals worldwide will reach in excess of 930 million by the year 2010. This will mean that international tourism will have doubled in the 20 years between 1990 and 2010. Figure 2 shows both world and major regional forecasts for international tourism arrivals for the period 1990 to 2010. This figure indicates not only major growth in tourism in these two decades but also some major changes in the patterns of that tourism with a change away from Europe and the Americas as prime destinations for international travellers and a move towards East Asia and the Pacific as destinations. This change in the regional market share of tourist arrivals is clear in Fig. 3. The GBRWHA is thus located in one of the fastest growing tourism destination regions in the world. Another major change in international tourism is predicted for the sources of international travellers with the fastest outbound growth occurring in all parts of Asia, Africa and the Middle East. In particular there is clearly a trend towards more intraregional growth. In other words, international travellers from East Asia and the Pacific are increasingly visiting other countries in East Asia and the Pacific. Specifically the WTO notes that in 1990 73% of international arrivals were generated from countries within the same region and they predict that this will grow to 80% in the year 2010.

The WTO does not directly monitor domestic tourism, that is travel within one's own country, but their assessment is that this will also continue to grow at rates similar to that experienced and forecasted for international tourism. Again growth in domestic tourism is likely to be greatest in East Asia and the Pacific and South Asia.

*Data in the preceding section was based on tables reported by the WTO (1990, 1991, 1993) and McIntosh, Goeldner and Ritchie (1995).*

In addition to these changes in the spatial distribution of tourism a number of other trends in tourism have been identified at the global level. These can be seen as falling into two major categories, changes in the structure of the travel experience sought, and changes in the technology associated with tourism. In the first category are such changes as:

1. decreasing use of package tours and increasing demand for individualised itineraries and independent travel;
2. increasing demand for multiple activity opportunities;
3. moves towards shorter breaks;
4. increasing travel experience and demand for quality services.

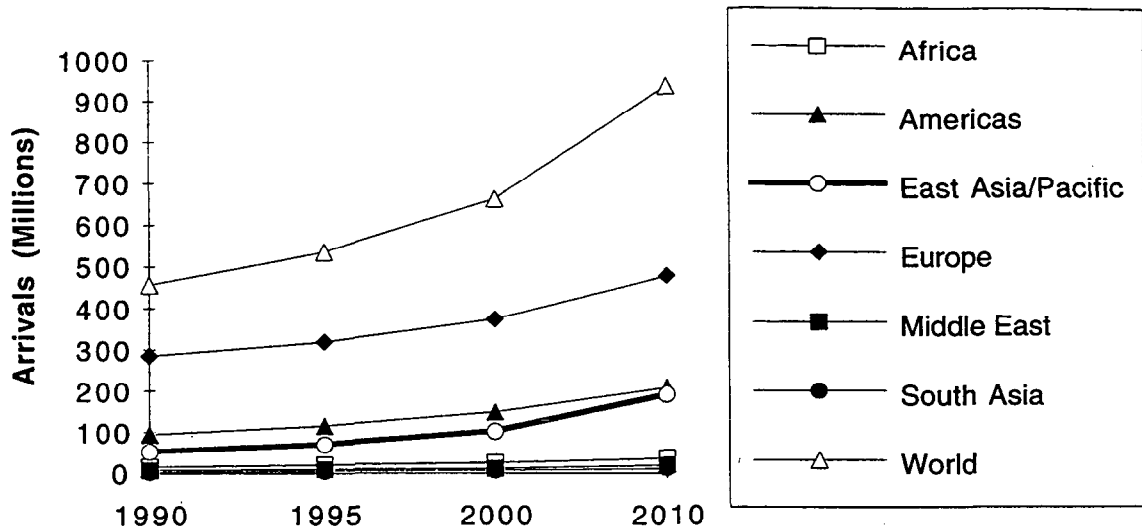


Figure 2. World and regional forecasts for international tourist arrivals, 1990-2010

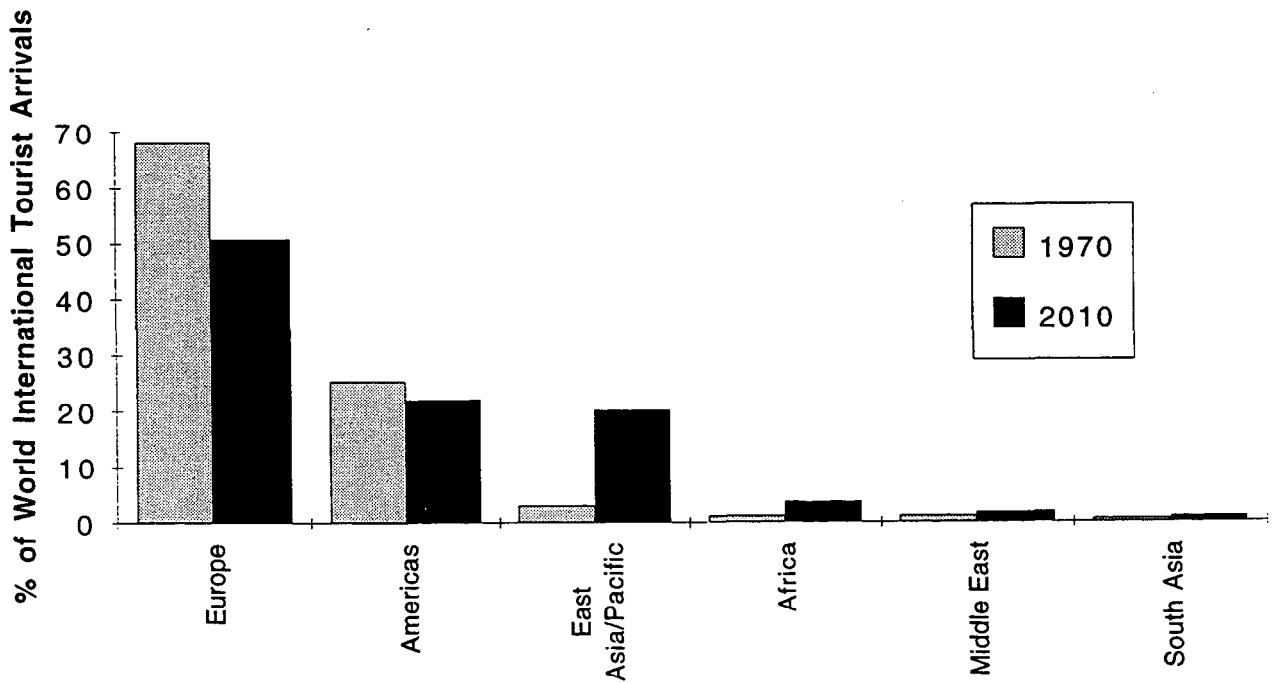


Figure 3. Trends in regional market share (1970-2010)

The second category includes changes to transport capacity, the increasing use of computer systems for reservation and promotion, and the use of technology to create tourist experiences. Changes to transport technology are likely to have the most visible impacts on tourism. Currently growth in tourism is limited by capacity at major international airports and a number of changes in aircraft technology are likely to substantially alter this situation in the early years of the 21st century. These changes include:

1. the use of satellite navigation which will allow for much greater use of airports and shorter more direct flight paths.
2. increases in the capacity of aircraft. All major aircraft manufacturers are developing planes with the ability to carry between 850 and 1000 passengers. These are expected to be operational by the year 2003.
3. decreases in flight times. Boeing, for example, is developing new aircraft with the capacity to cut flight times between Australia and the Americas by half.

In summary, it is likely that within the next decade that Australia will no longer be a long haul expensive destination for international travellers.

There are several other technological developments of relevance to the GBRWHA. In 1989 the use of small submarines taking 10-20 tourists into marine environments was predicted. Such tour opportunities are now available and are a feature of many reef day trip tours in the Caribbean. The use of virtual reality has also become widespread and is being used increasingly in tourism to provide virtual experiences of a range of environments and activities including such things as snow skiing and horse riding. These developments have the potential to both increase pressure on the GBRWHA through the provision of more ways to access the reef environment, and to decrease pressure by developing alternative tourist experiences. *Information in the preceding section was derived from WTO (1990 and 1993), Ballantyne (1995) and Shafer and Moeller (1989).*

Another major change in global tourism is the growth of cruising. In 1990 11 million people were listed as cruise passengers making this the 11th largest travel concentration in the world. Growth in cruising in the last 15 years has been in excess of 10% per annum and this growth is supported by major increases in capacity. In 1990 14 vessels with a capacity of in excess of 1000 passengers were being built. Three of these vessels will carry more than 4000 passengers and crew and use large catamarans as transport vessels to carry passengers to islands and reefs. Cruising is currently dominated by North American passengers cruising in the Caribbean (accounting for nearly half of all cruising). As with all other aspects of tourism this emphasis is shifting towards increased cruising opportunities in the Asia Pacific region. If, as predicted, there are increased opportunities for shorter, cheaper air travel to the Asia Pacific then cruising will be able to grow dramatically in this area.

*Information in the preceding section was taken from WTO (1990, 1991), the Cruise Shipping Report (1990) and CLIA (1994).*

#### *Explanatory factors*

In attempting to understand the patterns of international tourism outlined in the previous section the WTO has identified a number of social, demographic and economic factors which are related to tourist behaviour. Table 2 lists these factors. The first two sets of factors are those related to capacity to travel. In general, rising living standards and the spread of democracy have resulted in greater opportunities for travel especially from developing countries in Asia. Changes in the structure of the family with increasing participation of women in the workplace and decreasing birthrates have allowed for more flexibility in organising travel times and thus the increase in shorter breaks. These factors combine to make travel a more commonplace activity resulting in greater experience and the pressure for more intensive, specialist and independent travel.

**Table 2.** Factors influencing growth and patterns of international tourism

<p><b>1. Socio-Economic Factors</b></p> <ul style="list-style-type: none"><li>- increasing standards of living accompanied by,</li><li>- increasing discretionary disposable income,</li><li>- increasing paid leave, and</li><li>- earlier retirement.</li></ul>
<p><b>2. Political Factors</b></p> <ul style="list-style-type: none"><li>- relaxation of immigration restrictions,</li><li>- spread of democracy.</li></ul>
<p><b>3. Demographic Factors</b></p> <ul style="list-style-type: none"><li>- aging global population, lower birth rates,</li><li>- increase in working women and dual income families,</li><li>- trends towards later marriage,</li><li>- increasing standards of education.</li></ul>

*Implications for the management of tourism in the Great Barrier Reef World Heritage Area*

This overview of global tourist trends can be seen as having five major implications for the management of tourism in the GBRWHA.

1. Managers can expect increasing numbers of both international and domestic tourists to come to the region. This growth in tourism is likely to continue at least at the same rate as in previous years. If the predicted changes to transport technology eventuate it is likely that numbers of international tourists to the region could expand very quickly. The pressure to provide access and facilities so that tourists can visit the GBR will increase.
2. Managers can expect that international tourists coming to the GBRWHA are increasingly likely to be from Asia. Tourists from these countries are rapidly increasing in travel experience and thus are increasingly likely to be independent travellers and to visit more often for shorter periods. Managers will have to think carefully about their current images of international travellers; the reality is changing rapidly.
3. For all tourists increasing travel experience and education will result in demands for more active experiences and greater quality in services. Expectations for quality interpretation will rise.
4. Managers can expect pressure to introduce submarines to provide greater reef access.
5. Large scale cruising could become a major activity in the GBRWHA. Again, predicted changes to transport technology could make Cairns a cheaper and more accessible destination and provide the necessary tourist markets to support the use of large cruise vessels moving through the GBRWHA.

**International visitors to Australia**

The major source of information about international visitors to Australia is the International Visitor Survey (IVS) conducted for the Bureau of Tourism Research (BTR). The IVS has been conducted since 1991 and each year involves personal interviews conducted with

approximately 12 000 short-term international visitors aged 15 years or older. The interviews are conducted in the departure areas of major international airports (including Sydney, Melbourne, Brisbane, Cairns, Perth, Adelaide and Darwin). The aim of the IVS is to provide an estimate of numbers of international visitors in various categories. The IVS collects data on where visitors go, what activities they engage in, duration of stay, accommodation and transport used and expenditure. The sampling frame allows for some analyses of visitors who include particular regions in their Australian travel. Thus it is possible to gather some information on international tourists who visit the regions adjacent to the GBRWHA. The IVS has four regions which are of relevance to the GBRWHA, the Far North Queensland region (which extends from Rollingstone in the South to the top of Cape York), North Queensland region (which extends from Bowen to Rollingstone), the Mackay/Whitsundays region (which extends approximately from St. Lawrence to Bowen) and the Fitzroy region (which extends from Agnes Waters to St. Lawrence). It is important to note that many of the questions asked refer to the visitor's entire Australian trip and therefore cannot be used at a regional level. Despite these limits the IVS can provide some information on the characteristics of visitors coming to the GBRWHA region. The following section will review these characteristics after looking at Australia wide patterns of international visitation. With a few exceptions, this discussion will concentrate on the most recent data available, which are for year 1993.

*Summary of data*

In 1993 nearly 2 800 000 international visitors came to Australia and nearly one third of these (approximately 750 000) visited at least one of the four regions adjacent to the GBRWHA. The Far North Queensland (FNQ) region was the major focus for these visitors with an estimated 464 000 international visitors. This dominance of the FNQ region partly reflects the increasing use of the Cairns international airport as a point of arrival and departure. Table 3 shows the changes in patterns of international travel in and out of Australia between 1990 and 1993. Clearly Cairns has grown at a rate considerably higher than that of Sydney, Australia's major airport.

**Table 3.** Arrival and departures of international visitors to Australia through Cairns and Sydney, 1990 and 1993 (000s of visitors)

<b>Arrived</b>	<b>Departed</b>	<b>1990</b>	<b>1993</b>	<b>% Change</b>
Sydney	Sydney	751	921	+23
Sydney	Cairns	48	64	+33
Cairns	Sydney	25	84	+236
Cairns	Cairns	52	112	+115
<b>Totals</b>		<b>1990</b>	<b>1993</b>	<b>% Change</b>
Total arrivals Sydney		1133	1223	+8
Total departures Sydney		1199	1314	+10
Total arrivals Cairns		187	228	+22
Total departures Cairns		187	202	+8

The other major information that the IVS can provide is that of the source of international visitors. Table 4 contains the profiles of international visitors to Australia as a whole, the GBRWHA regions combined and the FNQ region for 1990 and 1993. Looking firstly at the situation in 1993, it can be seen that Japan is a prime source of international tourists for both Australia and the GBR regions. Japanese visitors are particularly dominant in the FNQ region. The GBR regions are also more likely than the rest of Australia to receive visitors from the Americas, and Europe, but less likely to receive visitors from New Zealand. The FNQ region is also less likely than the GBR region as a whole to receive visitors from Europe. The other pattern to examine in the table is the change in profiles of visitors from 1990 to 1993. For Australia as a whole there has been little growth in the Japanese sector, but there has been

substantial growth for the GBR regions. On the other hand, the growth in visitation from other Asian countries has been marked for Australia as a whole but this is not reflected in the profiles for the GBR regions. It should be noted, however, that at the time of preparing this paper the most recent data available were collected in 1993. Anecdotal evidence suggests that the FNQ region is experiencing growth in visitors from other Asian countries.

*Data in the preceding section were analysed using the CD MOTA package provided by the BTR.*

**Table 4.** Major sources of international visitors, 1990-1993

Source	Australia 1990-1993	Total GBR Region 1990-1993	FNQ Region 1990-1993
Japan	22% / 23%	13% / 24%	20% / 32%
Other Asia	14% / 22%	3% / 5%	3% / 5%
New Zealand	19% / 16%	9% / 4%	8% / 3%
Americas	14% / 12%	24% / 19%	26% / 21%
UK/Ireland	13% / 11%	21% / 16%	18% / 15%
Other Europe	12% / 11%	28% / 29%	22% / 21%

#### *Explanatory factors*

Numerous factors might explain such differences in growth and profiles of international visitors to Australia and the GBR regions, including the structure of airline agreements which influence points of entry and departure into Australia, the nature of promotional exercises conducted by various tourist authorities and perceptions of the GBR region held by various visitors. None of these factors has been systematically investigated to date and attempts at explanation are therefore speculative. The overall patterns of visitation to Australia, however, are consistent with those identified at a global level by the WTO.

#### *Limitations*

In discussing the limitations of any data set it is important to remember two points. Firstly, that it is not possible for any single study to answer more than a few questions reliably and with any validity. Secondly that the discussion of limitations must be undertaken bearing in mind the original aims and purpose of the study. The primary aim of the IVS is to understand international visitors to Australia as a whole. It is not economically feasible to collect a sample size sufficient to address most regional questions and this represents a major limit to the use of these data for investigating tourism to the GBRWHA regions. In particular the IVS surveys conducted to 1993 do not allow for the identification of international visitors who went to the GBR. The other major limit in these data is that they are focused exclusively on sociodemographic variables and thus provides no information on the motives, images, or expectations of visitors. It does, however, offer an excellent opportunity to examine sample biases in other smaller and more specific studies. In other words, it is possible to compare the sociodemographic profiles of samples used in more specific studies of reef visitors to the profiles available from the IVS to indicate any potential biases. Unfortunately this does not appear to have been done very often.

#### *Implications for the management of tourism in the Great Barrier Reef World Heritage Area*

The data reviewed from the IVS support and reinforce the implications set out in the section on global tourist trends.

1. Specifically they suggest that international tourism to the GBRWHA will continue to grow and that this growth is supported by increasing use of the Cairns airport. The IVS provides



slightly greater focus in this respect as it indicates that the FNQ region is the most visited region and the area likely to have the fastest growth rate.

2. The trend towards increasing numbers of visitors from a range of Asian countries is also highlighted in the IVS although Japan still dominates the GBRWHA region. A major point to be made here is that managers must recognise that there are major cultural differences between Asian visitors and decisions and management actions will have to become more aware of these cross cultural differences if they are to be effective.

3. The other major implication from the IVS analyses is that there is variation within the GBRWHA. The pattern of international tourism in the FNQ region is not typical of that for other regions adjacent to the GBRWHA. This pattern is qualitatively different. That is, it is not simply that there are fewer international visitors in the other regions, but that there are different types of international visitors.

4. In an attempt to get more value from the IVS for the GBRWHA regions researchers from the CRC Reef Research Centre Project 2.2.1 on Market Segmentation of Reef Visitors have negotiated with the various state and federal tourist bodies to include a question in the IVS which will identify international visitors who have been to the GBR during their stay. This question was included in the 1994 survey and those data have recently been released for analysis. These analyses will be able to provide both a more detailed profile of international tourists who visit the GBR and a comparison with those who do not. This more reef specific information should have more direct implications for the management of tourism in the GBRWHA.

#### Domestic tourism within Australia

The BTR is also responsible for monitoring domestic tourism within Australia and to achieve this conduct a household survey with Australians aged 14 years and older. Each year this Domestic Tourism Monitor (DTM) survey is conducted with 65 000 respondents. Although this is a large sample the actual number of respondents who have travelled to any particular region in the previous year is often very small and so again much of the information collected is not reliable at a regional level. This survey includes information on the destination and length of overnight trips, as well as accommodation and transport used and demographic details of the respondent. The DTM uses the same regional boundaries as described for the IVS and provides similar information on domestic tourists. The DTM operates on a financial year and the most recently analysed data are for the 1993-1994 financial year. Further, the DTM provides information on both trips and visits. A trip is defined as a journey involving a stay of one or more nights but less than three months away from home, while a visit refers to every place during that trip where the tourist spent a night. Each night at a particular destination counts as one visit. The more accurate indicator than of tourist numbers is trips and all analyses in the following section will be of trips.

#### *Summary of data*

As with the IVS the DTM has a prime role in providing information on numbers of visitors to the regions of interest. Table 5 contains the number of trips made to the GBRWHA regions in 1989-90 and 1993-94. Unlike international travel, domestic travel has not continuously grown to the GBR regions, with the exception of FNQ. The actual figures, however, are still substantial showing that overall more than two million trips were taken to the regions adjacent to the GBRWHA. Table 6 contains the profile for each region's domestic visitation in terms of where tourists come from. Intrastate tourism dominates the profile in all four regions. The majority of domestic visitors come from within Queensland. The next largest source of

domestic visitors is Sydney and New South Wales. An important feature of these profiles is the difference between the regions with a greater proportion of Queensland country visitors to the FNQ and NQ regions.

**Table 5.** Domestic tourism visitation to the Great Barrier Reef World Heritage Area regions, 1989-90 and 1993-94 (000s of trips)

Region	1989-1990	1993-1994	% Change
FNQ	634	806	+27
NQ	582	449	-23
Mackay/Whitsunday	582	336	-42
Fitzroy	585	486	-17
TOTAL	2383	2077	-13

**Table 6.** Area of origin of domestic trips, 1993-94 (percent of trips)

Area	FNQ	NQ	Mackay	Fitzroy
Qld Country	67	68	53	56
Brisbane	9	12	13	19
Sydney	6	4	11	5
NSW Country	4	3	7	6
ACT	1	1	1	<1
Melbourne	6	3	7	4
Vic Country	2	1	2	2
SA	3	3	2	1
WA	2	5	1	3
NT	<1	<1	1	<1
Tasmania	1	1	2	1
<b>Total Interstate</b>	24	30	34	25

The final two tables extracted from the DTM data are concerned with the life cycle profiles of domestic visitors to the regions (Table 7) and the main form of transport used (Table 8). Again there are some substantial differences between the regions in terms both of the transport used to get to the region and type of life cycle profile of visitors. Younger single visitors make up a greater proportion of the visitors for both the FNQ and Mackay/Whitsundays regions, with families being a greater proportion of the NQ and Fitzroy regions. Older couples also constitute a greater percentage of the visitors to the two more southern regions than to the two northern regions. The FNQ and Mackay/Whitsundays regions also differ from the other two regions in terms of a lesser proportion of visitors using private vehicles and correspondingly a higher proportion of visitors using planes as transport to the region. Overall, it should be remembered that despite these differences, the great majority of domestic visitors travel to the GBRWHA regions in private vehicles.

*Data in the preceding section were analysed using the CD-MOTA package provided by the BTR.*

**Table 7.** Life-cycle descriptions of domestic travellers making trips to GBRWHA regions 1993-94 (percent of trips)

Life-cycle stage	FNQ	NQ	Mackay	Fitzroy
Families	40	48	36	47
Younger couples	14	12	10	8
Older couples	15	15	20	22
Younger singles	27	18	30	18
Older singles	4	9	3	6

**Table 8.** Main form of transport to the destination (% of trips)

Transport	FNQ	NQ	Mackay	Fitzroy
Private Vehicle	69	75	71	80
Plane	23	15	20	10
Bus/coach	5	3	7	5
Train	3	6	1	4
Hire Vehicle	1	<1	<1	1
Other	<1	1	<1	<1

*Explanatory factors*

As with the IVS there has been little in the way of systematic scientific investigation of the factors which might account for the patterns of domestic visitation that can be described. Again the factors which might explain such differences include the nature of promotional exercises conducted by various tourist authorities, the sorts of tourist experiences offered by the regions and the images of the GBR regions held by various visitors.

One study which offers some insight into the images of Queensland destination regions held by domestic visitors was conducted in 1991 for the QTTC. This study, which is referred to as the Domestic Market Segmentation Study (DMSS), investigated the images of, and experiences of visits to, Queensland regions with a sample of 3600 domestic tourists. Table 9 summarises the answers given to a set of structured questions about images of North and Far North Queensland. (The North Queensland region in this study included the Mackay/Whitsundays area). It is clear that the FNQ region is seen as more expensive and more developed than the two more southern regions. This is consistent with a lower level of visitation by families and older couples. Clearly there is considerable scope for more investigation into the factors which influence domestic visitation to the region.

*Data reported in the preceding section were taken from the DMSS reports for North and Far North Queensland prepared for the QTTC by Brian Sweeney and Associates.*

**Table 9.** Images of the Great Barrier Reef World Heritage Area regions . A: % of sample nominating the description

Description	FNQ	NQ
Lots of interesting countryside and wildlife	82	65
Good beaches/lots of water activity	73	73
An opportunity to get away	65	57
Wide variety of things to do	65	57
High quality accommodation	55	45
Opportunity for sporting activity	49	49
Good restaurants	58	41
Too expensive to get there	42	33
Opportunity for adventure activities	42	28
Low cost accommodation	41	44
Lots for the kids to do	33	32
Good service	33	30
Too expensive when you're there	28	20
Good shopping	28	25
Lots of nightlife	27	25
Too many tourists	22	15
Over developed	13	8

*Limitations*

The DTM has similar limits to those identified for the IVS. Again the primary aim of the DTM is to understand domestic travel within Australia as a whole, and for many questions at a regional level the data cannot provide reliable answers. This data set is also focused exclusively on sociodemographic variables and thus provides no information on the motives, images, or expectations of visitors. As with the IVS it is not possible to look at domestic tourists who went to the GBR. Again the opportunity exists to examine sample biases in other smaller and more specific studies by using regional demographic profiles from the DTM.

*Implications for the management of tourism in the Great Barrier Reef World Heritage Area*

1. The dominance of both intrastate visitors and the use of private vehicles to reach the GBRWHA regions offers some clear directions for the provision of interpretive services. The use of visitor centres located along the highway, for example, would be supported by this information.
2. The DTM data describe differences in the profiles of visitors within the regions adjacent to the GBRWHA and there is some evidence that this may be related to differences in the images visitors have of these regions. There is preliminary evidence that there are differences in the types of experiences sought by tourists and that some tourists will try to avoid popular tourist destinations. If a goal of management is the support of a diversified tourist industry then regional planning must consider providing opportunities for a range of different types of tourism.

*Tourists to Queensland*

The QTTC conducts an ongoing state wide survey of international and domestic visitors using commercial accommodation. The prime purpose of this survey is to determine numbers and profiles of visitors to the various regions within Queensland. The Queensland Visitor Survey (QVS) collects data similar to the IVS and DTM but the sample allows for more detail to be reliably examined at a regional level. Further, the QVS investigates a slightly broader range of variables including the nature of the experience being sought by the surveyed tourists. A point to note for the QVS is that visitors staying predominantly with friends and relatives will not be included in the sample and this may account for lower levels of intrastate visitation reported in the QVS.

*Summary of data*

The QVS includes domestic and international travellers in the same data set and this allows for an overall profile of visitors to be described for each of the GBRWHA regions. Table 10 shows both the importance of the four GBRWHA regions in tourism to Queensland as a whole and the division of visitors to each region in terms of international, inter- and intra-state origins. The FNQ region is a major destination for international visitors.

*These results were taken from the QVS Executive Summary for 1993-94.*

**Table 10.** Profile of visitors in commercial accommodation in Great Barrier Reef World Heritage Area regions

<b>Region</b>	<b>% of Qld</b>	<b>% of International</b>	<b>% Interstate</b>	<b>% Intrastate</b>
Mackay	10	20	35	45
Fitzroy	5	12	22	66
NQ	6	18	28	54
FNQ	18	48	26	26

Of most interest in the QVS is a question which asks visitors to check from a list of 21 features, attractions or activities, those which prompted them to visit the region in which they were interviewed. This question begins to access the type of experience being sought by visitors and thus moves closer to the issues faced by managers in the developing of plans for access and facilities. The authors have been involved in a project which has cluster analysed visitors on the basis of their responses to this question (see Pearce, Morrison, Scott, O'Leary, Nadkarni and Moscardo 1996 for further methodological details of this process). The analysis revealed six different types of visitors or visitor segments each seeking a different type of experience on their Queensland holiday. Table 11 provides a summary description of each of these visitor segments. There are two groups which give the Barrier Reef as an attraction, the Barrier Reef group and the Active Nature Oriented group (these two groups account for 25% of the sample). The Barrier Reef is not a major attraction in any of the other groups, although a quarter of the Beach Oriented Relaxation group give it as reason for visiting the region. The Barrier Reef group and the Active Nature group are similar in many features, the exception is that the Barrier Reef group places a higher emphasis on the GBR, while the other segment places primary emphasis on the rainforest and is generally more interested in a range of different activities.

Table 11. Major features of six tourist segments

Segment	Family Oriented, Beach and Developed Facilities	Low Involvement	Beach Oriented Relaxation	Barrier Reef	Touring/ Sightseeing	Active Nature Oriented
% of Sample	17	23	15	10	19	15
What they are seeking	Warm weather (70%) Beaches (66%) Theme Parks (47%) Shopping (42%) Activities for family (32%) Barrier Reef (2%) Scuba diving (<1%)	Relaxing (24%) Passing through (24%) Warm weather (21%) Visit friends and relatives (21%) Barrier Reef (4%) Scuba diving (<1%)	Beaches (85%) Warm weather (80%) Relaxing (74%) Sightseeing (35%) Barrier Reef (25%) Scuba diving (7%)	Barrier Reef (97%) Warm weather (59%) Rainforests (49%) Sightseeing (33%) Beaches (26%) Scuba diving (20%)	Touring (62%) Sightseeing (56%) Warm weather (41%) Relaxing (30%) Barrier Reef (10%) Scuba diving (20%)	Warm weather (87%) Rainforests (84%) National Parks (88%) Relaxing (72%) Barrier Reef (61%) Scuba diving (20%)
Other Descriptors	Most likely to have dependent children. Least likely to be international. Mostly 35-44 years Highest spenders	Older group Most likely to be from within QLD.	Second highest percentage with dependent children. Second highest percentage from intrastate	Younger group. Most likely to be international Highest percentage of solo travellers.	Oldest group. Highest percentage of retired people. Most likely to be interstate visitors	Youngest group. Lowest percentage with dependent children.

As would be expected, the four GBRWHA regions differ in terms of the distribution of these six visitor segments. The Family Oriented Beach and Developed Facilities group do not appear in any of the four regions of interest. Table 12 contains the distributions of the visitor segments for each of the four regions. The FNQ region is dominated by the two nature oriented groups

reflecting the greater access and promotion of this region. (Further details on the segments are provided in a series of regional reports prepared for the QTTC, see Woods, Moscardo, Verbeek and Pearce 1995a, b, c, and d).

**Table 12.** Distribution of segments in the Great Barrier Reef World Heritage Area regions

<b>Segment</b>	<b>FNQ (%)</b>	<b>NQ (%)</b>	<b>Mackay (%)</b>	<b>Fitzroy (%)</b>
Barrier Reef	32	12	16	12
Active Nature	32	19	18	12
Beach Oriented Relaxation	7	15	27	16
Touring/Sightseeing	17	25	18	25
Low Involvement	12	29	21	35
<b>TOTAL</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>

*Limitations*

The QVS provides some insight into the types of experience sought by tourists but this insight is concentrated on what attracted visitors and does not provide any information on what tourists actually do in the region. Thus, while we now know that there are two groups attracted by the GBR, we do not know if and how they get to the GBR and what they do if they get there.

*Explanatory factors*

The inclusion of questions which assess the nature of the experience being sought creates some potential for explaining and predicting where visitors might go and what they might do when they visit the GBRWHA and its adjacent regions. This relationship between types of experience sought and choice of activity and location is not, however, a direct one. The actual behaviour of visitors is also dependent on the opportunities that are available and affordable in terms of cost and time.

*Implications for the management of tourism in the Great Barrier Reef World Heritage Area*

There are two major implications for managers that can be drawn from the analyses of the QVS reported in the preceding sections. The most obvious is that it is possible to identify groups or segments of tourists who seek different reef experiences. The less obvious, but arguably more important, implication is that managers need to think about and categorise visitors in terms of these experiences sought rather than by the easier and more visible categories of age, country or place of origin, or life cycle stage. While the examination of the six clusters did find some relationships between the type of experience sought and demographic characteristics, these were trends only and for every type of experience sought there were visitors of every age, in every life cycle stage and from a range of countries or places of origin. Table 13 shows the distribution of source of visitor and age across the different visitor segments. While it can be seen that the Barrier Reef group has the highest percentage of international visitors, these visitors still account for less half of the segment. Similarly, the highest percentage of visitors aged more than 60 years occurs in the Tourism segment, but these are still less than half of the segment. For managers it is more useful to think about visitors in terms of experiences sought or actual behaviours than in terms of demographic characteristics.

**Table 13.** Source of visitor and age distribution across segments

**A: Source (%)**

	<b>Family oriented</b>	<b>Low involv.</b>	<b>Beach Relax</b>	<b>Barrier Reef</b>	<b>Touring</b>	<b>Active Nature</b>
<b>Intrastate</b>	29	38	32	12	25	25
<b>Interstate</b>	59	41	53	50	57	51
<b>Internat.</b>	12	20	16	38	18	34

**B: Age (%)**

<b>14-19</b>	3	2	1	2	2	1
<b>20-26</b>	8	8	9	10	7	13
<b>25-34</b>	22	17	20	28	13	27
<b>35-44</b>	29	15	17	18	13	16
<b>45-59</b>	24	28	26	25	23	20
<b>60+</b>	15	30	26	18	42	24

Visitors to the Far North Queensland region

The previous sections have all highlighted the dominance of the FNQ region in terms of both the numbers of tourists visiting the region and those visitor segments which state that the GBR is an attraction. It seems appropriate to examine some market survey data which examine visitors to that region. This information has been collected as part of the CRC for Tropical Rainforest Ecology and Management with the aim of understanding tourism to the Wet Tropics World Heritage Area. Despite this focus the survey examined participation in a wide range of activities including those concerned with the GBR. It also examined patterns of travel in the region. It is these data that will be examined in the present paper. Full details of the survey can be found in Moscardo 1996.

*Summary of data*

As with the QVS a cluster analysis was conducted to identify the major segments or types of visitors that were coming to the FNQ region. In this instance the analysis was based on actual and intended participation in 56 activities. Five major visitor segments were identified and these are described in Table 14. There is consistency between the segments identified in this study and those described in the QVS. In both cases there is a specific GBR group, a more general active nature based group, a low activity or involvement group, a beach relaxation group, and a group more interested in relaxation and developed facilities.

The value of the present study is that it provides greater detail on actual participation in a variety of reef activities by the various groups and these data are summarised in Table 15. The major point to note here comes from comparing what visitors actually do (as measured in this study) to what they say attracts them to a region (as measured in the QVS). The Reef group, for example, has the highest level of participation in SCUBA diving at 34%. This is higher than the interest expressed by the Barrier Reef group in the QVS where 20% stated that SCUBA diving was a reason they came to the region. Further, there are reasonably high levels of participation in large reef day trips for all groups. This more detailed examination of activity participation shows that there are several different types of visitors accessing the GBRWHA, including those who do not see the GBR as a major attraction for their visit to the region.

**Table 14.** Summary profiles of activity segments

<b>Low Activity Beach and Sightseeing</b>	<b>High Activity Touring</b>	<b>Sightseeing, Beach and Developed Activities</b>	<b>Outdoors, Reef Activities</b>	<b>Nightlife, Entertainment</b>
33% of sample	23% of sample	18% of sample	17% of sample	9% of sample
Low participation in 52 out of 56 activities.	Highest participation in 38 out of 56 activities.	Highest participation in visiting small towns (86%), festivals (42%), shopping (58%), National Park and general sightseeing (87% and 89%)	Highest participation in small reef trips (34%), bushwalking (63%), camping (74%), mangrove visits (25%), and scuba diving (75%)	Highest participation in nightlife (48%), visiting casinos (35%), theatre (15%), cinema (33%)
Popular activities were National Park sightseeing (50%), general sightseeing (50%), relax (43%) and visit beaches (30%)	Highest participation for reef day trips with pontoon (47%), rainforest day trips (71%), visit islands (73%), and outback tours (21%)			
older group mostly interstate	younger group international and interstate	oldest group interstate and intrastate	youngest group most internationals	---
couples/ friends/ family	alone/couple	couple	couple	---
private car/ campervans	---	private car/ campervans	private car/bus	private car/bus
shortest stay	longer stay	---	longest stay	---
most experienced	not experienced	experienced	least experienced	experienced

**Table 15.** Participation in reef or related activities by the five visitor segments

<b>Activity</b>	<b>Low Activity</b>	<b>High Activity</b>	<b>Beach and developed facilities</b>	<b>Reef</b>	<b>Nightlife</b>
Big reef trips	21	55	18	54	35
Small reef trips	10	27	23	34	6
Fishing/diving charter	3	8	2	10	6
Visit islands	19	73	54	62	42
Mangrove visits	6	37	25	13	6
Visit beaches	30	87	80	47	75
SCUBA diving	5	24	2	34	29
Snorkelling	8	64	9	61	48
Reef walking	3	33	6	11	10
Coral viewing	11	54	27	10	10
>1 night cruises	1	15	0	6	4
Sailing	2	17	3	24	11
Reef fishing	17	74	41	44	15

*Limitations, explanatory factors and implications for the management of tourism to the Great Barrier Reef World Heritage Area*

This survey provides no information on satisfaction or on specific motives for the reef activities listed. It is possible, however, to describe the sort of information that can be generated from such more specific questions by briefly reviewing the results from this survey which pertain to rainforest specific motivation, images and satisfaction. The differences between the visitor



segments in terms of motivation for visiting rainforest, images of rainforest and satisfaction with rainforest experiences are set out in Table 16. It is possible to summarise this information by saying that currently there are two segments with high levels of visitation to the rainforest, the High Involvement and Developed Facilities groups. It is already clear from the description of the segments that these groups participate in different activities. They also differ in terms of the words they use to describe the rainforest with the former group more consistent with the images being portrayed in interpretive material. They also want different things from their rainforest experience with the High Involvement group seeking to be active and to get close to nature. It is also this group that is least satisfied with their experiences. Arguably the managers of these areas are not providing the opportunities being sought by this group. By understanding patterns of motivation and satisfaction managers can begin to understand the impact their decisions have on tourism to the area of concern.

**Table 16.** Relationships between segments and rainforest motivation, satisfaction and images

<b>Low activity Beach and Sightseeing</b>	<b>High Activity Touring</b>	<b>Sightseeing, Beach and Developed Facilities</b>	<b>Outdoors, Reef Activities</b>	<b>Nightlife, Entertainment</b>
Limited travel flows, low use of the Reef	Most extensive travel flows (except for Reef and Islands)	Extensive travel flows, most use of Atherton Tablelands	Travel flows limited to the Reef	Travel centered in Cairns
Low interest in and visits to Rainforest	High interest in and visits to rainforests	High interest in and visits to Rainforests	High interest in, but low number of visits to Rainforests	Lowest interest in and visits to Rainforests
Most concerned with being with friends and family on rainforest visits	Most concerned with being physically active and close to nature	Least concerned with being physically active	Most concerned with being close to nature and physically active	Least concerned with being close to nature/ telling friends about the experience, want to be active
Least use of complex, wilderness and interesting to describe rainforest	Most conscious of rainforest, most likely to use wilderness and threatened	High use of complex, valuable, unique and threatened to describe rainforest	See rainforest as not easy to get to, but threatened and full of life	Least use of complex and threatened to describe rainforest

### Summary

It is appropriate to summarise the discussion on existing data thus far and to contemplate the extent to which existing information provides answers to the questions set out at the end of the first section. In other words, To what extent do we understand the spatial distribution of tourists in the GBRWHA?, What do we know about reef tourists?, How effective are current management actions in terms of influencing tourist behaviour and creating positive experiences?, What do residents think of tourism in the GBRWHA?, and How well can we explain the present and predict the future?

### *The spatial distribution of tourism in and near the Great Barrier Reef World Heritage Area*

This is the area which has been given the greatest attention. The data available through the collection of the Environmental Management Charge (EMC) provide information on the total number of visitors to the GBR, the size of the boats operating in the GBRWHA, the relative

proportion of visitors using these different size boats, and the destinations of these boats. Such information is useful in seeking spots of potential impacts and conflict. It does not, however, tell managers very much about the activities being engaged in or who the visitors are.

The data reviewed in the previous sections indicate that there are different types of visitors in terms of both the experiences they seek in the GBRWHA and the activities they engage in. It is the spatial distribution of visitors of these different types that should be of most value for managers in deciding on what types of activities or tourist operations to allow in different areas. This information is not currently available.

It is also important for the management of tourism to understand the patterns of visitation. This would include knowing the answers to such questions as:-

1. How often do tourists access the GBR both on a specific trip and across all their visits to the region? Experience and familiarity are both factors which influence the type of experience sought and what information is necessary.
2. If tourists visit more than once, where do they access the GBR from? and what sort of operator do they choose? If visitors change their patterns of reef behaviour as a consequence of their experiences it is important to understand the patterns of these changes to be able to predict changing requirements and pressures.

Currently there is little information which can be used to answer these questions.

#### *The nature of the market*

The previous sections have outlined some consistent patterns of types of tourist who seek different experiences. These patterns exist for both the sorts of attractions and activities being sought and the actual activities chosen. Further, these patterns have been identified in large scale surveys conducted at a regional level. There is another source of information on reef visitors which has not been previously referred to in this paper. This is the large set of smaller scale studies that have been conducted on visitors engaging in specific activities or at specific reef sites. Within this set, there are numerous investigations of tourist motivations and expectations. There are, however, some difficulties in using this information to guide planning and management. The first and most obvious is that of the scale and representativeness of the data. In many cases the studies are based on small sample sizes which can limit both the reliability and representativeness of results. A particular problem in this respect is that it is difficult to judge just how much of a problem a sample may have as it is not possible to compare the sample to some reliable set of indicators on who reef visitors are. It is possible to make comparisons to the data available on visitors to the regions adjacent to the GBRWHA, but we know that reef visitors are only a subsection of this group. It would be most useful to have a reliable description of reef visitors that could be used to assess samples in smaller scale studies. Such measures should be available in the near future through the IVS and through other reef wide research being undertaken within the CRC Reef Research Centre. The next challenge is to systematically review these smaller, more specific studies and identify patterns which are consistent. This is a considerable task.

#### *Visitor evaluation of their experiences*

There is currently no reef wide, large scale research which has concentrated on visitor evaluations of their experiences. Again there is some information available in the smaller, more specific studies which were discussed above. The challenge is to be able to judge systematically the quality of these data and to find descriptions of visitor responses to experiences and management actions.

*The nature of community perspectives on tourism in the Great Barrier Reef World Heritage Area*

This is an area in which it appears that very little research has been conducted with communities in the regions adjacent to the GBRWHA.

*The factors which explain and predict patterns of tourism*

The existing research and literature in tourism management and planning suggests that there are two major sets of factors which influence tourism; factors which are external to the tourist and those which can be seen as connected to individual tourists. The external factors include such things as transport access, availability of tourism products and promotional exercises. The factors more closely related to the individual tourist include such things as constraints of time and money, life cycle stage, motivations and expectations and experience. It is possible to discuss these factors and how they influence the behaviour of tourists in general. What is not currently possible is to describe these relationships specifically for the GBRWHA. These questions require the development of cumulative reliable and valid research data. Such a development requires data collected with relatively large samples of visitors across the entire GBRWHA.

**Looking to the future: the CRC Reef Research Centre**

There are several projects within the CRC Reef Research Centre which are directed towards understanding aspects of tourism use of the GBRWHA. Of particular interest to the present discussion is Project 2.2.1: Tourist Market Segmentation. The major aim of this project is to conduct large scale surveys of tourists across the entire GBRWHA and its adjacent regions to develop a detailed picture of what sorts of visitors or market segments exist, where they go and what they do in the GBRWHA, their images of the GBR and their satisfaction with their experiences. Table 17 contains a list of the questions which will be addressed by this survey. At this stage nearly 1700 surveys have been completed from tourists surveyed in the Bowen to Mission Beach region and surveys in the Cairns and Port Douglas region should begin in April 1996. This survey information will not only directly address many of the gaps identified in the tourism research area but will also provide a benchmark for other researchers to use in assessing the representativeness of their own samples.

**Table 17.** Questions to be addressed in CRC Reef Research Centre's Project 2.2.1

<p><b>1. Understanding Tourists:</b></p> <ul style="list-style-type: none"><li>◆ Who goes to the GBR and who does not?</li></ul> <p>For those who go to the GBR:</p> <ul style="list-style-type: none"><li>• What activities do they engage in?</li><li>• What motivations do they have?</li><li>• What are the different visitor segments?</li><li>• What images of the GBR do these visitors have?</li><li>• How satisfied are they with their experiences?</li><li>• What levels of experience do they have?</li></ul> <p><b>2. Patterns of Reef Access:</b></p> <ul style="list-style-type: none"><li>• Where do visitors access the GBR?</li><li>• What sorts of tour operations do they use?</li><li>• How often do they visit the GBR?</li></ul>
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In addition to the reef specific surveys, researchers in Project 2.2.1 have developed several partnerships with the BTR, QTTC and the Departments of Forestry and Natural Resources and Restaurant, Hotel, Institutional and Tourism Management, at Purdue University, Indiana. The partnership with the BTR has resulted in the addition of questions to the IVS which will identify international visitors to Australia who have visited the GBR. The partnership with the QTTC has resulted in the addition of several sets of questions to the QVS which will elicit more information on images of the GBR regions and activity participation. These two changes will allow for more GBR specific analyses to be conducted with these data sets. The partnership with Purdue University has given the CRC Reef Research Centre's researchers access to the Pleasure Travel Markets (PTAMS) survey data. These surveys provide valuable insights into international long haul pleasure travel. It consists of a series of large scale surveys (with sample sizes in excess of 3000 for each survey) conducted in various countries including the UK, Germany, Japan, South Korea, and Taiwan. These surveys examine in detail motivations for travel and patterns of travel.

### **Conclusions**

The overall conclusion that can be drawn from this paper is that there has been very little GBR specific, large scale, reliable, or cumulative data collected on tourism. Further, there is a substantial set of studies which have not been used to their full potential. There are however, several options being developed which should greatly improve this situation. In concluding this paper it is worth noting that there are several issues which will need to be addressed if the management of tourism in the GBRWHA is to be effective. These issues include, the need for tourism research to be reliable, valid and cumulative, the need to integrate tourism data with data available on the physical resource, the need to explore the potential value of reef tourism for Aboriginals and Torres Strait Islanders, and the need to use research to ensure quality tourism in the GBRWHA.

There are two major limitations to the use of research in management. The first is the quality of the research. An extensive search of the journals concerned with tourism and environmental management found very few references to research conducted in the GBRWHA. Publication in international, refereed journals is the best measure of research quality currently available. While managers may not use these publications their existence can and should be used by managers as a mechanism for ensuring that the results from the research they are given are valid and reliable. The second major limitation is the preparedness and ability of managers to use research to guide decisions. Tourism is a new phenomenon and it may be valuable to explore opportunities for developing the skills of managers in understanding and using tourism research.

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# Monitoring activities in the Great Barrier Reef World Heritage Area, challenges and opportunities

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## Introduction

To implement the 25 Year Great Barrier Reef World Heritage Area (GBRWHA) Strategic Plan vision of management for ecologically sustainable use, stakeholder agencies need to take a holistic perspective of the Area to include both its physical and human components and their interactions. Managing for ecologically sustainable use is more than managing to minimise ecological impacts of direct uses. It is to minimise social, cultural and economic impacts, ensure equitable opportunities for use and maintain and enhance a socially desirable range of values.

Information on reef use and values not only provide the basis for effective management of direct uses but also allows us to understand direct and indirect causes of observed patterns of use and assist in anticipating undesirable ecological impacts on the Great Barrier Reef (GBR). While the Great Barrier Reef Marine Park Authority (GBRMPA) planning and management activities have concentrated on managing uses, research effort to date has focused on developing an understanding of the GBR ecosystem, and monitoring major ecological impacts of reef related activities. This has not been matched by the development of an information base of the nature of reef activities and reef values. As a result, the available information base is often inadequate to respond to management needs.

This paper describes the status of existing information on reef use, initiatives taken by GBRMPA and other agencies and addresses the need for an integrated approach to the development of long-term reef use datasets. Tourism related projects initiated by the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef (CRC Reef Research Centre) are described elsewhere in the proceedings (e.g. Valentine et al. in press; Pearce et al. in progress; Inglis and Shafer in progress).

## Typology of reef related activities

Reef related activities can be broadly classified as those that are GBR dependent and those which are not. In the first category are commercial fishing, tourism, private recreational use, indigenous use, vicarious use, scientific use and management. The second category includes shipping, port development, waste disposal, coastal and catchment development. Further classification include those activities occurring within the GBRWHA boundaries and those occurring in adjacent areas but potentially affecting the GBRWHA (Table 1).

The GBRMPA does not have direct jurisdiction over activities taking place outside the Great Barrier Reef Marine Park (GBRMP), however, it has responsibility for ensuring the protection of the GBR under the *Great Barrier Reef Marine Park Act 1975*. The GBRMPA has management arrangements with relevant stakeholder agencies including a range of government departments and agencies at federal, state and local levels depending on the extent of their jurisdictional boundaries and statutory responsibilities. A consequence of this multiplicity of jurisdictions is that information on patterns of use is held by a range of agencies. Information on ecological impacts of use on the GBR forms most of the GBRMPA research and monitoring effort.

**Table 1.** Typology of reef related activities

<b>Reef related activities</b>	<b>Within Area</b>	<b>Outside Area</b>
Area dependent	Tourism and private recreation Commercial fishing Indigenous use Scientific use Management Conservation/protection Ecological services Storm protection	Vicarious use
Non-Area dependent	Shipping Waste disposal	Port development Coastal/catchment development

**Information needs**

The development of a GBRWHA wide integrated information base on reef related activities is at its beginnings. This paper focuses on selected uses (tourism, recreation, coastal demography) for which reef wide datasets are available. Restrictions in the nature of the information only permits an analysis of distributional patterns rather than socio-economic characteristics of uses. Commercial fishing, indigenous use, coastal and catchment land uses are discussed elsewhere in these proceedings.

Gaining information on the range of reef related activities will require further analysis of existing datasets as well as the development of specific data collection (e.g. indigenous use, recreational use, vicarious use) on distributional as well as socio-economic characteristics of those activities and factors affecting them. Cooperative strategies for data collection and information sharing protocols need to be further developed with relevant stakeholder agencies.

Key elements of informed decision making relate to the nature and quality of the information, its relationship to other information sources and its format. To this end, consideration of information needs should take account of:

- Forecasting, based on long-term datasets of uses and users;
- Linking of biophysical and socio-economic datasets;
- Defining appropriate management scale/spatial unit (e.g. bioregion);
- GIS requirements;
- Compatibility with existing datasets at regional and national levels; and
- Access/information sharing/protocols with GBRMP stakeholders and other agencies.

**Status of information on reef related uses**

Information on reef related activities is found in reports and databases scattered in various government agencies and organisations including GBRMPA. The extent and usefulness of that information varies greatly depending on who collected the data and for what purpose. Most of the GBRMPA reef use information relates to tourism and recreation, a reflection of the focus of planning and management activities and of the interest recreational management has attracted in research institutions and park management agencies in Australia and overseas. The main sources of information on reef use include GBRMPA research reports undertaken since its establishment in the late 1970s, reef specific databases and national and state databases.

**Overall trends in reef use**

Although its primary function is enforcement, the Aerial Surveillance Databases (Queensland Department of Environment (QDoE) and Coastwatch) provide a GBR wide source of

longitudinal data on reef use. From about 1989 up until November 1994, a stratified random sampling design was used to record vessel sightings in sectors and plots throughout the GBRMP. This data has been used to derive *generalised* spatio-temporal patterns of reef use (see Honchin 1991; Storrie 1993), but rigorous statistical analyses of the data by Pettitt and Haynes (1994a, b) showed that the prescribed sampling design was not strictly adhered to and that the quality of the data was variable between agencies and over years. Therefore, trends and rough estimates rather than actual figures should be inferred from analyses of the aerial surveillance data presented in this paper.

Spatial analysis of the dataset from 1990 to 1994, largely based on methods developed by Storrie (1993), showed no significant GBR wide trends in visitation levels (Table 2) and number of reefs visited (Table 3). However, visitation levels have increased in consistently high use areas such as offshore Cairns and in the Whitsundays (over 300 passengers/day on average). Most of the GBR is being used at low intensity (0-30 passengers/day on average) particularly in the more remote parts of the GBR such as the outer reefs and the Far Northern section which are generally areas of commercial fishing activity. About 90% of reefs in the GBR were visited at least once a year.

Pettitt and Haynes (1994b) also analysed the Coastwatch and QDoE aerial surveillance program data. Their analyses indicate that, on the whole, year is not important in explaining the variation in daily vessel sightings on the reef, but that vessel type, day type and reef are important in explaining the variation in vessel sightings. High use sites such as Norman Reef (16030), Green Island Reef (16049), Hardy Reef (19135), Michaelmas Reef (16060) and Moore Reef (16071) were among the top five consistently high use sites from 1989-90, 1990-91 and 1991-92.

For 1994, the distribution of vessel types per flight per section showed that overall, number of vessels sighted was greatest in the Cairns and Mackay/Capricorn sections compared to the Far Northern and Central section (see Table 4). As there are a large number of vessel types which operate in the Marine Park, vessels were recorded into five categories: yachts, commercial fishing (Comfish), large displacement vessels (Displ), miscellaneous vessels (Misc), speed boats (Speed), and aircraft (Acft) based on the vessel types in Table 5.

The distribution of vessel type showed a stable proportion of yachts throughout the GBR (about 15 to 20%) and slightly lower in the Far Northern section (10%). Commercial fishing accounts for 20% of vessel types sighted for most of the GBR except for the Far Northern section where it represented 45% of all vessel types. Private use as indicated by speed boats and yachts varied greatly from section to section with the highest proportion in the Central section and Mackay/Capricorn sections and the lowest in the Far Northern section (see Fig. 1).

#### *Trends in tourism use*

Tourism use of the GBRMP can be derived from permitted commercial use (permits database) and data returns from the Environmental Management Charge (returns tables). The permits database includes details of individual commercial operations, permitted activities, accessible sites and maximum vessel passenger capacity. The database allows differentiation between site dedicated and roving vessel operations.

The permits database can be used to derive potential numbers of visitors per year (Thomas 1993). Potential reef visitation by site specific commercial vessels expressed as potential visitors per year (PVY) exceeded 5 200 000 in 1994 (see Table 6). These same vessels were permitted to access 183 reefs. Most of the permitted use is concentrated in the Cairns and Central sections.



Table 2. Estimated average daily visitation to the top 50 most visited sites in the GBRMP

1990		1991		1992		1993		1994	
Reef id	Ave # daily pax	Reef id	Ave # daily pax	Reef id	Ave # daily pax	Reef id	Ave # daily pax	Reef id	Ave # daily pax
16030	603	16030	466	16030	463	16030	440	16030	422
20041	517	16049	458	16049	420	19135	373	23012	375
16049	415	16071	382	16071	412	23012	354	16071	373
19135	317	16060	264	19135	349	16071	289	16049	370
16060	312	16032	222	20732	337	16049	257	15099	346
15099	231	23012	218	23012	331	16060	233	19135	303
23012	211	19135	204	16751	300	15099	221	15096	275
16032	203	18030	193	16060	221	15096	181	16064	203
16071	191	15096	171	15096	215	19009	173	16060	179
19009	171	23082	164	15099	202	17051	164	23082	151
20732	165	15099	159	23082	180	18030	155	16015	134
20709	159	16028	151	18030	168	23082	142	18030	123
16054	153	19009	151	16032	158	14116	128	16054	116
20058	152	17051	124	16716	132	16064	117	17012	115
20712	150	20028	107	14116	126	16055	114	17053	113
16028	139	16029	107	20028	113	17053	113	17051	111
17053	130	20041	84	16068	109	16032	101	14116	105
14116	129	16057	83	14146	107	16054	95	20287	102
23082	126	14116	78	16054	103	16057	94	16025	90
18030	121	17053	71	16029	102	16709	89	18701	80
20028	109	16068	69	19009	100	15050	81	16020	77
18049	106	14042	66	17051	98	16707	75	23052	75
16716	96	17720	66	16064	89	23009	73	20271	74
14140	89	16054	61	16042	87	20287	71	18702	73
17001	89	14140	61	17053	83	18049	68	19009	66
17051	87	16067	61	16707	82	18701	66	18079	62
16701	87	23052	60	14140	77	17001	65	14146	62
20017	86	16025	55	16020	67	19137	64	16026	62
15096	82	16055	55	19726	67	21701	60	16716	61
16055	82	16026	55	16701	65	19006	59	20733	61
15719	70	14706	55	23052	65	16042	59	16068	60
16709	68	16015	51	18049	61	17012	56	16707	60
20014	68	20067	50	22052	60	16029	54	16032	56
19726	66	16716	49	16067	58	12016	52	19726	51
18702	64	19726	47	17012	58	18079	51	22133	51
20711	61	20287	46	16710	57	19717	51	15094	50
16067	53	23721	45	16025	55	14132	51	19035	50
16710	51	18049	44	18701	54	16026	50	23701	49
18095	51	22147	44	16046	54	23010	50	16057	49
20287	48	14146	42	15736	54	23052	49	18049	48
23049	47	14152	40	20041	54	16073	48	16029	46
19716	47	16065	38	24701	51	16065	44	23031	45
16029	45	17012	36	16709	50	16074	41	16701	44
14152	43	14022	35	23077	50	15091	40	21711	44
16073	41	23049	34	16715	47	14114	39	18080	43
18701	41	17011	34	15025	46	15714	38	16040	42
18086	40	23069	33	23004	44	15072	38	21433	41
17012	40	15719	32	16702	44	15041	38	17720	40
16064	39	23711	32	16028	42	15710	38	15703	38
15065	39	16006	31	23049	42	14140	36	19006	38

Notes:

- Figures are indicative only and should only be interpreted as trends, not actual numbers.
- Figures derived from Coastwatch and QDoE aerial surveillance programs.
- Only includes reefs where vessels have been sighted.
- Includes both reefs and some inter-reefal areas (indicated by xx7xx id codes)

• Pax (i.e. the number of passengers on board) is estimated for each class of vessel type. For example, small pleasure craft is estimated to have an average of three people on board at any one time, while large catamarans would have about 300 passengers on board.

**Table 3.** Number of reefs visited per average daily passenger classes

Passenger Class/year	1990	1991	1992	1993	1994
0-30	903	1022	1080	802	807
30-100	44	38	44	41	56
100-300	16	13	15	14	13
>300	5	3	7	3	6
<b>Total # reefs</b>	<b>968</b>	<b>1076</b>	<b>1146</b>	<b>860</b>	<b>882</b>

Notes:

- Figures are indicative only and should only be interpreted as trends, not actual numbers.
- Figures derived from Coastwatch and QDoE aerial surveillance programs.
- Includes reefs and some inter-reefal areas.
- Average daily use is grouped naturally into four average daily PAX classes.

**Table 4.** Reef visitation per vessel type in 1994 expressed as a percentage of total vessel type per flight (adapted from Aerial Surveillance Database)

GBRMP Section	Yacht (% of total sightings)	Comfish	Speed	Misc	Displ.	Acft
Far Northern	10	45	19	14	12	0
Cairns	15	21	27	21	15	1
Central	17	20	43	9	10	1
Mackay/Capricorn	19	22	34	9	14	2

The data returns tables are part of the permits database. The Environmental Management Charge (EMC) was introduced in July 1993 and is calculated on actual daily numbers of passengers carried to a reef site. Commercial operators are required by law to fill in log books with daily information on crew numbers, passenger numbers, vessel name, vessel registration number and sites visited.

Commercial tourism visitation in 1995 based on the EMC data returns was greatest in the Cairns section (911 359) followed by the Central section (555 537) the Mackay/Capricorn (117 800) and the Far Northern section (4410). The top fifteen tourist visited reefs make up 93% of all tourist visited reefs in the GBRMP (see Fig. 2), with 12% of total visitation occurring at Green island in the Cairns section.

#### *Latent visitor capacity*

Comparing potential visitation with actual visitation gives an indication of the latent tourist visitation capacity (see Honchin 1996). The extent of latent capacity in the GBRMP is a major challenge for GBRMPA and the tourism industry in terms of management of future use. Mechanisms are currently being developed to address this issue.

**Table 5.** Classification of vessel types

<b>Displ.</b>	<b>Comfish</b>	<b>Yacht</b>	<b>Speed</b>	<b>Acft</b>	<b>Misc</b>
Barge	Barramundi boat	Catamaran	Dinghy	Helicopter	Canoe
Bulk barge	Clam boat	Ketch	Half cabin	Plane	Miscellaneous vessels
Coastal vessel	Fishing vessel	Schooner	Outboard	Seaplane	
Container ship	Foreign fishing vessel		Pleasure craft		
DOT vessel	Game fishing vessel		Runabout		
General barge	Longliner				
General cargo ship	Lugger				
Hydrographic vessel					
Landing barge					
Landing craft heavy					
Launch					
Livestock carrier					
Merchant ship					
Motor sailor					
Naval vessel					
Oil exploration vessel					
Large passenger vessel					
Patrol boat					
Pilot					
Research ship					
Rollon/rolloff ship					
Seismic survey vessel					

**Table 6.** Potential visitation per year per section for 1994 (adapted from Valentine et al. 1994)

<b>Permit type</b>	<b>Far Northern PVY (# of reefs)</b>	<b>Cairns PVY (# of reefs)</b>	<b>Central PVY (# of reefs)</b>	<b>Mackay/Capricornia PVY (# of reefs)</b>
Site specific only	47 078 (8)	2 434 662 (45)	2 484 479 (105)	142 070 (25)
Mixed	24 592 (6)	986 582 (50)	1 945 723 (69)	209 411 (4)
Roving only	242 376 (735)	354 636 (291)	300 530 (510)	166 192 (1052)

Notes: Information based on existing permits only

*Impact of tourism use on other uses*

A major limitation with the aerial surveillance program is that tourism vessels and private vessels cannot be readily separated for the purposes of data analysis. However, visitation levels at high use sites based on both the EMC data returns and the Aerial Surveillance databases can be used to validate those respective sources and derive an indication of private use (see Table 7). This is based on the assumption that most non-tourism use at high tourism sites is private use, rather than commercial use, for example by commercial fishers.

Impacts of tourism on private use such as displacement of other uses (including indigenous peoples) can be seen in high use destinations such as Green Island and Michaelmas Reef. In other lower use destinations there is a better balance between tourism and non-tourism uses. Patterns of recreational private use needs to be verified by independent assessment of private use at those locations.

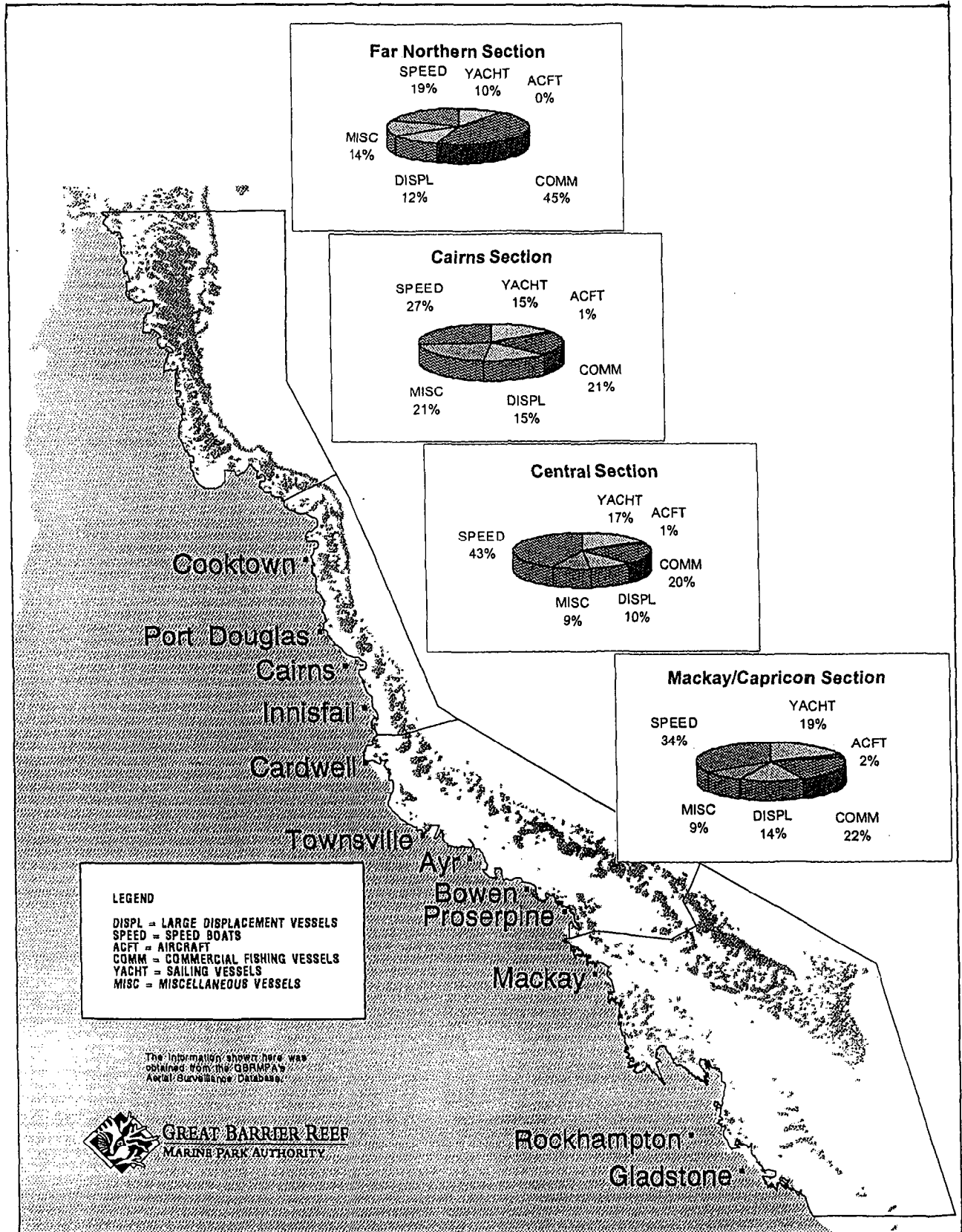


Figure 1. Aerial surveillance - Proportion of vessel types sighted (%) per section in 1994

**Table 7.** 1994 visitation levels at the 10 high use sites based on the EMC data returns and Aerial Surveillance databases

Reef	Average daily pax	Yearly EMC pax	Daily EMC pax	No. of EMC trips	Daily non-tourism use	% of non-tourism use
Norman	422	124812	342	1758	80	19
Great Keppel	375	23363	64	549	311	83
Moore	373	54853	150	1498	223	60
Green	370	200113	548	1807	-178	0
Agincourt 3	346	95134	261	1132	85	25
Hardy	303	94339	258	1779	44	15
Agincourt-4	275	91093	250	831	26	9
Arlington	203	19771	54	522	149	72
Michaelmas	179	66054	181	1474	-1	0
Lady Musgrave	151	20240	55	699	96	63

Notes:

- Figures are indicative only and should only be interpreted as trends, not actual numbers.

### *Diving on the Great Barrier Reef*

A recent study of diving activities (Windsor 1995) in the GBR by 532 permit holders (obtained from the Permit database) indicated that 803 000 dives take place in Cairns (see Table 8). This represents 62% of all dives (1 299 500 total), most of those being open water dives (including training dives) rather than open water certifications (18 000) (Windsor 1995).

**Table 8.** Pattern of diving activities for 1994 ( adapted from Windsor 1995)

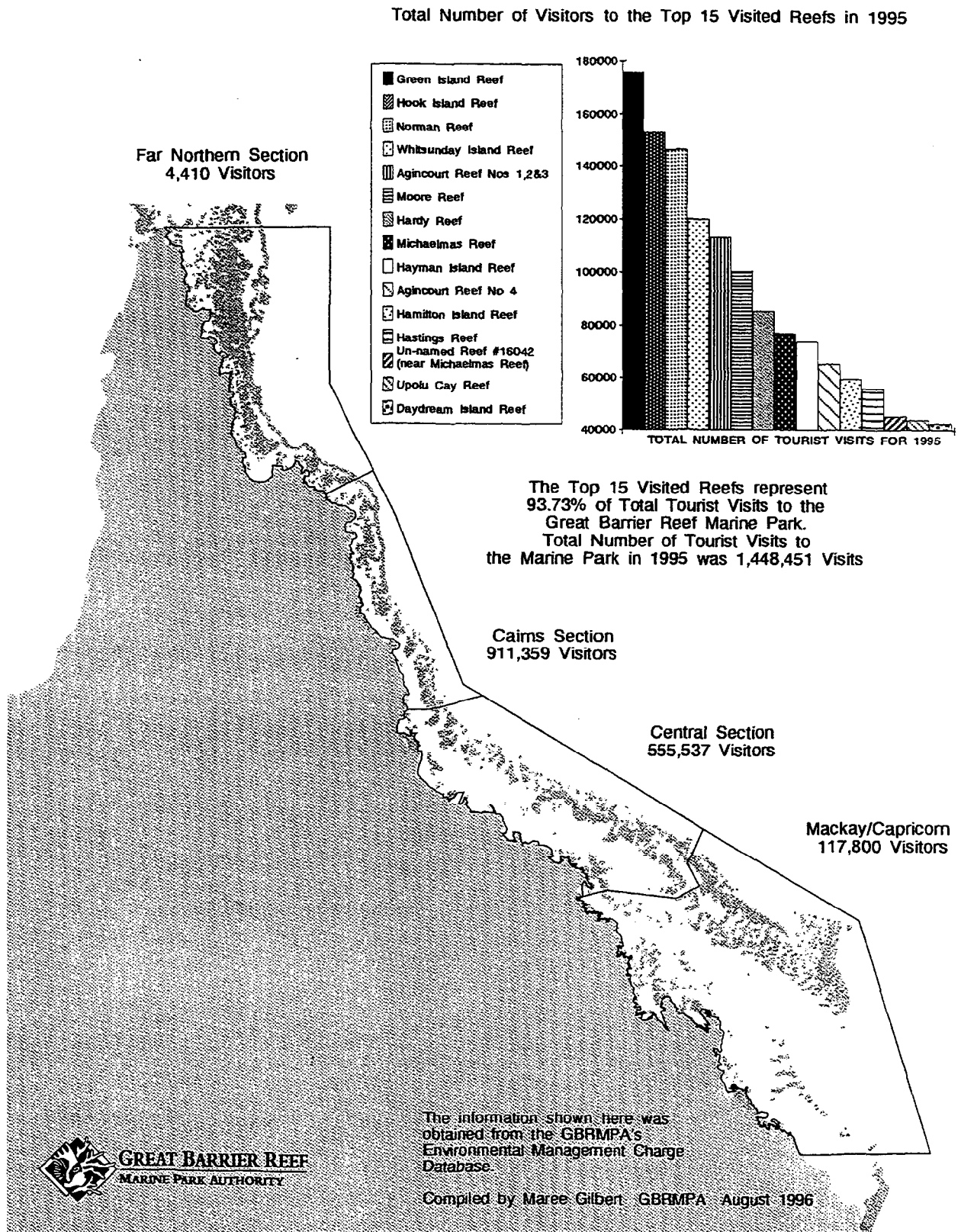
Location	Resort dives	Openwater certification	Openwater dives (including training dives)	Overall total dives (% of total)
Coral sea			42 000	42 000 (3.3%)
Cod hole			52 000	52 000 (4.0%)
Yongala			18 500	18 500 (1.4%)
Cairns	83 000	18 000	<u>720 000</u>	<u>803 000 (62.2%)</u>
Townsville	4 500	3 000	17 000	21 500 (1.7%)
Whitsundays	34 000	7 500	<u>214 000</u>	<u>248 000 (19.2%)</u>
Capricorn/Bunker groups	5 500	1 800	59 000	64 5000 (5.0%)
SE Qld (non-permit holders)	2 500	2 200	38 500	41 000 (3.2%)

A total value of diving industry in direct expenditure of \$103 240 000 was also estimated based on an average cost of \$80 per dive. Diving activities may result in the degradation of high use sites such as Cairns through diver damage (see Roupheal and Inglis 1995) possibly with wider ecological, social and economic consequences.

### *Tourism in the Great Barrier Reef region*

National (e.g. Australian Bureau of Statistics, Bureau of Tourism Research) and State (e.g. Queensland Tourism and Travel Corporation) data collection exercises provide contextual information on the characteristics of tourism activities in the GBR region including visitor, trip and industry profiles. Most of those datasets have been in place for a few years and are used for trend identification and forecasting. Information on visitor characteristics (e.g. age, nationality,

expenditure, satisfaction) can be used to target particular market segments for GBR education, predict patterns of use and derive the economic value of tourism.



**Figure 2.** Commercial tourist visitation to reefs in the Great Barrier Reef Marine Park - 1 January 1995 to 31 December 1995

The usefulness of those datasets for management is limited for deriving regional and local estimates for methodological reasons. Other constraints include the absence of a reference to the GBR as a tourism destination, so that area specific visitation cannot be separated from overall tourism visitation to the region. A number of approaches have been proposed to remedy this situation (Benzaken 1995). They include incorporating questions in established data collection, redefining the spatial unit, developing regional data collection which are compatible and comparable with those datasets and ensuring that data collection is appropriately geographically referenced.

The CRC Reef Research Centre's initiative to incorporate a question which describes the GBR as a destination and provide a better taxonomy of reef tourism activities (Pearce et al. pers. comm.) has greatly improved the use of the International Visitor Survey (IVS) undertaken every year by the Bureau of Tourism Research.

#### Trends in private recreational use

The Queensland Private Boat Registration database (held by the Department of Transport) is designed for the administration of boat registration fees. It includes information on boat owners, place and postcode of residence and boat characteristics (e.g. length, power, sails). The data obtained from the Department of Transport for this analysis does not include personal details of boat owners for confidentiality and privacy reasons.

Data for 1995-1996 were spatially analysed using GIS to develop a profile and distribution of private boat ownership adjacent to the GBR region, as a surrogate measure of GBR based recreation (Benzaken et al., in progress). Estimates of GBR water based recreational use (estuarine/inshore, offshore reef) were derived using boat length as an indicator of maximum distance travelled. Boats under five metres were assumed to use primarily rivers, estuarine and inshore marine areas, while boat over five metres were assumed to potentially travel to offshore reefs (see Blamey and Hundloe 1993; Hundloe 1985). A profile of the private boat fleet was derived based on boat length, 'sails' and 'speed'. It showed that in the region adjacent to the GBRMP most boats are under five metres (33 912) and are most are 'speed' boats (39 849) as opposed to 'sail' boats (874) (Table 9).

**Table 9.** Profile of boats in region adjacent to the Great Barrier Reef Marine Park

Boat class	Region adjacent to Great Barrier Reef Marine Park	Queensland
Under five metres	33 912	
Over five metres	9616	
'Sails'	874	2620
'Speed boat'	39849	
Total sample	43 528	104 657

The spatial analysis of boat per size class per postcodes adjacent to the GBRMP (see Figs. 3 and 4) shows that boats under five metres are found in significant numbers in Bundaberg, Mackay, Cairns, Gladstone, Ingham, Ayr, Rockhampton and Townsville area. The over five-metre fleet is evenly distributed and follows settlement patterns with high numbers registered to the Cairns' postcode area.

By combining number of vessels with population estimates per postcodes (based on Australian Bureau of Statistics CDATE), a density of boat ownership per population can be obtained from which participation in water based recreation and 'recreational use catchments' can be derived. The combination of that information with data from the Aerial Surveillance database provides a

starting point to the development of a picture of recreational use. Further data collection can be developed using the Boat Registration database as a sampling frame.

Site specific studies of reef use

#### *Bramble Reef study*

A study by the CRC Reef Research Centre of the socio-economic impacts of the Reopening of Bramble Reef to line fishing will provide the basis for developing a survey methodology to obtain basic spatio-temporal patterns of recreational use. A technique for integrating the survey data into ARC/INFO is being piloted. The GBRMPA Representations database mapping units are used in conjunction with a coverage of boat ramps for the Queensland coast.

The Representations database includes spatially referenced information from public submissions received by GBRMPA during the zoning and planning reviews of the Central section (1987). Information on patterns of use, motivation, values of the area, expenditure and attitudes towards management collected for the Bramble Reef study can be interpreted with an historical perspective based on the last review of zoning in the area (Benzaken et al. in progress).

A complementary survey of households in the Ingham area provided the necessary background on participation in marine based recreation as well a general information relevant to management.

The Queensland Fisheries Management Authority is currently developing a recreational and boating database and is considering a range of approaches to assess the extent of recreational fishing and its impact on fish stocks.

#### *The human use database*

A review of 89 GBRMPA reports (from 1978 -1992) undertaken in 1992 (Benzaken 1993) showed that most studies had focused on variety of management research issues. These studies provide invaluable insight in the nature of visitor experiences, activities, perceived impacts of tourism on other activities as well as attitudes towards the GBR and its management. They also provide an historical record of the characteristics of tourism and recreation. Compilation of study results for areas of high visitation (where most studies have been undertaken) may be possible. However, they could not be used for trend identification for GBR wide reef use because of the variety of scale (site specific), locations, sampling design (small sample size), variables and analysis used which precludes comparative analyses.

#### *Trends in coastal demography*

##### *Demography of the coastal zone*

The Australian Bureau of Statistics undertakes a population census every five years. Population trends for the region adjacent the GBR are shown in Table 10.



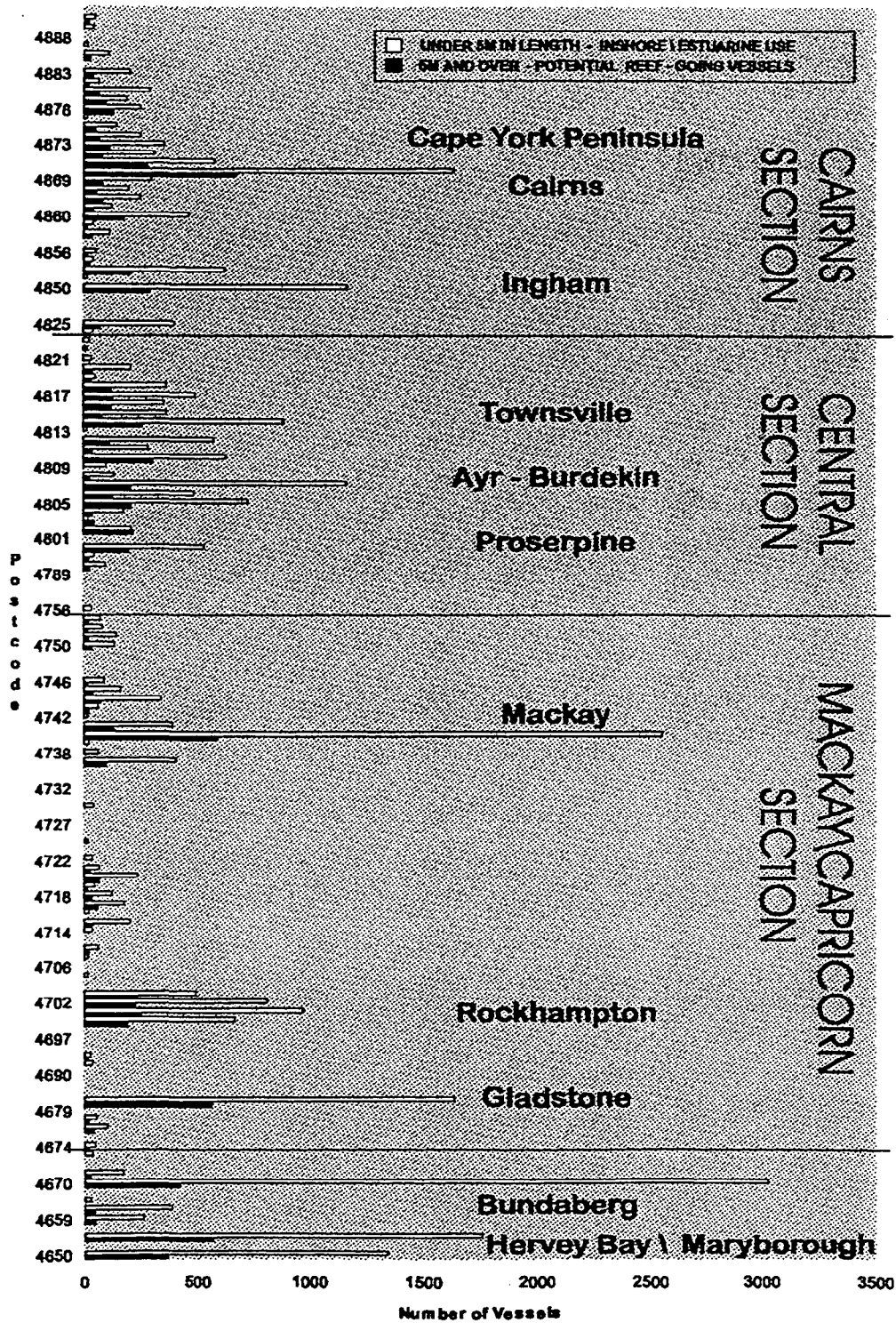
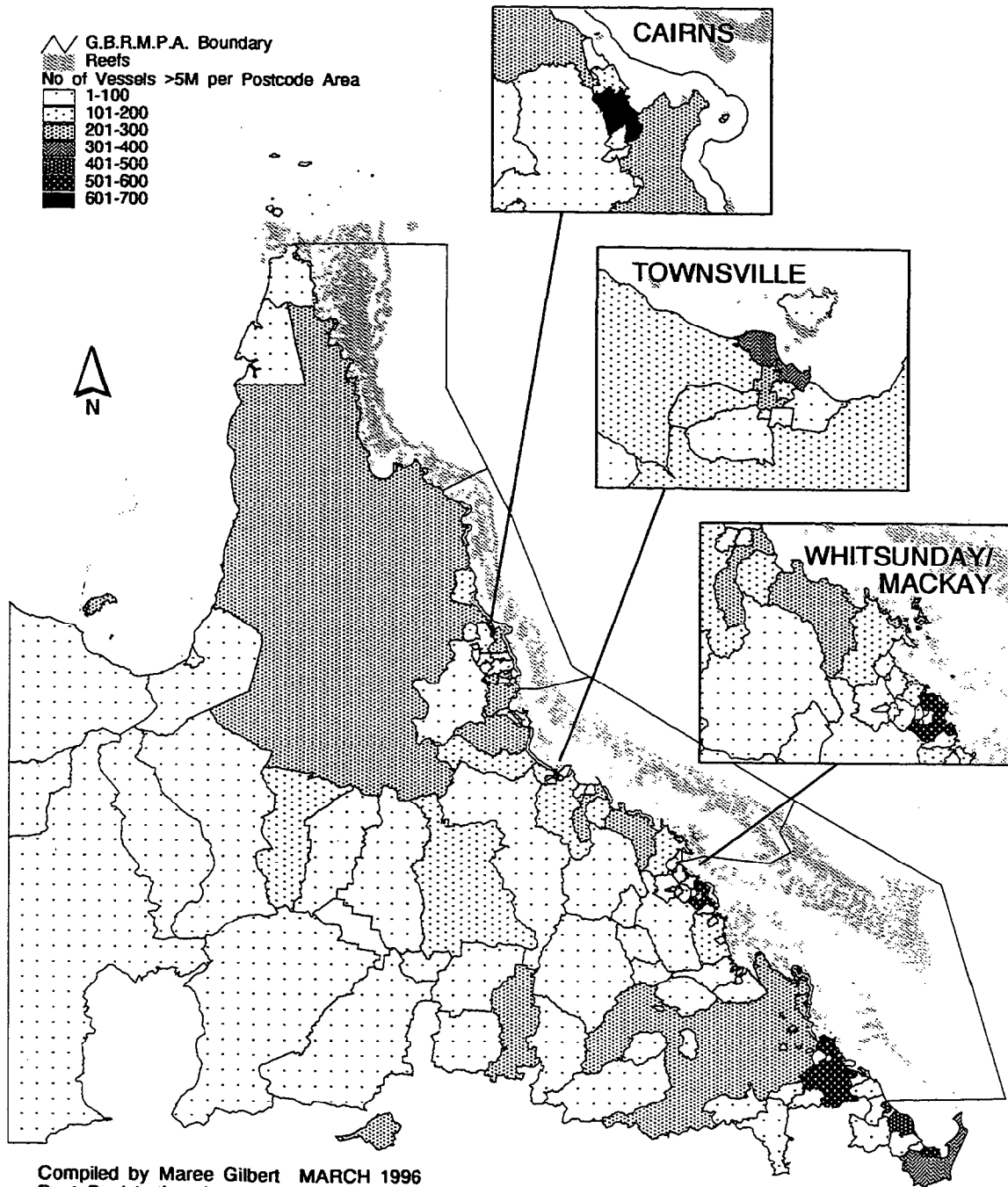


Figure 3. Distribution of privately-registered vessels in the postcode areas adjacent to the GBRMP. Data was obtained from Queensland Transport Boat Registration records as at 19 January 1996.



Compiled by Maree Gilbert MARCH 1996  
 Boat Registration data from Queensland Transport as at 19 January 1996  
 Postcode Boundary Coverage compiled by ERSIS AUST P/L - CDATE



**GREAT BARRIER REEF**  
 MARINE PARK AUTHORITY

**Figure 4.** Vessels five metres and over in length privately-registered to the postcode areas adjacent to the Great Barrier Reef Marine Park

Notes:

- not all postcodes have a unique identifier. For example, Cape York Peninsula shares its postcode within a small area near Cairns which makes it difficult to estimate numbers of registered boats in Cape York Peninsula
- the allocation of post codes to large populations centres is variable and not related to population size.

**Table 10.** Resident population changes in centres adjacent to the GBR (p: x preliminary estimates) adapted from Queensland Department of Housing and Local Government 1995)

Statistical division	1986	1991	1994 (p)
<b>Local Government area</b>			
<b>Mackay</b>	<b>103 499</b>	<b>110 301</b>	<b>116 317</b>
Whitsunday	9 676	11 429	12 252
Mackay	58 828	63 557	68 607
<b>Northern</b>	<b>171 744</b>	<b>182 581</b>	<b>192 432</b>
Townsville	82 064	86 245	88 855
Thuringowa	28 415	35 331	42 510
Hinchinbrook	15 536	15 501	15 365
<b>Far Northern</b>	<b>161 042</b>	<b>181 399</b>	<b>195 763</b>
Cape York Peninsula (Aurukun, Cook, Weipa)	7 840	8 289	8 413
<b>Cairns/Mulgrave</b>	<b>79 567</b>	<b>92 563</b>	<b>103 410</b>

Significant areas of population growth include the major urban and tourism centres (Fig. 5). Growth can be attributed to migration gain as a result of economic activity and urban overspill (Ward 1995). Areas like Cape York Peninsula and Torres however can be attributed to natural increase rather than migration (Ward 1995). An important trend is migration away from urban centres to non-metropolitan areas (Bell 1992 in Ward 1995, p. 9).

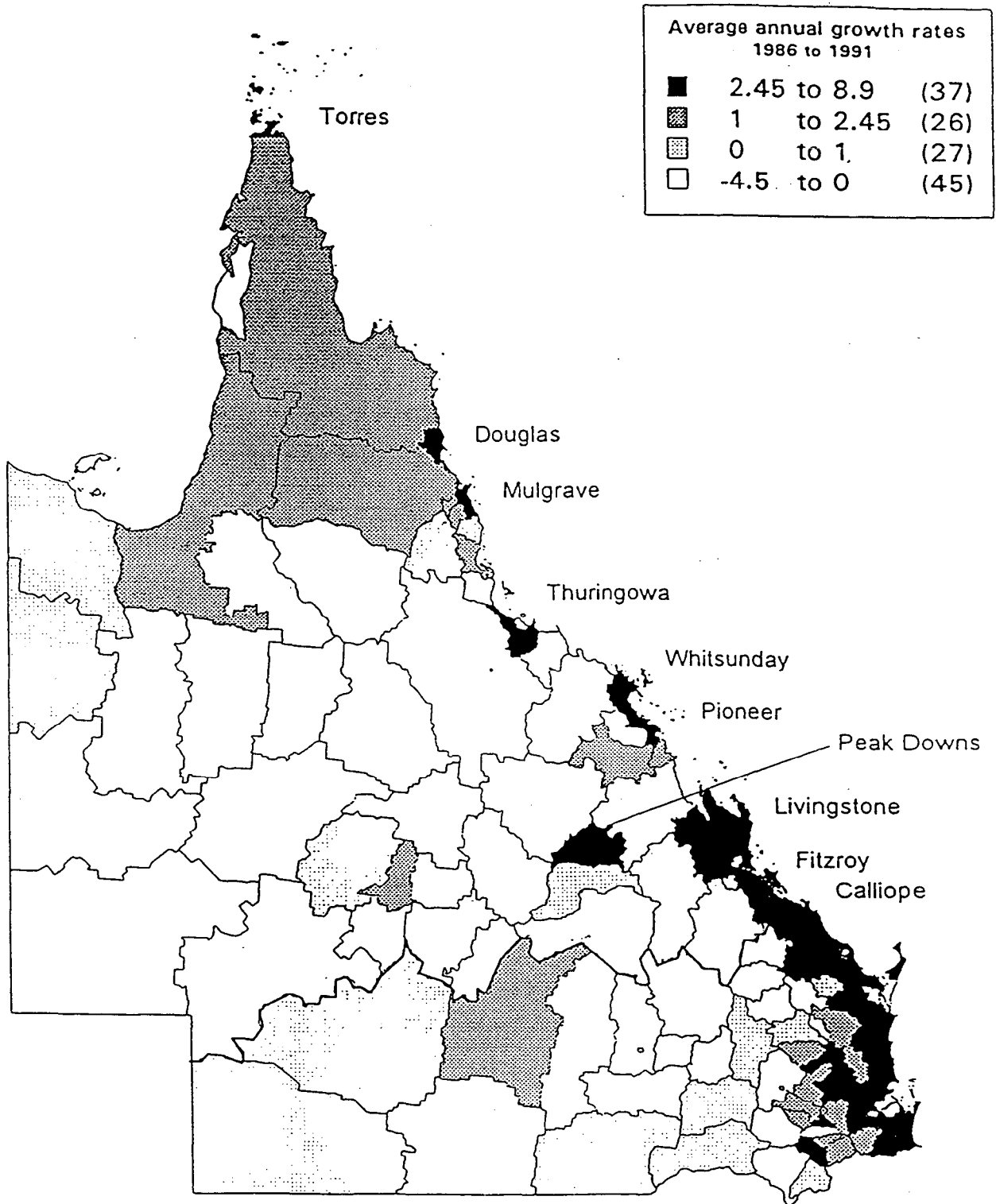
The Australian Bureau of Statistics census uses full enumeration and data can be aggregated at a range of spatial units, the smallest unit of data collection being the Collection District (200 households). Work is in progress to aggregate the data for catchments boundaries. This information can be used to estimate potential ecological impacts on the GBR (e.g. sewage effluent).

Australian Bureau of Statistics census data are also routinely used to derive regional socio-economic profiles (e.g. the Centre for Applied Economic Research and Analysis quarterly reports on regional economies for Cairns, Townsville and Mackay). Australian Bureau of Statistics census data have also been traditionally used to derive representative sample populations (based on demographic characteristics) for site specific studies on a range of topics.

### **Conclusion and future directions**

From the data available, overall trends in reef use and coastal resident populations have not changed dramatically at a GBR wide scale. Localised 'hot spots', where tourism is the dominant economic activity (Cairns and Whitsundays) have experienced growth both in the resident population and reef tourism visitation. However, current tourism use is well below permitted capacity in most areas of the GBR except in a few localised areas offshore Cairns.

Snap shots of recreational boat ownership in high use areas show a large fleet of private vessels over five metres with the potential to use the GBR. Some displacement of private use is evident at these reefs. Private boat ownership along the Queensland coast show nodes around the main urban centres with most of the fleet under five metres in length. These vessels are also most likely to use estuarine and inshore waters.



**Figure 5.** Average annual growth rates 1986 to 1991 per statistical Local Government Area based on Australian Bureau of Statistics CDATE (source Ward 1995)

Notes

- Census data are not useful for deriving remote areas population estimates (e.g. CYP) because data cannot be disaggregated below the Collection District for confidentiality reasons.
- CYPLUS recent study of CYP population indicates the difficulty of deriving accurate figures for remote areas (King 1994)

Trends and statistics derived from the sources of data have to be read with caution. In most cases, several datasets should be used in concert to get reliable information as any one dataset is likely to be deficient in some way. Initiatives both at GBRMPA and other stakeholder agencies are underway to develop a GBR wide information base. Cooperation and information sharing are essential elements of this process.

Steps for the future include:

- Improving the quality of existing long term datasets;
- Linking GBRMP datasets with datasets on catchment and coastal uses datasets;
- Developing appropriate reporting mechanisms which allow the translation of data into useable information by managers and other stakeholders; and
- Developing new data collection strategies to address information gaps.

### **Acknowledgments**

We acknowledge the assistance of Maree Gilbert in analysing and preparing the Boat Registration and EMC data, and producing the maps.

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# Values do matter: managing cultural and social diversity leads to better protection

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## Abstract

Values are social constructs arising from belief systems which provide individuals and society with a framework for organising and interpreting their surroundings and for acting according to agreed social norms. Valuing selected aspects of the natural or social environment is giving those aspects special significance according to shared beliefs about their importance. Environmental values therefore are not properties of the environment per se, but rather a statement by the beholder (individuals, groups, cultures society) of their importance. In environmental management, 'values' are defined as valued attributes of the natural environment for their ecological, social, economic and cultural significance.

According to the Great Barrier Reef World Heritage Area Strategic Plan vision, stakeholder agencies have the responsibility to maintain and enhance the Great Barrier Reef World Heritage Area aesthetic, ecological cultural and social value. Managing for a range of 'values' requires both knowledge of those values as well as equitable processes to maintain present and future values and opportunities for the local, national and global communities.

Developing an inventory of Great Barrier Reef 'values' (to whom, why, what, where) is the first step from which tools can be developed to assist decision making. Once identified, 'values' may be 'mapped' and integrated with other information such as distribution of reef use and reef ecology. Subjective maps of 'values' will assist the decision making process by making explicit what underpins stakeholder positions including the identification of areas of potential conflicts and common grounds. While values may be 'mapped' according to who holds them, geographical location or nature of interest, their weighting in decision making is problematic. Economic tools have been developed to address this issue either by assigning a dollar value to values traditionally not traded in the market (e.g. intrinsic value, ecological value, subsistence value) and by developing decision support tools such as multicriteria analysis and use allocation criteria based on highest economic value. While these techniques will assist the decision making process, they should not replace participatory decision making mechanisms where stakeholders' values are negotiated and traded off to achieve agreed outcomes.

The current status of knowledge on Great Barrier Reef values has been acquired through agencies' public participation exercises, commissioning research studies and post graduate research. Relevant information can also found in various databases. While information on values associated with direct use is available (e.g. tourism and recreation studies, economics studies) and has been compiled in various databases (e.g. human use database, Department of Tourism database), its use is limited to identify patterns and trends because of the scale and scope of those projects. Overall, the information base is incomplete particularly as it relates to values associated with indirect use (e.g. global and national community), non use (e.g. cultural, conservation) and values of those excluded from participatory processes. An integrated approach is required to ensure that time series at a range of scales can be developed in key areas such as World Heritage, recreation and tourism, indigenous use and economics. Recent reports to address Great Barrier Reef wide values include the economic value of the Great Barrier Reef World Heritage Area (Driml 1993), the development of a inventory of World

Heritage values, and a national survey of public perception of wilderness in the Great Barrier Reef.

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# **A long way together: the recognition of indigenous interests in the management of the Great Barrier Reef World Heritage Area**

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## **Introduction**

Contemporary indigenous interests in the Great Barrier Reef World Heritage Area (GBRWHA) arise from long standing cultural association with and use of the coastal and marine environments of the GBRWHA. The interests of indigenous groups were largely unrepresented until a decade or so ago. Since then the special cultural, spiritual and economic relationship Aboriginal and Torres Strait Islander peoples have with the environment has been recognised at a national and international level as being important for their survival as well as for conservation and ecologically sustainable development. In Australia significant legal and political developments have given visibility and strength to indigenous people's claims to land and access to natural resource management, policy development and implementation. These factors combined with indigenous expectations and a favourable political and social climate have influenced the way in which the Great Barrier Reef Marine Park Authority (GBRMPA) has accommodated indigenous interests in the management of the GBRWHA.

This paper first reviews the nature of indigenous people's relationship to the marine and coastal environments and their contemporary interests in the GBRWHA. Then it outlines the legal and policy context at national and international levels which have influenced relationships between the management of the GBRWHA and indigenous people of the area. Finally, it presents an overview of how the GBRMPA has responded to indigenous demands in the context of its statutory obligations and management arrangements. Achievements and future directions are discussed.

## **Indigenous people of the Great Barrier Reef World Heritage Area**

Coastal Aboriginal peoples and Torres Strait Islanders constitute the indigenous peoples of the GBRWHA. Both groups have significant cultural, historical and economic associations and interests in the GBRWHA.

Aboriginal peoples are known to have occupied the Australian continent for at least 40 000 years with recent archaeological evidence suggesting initial occupation commencing as early as 60 000 years ago (Roberts et al. 1990, 1993). During this period of time the Australian coastline was dynamic with sea levels rising and falling as a result of climatic changes. The last sea level change was a significant rise at the onset of the Holocene, between 12 000 and 8000 years ago. This rise had the effect of submerging coastal areas of land occupied by Aboriginal peoples in what is now the Gulf of Carpentaria and most areas along the Australian continental coastline. It was during this period that Bass Strait was created and the Torres Strait Islands were formed (Campbell 1988; Chappell and Thom 1977). Current archaeological evidence indicates that the permanent occupation of the Torres Strait Islands occurred approximately 2500 years ago (Sing 1989; Campbell 1988). The islands were occupied by seagoing Melanesian people, the descendants of whom are amongst the present day Torres Strait Islanders.

Two hundred years of European occupation, development and government policies has had a significant effect on indigenous patterns of settlement and economics. Today, Aboriginal and Torres Strait Islander peoples live in most major towns in the region adjacent to the GBRWHA, such as Townsville and Cairns (Table 1) as well as in more remote areas.

**Table 1.** Indigenous populations living in major urban centres adjacent to the Great Barrier Reef World Heritage Area (CDATA 1991, Australian Bureau of Statistics)

Location	Aboriginal Population	Torres Strait Islander Population	Total Population
Cairns	1928	1598	64 481
Townsville/Thuringowa	2680	1141	101 205
Mackay	697	726	40 245
Rockhampton	1521	191	55 722
Gladstone	508	124	23 424
Bundaberg	681	67	38 040
TOTAL	8015	3847	323 117

There are approximately eleven Aboriginal and Torres Strait Islander Deed of Grant in Trust communities adjacent to the Far Northern Region of the GBRWHA (Table 2) with a total resident population of about 11 000 (Bergin 1993; King 1995) representing 51.2 % of the total population for that area (King 1995).

The relevant demographic characteristics of indigenous communities in remote areas are a mean household size of 7.9 compared to the Australian mean of 3.3 (King 1995) and high mobility. Mobility patterns are linked to kinship obligations, custodial responsibilities, subsistence activities and economic realities of remote areas such as low employment (King 1995). Permanent and seasonal outstations are major features of Aboriginal lifestyles and economies. There is a strategy, supported by the Cape York Land Council and the Aboriginal and Torres Strait Islander Commission (ATSIC), to establish outstations away from major communities in more remote locations in Cape York Peninsula adjacent to the World Heritage Area (Cooke 1994). As these outstations are established, there will be a new set of dynamics with implications for management of the area.

### **Cultural significance of the Great Barrier Reef World Heritage Area**

Despite the major changes associated with European occupation, indigenous people of the GBRWHA still have strong cultural and economic interests in the Area. This is due to their use of marine and coastal resources and a spiritual association with their customary estates coupled with their desire to maintain indigenous lifestyles and culture. These points have been recorded in many inquiries and in submissions by indigenous people's organisations in recent years (for a review see Sutherland 1996). The GBRMPA itself has commissioned a number of reports which specifically document indigenous values, interests and involvement in the GBRWHA (Smith 1987; Smyth 1989, 1990, 1992; Bergin 1993).

Aboriginal association with the land and sea originates in the belief that both landscapes/seascapes and people were created by mythical Ancestral Beings. These Ancestral Beings not only caused the physical landscape to be shaped in a certain way, but spread social groups and their languages across the landscape in a particular manner (Brockwell et al. 1995).

**Table 2.** Resident populations and employment status of major ATSI communities on Cape York Peninsula (adapted from King 1993). CDEP = Community Development Employment Programs. Note: Estimates are based on a range of sources and community census counts in 1994. Estimates are about 17 to 20% higher than ABS census counts. Therefore ABS population growth predictions are underestimates.

Location	Population (1994 field work including outstations)	Number on CDEP	Council houses
Wujul Wujul	458 (6-8)	210	
Hopevale	1000		
Laura	100	28-29	
Coen	365(50-85)	92	
Lockhart River	470 (20)	150	
Umagico	250	95	29
Injinoo	500	220	50
Bamaga	1200	144	142
Seisia	120	47-50	18
New Mapoon	250	84	48
Prince of Wales	150		
Thursday Island	3500		136
Horn Island	600		
Napranum	1080 (80)	400	148
Mapuna	150	50-60	4
Aurukun	1000	400-45	148
Pompuraaw	438 (13)		106
Kowanyama	1012 (12)		100
<b>TOTAL</b>	<b>10 844-11 065</b>		

Ownership of, and responsibility for, particular tracts of land and sea, commonly referred to as clan estates, rest with particular groups within an identified language group. These rights and responsibilities are inherited through lines of descent. Individual members of a language group share the responsibility for the well being of customary estates, sites and story places. This responsibility is expressed and discharged through the performance of ceremonies and the enforcement of customary laws (Taylor 1984; Von Sturmer 1978).

Customary law governs people's use of coastal and marine resources, their cultural practices and methods of resource management. Contemporary cultural meanings and links to the coastal and marine environments are maintained through people's continuing use and teaching of stories which relate individual sites to society and history. Aboriginal peoples identify their clan estates as areas of great importance historically, culturally, socially and economically. Within clan estates, there are several types of sites that range in significance and include:

- sacred sites where visitation is prohibited or is restricted to certain people;
- sites classified as important with restrictions on entry and use, usually with behavioural observances;
- sites with no restrictions other than a requirement to be respectful and leave only 'footprints'.

Sites may be specific locations or part of larger areas. Coastal sites are often linked to islands, cays or reefs and include underwater features. Areas submerged during the last sea level rise are still considered by Aboriginal and Torres Strait Islander peoples to be part of contemporary estates (Smyth 1995). Recent ethnographic maps indicate there are some 40 Aboriginal coastal and marine estates which extend to offshore islands of the World Heritage Area (Fig. 1).

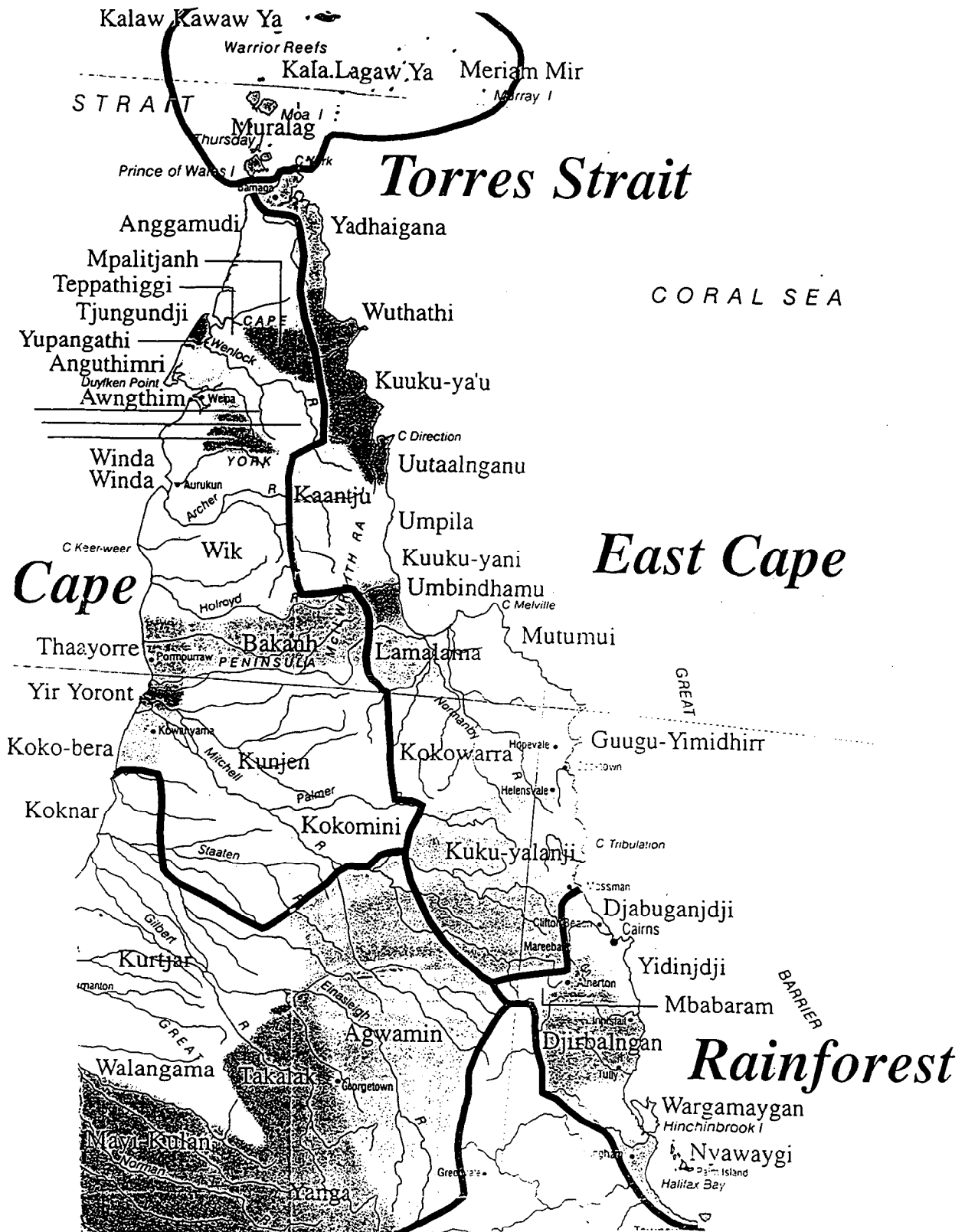


Figure 1. Representation of Aboriginal and Torres Strait Islander language group estates - coastal north Queensland and Cape York Peninsula. Taken from Horton 1994: AIATSIS

The creation of features within the natural environment plays a very important role in story places, story lines and important sites. These pathways are not restricted to any specific place. Story places and story lines can cover a whole clan estate or several clan estates sometimes over hundreds of kilometres. As an example, in the GBRWHA some reefs are identified as wind story places and are believed to be places where winds are generated. Local people have experienced high winds when visiting those places without permission. This gives credibility to those rules associated with these story places. Creation stories link places to people over large tracts of country.

Not all sites have their origin in the Creation stories. Some sites are designated in relation to recent events and people, for example the location of where an indigenous person was lost at sea, or birth places. Such sites while not sacred are of great importance culturally.

Many sites within the Area have no visible signs of cultural association, either historical or contemporary. There are other sites which have archaeological remains like middens, remnant stone fish traps and rock art.

### **Contemporary use and interest in the Great Barrier Reef World Heritage Area**

#### Subsistence activities

Hunting, fishing and gathering have a significant role in the cultural life and economy of indigenous communities. In remote locations, indigenous people continue to rely on marine resources for a substantial part of their diet. Seafood consumption by Murray Islanders for example is among the highest in the world (Nietchmann 1989). Numerous studies of the contribution of subsistence activities to indigenous welfare and economy have been undertaken in the Northern Territory (Altman 1987; Meehan 1982; Jackson 1995).

Turtle and dugong hunting is an important aspect of the indigenous economy and cultural life in the GBRWHA and is based on collectively accumulated ecological knowledge, skills and continued cultural association with the species (Williams 1996). Under Great Barrier Reef Marine Park (GBRMP) zoning plans dugong and turtle hunting require permits which are granted to indigenous people for customary purposes. However permits may not be required under section 211 of the *Native Title Act 1993* in some areas where 'native title rights and interests exist' (S211(2)(b)).

Little is known about the current status of indigenous fishing and shell collecting in the GBRWHA in terms of effort, impact on the sustainability of resources and contribution to local and regional gross value of fisheries production (Altman, Arthur and Bek 1994; Smith 1987). It is also unclear how significant the contribution of subsistence fishing is to overall fisheries production. A survey undertaken by the Australian Bureau of Statistics in 1994 indicated that 11% of the 49 500 indigenous people involved in unpaid work engaged in hunting, fishing and gathering (Madden 1994).

A recent study of subsistence activities on Cape York Peninsula indicates that as much as 80% of protein is derived from fishing and hunting. This is a significant contribution to the diet, health and economy of people in remote communities where the availability of alternative food items is irregular and often of poorer quality. Some economic analyses of indigenous fishing have been undertaken in the Torres Strait (Altman et al. 1994), Cape York Peninsula (Asafu-Adjaye 1994), and in the Ingham area (Benzaken et al. in progress). Those studies show that subsistence activities contribute a significant part of the household income, which otherwise consists of payment under the Community Development Employment Programs (CDEP) equivalent to unemployment entitlements.

Information on the level of subsistence fishing and hunting in urban areas is yet to be investigated although anecdotal evidence suggests that it may be substantial and linked to the importance of seafood in the diet of indigenous peoples as well as being a culturally significant activity.

#### Participation in commercial activities

Torres Strait Islanders have a long history of involvement in commercial harvesting of pearl shell, trochus and beche de mer (Smyth 1995). Currently, a special 50 tonne quota of the Northern Trochus Fishery, from north of Lockhart River to the tip of Cape York, has been set aside specifically for sharing between Aboriginal and Torres Strait Islander communities. The Injinoo community has obtained a license for 15 tonnes of this quota.

Cape York communities have also investigated tourism as an avenue for raising revenue and better managing impacts of tourism on their communities. For example, the Injinoo community has developed a tourism management strategy (funded under the Regional Tourism Development Program by the Commonwealth Department of Tourism). The Community has established camping grounds and operates a vehicular ferry on the Jardine River. Fees generated contribute to the production of cultural information for visitors and maintenance of camping grounds and roads. The Injinoo community also owns and runs the Pajinka Lodge. The Seisia community operates a camping ground to the west of the tip of Cape York Peninsula. All of the Northern Peninsula communities derive some income through the provision of supplies and services to, largely seasonal, land based tourists.

#### **Contemporary interests in the management of the Great Barrier Reef World Heritage Area**

Aboriginal and Torres Straits Islander groups continue to identify themselves as traditional owners and custodians of marine estates and are keen to have their traditional claim to ownership of estates legally recognised. The recognition of sea rights is not only a matter of identity and compensation for past wrongs, but also an avenue to claim management responsibility for the protection of important sites and to develop an economic base from the use of marine and coastal resources (Bergin 1993).

#### Indigenous perspective on management of land and sea

Indigenous peoples have expressed strong views on the principles underlying the management of the environment which arise from differing views of nature and the place of humans. From an indigenous perspective, coastal landscapes and seascapes are part of an integrated cultural domain comprising defined owned clan estates to which affiliated groups belong, and from which they get their identity and customary rights to own and exploit other resources. This is in contrast to the European concept of coastal and marine systems as separate domains, the common property nature of marine resources and concepts of naturalness.

These contrasting perspectives have been articulated around the concept of wilderness and wilderness management. Wilderness is perceived by indigenous people as a negation of prior occupation and property rights and another form of dispossession even though there may be congruence between indigenous aspirations and conservation goals (ATSIC 1994). Langton (1996) strongly argues that wilderness maintains the invisibility of indigenous people and that the whole notion of protected area management must be reconsidered. Langton argues that 'the modern supporters of this wilderness cult divide aborigines in two extremes- the noble savage in harmony with the environment and the modern aborigines who threaten extinction of rare and endangered species' (ibid: p17).

At the Ecopolitics IX conference on Perspectives on Indigenous Peoples Management of Environmental Resources (1995) a resolution was passed regarding the use of the term wilderness:

'Noting the changes which have occurred in statements from some conservation agencies, that Ecopolitics IX reiterates the unacceptability of the term 'wilderness' and related concepts such as wild resources, food, etc. as it is popularised. The term has the connotations of terra nullius theory and as such all concerned people and organisations should look for alternative terminology which does not exclude indigenous history and meaning' (Ecopolitics IX 1996, p3).

Furthermore, the integration of an indigenous perspective into protected areas management may not necessarily satisfy contemporary indigenous aspirations to develop viable economies and lifestyles in remote areas where they are a significant proportion of the resident population.

#### Economic interests in the Great Barrier Reef World Heritage Area

Indigenous peoples have a range of interests in fisheries which many have sought to have recognised and protected by participating in government inquiries and consultation processes (e.g. Review of the Far Northern section (FNS) of the GBRMP, the Resource Assessment Commission Coastal Zone Inquiry). They desire to be actively involved in fisheries management and have expressed a strong desire for deriving economic benefits from fishing activities.

Those interests have ranged from protection of subsistence fishing grounds, development of small scale mariculture ventures and lobster fishing (Smyth 1995), involvement in commercial fishing either directly or through royalty payments or benefit sharing arrangements in customary marine tenure areas (Sutherland 1996). Torres Strait Islanders involved in the trochus industry have objected to restrictions placed on commercial fishing within conservation zones of the FNS and lack of consultation (Smyth 1993).

#### Protection of cultural and natural heritage

Indigenous people have also sought to be involved in management of the Area. Most coastal Aboriginal communities north of Townsville employ community rangers to protect cultural and natural heritage and manage tourism in their areas. Increasingly these rangers are working with management agencies and provide both an unofficial and, in the case of those appointed as GBRMP Inspectors, official management presence in remote areas (Smyth 1995).

Some Aboriginal people have consistently expressed their concerns about the impacts of reef use and the lack of recognition of their management principles and responsibility for the management of their estates. Most common reports about Aboriginal concerns include:

- the degradation of the marine and coastal environment due to impacts of other reef use in their estates and elsewhere;
- the impacts of other reef use on subsistence activities and sites of cultural significance particularly in areas of high tourism and commercial fishing;
- limited or inappropriate involvement in marine park management; and
- lack of recognition of the value of indigenous knowledge and intellectual property rights.

Commonly expressed views include a concern about overfishing and habitat degradation of 'traditional sea country' by commercial fishing and by catch impacts on turtle and dugong populations and habitat (Sommer pers. comm.). Those concerns are often based on anecdotal evidence of local decline of some species and decreases in catch rates.

High levels of heavy metals in fish, turtles and dugongs have been reported in the Torres Strait. There has not been conclusive scientific evidence to substantiate the source of the heavy metals. There is some concern that eating offal, in particular, may result in over exposure to heavy metals with consequent adverse health impacts. This is currently being communicated to Torres Strait Islanders (Williams 1996).

The potential impacts of oil spills and other effects of shipping using the inner channel, as well biological imports in ballast water, are also of concern.

Tourism and coastal development have had an incremental and cumulative impact on indigenous estates resulting in potential impacts on important cultural sites and displacement of subsistence activities either directly or indirectly. The displacement of dugong populations, perceived to be as a result of increased boating traffic (as in Yarrabah near Cairns) and habitat loss and degradation due to coastal development are also of concern.

#### Intellectual property rights

Following the recognition of the value of indigenous knowledge of natural systems, species and biodiversity, indigenous people and advocates of indigenous rights world wide and in Australia have campaigned for the protection of indigenous intellectual property rights in biodiversity (for a review see Posey 1996; Christie 1996 and Fourmile 1996 for an Australian perspective).

Two major themes have emerged from this debate, firstly, the legitimacy of indigenous peoples' rights and control of the use of their environment and knowledge. Secondly, a need for appropriate legal instruments to accommodate indigenous intellectual property to ensure that benefits arising from the use of the environment and knowledge be shared with the indigenous owners.

While these questions have largely been debated at an international level primarily in relation to bioprospecting and commercial use of biodiversity, they are increasingly being put to management agencies in the context of use of indigenous traditional knowledge in management and most specifically research (Fourmile 1996). At present there is no legal framework in Australian law to accommodate traditional indigenous knowledge held in common by indigenous groups.

### **Recognition of indigenous interests in the management of the Great Barrier Reef World Heritage Area**

#### Legal and policy framework

##### *International and national considerations*

As a signatory to international conventions such as the United Nations World Heritage Convention (1972), the Declaration of the 1981 Human Rights Convention (1985) and the Convention on Biological Diversity (1993) Australia has developed national policy and legal instruments which incorporate the principles outlined in those conventions. Australia has played an active role in the development of those conventions.

The main thrust of those international instruments rests on:

'The recognition of (indigenous peoples') rights to own (be compensated for), to use and control traditional lands and sea estates and derive economic cultural and social benefits



though the exercise of traditional laws and institutions (Declaration on the rights of Indigenous People, paragraphs 16 to 21, 1985)'

'The need for developing institutional arrangements for integrated coastal management which involve indigenous people to ensure the ecologically sustainable use of marine and coastal resources through establishing a process which empowers indigenous people, strengthens their participation in policy formulation and involvement in natural resource management (Agenda 21 Chapter 26)'

'Recognise the dependence of indigenous people on renewable resources of ecosystems and the need to ensure that indigenous use, values, knowledge and resource management are protected from unsustainable practices (Agenda 21 Chapter 26).'

'Recognise the role of indigenous knowledge and practices in the conservation and sustainable use of biological diversity (convention on biological diversity 1992, Rio Declaration 1992 ) through ownership of intellectual property (Article 8), protection of customary use of resources in accordance with traditional cultural practices (Article 10) and development of technical and scientific cooperation (Article 18, convention on Biological Diversity).'

'The obligation to protect cultural heritage of World Heritage properties even if listed under natural properties (World Heritage Convention Article 4).'

These principles have been incorporated into national policies and inquiries such as the Australian Law Reform Commission report in the *Recognition of Aboriginal Customary Laws* (1986) the National Strategy for Ecologically Sustainable Development (Ecologically Sustainable Development Steering Committee 1992), the Resource Assessment Coastal Zone Inquiry report (1993), the strategy for the conservation of Australian biodiversity (1993) and in legal instruments such as the Land Acts (Queensland) Act 1991 and the Native Title (Commonwealth) Act 1993. For a review of Commonwealth policies, inquiries recommendations and legislation see Sutherland (1996).

#### *The land acts*

In response to its international obligations under the above conventions, and under pressure from indigenous groups to secure legal recognition of their customary ownership of land and sea, Australian Federal and State Governments have passed legislation which makes it possible for Aboriginal and Torres Strait Islander peoples to have their traditional ownership of land recognised.

While traditional claims to land have been recognised in the Northern Territory since 1976, land rights legislation in Queensland was only introduced in 1991. The Queensland Land Acts provide an avenue for traditional owners to claim gazetted vacant crown land, some national parks and Trust Areas known as Deed of Grant in Trust (DOGITs). The Queensland Act also provides for intertidal land to be returned to Aboriginal and Islander ownership. By mid-1994, several former Aboriginal reserves and three coastal National Parks including Cape Melville and Flinders Island had been transferred to Aboriginal ownership.

One important limitation of the Acts is that the Queensland Government retains control over land available for claims. While indigenous rights do not currently include sea rights, the implications for the management agencies responsible for the GBRWHA are substantial as it identifies indigenous owners as important stakeholders and users of the GBRWHA (Smyth 1995).

### *Native title claims*

Under the Commonwealth Native Title Act (1993), indigenous peoples' are seeking formal recognition of their rights to land and sea. Seven claims have been made over extensive areas of the GBRMP. The claims total 1.75 million hectares or 5% of the total Marine Park. Five of the claims are in the Cairns section, equal to 22% of that section, two are in the FNS, equal to 11% (Fig. 2).

The claims are extensive in nature as well as area. In summary the claims are for recognition of prior and exclusive ownership (of islands, waters, sea bed, reefs, cays and marine resources), use rights, rights to control access of others, rights to enter into management arrangements and rights to derive economic benefits from the use of marine resources. The seven claims in the Marine Park area have been accepted for mediation with four having commenced prior to Christmas 1995 (Fig. 2).

The position of the Commonwealth, that native title is not capable of existing in offshore waters, will be tested by the Federal Court hearing on the Crocker Island claim (Northern Territory) commencing in April 1997.

### *Regional agreements*

Section 21 of the Native Title Act provides a legislative framework for agreements between governments and holders of native title on a regional basis with regards to Aboriginal and Torres Strait Islander interests in and the use of, land or waters through surrender of native title rights or interests, or through authorising future acts affecting native title (Native Title Act, Preamble and Section 21).

The Cape York Peninsula Head of Agreement between Aboriginal peoples, pastoralists and conservationists negotiated in 1995 was seen as an important step in the recognition of indigenous rights and the role of agreements in the determination of equitable land use arrangements (Cape York Heads of Agreements 1995). While the final decision rests with government, such agreements indicate willingness of those affected by native title claims to negotiate outcomes.

In summary, national and international legal norms support Aboriginal people with regards to entitlements to coastal marine resources, as well as their strong interest as partners in co-management regimes. While international treaties and conventions are not legally binding, and not necessarily incorporated in Australian law, they have been influential in Australian courts (Bergin 1993).

### *Integration of indigenous interests by the Great Barrier Reef Marine Park Authority*

The recognition of indigenous interests by the GBRMPA has been an evolutionary process shaped by government policy and legal instruments and increasing indigenous demand for recognition and involvement in management of their areas of interests (as described above).

The GBRMPA is committed to positive interaction with indigenous peoples. There has been an increasing number of programs, projects and policy which have given greater recognition to rights and interests of indigenous Australians and have provided greater opportunities for active involvement in all aspects of the planning and management of the GBRMP (Kelleher 1993; McPhail 1995).

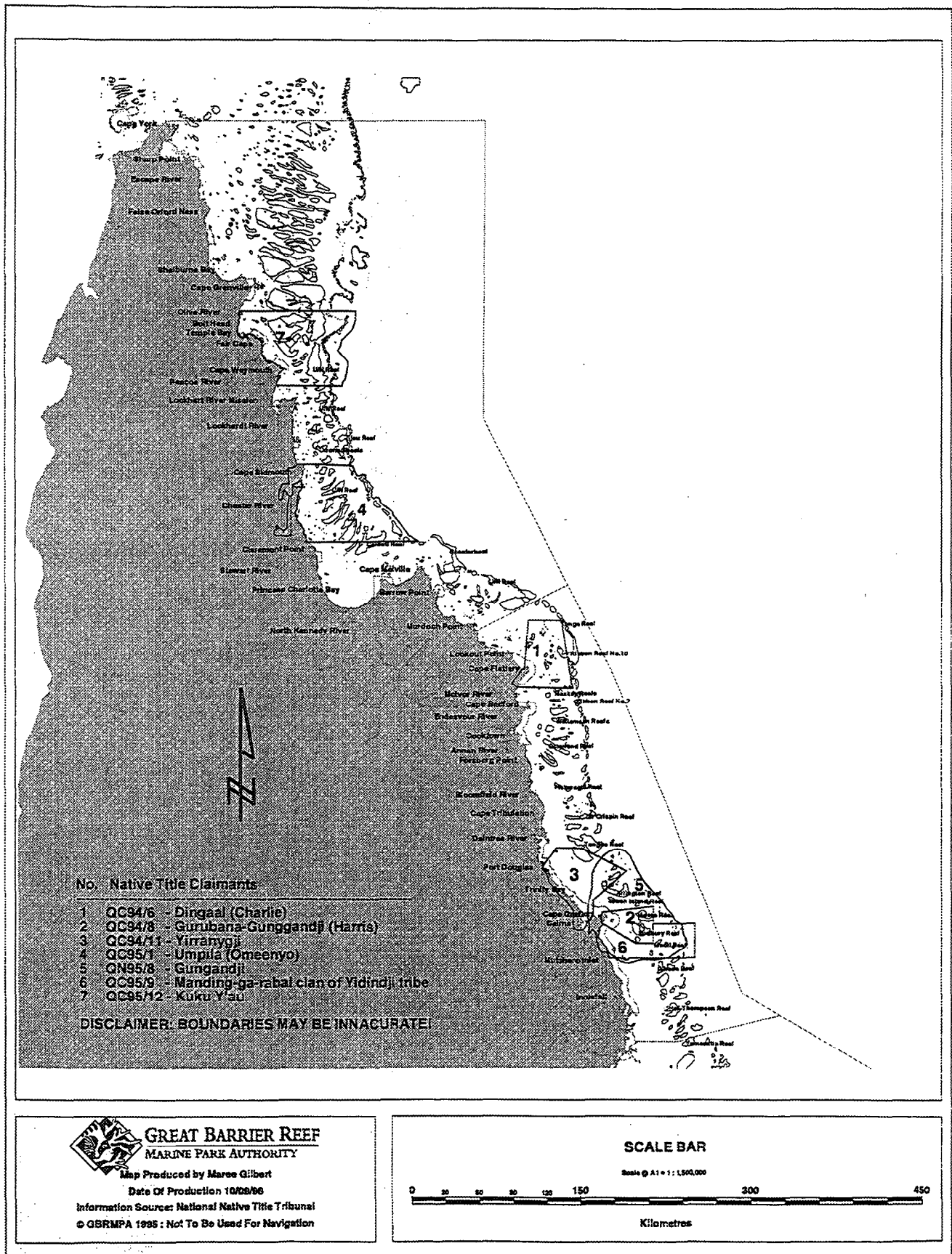


Figure 2. Native title claims in the Far Northern and Cairns Sections of the Great Barrier Reef Marine Park

The Authority has partly accommodated indigenous interests through the amendment of its Act and Regulations, by involving indigenous people in planning programs, impact assessment procedures, day to day management, by providing employment opportunities, by documenting indigenous values, knowledge and interests in the GBRWHA and integrating indigenous perspectives into its education and extension programs.

#### *Historical perspective*

The *Great Barrier Reef Marine Park Act 1975* which created the GBRMP made no specific reference to indigenous people but provided for statutory structures and mechanisms for public involvement in the operations of the Authority. Little reference to indigenous interests appears in early zoning plans and the decisions of the Marine Park Authority (MPA). The earliest mention of indigenous use and interests can be found in the first Cairns zoning plan (1983) where traditional hunting and fishing was identified as a category of use and a definition of traditional inhabitant was provided. Zoning Plan provisions allowed traditional inhabitants to carry out traditional hunting and fishing although no special provision in the zoning identifies designated areas to that effect (Bergin 1993).

Early consultations included a workshop in 1978 for the Cairns Zoning Plan and a workshop in 1985 on Traditional Knowledge and the Marine Environment (Zann and Gray 1988). A representative of the then Queensland Department of Aboriginal and Torres Strait Islander Advancement was appointed as early as 1976 on the Great Barrier Reef Consultative Committee, the cross sectoral committee appointed by the Minister (Smalley pers. comm.).

Some limited reference to historical indigenous associations with the Marine Park was also described in the nomination document of the GBR on the World Heritage List (1981). This description was by no means comprehensive and failed to describe contemporary and continuing use and cultural association with the Area.

Early MPA decisions refer to traditional hunting of dugongs and turtles and its potential impacts. Interim management arrangements were approved for dugong hunting within the GBRMP by the Hopevale community and legal requirements were in place by November 1983. The first mention of the need for a ranger training program for the FNS based in Cairns dates back to 1984.

GBRMPA commissioned a number of reports (Smith 1987; Smyth 1989, 1990) and organised workshops to document indigenous use and interests in the Marine Park (FNS workshop 1978; Zann and Gray 1985, Lawrence and Cansfield-Smith 1990).

#### *Basis for current regime*

The Smith report on the 'Usage of Marine Resources by Aboriginal Communities on the East Coast of Cape York Peninsula' (1987) was the first of a number of reports the Authority commissioned between 1988 and 1993 to investigate indigenous maritime interests and recommend a strategy for the recognition and involvement of Aboriginal and Torres Strait Islanders in the management of the Marine Park. The recommendations in these reports (Smyth 1989, 1990, 1992, 1993; Marsh 1992; Ziegelbauer 1991) and others of relevance (Cordell 1991; Ecologically Sustainable Development Working Groups 1991) are summarised and discussed in Bergin's report on 'Aboriginal and Torres Strait Islander Interests in the Great Barrier Reef Marine Park' (1993).

All reports clearly establish the nature of indigenous interest in the GBRWHA, identify indigenous concerns and report on the limited involvement of indigenous people in management as a major area of concern.

Smith (1987) acknowledged the importance of marine resources to coastal communities for subsistence and spiritual needs and indigenous resource management practices. He highlighted the need for appropriate consultation mechanisms including:

- The establishment of an indigenous consultative committee (Hopevale and Lockhart communities) to address management issues of indigenous marine estates, specifically dugong hunting.
- The appointment of an east coast Peninsula representative on the Great Barrier Reef Consultative Committee.
- A revision of conditions of the dugong hunting permit system to be negotiated with the relevant community councils.
- The development of educational programs on the GBRMP and their management.
- The employment of Aboriginal and Torres Strait Islander liaison personnel.
- The control of illegal fishing activities near hunting/fishing areas, monitoring of hunting activities and further anthropological and social research to better understand indigenous use and values and attitudes towards management.

Smyth (1990) documented indigenous maritime interests and use of the FNS of GBRMP from inshore waters to the outer reefs, outlined the overall poor understanding of Marine Park management provisions by indigenous people, their concerns about impacts of other uses of the Marine Park near communities (i.e. commercial fishing and Torres Strait Islander fishing) the lack of adequate for a for discussion and their desire to be actively involved in the management (Smyth 1992). Smyth (1992) recommended that the Authority commence, as soon as possible, consultations and negotiations with Aboriginal maritime groups to further explore the establishment of a consultative committee for the Cape York Peninsula; increase administrative responsibilities in the management of Aboriginal Management Zones; the preparation of education material and; further indigenous controlled research into maritime culture.

Steps taken by the Authority with regards to indigenous interests and involvement in management based on the recommendations of those early reports included:

- An Aboriginal person was appointed to the Great Barrier Reef Consultative Committee (1988).
- Aboriginal and Torres Strait Islander interests were acknowledged in a special section of the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area (1992).
- A community ranger program was developed and funded jointly with the Australian Nature Conservation Agency for three years (1992).
- Aboriginal and Torres Strait Islander communities were involved in the preparation of a dugong and turtle strategy and permit arrangements for management of traditional hunting by Council's of Elders.

- An employment strategy was developed and an Aboriginal liaison staff member was appointed (1992).
- Assessment criteria for permit applications under zoning provisions in the Cairns, Central and Mackay Capricorn Sections were changed in April 1992 to read 'the need to protect the cultural and heritage values held in relation to the Marine Park by traditional inhabitants and other people' (Sub-regulation 13AC(4)(b)).

In 1993 Bergin concluded 'Over the last ten years, the Authority has made a number of limited efforts to offer participatory opportunities and there has been an improvement in liaison over the years' however, the approach had been largely reactive. 'The process of recognition of indigenous issues, the implementation of self management strategies and the recognition of such cultural and life style issues as protecting sites and greater self management in dugong and turtle management needs to be addressed' (Bergin 1993 p. 55).

Bergin made 18 recommendations which were considered by the Authority (MPA meeting 145) in conjunction with earlier recommendations made by Smyth (1992). They included:

- Statutory representation of indigenous interests including both Aboriginal and Torres Strait Islanders (appointment on the Great Barrier Reef Consultative Committee and an Aboriginal and Torres Strait Islander consultative committee) and recognition of customary law and maritime clan boundaries in the *Great Barrier Reef Marine Park Act 1975*.
- Greater involvement in decision making in areas near communities through the setting up of indigenous management zones based on estate boundaries, joint management arrangements and involvement of community rangers.
- Greater resources to the indigenous Liaison Unit in terms of staff level, seniority and funding.
- Collaborative research programs including recording of sites, the documentation of marine tenure boundaries and usage, local knowledge and management practices of Aboriginal and Torres Strait Islanders should be conducted.

At MPA meeting 145, the Authority decided, in relation to indigenous involvement in Marine Park Planning that:

'its overall aim is to achieve a situation where the Aboriginal and Torres Strait Islander communities and wider Australian community are satisfied with and have ownership of the outcomes of the Authority's planning and management operations' and

'to integrate indigenous views in all activities of the Authority including zoning, management planning and permit assessment processes'.

Specific decisions in response to the recommendations of the Bergin Report included:

- that an Aboriginal person and possibly a Torres Strait Islander person be appointed on the Great Barrier Reef Consultative Committee;
- that the review of the FNS include negotiation of appropriate consultation mechanisms with relevant communities including a proposal for establishing a specialist indigenous advisory group;
- to investigate and negotiate co-management and heritage zones with appropriate groups during current and future reviews and other planning and management activities (consequence of Australian Law Reform Commission Report);

- to continue seeking further funding to increase staff and seniority of the Liaison Unit, to expand the scope of the community ranger program, to initiate new collaborative research programs;
- to seek further funding for consultation other than for the FNS review given the low level of support currently provided to Torres Strait Islander involvement (Torres Strait Islander liaison person on the Torres Strait Baseline Study, Ocean Rescue 2000 and consultation for the FNS);
- to give special attention to the implications of commitments of the 25 Year Strategic Plan at a corporate level (MPA decision 145/14 December 1993).

Current status and future directions

#### *Legal and policy framework*

##### World Heritage obligations

The GBR was inscribed on the list of World Heritage natural properties in 1981 for its outstanding natural value, although it was recognised that the property had significant indigenous and non indigenous cultural features.

Greater emphasis on World Heritage management has resulted in a review of the 1981 listing. The review has raised the issue of protection of cultural values of natural properties based on Article 4 of the Convention. Article 4 states that State parties must to 'do all it can' and to the 'utmost of its resources' to ensure 'the identification, protection, conservation and transmission to future generations of the cultural and natural Heritage referred in Article 1 and 2 and situated in its territory' (Convention 1972 Article 4). The recognition of the significance of interactions of people and landscapes has led to the creation of a third category of World Heritage properties, cultural landscapes/seascapes (Droste et al. 1995). The application of the concept of cultural landscape to the GBR may provide a useful framework for addressing the range of cultural values associated with the GBR.

##### 25 Year Strategic Plan and Great Barrier Reef Marine Park Authority Corporate Plan

The 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area was developed in conjunction with other government agencies and community groups. The Plan, which was endorsed by the Federal and State governments, includes a significant and integral component dealing specifically with the recognition of Aboriginal and Torres Strait Islander peoples' interests in the GBRWHA (GBRMPA 1994) (Box 1).

The Plan was not endorsed by the Aboriginal and Torres Strait Islander peoples at the time due to concerns about potential impacts on native title and the need for further negotiation on their involvement in management. A time table of 12 months was given to negotiate and make amendments to the Plan.

The objectives of the 25 Year Strategic Plan have been incorporated into GBRMPA corporate directions and a new aim of the Authority has been adopted. This aim is:-  
'To provide recognition of Aboriginal and Torres Strait Islander traditional affiliation and rights in management of the Marine Park' (GBRMPA Corporate Plan 1994 - 1999)

##### Amendment of the Great Barrier Reef Marine Park Act and Regulations

In 1995, the *Great Barrier Reef Marine Park Act 1975* was amended to give greater representation of indigenous interests in management. Amendments include:

- provision for the appointment of a 4th member to the MPA, the statutory decision making body ' to represent the interests of Aboriginal communities adjacent to the Marine Park' (s10.1 (b)),

- the introduction of Part VB to the Act to provide for the development of statutory management plans and to enable management arrangements to be entered into with 'community groups having a special interest in areas of the Marine Park (39Y(a) and 39Z).' Section 39Y provides that an object of these plans can be to ensure that, for a planning area, the Authority develops proposals to reduce or eliminate threats to cultural and heritage values, amongst other things (39Y(A)).

### **25 Year Objective**

To have a community which recognises the interests of Aboriginals and Torres Strait Islanders so that they can pursue their own lifestyle and culture, and exercise responsibility for issues, areas of land and sea, and resources relevant to their heritage within the bounds of ecologically sustainable use and consistent with our obligations under World Heritage Convention and other Commonwealth and State laws.

### **Broad Strategies**

- Where such plans are appropriate, Aboriginals and Torres Strait Islanders to develop, with stakeholder agencies and organisations, management plans to ensure that their traditional use of resources is ecologically sustainable.
- Consider the legal implications of the Mabo ruling for the legislative framework for, and development of resource management plans.
- Ensure that use by Aboriginals and Torres Strait Islanders is taken into account in the development of resource management plans.
- Ensure that Aboriginal and Torres Strait Islanders have opportunities for membership of, and full involvement in, the relevant decision-making and consultative bodies.
- Provide the full range of employment opportunities for Aboriginals and Torres Strait Islanders in agencies and industries of the area.
- Educate the general community, other users and managers about the cultural heritage and aspirations of Aboriginals and Torres Strait Islanders.
- Develop culturally appropriate and understandable formats for regulatory and informative material that is distributed to Aboriginals and Torres Strait Islanders.

(Box 1)

(Keeping it Great: The Great Barrier Reef: A Strategic Plan of the Great Barrier Reef World Heritage Area 1994: 35)

### *Aboriginal involvement in planning*

Indigenous peoples are seeking increasing involvement in management of the Marine Park. This has been expressed through consultants reports to the Authority, as well as directly through Native Title claims and during major planning exercises involving indigenous peoples. The Authority is supportive of the concept of developing a closer management relationship with indigenous peoples in order to ensure that cultural and heritage values and contemporary uses are maintained. A number of planning exercises are currently under way including the review of the FNS and the Cairns, Shoalwater Bay and Whitsunday plans of management. Consultation and negotiation with Aboriginal peoples is included in these programs.

### **Review of the Far Northern section of the Great Barrier Reef Marine Park**

Over a period of 18 months, the review process has provided a range of avenues for indigenous input including, a four-day Pajinka workshop where joint management issues for consideration in the review were presented to the Authority, ongoing visits to communities, attendance at the Cape York Peninsula Aboriginal Land Summit, a series of community based workshops were



conducted for information exchange where local issues were discussed and planning groups established. Further meetings, workshops and discussions with traditional owners have provided general information on people's values interests and concerns and clarify the role and responsibilities of GBRMPA and Queensland Department of Environment in the review process (Sommer pers. comm.). Personnel from the Cape York Land Council were contracted to assist indigenous input and a consultant was appointed to provide supporting expert advice.

A number of planning options have been considered and submitted to the MPA with regards to the incorporation of indigenous interests. Consideration has been given to the joint development of area specific management plans in the vicinity of coastal communities under Section 39ZA of the *Great Barrier Reef Marine Park Act 1975*. This may result in significant Aboriginal involvement in the management of their traditional estates and will alleviate the burden on permit assessment procedures for appropriate consideration of cultural values in management.

#### Cairns plans of management

Within the limited budget and time constraints of the Cairns planning project, provision was made for gathering of information relevant to the identification and protection of cultural values in the planning area. Two consultancies were let to indigenous organisations to compile information and make submissions. The results of these consultancies were limited by inter group rivalries and native title claim complications. The Authority is continuing to discuss means for greater involvement of indigenous peoples in identifying and managing culturally important areas. What has been clearly identified is that indigenous people of the area feel disempowered and are concerned that increasing tourism and recreational use of the area offshore Cairns is further eroding their values and uses of the area.

#### Whitsunday planning

The Giru Dala people of the Whitsunday area are working with the Department of Environment and GBRMPA to ensure that cultural sites are identified and adequate protection is provided for them during the Whitsunday planning process.

#### Shoalwater Bay

The Shoalwater Bay Inquiry identified the Darumbal-Noolar Murree people as the original inhabitants of the Shoalwater planning area. The Darumbal are part of the planning committee for the area and have been commissioned to prepare a report on their interests and needs in the marine area by the GBRMPA. They are also working with the Queensland Department of Environment and Defence on a cultural site identification program within the defence area. Partly as a consequence of the planning process the Darumbal people have entered into a formal Memorandum of Understanding with the Authority agreeing to suspend their right to hunt dugong in the area until 1999. Hunting pressure in the area has been low for some years and the recovery of dugong populations requires strategies to reduce threats from other uses as well.

#### *Permits and impact assessment procedures*

Under Zoning Plans, some specific activities require a permit. Criteria contained in the GBRMPA Regulations 13 AC(4) (for all permits) and 13 AC(5) (for traditional hunting permits only) require that the cultural and heritage values be identified and considered for any location where a permitted activity is proposed. Cultural and heritage values are meant to acknowledge contemporary cultural links notwithstanding displacement and removal from clan estates. The implementation of the criteria is particularly challenging as it requires appropriate consultation, correct assessment of values and has to take into account the movement of indigenous people to other centres where they continue to practice customary traditions (Cook 1995). The application

of those criteria to traditional hunting and to the assessment of a proposed tourism development are presented below.

Traditional hunting permit assessment - Council of Elders

Traditional fishing, hunting and gathering may only be undertaken with a permit, except where Section 211 of the Native Title Act applies. Under Zoning Plan provisions, traditional fishing, hunting and gathering is defined as 'fishing or collecting in an area by a traditional inhabitant or group of traditional inhabitants for the purposes other than recreation, sale or trade.' Traditional inhabitants include those people who can demonstrate descent, are recognised by the community and identify as an Aboriginal or Torres Strait Islander person. This broad definition can include both traditional owners and other residents with historical associations with an area where they currently reside.

Until recently two types of hunting permits were available; one year community permits granted to Community Councils of reserves or Deed of Grant in Trust (DOGIT) and individual permits to traditional inhabitants not residing in traditional coastal communities (Fig. 3).

In response to the increasing number of individual permit applications received by GBRMPA (3 in 1990; 190 in 1993), the Queensland Department of Environment and the Queensland Department of Primary Industries, increased administrative costs and delays, potential cumulative impacts of individual permits, and legal and policy changes regarding recognition of indigenous rights, a community based application and assessment approach was proposed outside DOGIT areas. In 1993, a pilot project to form a 'Council of Elders' (the council) in Mackay was initiated (Cook 1993).

The community based application would provide for the allocation of hunting permits (under 13AC5) and assessment of cultural heritage values of the area (13AC4(b)). GBRMPA would grant hunting permits to the 'Council of Elders' who would issue 'authorities' up to the agreed limit for their clans' areas based on the ability of the species to sustain the take. Individual hunters then would apply to the Council for an authority and would have to satisfy the Council of the cultural appropriateness of the hunt (Cook 1994). Critical to the approach is the identification of the 'right people' who can 'speak for the country' for an area and correct identification of their cultural and heritage values (Cook 1995).

The assessment methodology provides for shared responsibility, the Authority determining environmental requirements whilst the council determines cultural and heritage values. In addition the Council would then manage individual hunting permits to ensure that both environmental and cultural conditions of the permits are complied with (Cook 1993).

This approach is a step toward enhanced indigenous participation in the management of the dugong population and the protection of cultural and heritage values in the areas. It is also consistent with GBRMPA policy of recognition of Aboriginal and Torres Strait Islander interests and a number of legal and policy initiatives (e.g. Native Title Act, recommendation of the Royal Commission into Aboriginal Deaths in Custody).

The Council of Elders concept has proved worthwhile and is being developed in other areas, usually with some modification to suit the particular location. There are currently five permitted community hunting areas in the GBRWHA (see Fig. 3). There is potential for a broadening of the role of the Councils to assist with general assessment of the impact of proposals on cultural and heritage values of traditional inhabitants. A pilot project to develop an impairment model is in progress. The project is aimed at identifying those permitted activities which impact on cultural values and categorising estate values, as defined by Council of Elders, to develop a process which limits case by case assessment (Cook pers. comm.).

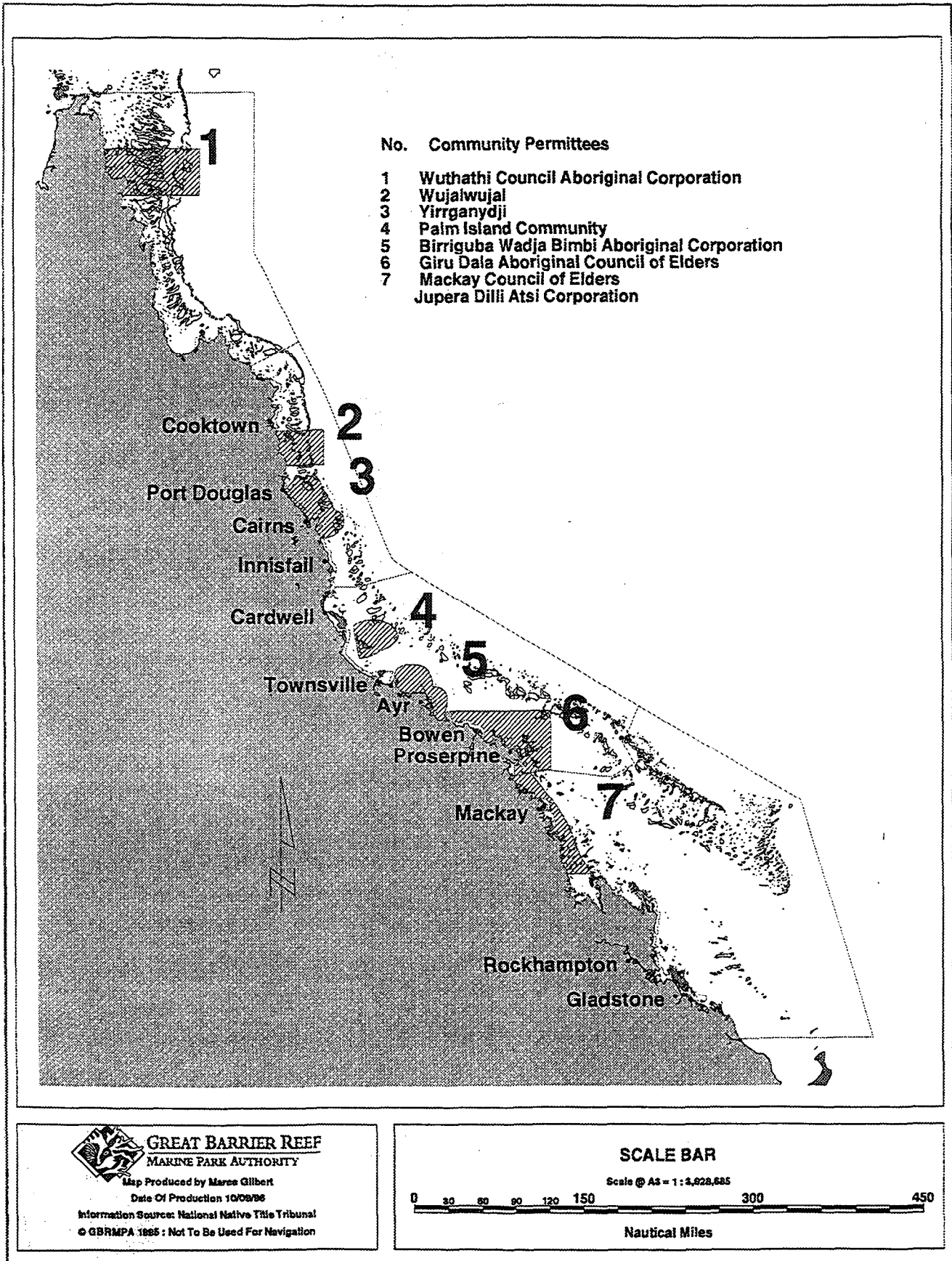


Figure 3. Permitted community hunting areas in the Great Barrier Reef Marine Park

#### Recognition of cultural values in permit assessment procedures

In 1995, the Authority refused an application by Reef Management Pty Ltd which sought permission to install and operate a pontoon and associated facilities on Green Island Reef within the Cairns section of the GBRMP. The basis of the GBRMPA's decision was regulation 13AC(4)(b).

The Authority considered that the proposed activities would have an unacceptable impact upon the cultural and heritage values of traditional inhabitants who currently reside in the nearby coastal community of Yarrabah. The decision was appealed in the Administrative Appeals Tribunal but not determined due to the withdrawal of the proponent.

The proponent argued that the consultation process had not been conclusive in demonstrating evidence of traditional associations with the proposed site and recent use of the area by the people currently residing at Yarrabah. The Authority's identification of the traditional inhabitants and assessment of the impacts was supported in the light of further anthropological evidence. The legitimacy of the consultation process combined with the advice that absence of recent use *did not constitute absence of cultural value* was supported by expert evidence (Smyth 1993; Cordell 1995). This case is the first where impact upon cultural values has been the main argument for refusing a permit.

#### *Involvement in day to day management - community ranger program*

The Community Ranger program began as a joint initiative between the Aboriginal Co-ordination Council, the Department of Family Services (Aboriginal and Islander Affairs) and Aboriginal Communities in the late 1980s. It was initially designed to provide employment opportunities in land management in remote communities.

Some four years ago the Authority became interested in the Community Ranger program as an opportunity to develop community contacts and a vehicle for extension programs in remote communities. The Authority became involved in the Technical And Further Education training for rangers assisting in curriculum development and teaching.

Under the Contract Employment Program for Aboriginals in Natural and Cultural Resource Management (CEPANCRM) program, administered by the Australian Nature Conservation Agency, a program was developed to increase the role of rangers in day to day management. Supplementary wages and some operational funds for a three to five year period were provided and contracts were entered into with Community Councils.

The contracts provide for two days paid work, per week, on marine/coastal issues above Community Development Employment Program (CDEP) work. Eight rangers in five communities were employed. A coordinator was employed by the GBRMPA to administer contracts, set up training and work programs and establish networks with other agencies.

Eight Community Rangers have recently been appointed as inspectors under the *Great Barrier Reef Marine Park Act 1975*. These rangers, mainly in remote locations, are strategically situated to deal with a range of issues relevant to marine and terrestrial parks management as well as customs and quarantine duties (Turner 1995). At this stage however, community rangers are not appointed as inspectors under the *Queensland Marine Parks Act (1982)* where a large part of customary estates lie.

#### *Employment strategy*

Under its Equal Employment Opportunity (EEO) Policy the GBRMPA has developed an Aboriginal and Torres Strait Islander employment strategy based on increased recruitment and

retention of Aboriginal and Torres Strait Islander staff. To date, two identified liaison positions have been created and representation among staff has increased from 1% to 5%, the 5% target being representative of the Aboriginal and Torres Strait Islander population in the GBR region (GBRMPA Annual Report 1995-6)

#### *Mainstream education and cross cultural awareness*

The Authority has endeavoured to include an indigenous perspective in its educational and interpretive material (e.g. brochures, newsletters, publications and videos) and extension and consultation programs with industry (tourism and fishing) and other interest groups of the GBRWHA (indigenous interests are represented in Regional Marine Resource Advisory Committees). The Authority has also developed culturally appropriate extension material about the GBRMP and its management for indigenous people.

Cross cultural awareness workshops have been organised to improve Authority staff understanding of indigenous perspectives and values and an indigenous component has been included in GBRMPA staff induction.

The Authority has also been extensively involved in the design and delivery of tertiary courses on indigenous involvement in resource management (e.g. Integrated Coastal Zone Management, Caring for Country).

#### **Discussion and future directions**

The Authority has made substantial efforts in a relatively short time to accommodate indigenous interest in the GBRMP. Strategies used include amending legislation, developing new policy initiatives such as the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area as well as the reinterpretation and consolidation of its current statutory functions, extensive liaison and a range of negotiation and consultation opportunities during planning exercises.

The Authority can be credited for having developed the basis for a good relationship with indigenous peoples of the GBRWHA through extensive involvement of its indigenous Liaison Officers, training and staff development, the development of a legal and broad policy framework for effective recognition and involvement of indigenous interests, and the recent appointment of the 4<sup>th</sup> member of the Authority (December 1996). Lessons learnt from this experience will be useful to other agencies. Whilst achieving a framework for increasing indigenous involvement in management of the GBRMP, further progress in implementing broad policies is likely to be limited by resource and political constraints. Uncertainties surrounding Native Title claims and the possibility for Native Title offshore may also complicate and delay progress.

The position of Aboriginal and Torres Strait Islanders in management remain uncertain. There is still no mechanism in place to negotiate amendments to the Strategic Plan as was proposed to secure endorsement by indigenous groups. Aboriginal contribution to the Great Barrier Reef Consultative Committee, although valuable, remains limited (only 1 of 15 members) and there is no Torres Strait Islander member considered at this stage. Co-management arrangements and heritage zones have been partially addressed though permit assessment but are still not reflected in zoning and management plans although they are being considered in the review of the Far Northern section. Additional funding for increasing the role of indigenous peoples in day to day management is required. Collaborative research has been undertaken though planning processes although the issue of property rights remains unresolved.

For the Authority, the issue of governance, which is at the basis of the recognition of indigenous rights and interests in management, is complex. It involves different cultural and legal perspectives of ownership and responsibility for management, consideration of public versus private interests and the need to accommodate indigenous rights with conservation and a multiple use context. The recognition and integration of indigenous interests and participation in management should be seen as a long term interacting process involving many players and levels of decisions, some of which are under the Authority's control, others not. Such a process needs cooperation between various agencies with a stake in the GBRWHA, as well as time and support from the wider community and greater awareness from users of the GBRWHA of indigenous interests.

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# **Recognition of Aboriginal maritime culture in the Great Barrier Reef Marine Park: an evaluation**

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## **Introduction**

Aboriginal maritime interests in the Great Barrier Reef Marine Park (GBRMP), and the recognition of those interests in contemporary management of the Marine Park, are detailed in the preceding paper (Benzaken et al.). This short accompanying paper seeks to evaluate that recognition and provide some discussion as to where this evolving process might lead.

This evaluation is not based on recent consultations with coastal Aboriginal peoples associated with the Marine Park. Rather it is based on an examination of steps taken by the Great Barrier Reef Marine Park Authority (GBRMPA) in the context of earlier documentation of Aboriginal maritime interests (Smyth 1989, 1990, 1992, 1993 and 1995) and in the context of undertakings made in the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area (GBRMPA 1994).

This paper is therefore a personal perspective of developments in this field over the 20-year history of the GBRMP, with some thoughts on future developments. As a personal perspective, it should be clear that I do not seek to speak on behalf of Aboriginal people associated with the GBRMP; rather I am seeking to reflect on the extent to which Aboriginal maritime interests, as expressed to me during earlier consultations, are currently and potentially reflected in the management of the GBRMP.

## **Kinship: the basis of Aboriginal maritime culture**

The basis of Aboriginal maritime culture is kinship. That is, an inherited relationship to places on land and sea, other people, animals, plants, sacred and other cultural sites and Dreaming tracks. Associated with the comprehensive relationship between individuals and groups and their physical and cultural environments are knowledge and belief systems which are a composite of 'traditional' Aboriginal and contemporary Australian knowledge and beliefs.

It is important to acknowledge that while kinship in this widest sense is associated with knowledge and belief, it is not utterly dependent on them. Younger coastal Aboriginal people may retain the strong sense of kinship with community members and coastal environments without necessarily having a comprehensive store of 'traditional' knowledge or beliefs. Kinship should be understood therefore as meaning 'belonging'. It is the kin relationship between Aboriginal people and their environment that distinguishes them from other Australians with an interest in the Marine Park.

It is from this reality of belonging to a place, to a clan, to a clan estate and to a community that all the implications of rights and responsibilities derive. It is the partial recognition of these rights and responsibilities that in turn have lead to Aboriginal involvement in the management of the GBRMP.

## **Recognition of rights and responsibilities**

Table 1 attempts to summarise the key Aboriginal maritime rights and responsibilities and the extent to which they are recognised in current management of the Marine Park. Some of these issues are explored further below.

**Table 1.** Recognition of customary Aboriginal rights and responsibilities in the context of contemporary Marine Park management

<b>Rights and Responsibilities</b>	<b>Recognition</b>
Economic exploitation of marine resources, including subsistence hunting, gathering and fishing	Subsistence activities recognised in zoning plans not as rights, but regulated through use of permits and some small prohibited zones. Economic rights have not been allowed to develop into contemporary commercial rights.
Transmission of maritime culture between generations	Encouraged by recognition of subsistence activities. Discouraged by many other social and political factors relating to past government policies beyond the scope of Marine Park management.
Control of access by outsiders to maritime clan estates	Not widely recognised. Limited recognition through control of hunting permits by Councils of Elders in some areas.
Control of seasonal take of resources	Not recognised
Control of distribution of resources within groups	Not recognised (e.g. restrictions on transport of dugong meat to family outside Trust Areas)
Access to sacred and other cultural sites	Not explicitly recognised. Restrictions imposed by coastal development, including aquaculture, rather than GBRMP management.
Opportunity to derive economic benefit from maritime estates.	Limited to subsistence take, essentially 'freezing' local economies; no direct control by traditional owners of economic activities of outsiders (fishing, tourism, shipping etc.)
Opportunity to maintain sustainable use of maritime estates.	Limited control over subsistence take only; no control by traditional owners over other depleting and polluting activities.

### **Economic issues**

Prior to European colonisation, the maritime environment provided the total economy of coastal Aboriginal people - that is, food, shelter and material possessions. Since colonisation, Aboriginal economic opportunities in maritime environments have diminished, while the overall economic exploitation of the marine environment (fishing, shipping, tourism etc.) has increased.

The establishment of the GBRMP has provided a degree of security for the continuation of Aboriginal subsistence economy, by permitting traditional hunting and fishing and by establishing a management regime aimed at protecting habitats, species and ecological communities. However, with the exception of some short term, part time Community Ranger employment, Marine Park management has not facilitated a broadening of economic benefit to Aboriginal people.

Because of the reluctance of governments to recognise the totality of the relationship between coastal Aboriginal people and the marine environment, Aboriginal economic benefits have

been restricted to pre-colonial activities. While there has been recognition that technologies associated with traditional hunting can legitimately evolve, there has been no recognition of an evolving economic relationship between Aboriginal people and marine resources. In particular, commercial fishing industries, involving the extraction and sale of resources from within Aboriginal maritime estates, have developed without the approval or involvement of traditional owners.

Aboriginal participation in planning and consultative processes, including membership of fisheries Management Advisory Committees (MACs) and Zonal Advisory Committees (ZACs) provides an indigenous voice in decision-making processes but does not reflect the ownership and custodianship roles indigenous peoples once had and to which they continue to aspire. This comprehensive role for coastal Aboriginal people is reflected in the several native title claims within the Cairns and Far Northern Sections of the GBRMP.

It can be expected that, whatever the outcome of native title claims, coastal Aboriginal people will seek a greater share of the economic benefits currently derived by the wider community from various extractive and non-extractive commercial uses of their estates within the GBRMP. For example, the current review of Aboriginal involvement in the management of the Far Northern section, being undertaken by the Cape York Land Council and funded by the GBRMPA, is examining the dollar value of commercial fisheries within specific clan estates in the GBRMP (Baker and Johnson, pers. comm.).

#### Transmission of maritime culture

Increasing recognition of Aboriginal maritime culture in GBRMP management has the potential to encourage the transmission of that culture between generations. At present, however, much of that cultural information is being provided to planners and managers for use by the managing agency, rather than being utilised directly by Aboriginal people in the management of their estates within the GBRMP.

Over the last five years, many Aboriginal people have generously shared their traditional knowledge of the reef with managers, planners and consultants in the belief that the GBRMP would be managed better and that their long-standing role as marine managers would be formally recognised. While considerable advances have been made, that formal recognition has yet to make a substantial difference on the water and the actual involvement of Aboriginal people in day to day management remains minimal.

The support given by GBRMPA, the Queensland Departments of Environment and Primary Industry and other agencies to the Community Ranger Training program has provided further encouragement to the transmission of Aboriginal maritime culture between generations. Aboriginal involvement in such training programs has occurred in the belief that employment opportunities and management roles would follow. Government management agencies now have a responsibility to ensure that this occurs.

#### Control of access to maritime estates

Traditional owners of maritime estates have virtually no formal control over access by others to their sea country. Limited control has been granted over the use of resources within clan estates by other Indigenous people, via the establishment of Councils of Elders in some areas. The reality for most traditional owners, however, is a situation of ongoing trespass into and through their sea country by outsiders.

The GBRMPA is limited by current legislation in its capacity to recognise Aboriginal customary rights to control such access. Negotiations to establish Aboriginal Management Areas, and efforts to mediate native title claims within the Far Northern section, represent an opportunity to resolve this issue. It should be stressed, however, that control of access does not equate with exclusive use. Aboriginal traditional owners and custodians have long expressed a willingness to share their sea country with other Australians, in the context of recognition of their customary rights and responsibilities.

#### Distribution of subsistence resources

Current restrictions over the distribution of subsistence resources, such as dugong and turtle meat, represent a limitation on the expression of contemporary Aboriginal culture. Families who are obligated and wish to share traditional foods with kin living outside communities come into conflict with state laws. Recognition that contemporary kin obligations can span many hundreds of kilometres and beyond state borders presents a challenge for law makers and managers. It is, however, a management issue which should be addressed in order to promote the continuation and transmission of culture.

#### **The process of change**

Progress towards the recognition of Aboriginal interests in managing customary estates within the Marine Park has largely resulted from a process of interaction between Aboriginal groups and Marine Park managers and planners over many years. It is important to acknowledge the pivotal and patient role played by key indigenous individuals and organisations in helping agency staff to understand the significance of Aboriginal maritime culture to contemporary Marine Park management.

This personal approach has been assisted by several significant events, including:

- The appointment of specialist Aboriginal liaison staff within GBRMPA and the Department of Environment;
- Funding several consultancies documenting Aboriginal maritime culture within the GBRMP;
- Employing agency staff with experience in the joint-management of protected areas elsewhere in Australia;
- The *Mabo* native title decision;
- Increasing support from GBRMPA executives to seek strategic resolution of indigenous issues in GBRMP management;
- The development of the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area.

The impact of these events, supported by the personal commitment of indigenous people to the cultural education of agency staff, has resulted in the initiatives noted in the preceding paper and a general change of status of indigenous peoples from being a minor user group to a partner in management.

It should be noted however, that these changes have occurred largely within the managing agencies in relative isolation from other arms of government and the general community. Indigenous peoples have interacted with and responded to Marine Park managers and planners in an attempt to have their broader marine environmental and resource management rights and interests recognised. It is now clear, however, that significant indigenous rights and interests are beyond the capacity of the Marine Park agencies to recognise alone, and will require the involvement of other agencies as well as the support of the wider community.

It can be expected therefore that the next phase of the process must involve other government agencies and the wider community. While maintaining the personal links already established with agencies, it may be appropriate for indigenous groups to make a strategic shift from agency by agency interactions to negotiations with whole of government.

Current negotiations to establish a 'Sea Council'<sup>1</sup> for the Far Northern section is an indication that that process is already underway. It is an attempt to encourage governments to recognise that Marine Park management is a sub-set of indigenous maritime management issues. Recognition of wider indigenous interests, and good environmental and resource management, will not be achieved until the broad relationship between indigenous peoples and the sea is acknowledged.

It is beginning to be acknowledged that indigenous maritime interests within the GBRMP cannot be successfully addressed unless there is a resolution of fisheries, tourism, shipping and other issues. It is to be hoped that the experience of GBRMPA and the Department of Environment can rapidly assist other maritime agencies to become involved in the process. Without that integrated approach it is doubtful if recognition of indigenous interests within the GBRMP can progress much further.

Marine Park management agencies have an opportunity and an obligation to pass on their experience of the last twenty years to other agencies and the wider community. In doing so they will be doing a service not only to indigenous peoples of the reef, but to the management of the reef itself.

#### **Indigenous maritime culture and the state of the reef**

Early progress towards the recognition of indigenous interests in Marine Park management largely took the form of agency concessions. That is, dugong and turtle hunting is a concession to the practice of indigenous culture; indigenous membership of advisory committees is a concession to indigenous peoples as a special interest group.

More recently, indigenous involvement is seen as a necessity; indigenous demands for involvement are not going to go away, so they need to be addressed strategically. This need is supported by increasing requirements placed upon governments to permit the full expression of indigenous cultures, as a result of international conventions and other agreements.

The next, and possibly more difficult phase, is to achieve recognition not only for these pragmatic reasons, but also because full expression of indigenous rights and interests is good for the state of the reef itself. This involves recognition that the link between indigenous peoples and reef is two way. Indigenous maritime culture is part of what the reef is.

Traditional knowledge, stories, ceremonies, hunting activities etc. are all part of the 'software' of the reef ecosystem. The current Great Barrier Reef environment has only existed in the presence of Aboriginal and Torres Strait Islander peoples. Without them and their culture the reef itself is diminished.

As in the past, the connection between indigenous peoples and the reef environment requires management to be kept in balance. As in the past, the best people to achieve that balance are the indigenous peoples themselves.

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<sup>1</sup> It is proposed that the Sea Council would include representatives of coastal Aboriginal groups and Government Marine Park and fisheries management agencies.

The concept of indigenous culture as a component of what the reef is has implications for future monitoring of the state of the reef. Much of the cultural connection between indigenous groups and the reef has already been lost; but much has been retained, and not only in the far north. For a healthy state of the reef it will be necessary to ensure that its cultural connections are nurtured. This is a complex task, which will include:

- Community education about indigenous maritime culture;
- Recording of indigenous maritime culture by and under the control of indigenous peoples;
- Training, education and employment opportunities which enable indigenous people to become increasingly directly involved in research, planning and management of the reef;
- Recognition that indigenous cultures will continue to change and adapt;
- Whole of government strategic planning to recognise indigenous interests in marine management.

The resolution of native title claims in the sea should be seen as an opportunity to take the necessary strategic, whole of government approach. In particular, the possibility of negotiating regional agreements in which indigenous maritime interests are addressed in the context of the historical and legal rights and interests of other groups is likely to be particularly rewarding.

Indeed, the development of a zoning plan, such as is currently being undertaken in the Far Northern section, should be seen in the context of an emerging regional agreement. The establishment of a Sea Council for the Far Northern section could provide the forum for addressing both the GBRMP and fisheries issues which would form the cornerstone of any maritime regional agreement in the far north, and elsewhere in the GBRMP.

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# Reef use and values: knowledge about visitor experiences in the Great Barrier Reef World Heritage Area

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The presentation will briefly review some of the studies about visitor experiences within the Great Barrier Reef World Heritage Area. These include a detailed study of Lady Musgrave Reef and Island, day visitor experiences at Norman Reef, studies of visitors to the Whitsundays and other previous point-based data. Related work on the quality of experiences within the Great Barrier Reef World Heritage Area is also reviewed in an attempt to document some of the conditions which have generated conflict amongst visitors and other users. It is noted that a number of current studies will deliver additional point-based data which will improve the broader appreciation of Great Barrier Reef World Heritage Area experiences especially those associated with snorkelling and diving.

These visitor experience studies lead to several specific conclusions including:

- little detailed knowledge exists about visitor experiences within the Great Barrier Reef World Heritage Area except at a few specific locations;
- the interaction between different users or interests has been studied at very few sites;
- nature is the most important element in positive experiences of people visiting the Great Barrier Reef World Heritage Area;
- where studies have examined large-scale day visits the experiences of visitors has been dominated by excitement and novelty and these have been judged of very high quality by the visitors;
- there are a variety of different experiences sought by visitors to the Great Barrier Reef World Heritage Area;
- crowding is perceived by a high proportion of visitors of all categories, even when visitation levels are not at the maximum permitted levels;
- different types of users may resent other users and yachting and boating visitors and campers are less tolerant of crowding and of development infrastructure than day-trippers;
- one important knowledge gap is in the absentia benefits of the Great Barrier Reef World Heritage Area (including associated experiences) and the likelihood that such benefits may form the basis for conflict over various proposed and continuing uses within the Great Barrier Reef World Heritage Area;
- another reef wide issue related to the allocation of specific sites for particular purposes with some users objecting strongly to perceived degradation of 'their' reef due to (especially) resort developments or other forms of intensive tourism, which impact on their favourite places (the Whitsunday Islands is a good example of this).



# Managing catchments to minimise downstream effects

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## **Abstract**

Change agents from catchments that may have downstream effects on the Great Barrier Reef lagoonal, reefal and associated estuarine environment include:

- increased export of sediments and increased turbidity in marine waters;
- changes to freshwater input hydrographs;
- increased export of nutrients and heavy metals;
- export of poisons such as pesticides and weedicides; and
- direct destruction of habitat such as foreshore mangrove communities and fresh to brackish floodplain wetlands.

While data is being collated on the magnitude of these potential change agents, there is a lack of data on the impacts of these agents on the suite of communities that comprise the Great Barrier Reef World Heritage Area.

In this environment of poorly defined impacts, resource managers are working under the precautionary principle that the closer change agents mirror the pre-European 'natural' conditions, the less will be the impact on the Great Barrier Reef and its environments.

Resource management activity within contributing catchments is proceeding on a series of fronts. These include the formulation and implementation of community based Catchment Management and River Management Strategies, the direction of land allocation within an integrated resource management framework, Landcare and property management planning initiatives which address the combined goals of sustainability and productivity, vegetation management and revegetation programs, formulation of policy and its implementation for floodplain management and improved techniques for on farm and urban land management. Implementation is undertaken cooperatively through partnerships between Government and community wherever possible. Regulatory mechanisms reinforce these resource management activities and include licensing, prosecution and special area management such as fish habitat areas.

This paper reviews information available on change agents, details resource management activity and calls for a more integrated and focused research development, extension and implementation program which will both document the impact of change agents on those Great Barrier Reef World Heritage Area key environments likely to be affected, particularly the Great Barrier Reef lagoon, and secondly, minimise the nature, extent and size of these change agents beyond what is considered to be baseline.

## **Scan of the catchments and resource condition**

### **Contributing catchments**

From the basin of the Burnett River, along Queensland's east coast to the Torres Strait, there are over 410 000km<sup>2</sup> of land draining into the Great Barrier Reef lagoon. As shown in Fig. 1,

this is a substantial proportion of the State's drainage basins. Within these catchments are some of Queensland's most extensive river systems. In terms of mean annual discharge, the Burdekin River (10 100 000 ML) and the Fitzroy River (7 130 000 ML) are the largest. Other significant discharging catchments include the Herbert, Johnstone and the Tully-Murray Rivers, with mean annual discharges between 3 and 4 million ML for each of these catchments.

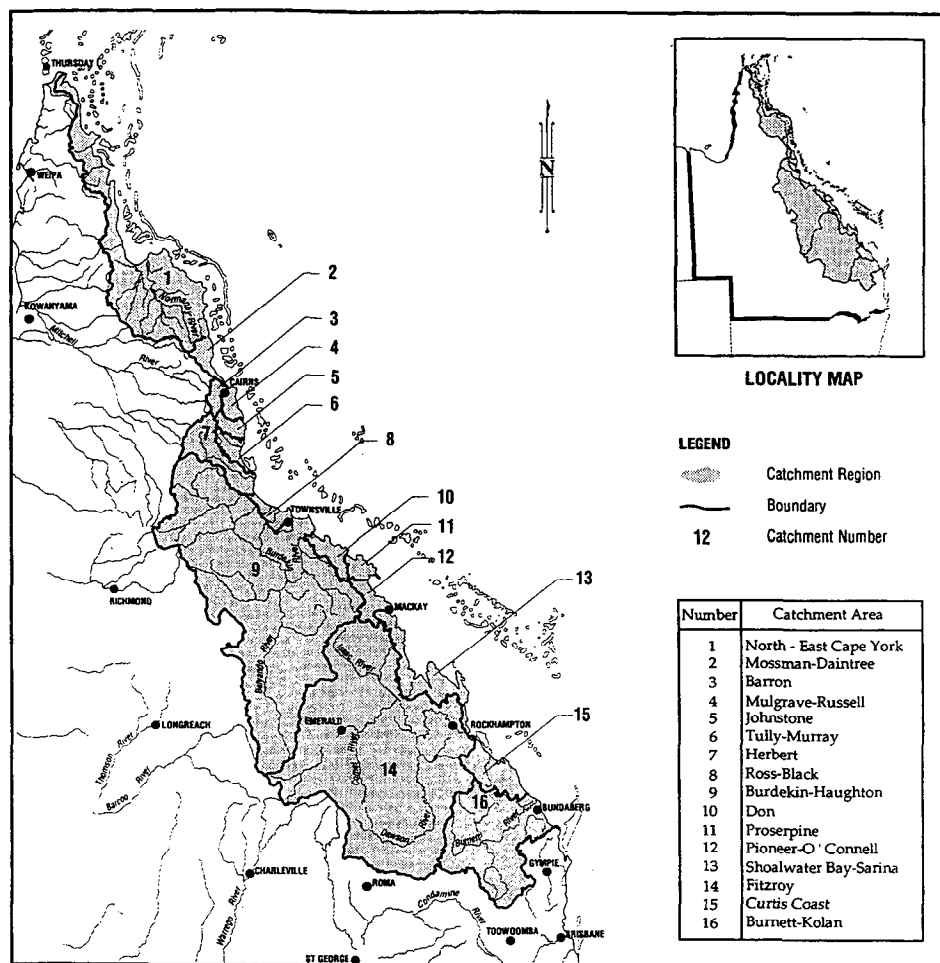


Figure 1. Catchments contributing to the Great Barrier Reef lagoon

Prior to colonisation, these rivers would have flowed through 'pristine' vegetated catchments comprising woodlands and grasslands in lower rainfall areas of some upper catchments, dry sclerophyll and wet sclerophyll forests, rainforests for much of the range section and rainforest/wetland systems for the coastal floodplains. Riparian and wetland communities would have been intact, and the water that drained from these basins would have contributed to the Great Barrier Reef lagoon's natural biological, chemical and geological processes. Pulses of floodwater carrying abnormally large loads of sediments and nutrients certainly occurred, as evidenced by the extensive floodplain development on all major catchments. However as various catchment based studies on the impact of land uses have shown, the levels of sediment discharged to the marine environment would likely be at most in the range of  $\frac{1}{8}$  to  $\frac{1}{6}$  of sediment yield from current day catchments which are dominated by agricultural and urban land uses. Additionally, the discharge pattern would be close to a modulated sinusoidal pattern as compared to the high peaks and rapid recessions of flow that typify disturbed catchments.

Vegetation change

Vegetation change that has accompanied land use development and changes to water quality and quantity has been substantial. As one example, consider floodplain wetlands. Figure 2

details changes in areal extent to floodplain wetlands in the last 50 years for the Johnstone catchment. In summary, much of the fresh to brackish and fresh wetland of the floodplain has been drained to support agriculture, principally sugar cane.

Common practices for reclamation have included the construction of drains with some existing water courses channelised and their riparian vegetation removed or severely depleted. Flood gates or tidal gates are commonly installed to prevent inundation by floodwaters or tidal backup. These severely limit fish access and therefore available habitat. The trend is towards simplified, reduced area, weed infested wetlands and a reduction in diversity amongst estuarine communities, particularly a decline in seagrass beds and the brackish fringing vegetation to mangrove communities.

Impacts are various, including loss of habitat, reduction in fish carrying capacity and thus fish populations, more rapid water discharge following rain events, reduced dampening of flood events and reduced filtering out of sediments and nutrients from run-off. It is also interesting to note that mangrove areas have increased. This reflects increased sedimentation with muds replacing sand spits and mangroves aggressively colonising these areas. Declines in aquatic and estuarine habitat such as seagrass beds have also occurred. While there is world wide scientific evidence to confirm that land use impacts would have caused a decline in seagrass extent and productivity, no quantitative data is available on changes to seagrass extent since European settlement. Investigations are warranted and may need to focus on changes to the nature of sediments and to light penetration levels as an indication of changes to biota such as seagrasses.

#### Riparian lands

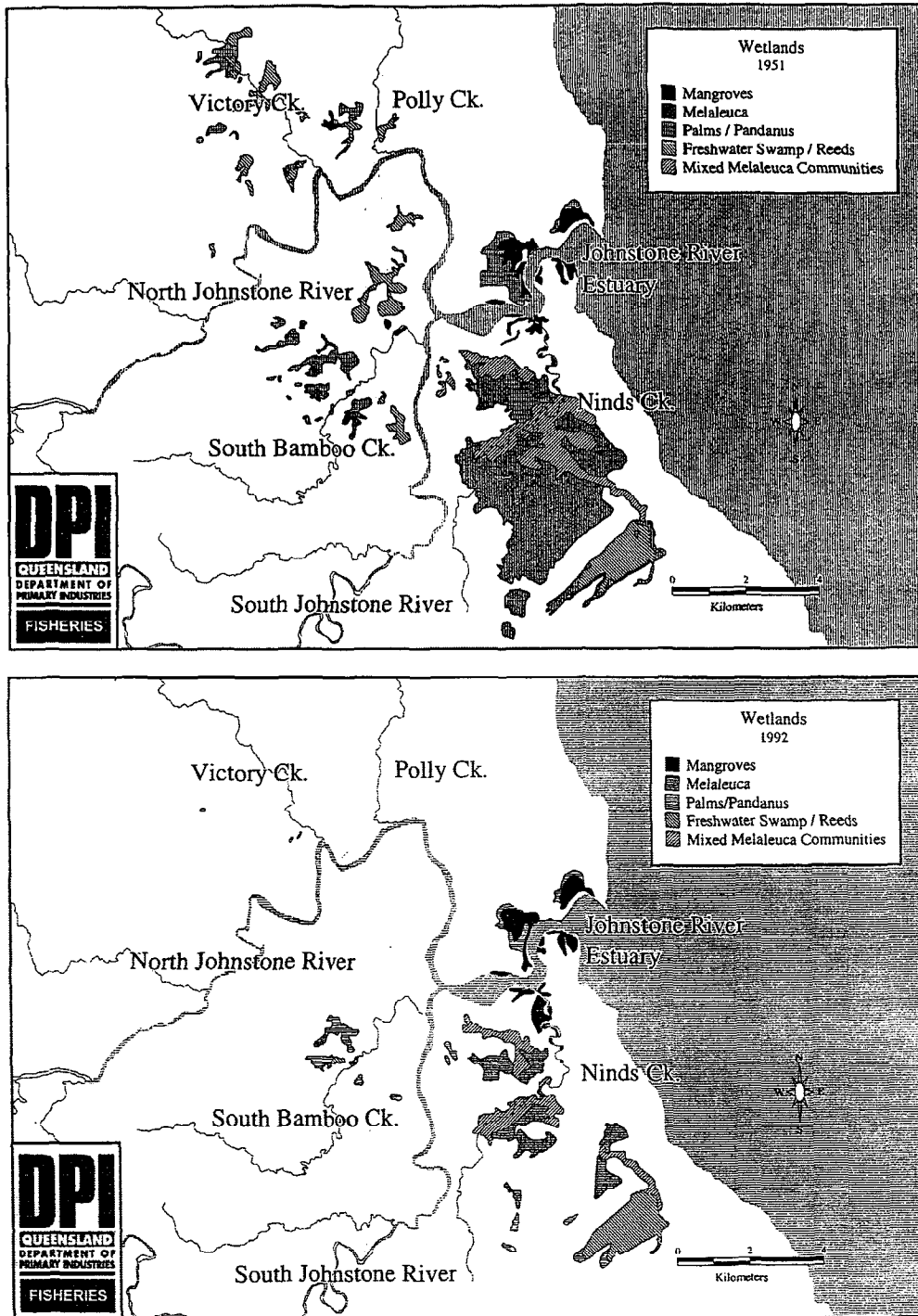
The rapid assessment protocol for determining riparian condition (Russell et al. 1994) demonstrates the link between adjacent land use and riparian condition. Most sites assessed on the tablelands (80%), and coastal lowlands (72%) adjacent to agricultural uses were in poor or very poor condition. Sites on the coastal range, most of which fall within the World Heritage area, were in either good or excellent condition. Similarly, a high proportion of sites (60%) in the estuarine zone were classified as either in good or excellent condition.

The structure of the riparian zone, both in terms of width and composition, is also an important indicator of condition. On the tablelands and coastal areas there are few sites where the riparian zone consisted of tree corridors greater than 30 metres wide.

Consequences of degradation of the riparian zone include a decrease in shading and subsequent increase in weed growth (Gregory et al. 1991) and increased erosion and sedimentation (DeLong and Brusvan 1991). The proliferation of para grass (*Bracharia mutica*), an introduced pasture species which can invade shallow water courses (Middleton 1991), has caused problems by restricting water flow and promoting sedimentation. Para grass can also affect the distribution and abundance of some fish species (Arthington et al. 1993). Overall, without concerted community action, the trend is towards depauperate riparian lands, weed infested and fragmented in extent.

#### Water quality

Depressed pH values, as low as 2.8, are a feature of lower floodplain locations and indicate problems associated with the disturbance and drainage of acid sulphate soils. Fish kills and red spot disease problems are well documented. Turbidity and siltation are endemic problems in all but the high velocity gorge sections of the rivers.



**Figure 2.** Change in wetlands - Lower Johnstone River catchment (from Russell and Hales 1993). a) Wetlands of the Johnstone Floodplain, 1951. b) Wetlands of the Johnstone Floodplain, 1992

Wetland	1951 (ha)	1992 (ha)	Net Change (ha)	
Mangroves	176	202	26	(15%)
<i>Melaleuca</i> forests	1277	282	-995	(-78%)
Mixed <i>Melaleuca</i> communities	462	258	-204	(-44%)
Palm/Pandanus	439	160	-279	(-64%)
Freshwater Reed Swamps	499	225	-274	(-55%)
<b>TOTAL Wetland</b>	<b>2853</b>	<b>1127</b>	<b>-1726</b>	<b>(-60%)</b>

For the Tully Murray floodplain with its high incidence of perched floodplain lagoons, a high correlation exists between oxygen levels and diversity of fish species in these lagoons. Low oxygen levels are related to the drainage network and run-off characteristics that now dominate the floodplain together with the impact of acid sulphate soils. Without ameliorative action the trend is towards continuing pH problems and high sediment and nutrient loads.

Land use pattern and key sources of change agents

Under current land use patterns, the catchments adjacent to the Great Barrier Reef contain approximately 80% of the state's sugarcane and banana crops (Kingston et al. 1991) most of which are on the coastal floodplains. Grazing is, in terms of area, the primary land use, occupying approximately 75% of the sixteen catchments. The coastal strip also contains expanding industrial and urban centres, including Gladstone, Mackay, Townsville and Cairns. Figure 3 gives a broad overview of land use by area, throughout the region.

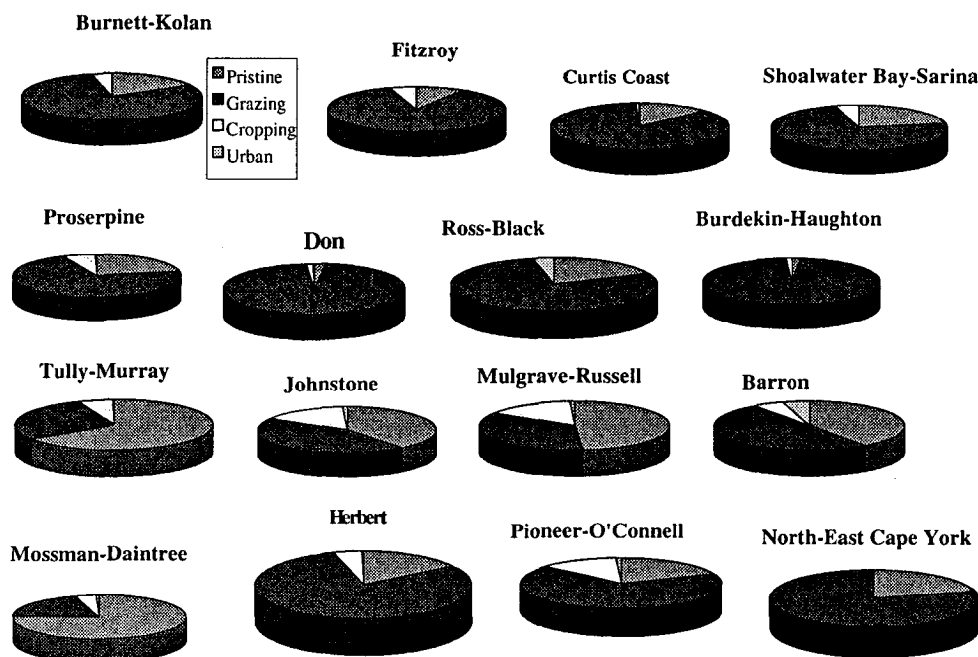
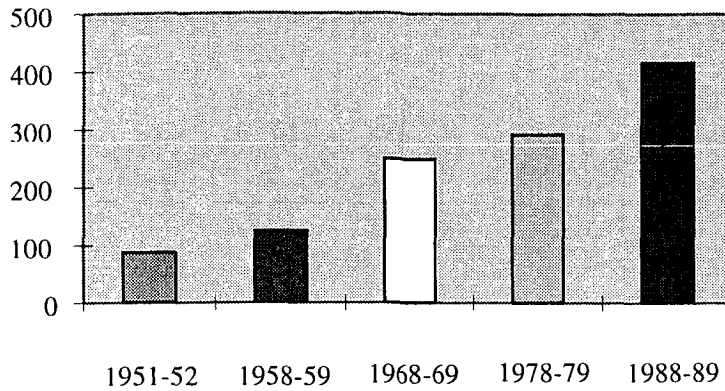


Figure 3. Land use in catchments influencing the Great Barrier Reef (Queensland Department of Primary Industries 1993)

Urban and industrial developments are mostly linked to point sources of nutrients, of which sewage is the largest input (Brodie 1991). Cleveland Bay, Townsville, is one area where point sources are damaging fringing reefs (Brodie 1991). The aggregate nutrient content of urban run-off is much less in magnitude than that sourced from river discharge (Brodie 1991). Non-point sources of nutrients from agriculture cannot be measured as easily as sewage and are of concern. As a gross indication of changes in practice that may have contributed to nutrient levels, Fig. 4 displays the area of fertilised land. Rangeland grazing would also be contributing to nutrient exports, albeit probably at lower levels per hectare because of the reduced stocking densities of unimproved pastures. Much of the nutrients exported from the catchments are absorbed to soil particles. Control of soil erosion and appropriate cropping and grazing practices would reduce catchment nutrient exports, maximise effectiveness of fertiliser applications and of course, reduced the export of sediments, which in themselves, cause significant impacts to lagoon and reefal environments.



**Figure 4.** Area of fertilized land in central and north Queensland (000 ha) [Pulsford 1991]

In the last decade, there has been a realisation that catchment land use and subsequent exports of sediments, nutrients and poisons may be of a magnitude great enough to exert substantial influence on the health of the Great Barrier Reef. Cyclone Sadie, which caused extensive flooding in the Wet Tropics catchments in early 1994, demonstrated the possibility that riverine exports could reach the outer reefs (DEAP 1994). Terrestrial run-off has been surmised to be connected with many degradation problems in the Marine Park, even outbreaks of the crown-of-thorns starfish (Bell 1995). It is an important objective of the Great Barrier Reef Marine Park Authority's Strategic Plan to quantify the impacts of these catchment exports on the Reef.

#### **Catchment impacts on the Reef - what do we know?**

The variety of land-based inputs which may threaten the health and stability of the lagoon and reef, can be categorised into three groups - sediments, nutrients and poisons (heavy metals and other toxins). The export of these materials from the land is influenced by rainfall, soil type, land cover and land use (Furnas and Brodie 1995). The change in land use patterns on Queensland's east coast, has not only made available more material for transport, due to inputs such as fertiliser and pesticides, but increased the rate at which they are lost from the land, since vegetation cover has been reduced. The transport of these materials through drainage basins is often directly related to flow velocities and in many cases this too has increased as a result of changes in catchment hydrology.

Research has shown that even minor changes in water quality parameters can be lethal to coral communities (U.S. Department of Commerce), and yet the fate of contaminated materials entering the Great Barrier Reef lagoon is still poorly understood (Finlayson and Silburn 1995). This may in part be related to the previous and current focus of research on the Barrier Reef itself whereas most of the impacts are likely to be upon the lagoon and near shore reef environments, both of which to date have been poorly researched and monitored.

Much anecdotal information is available on impacts upon fringing reefs. For example Banfield in *'Confessions of a Beachcomber'* recounts changes in the fringing reefs of Dunk Island as a result of a flood event and a subsequent prolonged period of sediment loaded freshwater within the fringing reef lagoon.

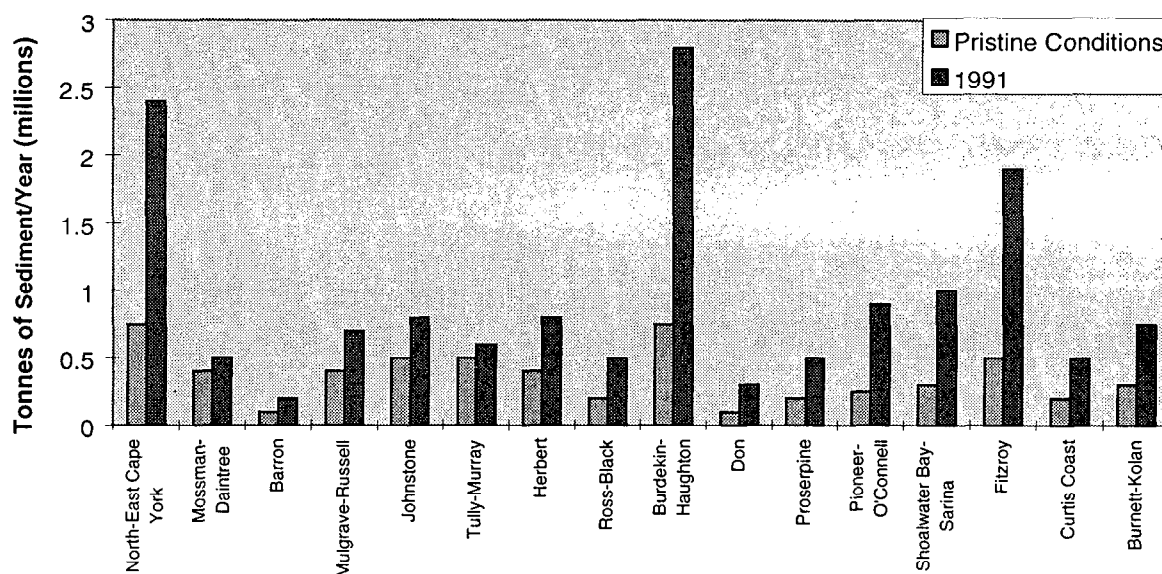
#### **Sediments**

Much of the change in land use in the catchments contributing to the Great Barrier Reef lagoon has involved both a reduction in vegetation cover and actual soil disturbance through cultivation, grazing, infrastructure development, roading and urban uses. This has resulted in

less soil protection, higher rates of erosion and ultimately a greater sediment load in creeks, rivers and estuaries. Changes in catchment hydrology and use have also promoted changes to river morphology with river bank erosion contributing greatly to total bed load.

Figure 5 shows the increase in sediment load over the last century for each catchment in the region. These figures give a total increase of 261%. This is possibly an underestimate of aggregate changes since European settlement. Conversion of land from natural vegetation to crops or pasture, can increase the sediment load by up to fifteen times (Neil 1995), with excessive grazing, particularly exacerbated by annual and prolonged drought conditions contributing similar increases to that from cropping.

**Change in Sediment Loads from Pristine Conditions to 1991**



**Figure 5.** Increase in sediment loads (Moss et al. 1992)

It is suggested that up to 80% of eroded sediment stays within local drainage lines (Prove and Hicks 1991) and is then progressively reworked during major events. The finer silt will generally be immediately carried into the stream load with coarser particles staying within upper catchment streams and over time sorted and transported down to estuaries and thence the lagoon. The highest sediment loads occur after storm events, when sediments previously trapped in drainage lines are reworked and transported downstream (Brodie and Furnas 1991) in addition to the transport off paddock through to the lagoon of finer particles such as clays. The majority of river sediments are deposited in the near shore zone of the Great Barrier Reef lagoon and estuaries (Prove and Hicks 1991). Coarse particles are deposited closer to the shore while finer particles may reach up to 15 km offshore and during major events are observed in colloidal suspension on the Barrier Reef proper.

Within the near shore zone, sediments are influencing biophysical processes in communities such as seagrass beds and sand spits (pers. comm. Coles and Lee Long). Wetland mapping has also displayed increased extents of mangroves where muds have prograded over sand spits and then been colonised by mangrove species. As well as the physical processes of smothering, one of the major consequences of excess suspended solids, is increased turbidity and therefore a reduction in the light available for fish, crustacea and to benthic organisms, both seagrasses and corals. Corals may also suffer abrasion. The efficiency of filter feeders is reduced, as is gill-breathing and macrophyllite algae are favoured on both seagrass and corals. Furthermore, sediments may reduce coral larval settlement, providing a more suitable substrate for algal

colonisation (Bell 1992) and thus incremental and possibly irreversible changes to community structure. The microhabitats which exist in coral cavities can also be plugged by sediments, directly impacting on other components of the community.

After a cyclone and a period of flooding in 1992, die off occurred in 1000 km<sup>2</sup> of seagrass beds. In shallow areas, a lack of full recovery was linked to sediments burying propagules (Preen 1995). The primary cause of seagrass die-off is thought to be light reduction - a consequence of increased sediments (Robertson and Long 1991). An ongoing monitoring program of lagoonal habitats, focussing on seagrasses and historical changes to bottom sediments would assist in quantifying the biotic impacts of increased sediments to the Great Barrier Reef.

#### Nutrients

Agricultural, residential and industrial land uses across catchments all contribute nutrients to river systems. Residential and industrial related nutrients are generally exported as point sources. Sewage contains the highest concentration of nutrients with stormwater run-off containing about 10% the nutrients of sewage, being diffuse sources of nutrients from within urban and industrial areas. More difficult to manage are the nutrients lost from agricultural and grazing lands.

The three nutrients of major concern are carbon, nitrogen and phosphorus. Carbon is mostly connected with point discharges from sewage plants, sugar mills and abattoirs (Hunter and Rayment 1990). Carbon is readily quantified and data available suggest that carbon does not pose a threat in comparison to nitrogen and phosphorus.

The addition of nitrogen and phosphorus as fertilisers has increased with the expansion of agricultural lands. The loss of these nutrients from the land is closely related to the movement of sediments, as 40% of nitrogen and 80% of phosphorus are bound to soil particles. Therefore, the rate of increase in nutrient export from fertilisers is likely to be in the same order of magnitude as the increase in sediment load shown in Fig. 5.

Sediments act as sinks for nutrients until large flood events lead to their transportation (Mitchell et al. 1991). During periods of high flow, a higher percentage of nitrogen (N) and phosphorus (P) are particle bound (Hunter and Rayment 1991). Storm flow derived nutrients probably contribute to a large proportion of the total nutrients that are transported annually (Pailles and Moody 1995). The rate and location at which nutrients dissociate from soil particles is often influenced by salinity in estuarine areas. Up to 80% of phosphorus is lost from fluvial sediment before reaching the marine environment (Pailles and Moody 1995).

Nutrients may impact on the reef in a variety of ways. Phosphorus affects calcification in corals (Furnas and Brodie 1995) and the number of cavities in the coral matrix. Nitrate is toxic to prawn larvae (Hunter and Rayment 1991). Organic sediments can also lead to the production of hydrogen sulfide which promotes the growth of filter and detrital feeders, potential competitors with coral (Bell 1992).

Of primary concern, however, is the growth of algae which is encouraged by increased nutrients. The blue-green algae, *Trichodesmium*, can block light from corals and hence affect calcification processes (Bell 1992). Seagrasses can suffer from smothering, if nutrients lead to extensive growth of epiphytic algae (Robertson and Long 1991).



### Heavy metals and other toxins

There is a large variety of potentially harmful materials which find their way from catchments to the Great Barrier Reef lagoon - for example, pesticides, weedicides and heavy metals. In many cases such materials are sprayed or added to vegetation or the top layer of soil, leaving them extremely vulnerable to erosion in surface run-off.

Heavy metals are added to soil in fertilisers. Copper and zinc are added to the land intentionally as essential plant nutrients. The other important heavy metal, cadmium, is not a plant nutrient, but is present in many phosphate fertilisers (Hunter and Rayment 1991)

Pesticides and weedicides, commonly sprayed on the surface of vegetation, are easily washed into receiving creeks and rivers. More soluble pesticides such as 2, 4-D are much more likely to travel further. Other pesticides, weedicides and heavy metals being particle bound, their movement, like nutrients, is closely related to sediment transport (Finlayson and Silburn 1995).

Once in the marine environment, heavy metals are extremely persistent (Guzman and Jimenez 1992). Coral bleaching is a stress response in cnidarians to heavy metals (Guzman and Jimenez 1992). They can also concentrate in shellfish tissues where they may interfere with reproduction (U.S. Department of Commerce 1994). In the Great Barrier Reef at present heavy metals and other miscellaneous toxins are considered to be well below dangerous levels and therefore, thought to be insignificant (Hunter and Rayment 1991).

### **Community perceptions and changing attitudes to catchment management**

Effective catchment management is achieved through community recognition of the range of values of catchments and the implementation of management practices which protect those values. The key would appear to be firstly, the implementation of extension and awareness programs that describe the roles of catchments and secondly, to reinforce this awareness through community involvement in actual works and activities that repair and manage the catchment process and systems.

Community involvement in catchment management and rehabilitation relies upon:

- development and acceptance of locally appropriate management procedures by community based forums;
- lead agencies such as Local Authorities, River Trusts and Catchment Coordinating Committees actively promoting particular management techniques through demonstration works projects, and through enforcement;
- individuals (early adopters) influencing adjacent landholders with these change agents generally also being the leaders in the Landcare movement; and
- developing then demonstrating solutions to productivity problems where these solutions also incorporate improved catchment management (e.g. revegetation to reduce rat habitat).

Through a range of extension and awareness mechanisms, the Queensland community have become increasingly aware of the multiple values of their catchment and river systems and the need for reduced downstream effects on the Great Barrier Reef.

### Integrated catchment management process

Integrated Catchment Management (ICM) aims to integrate the management of land, water, vegetation and other biological resources on a catchment basis to achieve the sustainable and balanced use of these resources (Queensland Government 1991). Integrated Catchment Management involves the community and government working together through Catchment

Coordinating Committees to develop and implement strategies for the better management of catchments.

There are Catchment Committees in the Mossman/Daintree Rivers, Barron, Russell/Mulgrave, Johnstone, Tully/Murray, Herbert, Pioneer, Fitzroy and Burnett catchments, all of which discharge into the Great Barrier Reef lagoon. These Committees are active in producing and then implementing Catchment Management Strategies that identify significant catchment issues and propose preferred ways of addressing these issues. Catchment strategies have been prepared by Committees in the Johnstone (Johnstone River Catchment Coordinating Committee 1994) Pioneer (Pioneer Integrated Catchment Management Association 1995) Russell Mulgrave and Herbert with a draft Strategy currently under review for the Fitzroy.

Catchment strategies have focused on the land and riverine based activities affecting the catchment. The extent to which they address potential concerns with the reef varies according to the information available on impacts and the nature of the changes needed to ameliorate these impacts. Most of the actions to address in-catchment concerns, have an impact on the quality and quantity of river discharges. For example soil erosion and stream bank erosion in the upper Pioneer river catchment are two issues targeted by the Pioneer Integrated Catchment Management Association. While the impact of sediment from the Pioneer on the reef is not quantified, by treating the causes of these problems, the benefits will flow on to the lagoon and reef.

Interest in catchment management has stimulated a range of monitoring, research and development projects in these catchments to improve understanding of the issues and to be able to better design strategies to reduce their impact. Substantial funding has also been made available to the Catchment groups that have Strategies in place to implement on-the-ground works tackling key problems as identified within their Strategies.

It is anticipated that as ICM grows to cover the remaining catchments discharging into the Great Barrier Reef lagoon, and Catchment Strategies are implemented, substantial reductions in land use impacts from catchments will occur.

#### Landcare action and property management planning

A third of the 56 Landcare groups in the State are located in the catchments of rivers draining to the Great Barrier Reef lagoon. Groups of local landholders and other interested people comprise these Landcare Committees. While their interests and activities vary, they are all working on improving the sustainable use of land and water resources in their area, generally on a farm by farm basis. A survey of issues of concern to Landcare groups in the region showed that 25-30% of groups felt water quality decline was a concern while 30-33% identified timber clearing as a concern (Curtis et al. 1994). A range of activities, from weed control to property management planning and water quality monitoring form the key interests of these groups and all contribute to the lessening of impacts of land use upon the catchments and their receiving waters - the Great Barrier Reef lagoon.

The ability of Landcare to make rapid major changes in the catchments is limited by the availability of funds to carry out the necessary works. Generally funding for Landcare provided under the National Landcare Program has been restricted to education, investigation and awareness building type activities. Nevertheless, change in practice through awareness and change in attitudes is one of the most effective means of ensuring long term change towards sustainable land use practices.

At the farm level, one area where Landcare has been influential is in promoting the use of property management planning. Approximately 68% of Landcare groups had members who had commenced property management plans by 1994 (Curtis 1994). That proportion has increased since that time as Landcare and Government resources have focused on increased support for property management planning.

Property Management Planning is a process designed to help landholders improve their whole farm management skills. The aim of Property Management Planning is to integrate planning processes for business and finances, family and personal goals, natural resources and production. This occurs at an individual property scale generally through group workshops. Property management issues like goal setting, soil recognition, farm layout mapping, soil management and managing for climate have been the key topics of interest in the cane areas that comprise the majority of the agriculture in the floodplains of the Great Barrier Reef catchments. Property Management Planning also provides a platform for the implementation of voluntary codes of practice and new technology. Voluntary codes of practice for the beef, horticulture, dairying and cane industries have been developed under the Integrated Catchment Management initiative and endorsed by farmer groups within the Wet Tropics.

From a 'new technology' perspective, the most significant gains have been in the management of sugar cane, where under green cane trash blanketing, soil losses can be reduced from 47-505 t/ha.year to < 15 t/ha.year (Prove et al. 1995). In 1994, 58% of the cane harvested in the catchments of the Great Barrier Reef was green although the proportion varied from 1% to 98%, the highest proportion was in the Herbert river catchment. By 1996 virtually all the cane harvested in the Wet Tropics was harvested green with in excess of 50% harvested green in Mackay Whitsunday. Green cane harvesting has not however yet been adopted in the Burdekin or Bundaberg areas with subsequent continuing impacts on air pollution, nutrient transport, soil loss and soil structure.

In the dairy and beef industries, improved stock handling systems and lower stocking rates, environmentally sound effluent disposal systems, safe use of chemicals and restricting stock access to creeks and rivers all contribute to better managed catchments. Again however much remains to be achieved, with stocking rates and grazing practices far from optimum throughout the Dry Tropics of Central and Northern Queensland. Key catchments requiring increased effort are the Burdekin and Fitzroy.

In horticulture, particularly in the Wet Tropics where Integrated Catchment Management has been promoted, drainage and run-off control systems, improved fertiliser management and the use of integrated pest management have decreased their impact on the catchment. While the cropping industry (cotton, grains) are adopting more efficient irrigation systems including recycling of tailwater and containment of run-off, Integrated Pest Management and crop rotations for more efficient farming and improved soil performance have yet to be widely adopted.

In summary, much remains to be done in the field of improved farming systems. Research and development and most importantly demonstration of improved farming systems is required in all industries to foster voluntary adoption of improved techniques. These demonstrations must be of medium term duration to cover season and market variability and must integrate all aspects of farm management/crop production. Farming systems must clearly demonstrate practical, cost effective, sustainable and productive solutions to the joint issues of increased production and improved environmental management.

### Community works and activities to reinforce catchment management principles

Community action requires support that goes beyond demonstration activities. Under the Catchment Management Implementation initiative funds are made available to Landcare, Catchment Committees and other groups to implement activities of Catchment priority. Most of the \$1M per annum provided under this initiative has to date been applied to works in the Wet Tropics, where, through community and agency commitment, Integrated Catchment Management is in a more advanced state than other catchments. Examples of works undertaken include:

- river rehabilitation and bank erosion control;
- dairy effluent management systems;
- riparian land revegetation and rehabilitation; and
- provision of nursery infrastructure to support rehabilitation programs.

Other sources of funds have also been focused on this works requirement to repair catchments and provide concrete support to community commitment and include:

- community led forums that have reached an agreed 'position' on the values of river systems and then developed strategies to implement remedial activities that will enhance these values;
- revegetation of riparian lands through Landcare, Wet Tropics Tree Planting and Community Rainforest Reafforestation projects;
- targeted sand and gravel extraction through the cooperation of commercial operators to re-create features such as deep holes and sand spits;
- monitoring projects that relate land use practice to river condition, such as Waterwatch; and
- the development of artificial lagoons on farms which maximise agricultural production, integrate drainage and water quality systems, perform as silt and nutrient traps and provide increased fisheries and wildlife habitat.

All of this community activity relies upon a close partnership with State and Local authorities. Authorities must be consistent and focused in their approach to catchment management, providing both the technical base and the catalysts for community action. The foreshadowed change in focus of the National Landcare Program should allow for additional funding of these essential activities of catchment repair with their flow on values for the Great Barrier Reef lagoon.

### **Reinforcing community action through integrated agency activities**

The partnership between community and government (e.g. Johnstone Catchment Coordinating Committee 1995) that galvanises community acceptance and actions towards improved catchment management requires a deliberate, strategic focus on the part of Government. At the same time, Government must be perceived as facilitating rather than directing community activity, working through and with the community's change agents. The following initiatives provide examples of how this can occur.

#### Development of floodplain management guidelines

The objective of these Guidelines developed for the Wet Tropics is to ensure coordinated development of agriculturally sustainable land, with minimal adverse impacts on the broader environment (both natural and existing developments). Equally important, the Guidelines provide a basis for a consistent approach by all agencies.

The Floodplain Guidelines are based upon five principles, as follows:

- Principle 1: Consider Multiple Values and Uses of the Floodplain.

- Principle 2: Understand the Natural System, both hydrological and ecological components.
- Principle 3: Evaluate and justify Land Development Proposals, both regionally and locally.
- Principle 4: Compile and Refer to a Catchment Plan.
- Principle 5: Maintain Key Natural Areas and Processes.

The Principles ensure that development occurs in a rational and integrated fashion with priority given to maintaining and enhancing key natural areas and processes.

Implementation of the guidelines relies on action by Sugar Cane Assignment Committees, Shire Councils, Catchment Coordinating Committees, River Improvement Trusts, Landcare Groups and Industry Organisations. The Guidelines target these key industry bodies assisting in their use allocation decisions and it was in consort with these bodies that the Guidelines were developed.

At the same time it should be noted that possibly an equal amount of effort was involved in bringing various State agencies to accept the values the Land Use Allocation Guidelines promote; to ensure a consistent approach across these agencies; and that all Government action would conform with the Guidelines.

Integrating development initiatives with protection and management of catchment resources

The Sugar Industry Infrastructure Package (SIIP) is a Commonwealth-State-Cane Industry initiative of \$40M government funds and total project costs in excess of \$200M across Queensland. The Project Selection Criteria provided the framework to ensure all projects funded under SIIP provided both economic benefit/increased sugar production and were environmentally appropriate/sustainable.

The SIIP process for project selection and development incorporated the following features:

- Project selection based on the recommendations of two working groups, one dealing with economic and benefit-cost considerations and the other, sustainability and environmental benefits. (The senior author of this paper chaired the latter Working Group.)
- Community input into individual project planning and development through Local Management Groups comprising representatives from the sugar industry, local government, Catchment Coordinating Committee, Drainage Boards, River Improvement Trust and Department of Environment.
- Project approval conditional on the acceptance of an Impact Assessment Study (IAS) and Environmental Management Plan (EMP). The EMP identifies all potential environmental impacts of a proposal and provides a detailed description of safeguard mechanisms to minimise or mitigate the potential for adverse impacts. Studies and assessments were undertaken to provide input into the IAS and to provide a benchmark to monitor and control project impacts (Queensland Department of Primary Industries 1995a).
- Community involvement was essential to promote an open decision making process that was not constrained by pre-determined outcomes. This provides a sense of community ownership and achieves a result that meets the needs of the community.
- The planning and approval process utilised the resources of other government departments (essentially Department of Environment) to ensure project objectives were compatible with the individual policies of each department. The process linked all stakeholders and reviewers in a defined process of 'consultation - review - consultation' so that all issues were adequately addressed and acceptable to all parties.

- On farm implementation was delivered through a property management planning approach, translating the Environmental Management Plan for each project into deliverables at the farm scale.

Overall, SIIP projects provide a model to promote best management practices, on farm and across catchment, and foster the adoption of environmentally sound and balanced development.

SIIP projects in the Wet Tropics provided concrete examples to the community of the application of the Floodplain Management Guidelines at the catchment scale and the role of property management planning at the farm scale. Project development and implementation provides the challenge to achieve an acceptable balance between the effects of industry expansion and the broader community demands for controlled and sustainable floodplain development.

Key outcomes for the SIIP Wet Tropics projects include:

- Existing cane growing areas will benefit from reduced periods of inundation from frequently occurring, high intensity rainfall events by coordinating drainage infrastructure based on consistent design criteria while at the same time developing nutrient and sediment detention basins.
- In areas of major industry expansion in Tully-Murray and Herbert, the projects will also establish frameworks for the sustainable development of potential agricultural lands while preserving essential natural resource systems and ecological processes of these sensitive areas.
- Significant environmental values such as water quality, floodplain wetlands and waterways and lowland habitat areas (including cassowary and mahogany glider habitat) will be preserved and enhanced through measures being incorporated into the design, construction and management of the projects.
- In addition to the environmental benefits for the floodplain areas themselves and the offshore marine environment (Great Barrier Reef) the projects will provide significant economic benefits at the local, state and national level through increased productivity on some 1500 ha of existing and potential canelands.
- Retention and protective management of key floodplain habitats. (The SIIP IAS process identified key public and freehold resources that need to be retained. As a result an additional package of \$16M was provided through Commonwealth and State Environment agencies to purchase freehold lands.)

Protective management of instream resources

The SIIP IAS process not only identified key natural resources and quantified the role of streams in floodplain management, but also galvanised community attitudes towards enhanced protective management of stream resources.

One mechanism for managing streams in Queensland is to establish Fish Habitat Reserves. A management plan can be written specifically for each reserve, to address and manage issues unique to that area. The community now recognises that a stream reserve is not a 'closed system' but will be affected by activities within the catchment and that the entire stream from headwaters to estuary to ocean requires protective management. Therefore there is a broad range of catchment issues that need to be considered when forming a Management Plan for a stream. Unfortunately, legislatively, the 1994 Fisheries Act does not seem able to cater for this community demand.

Issues considered for the proposed Tully and Murray Rivers Fish Habitat Area include: riparian vegetation; weed infestation and control; effects of agricultural drainage; sand extraction; water

abstraction; pollution; riverbank erosion control and perceptions of erosion causes; threats to instream habitat (e.g. removal of snags, sandbars); power station water-releases effecting fish spawning; recreation and amenity; and tourism. Many of these issues are related either to the needs of the user groups adjacent to the rivers (primarily cane and banana growers) or to wider community needs (Tully-Murray River Improvement Trust 1994).

Even without a reserve, these issues exist and need to be managed. Certain issues such as sand and water extraction are already being managed by permits under different legislation. Although this can be effective, permits generally address a single issue and do not always consider the overall effect. A wider approach is needed for effective management of streams. Reservation as Fish Habitat could provide legislation to empower a Management Plan and take this wider catchment approach. Queensland Department of Primary Industries officers are continuing work towards applying the Fisheries legislation to create Freshwater Fisheries Habitat Reserves. Should this be successful for the Tully Murray it will create an important precedent in integrated fisheries/catchment management with major positive impacts for the Great Barrier Reef.

#### Environmental repair of riparian and catchment lands

Fish Habitat, Catchment Management and Landcare initiatives aim to improve landholder and public attitudes to both riparian vegetation and to streams by emphasising the benefits these systems provide to land, water and habitat. These benefits include increased productivity for commercial and recreational fishing; improved aesthetics plus tourism and recreational potential; ecological benefits by maintaining natural diversity for aquatic flora and fauna; and functional benefits (e.g. baffling floodwaters, reducing erosion, nutrient capture, wildlife corridors, reducing weed and rat habitat).

Community groups and community based revegetation programs are providing a key catalyst to changing landholder attitudes to riparian vegetation. Two tree planting schemes, the Wet Tropics Tree Planting Scheme (primarily nature conservation focused) and the Community Rainforest Reafforestation Program (both farm forestry and environmental protection focused) utilise labour market programs to revegetate Wet Tropics catchments. Key riparian habitats requiring revegetation are identified in Catchment Management Strategies or related plans such as the Tully Murray Fish Habitat Reserve Management Plan and are being revegetated by these tree planting schemes under the direction of the Catchment Coordinating Committees and involvement of the Landcare Groups. Landholder involvement ensures the development of a stewardship ethic and reinforces the importance of riparian vegetation.

To date the Wet Tropics Tree Planting Scheme has planted in excess of 5M trees, with planting activity now focused through the development of community acceptable and Local Government approved Catchment Revegetation Plans. The Community Rainforest Reafforestation Program has planted in excess of 3000 ha in the Wet Tropics of Far North Queensland and a further 250 ha in Mackay Whitsunday. Unfortunately both schemes are currently facing severe budget constraints as a result of changing Commonwealth and State Government priorities. These constraints should lead to more focused revegetation activities with a higher level of landholder involvement, one of the long term aims of both schemes.

#### Enforcement

While the emphasis in catchment management in Queensland is on cooperative community and government action to protect and manage these important resources, enforcement provides a backup as a 'last resort' to ensure appropriate practices are undertaken by all.

The *Water Resource Act 1989* and the *Fisheries Act 1994* provide mechanisms to regulate and where necessary prosecute inappropriate actions in the following key areas:

- use, flow and control of water in watercourses, lakes and springs;
- extraction of quarry materials from watercourses and lakes;
- native vegetation, excavation and placement of fill in watercourses and fish habitats, now, both freshwater and estuarine;
- use of groundwater in declared areas;
- waterway barriers which inhibit movement of fish and other aquatic biota; and
- matters which affect water quality and stream pollution.

Regulation is achieved through licences and permits with conditions to ensure works are appropriate. Notices are issued to remove inappropriate works and rehabilitate areas affected by unauthorised works. Offence provisions provide for fines to deter unauthorised works.

The current legislation, while a useful backup tool has a series of deficiencies that inhibit the ability of State and Local Government in catchment management. These deficiencies are similar to those elsewhere in Australia, including:

- controls above and below tidal limit vary between Acts and involve multiple agency activity;
- controls over vegetation are limited to that within the actual watercourse and that defined as fish habitat;
- prosecution processes are by summons, are a lengthy legalistic activity and command a high use of scarce resources; and
- the legislation is in general, not well understood by the community, and due to various legal precedents, is somewhat restricted in its application.

Natural Resource Management legislation is proposed to be drafted in Queensland to replace the *Water Resources* and associated Acts, but will not fully resolve these somewhat generic deficiencies in legislation.

### **Concluding comments**

Catchment management is a partnership enterprise. This partnership is based upon an awareness of the multiple values of catchments, a commitment among agencies to work with and for the community and the implementation of a range of works initiatives which engender community stewardship of these common property resources. Much remains to be done and the resource condition is far from optimum, but through community activity the trend is towards improved natural resource systems based upon sustainable land use patterns.

From a 'pressure' or impact perspective while many of the gross impacts of changed land use in the catchments of the Great Barrier Reef have been identified and some quantified, there is still a lot unknown about the effects of land use changes and management on coastal and reefal communities. Without this understanding, any land use and management guidelines and practices can only be based on 'best bet'.

This information will assist in improving the rationale for management of the catchments. Additional to this, a major need is the development of farming systems and other land use systems approaches (e.g. for urban areas) which incorporate research and development with practical on-property solutions to joint production and environmental management problems. The basic unit of land use impact is the farm and the urban area. Much needs to be done to provide landholders with improved sustainable production practices.



Funds and effort are also required to enable these systems to be implemented. Important land and water management works are needed to address the issues of soil erosion, pasture management, vegetation rehabilitation, waste water management (urban and rural), riverine management and conservation of habitat. Incentive packages for both government and private land and water managers need to be continued and additional packages developed.

The 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area recognises the need for careful management of the reef and those areas with significant impacts on the Area. While it is apparent that many of the direct uses of the reef have obvious and often significant impacts on the reef (for example fishing, tourism etc.), the long term and more deleterious impacts of adverse catchment management practices and uses stresses the need for greater recognition of the reef, the lagoon and supporting catchments as an entity. This should be reflected to a greater extent in the policies and plans of the Great Barrier Reef Marine Park Authority and cooperatively by the agencies spanning the three tiers of Government involved in working with the community to sustainably manage catchments.

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# Day-to-day management of the Great Barrier Reef World Heritage Area: 'management at the crossroads'

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## **Introduction**

The Great Barrier Reef (GBR) is the largest coral reef ecosystem in the world. It comprises over 2900 separate reefs over its 2000 kilometre length. Larger than the total area of the United Kingdom and Ireland (or for North American readers, half the area of Texas), the Great Barrier Reef Marine Park is the largest marine conservation reserve on the planet. The Park supports tourism, commercial fishing and recreational uses that, in total, are valued in the billions of dollars to the Australian economy. Furthermore, the Park's value in conservation and cultural terms is inestimable. In contrast, the amount of field-based management which is devoted to the task is only approximately 1 field staff member per 1700 square kilometres and funding for field management is only of the order of \$25 per square kilometre per year.

The complexities over the jurisdiction of Queensland's offshore waters and the mutual desire of all levels of government to work in partnership for the good of the Reef has necessitated close co-operation between the State and Commonwealth Governments to ensure that the Great Barrier Reef Marine Park (GBRMP) and adjoining marine and island areas within the wider World Heritage Area are adequately managed and protected in perpetuity. This paper examines the origin and structure of the field component of management of the GBRMP (the so-called Day-to-Day Management or 'DDM') and makes observations on its capacity to cope with the increasing use of the Park.

## **What exactly is DDM?**

When agreements between the Commonwealth and the State were first prepared for the Great Barrier Reef Marine Park (GBRMP), the term 'day-to-day management' (or DDM) was used to collectively describe the activities undertaken by various State agencies within the Marine Park. The respective roles of State and Commonwealth agencies were carefully defined within a series of written agreements. Within these agreements, the program for management was established as being in accordance with programs (i.e. Three Year Rolling Programs and Annual Programs), policies and plans approved by the Great Barrier Reef Marine Park Authority. A summary of these agreements is at Appendix 1.

In those formative years of the GBRMP in the 1980s, DDM was frequently summarised as comprising '*administration, education and extension, monitoring, surveillance and enforcement*'. A broad analogy sometimes used in the early days of GBR management was that 'DDM was the 'wet' side (or the field side) of marine park management ...' (as distinct from the 'dry' side or office-based management tasks, such as planning and policy development).

As the DDM program and its supporting functions (e.g. issue based program development and co-ordination, management information systems, workplace health and safety) have developed and matured and new issues (e.g. aboriginal involvement in management, coastal zone planning and development, World Heritage Values, environmental impact assessment) have emerged,

the range of activities undertaken by DDM staff has increased dramatically. Today the 'dry' side occupies a large and growing proportion of DDM resources and has placed unforeseen and inordinate pressure on the 'wet' side or field presence. This has led to a reduction in the capability of DDM managers to address all issues effectively. Appendix 2 lists the range of DDM tasks currently undertaken.

The original DDM agreements have stood the test of time but have been refined through the adoption of various policies and operational procedures. Formal programs such as Rolling and Annual Programs are still developed each year, however, these are now structured to deal specifically with current issues as opposed to focussing on the tools of management as was the norm in the past. In the same vein, the role of DDM staff and the various State agencies have changed dramatically since those early days.

Evolving responsibilities of adjoining State Marine Parks and island national parks have added to the complexities of DDM. In addition to undertaking DDM over the whole of the GBR, State agencies currently undertake environmental management of a large proportion of Queensland's coastal zone. As well there are some 250 islands which are gazetted national parks under Queensland legislation, and other protected coastal areas.

In very broad terms, the current arrangements for DDM provide for:

1. Shared responsibilities for management - this basically means:
  - ensuring all zoning plans and management plans are successfully implemented;
  - conserving the natural and cultural values of the GBRMP, adjacent Queensland Marine Parks and island national parks whilst providing for reasonable use; and
  - managing the marine parks and island national parks for the benefit and enjoyment of its users.
2. Combined operations - with complementary management programs applying to the GBRMP, Queensland Marine Parks and island national parks; and
3. Shared costs. Both Governments contribute 50% of the recurrent costs of managing the above parks.

### **Who undertakes DDM?**

Day-to-Day Management within the Marine Park is undertaken primarily by State Government agencies:

- the Department of Environment (DoE) has the greatest involvement with DDM with a staff complement of 100 dedicated to the task. DoE staff are also directly responsible for the management of Queensland marine parks and island national parks;
- the Queensland Boating and Fisheries Patrol (QBFP) has the primary responsibility in enforcement in remote areas; and
- the Queensland Water Police also has a minor enforcement role.

In addition, some other management tasks which contribute to DDM are undertaken by other Commonwealth Government agencies (e.g. the surveillance role of Coastwatch as administered by the Australian Customs Service; the large vessel reporting role played by the Australian Maritime Safety Agency).

### **Day-to-day management functions**

The underlying goal of managing the GBRMP (to protect the natural reef ecosystem in perpetuity) is pursued largely by controlling human use and influences. Consequently many of the DDM tasks listed in Appendix 2 specifically involve the management of park users. Some of these activities are outlined below in more detail.

### Surveillance and enforcement

Surveillance is the systematic observation of the seas, reefs and islands to determine the extent, nature and purpose of any activities in the Park. Aerial and vessel surveillance patrols of the GBRMP, State Marine Parks and island national parks are undertaken as part of DDM. Surveillance patrols may be dedicated to a particular task or undertake a multitude of management roles as outlined in the following table.

1. Visible presence	To display a professional and responsive management presence to users of the marine parks/national parks.
2. Education	To facilitate direct field contact between park users and management staff for education/extension services.
3. Routine data collection	To gather information on activities and natural resources for DDM.
4. Enforcement	To detect, deter and investigate infringements in the GBRMP, State Marine Parks or on island national parks.
5. Response	To have a capability to respond to emergencies.
6. Transport	To access the various islands and reefs for project work and park maintenance.

Aerial surveillance is a particularly effective management tool, being undertaken both as part of national surveillance operations (Coastwatch) and by dedicated surveillance flights manned by Marine Park Rangers.

Vessel (surface) patrols are undertaken by DoE and the QBFP. DoE operates a Marine Park vessel fleet of 10 sea-going vessels between 7-18 m in size each of which spend an average of 140 days per year at sea. This is complemented by the QBFP which has additional vessels which provide ready access to the more remote and off-shore areas of the Reef.

Resources available for management will never be sufficient to manage by enforcement alone. While there is an emphasis upon achieving co-operation between users and management, enforcement actions concentrate on deliberate, blatant and persistent offenders. One of the major challenges for DDM has been the training of Marine Park Rangers to modify their personal management approach from one which previously was largely educational, to one which may, on occasion, need to be more assertive.

As the use of the GBR grows and the expectations and demands for it to be protected rise, surveillance and enforcement will remain as challenges for Marine Park managers. To date, the efforts of DDM staff in controlling illegal activity have been difficult to measure, however, figures show an increased success rate in prosecutions following the introduction of thorough enforcement training courses since 1989 (Great Barrier Reef Marine Park Authority 1992).

### Education

Public education is a cornerstone of the marine parks management philosophy; successful management depends to a large extent on users and visitors understanding and accepting the precepts of management and consequently voluntarily adopting a code of behaviour that is

compatible with the zoning and management plans and regulations. There has been and will continue to be a substantial emphasis on achieving management through the community's understanding and acceptance of the provisions of zoning, regulations and management practices.

One of the prime responsibilities of DDM is face-to-face contact with park users and the provision of interpretive activities with particular target groups (e.g. schools, recreational fishermen). DDM's main role in education is through the provision of on-park guidance, talks, guided walks and signage combined with the preparation and distribution of brochures, introductory guides and maps.

#### Extension

Extension is considered to be a primary function of all DDM staff as they represent the direct interface between management and the public. Extension programs with specific target groups are undertaken in a variety of ways. For example, marine park workshops for the staff of tourist operators have been very well received by industry and have helped considerably in ensuring messages about the reef environment are conveyed correctly. Groups which have been variously targeted by DDM for extension programs include island tour operators, commercial whale watching operators, recreational fishermen and commercial fishermen.

#### Monitoring

While most scientific monitoring on the reef or island is undertaken by researchers from specialist agencies including the Australian Institute of Marine Science, the Commonwealth Scientific and Industrial Research Organisation or universities, DDM staff are periodically involved in a number of monitoring programs of different types:

- Photographic monitoring - particularly of key sites, using video transects and fixed photo sites;
- Water sampling/testing of resort discharges - DDM staff assist in the collection of samples;
- Permit compliance monitoring - frequent checks on permit holders, including commercial operators, collectors, researchers, etc. The permit assessment system also provides managers with an opportunity for periodic contact with some of the more significant users of the marine park.

This role of providing support to other research and monitoring programs meshes well with the responsibility of DDM to acquire an overall appraisal of the health of the reef as a core function of DDM activity.

#### Planning

Until recently DDM field staff were rarely involved throughout planning programs. This reflected the early separation of responsibilities for policy development and field operations between the Authority and DDM. However, it is now recognised that if field staff are not actively involved in planning, then the plans lack local knowledge and input. Consequently, field staff may not have a firm commitment to or understanding of the plan, may be unaware of the decision-making that went into the plan and consequently are likely to be less effective in enforcing or interpreting it.

However, while this is easy to say, it is hard to do, as time spent on planning can interfere with field duties. The best possible solution is to involve field staff at key, relevant points throughout the planning program drawing on their experience and knowledge of the park.

### **The future of DDM**

In years to come, the success of the management of the Great Barrier Reef World Heritage Area (arguably the world's most valuable marine ecosystem), will be judged by the state of the marine parks and adjacent areas - in short, how well they have been managed. Good management requires liaison, education, surveillance, enforcement, etc. (i.e. all those tasks expected of DDM) delivered with a coordinated and effective program that is reactive to the real management issues.

It follows that the highest priority should be accorded to this aspect of management (i.e. DDM) to enable the Reef to continue in perpetuity. This means the provision of adequate capacity (finances, equipment and human resources) to undertake DDM effectively and efficiently. Unfortunately, as demonstrated in a number of recent reviews and reports (Gilmour et al. 1991; Barnes 1992), this has not been happening.

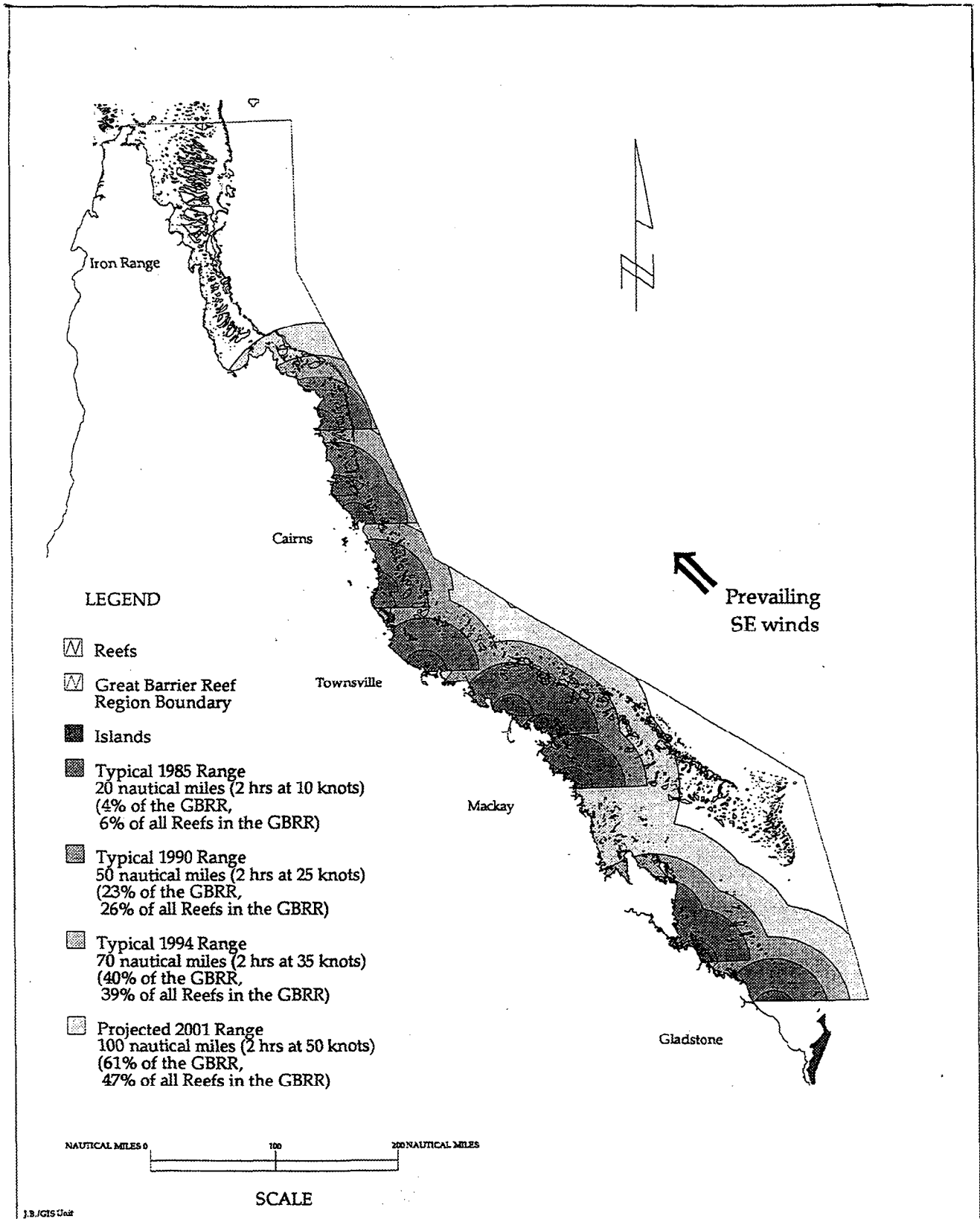
Given the need for complementarity in managing all the elements of the Great Barrier Reef World Heritage Area it would not be efficient to attempt to segregate marine parks from island national parks management or from those elements of coastal management that directly impact on adjacent marine areas. The management dilemma that this poses is that the dramatic increase in coastal management issues is taking up resources previously allocated to other elements of DDM. Even though some additional resources are to be provided the implementation of recent Queensland coastal management legislation will further increase demands on DDM staff.

There are real challenges in simply maintaining the current levels of management (including DDM) let alone coping with rapidly escalating levels of use and complexity of issues. Every year this becomes even more difficult amidst a world increasing demands for resource allocation, external influences, decreasing levels of funding and increasing bureaucracy. Figures 1-3 demonstrate the increases in use of the Marine Park over recent years.

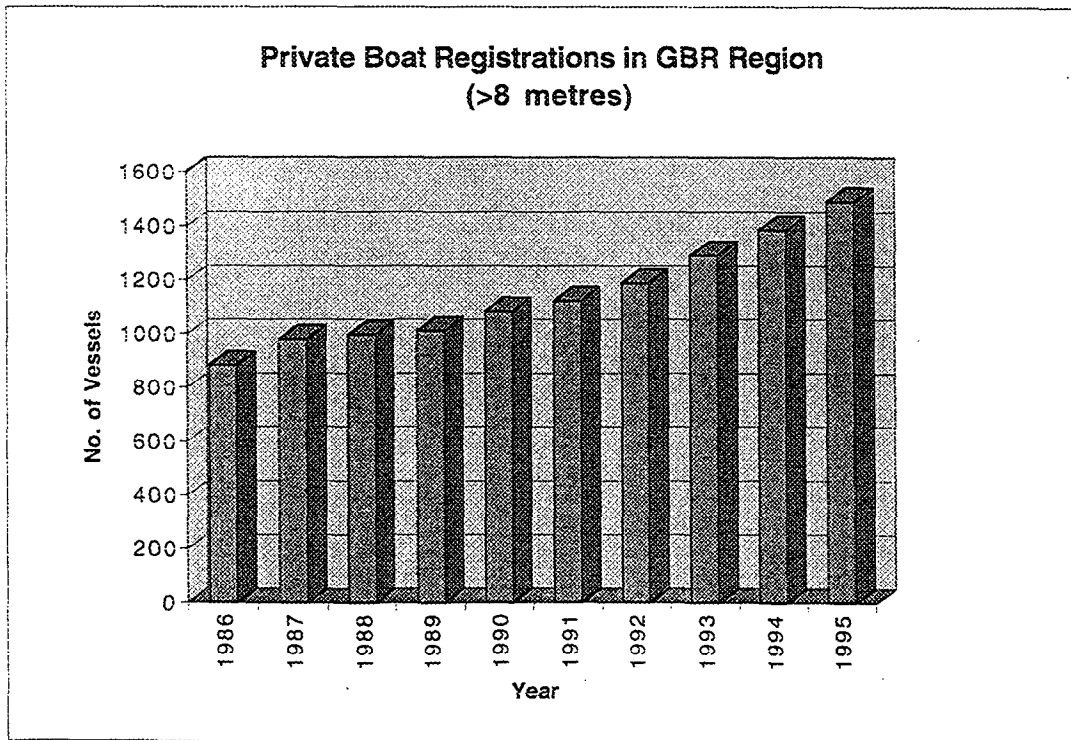
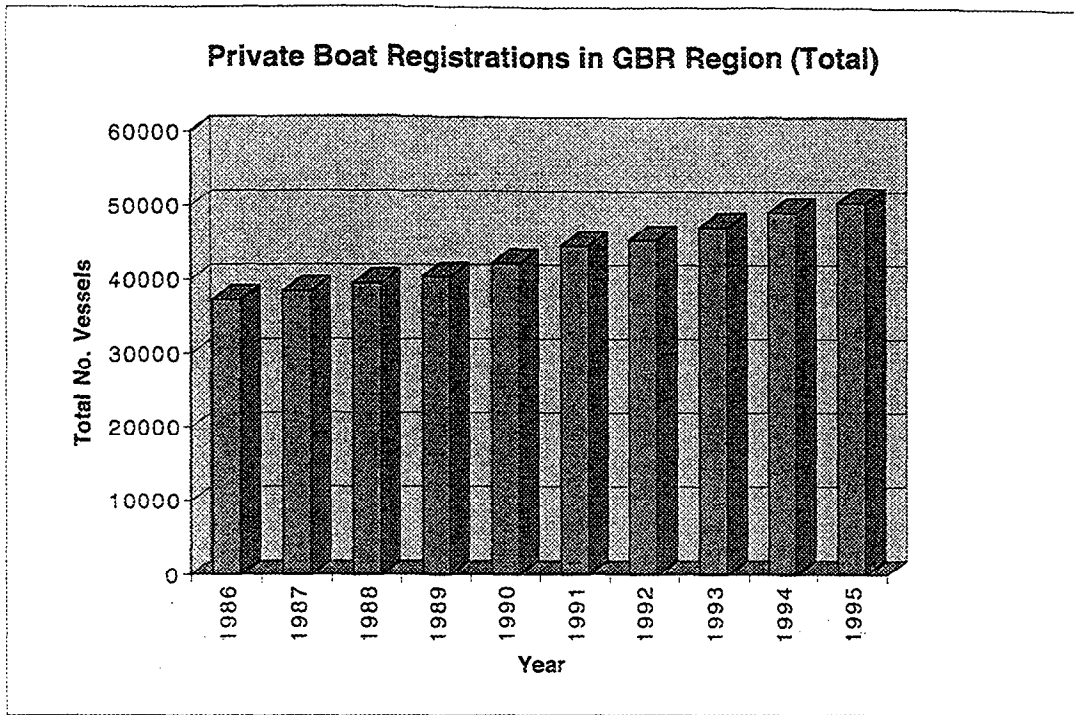
Of particular note is Fig. 1 which clearly demonstrates both the historic and projected geographic growth in tourism in the Great Barrier Reef. This growth trend poses not only policy and planning problems but also significant logistical and operational problems associated with managing the effects of tourism on the water. Figures 4-6 demonstrate that, over the same period, resources for DDM have slowed to the point where it is evident that management is not keeping up with the demands of use. This is particularly evident in Fig. 6 where the 'operating' budget (the capacity for DDM staff to actually get into the field) is diminishing over time.

What has been described in this paper should not be construed as an admission of failure of the field management of the Great Barrier Reef World Heritage Area. Despite the enormity of the task, DDM today is coping but is under increasing pressure to maintain the high expectations attached to the protection of such an important area. Rather, the major reason for the successes of DDM is the dedication and professionalism of all those involved, both within GBRMPA and within the Queensland agencies charged with the task of managing the Reef.





**Figure 1.** Actual and projected tourism day-trip access to the Great Barrier Reef Region for the years 1985, 1990, 1994 and 2001



**Figure 2.** Private boat registrations in the Great Barrier Reef Region. Vessels greater than eight metres are the category most likely to be visiting the Great Barrier Reef. Source: Queensland Department of Transport

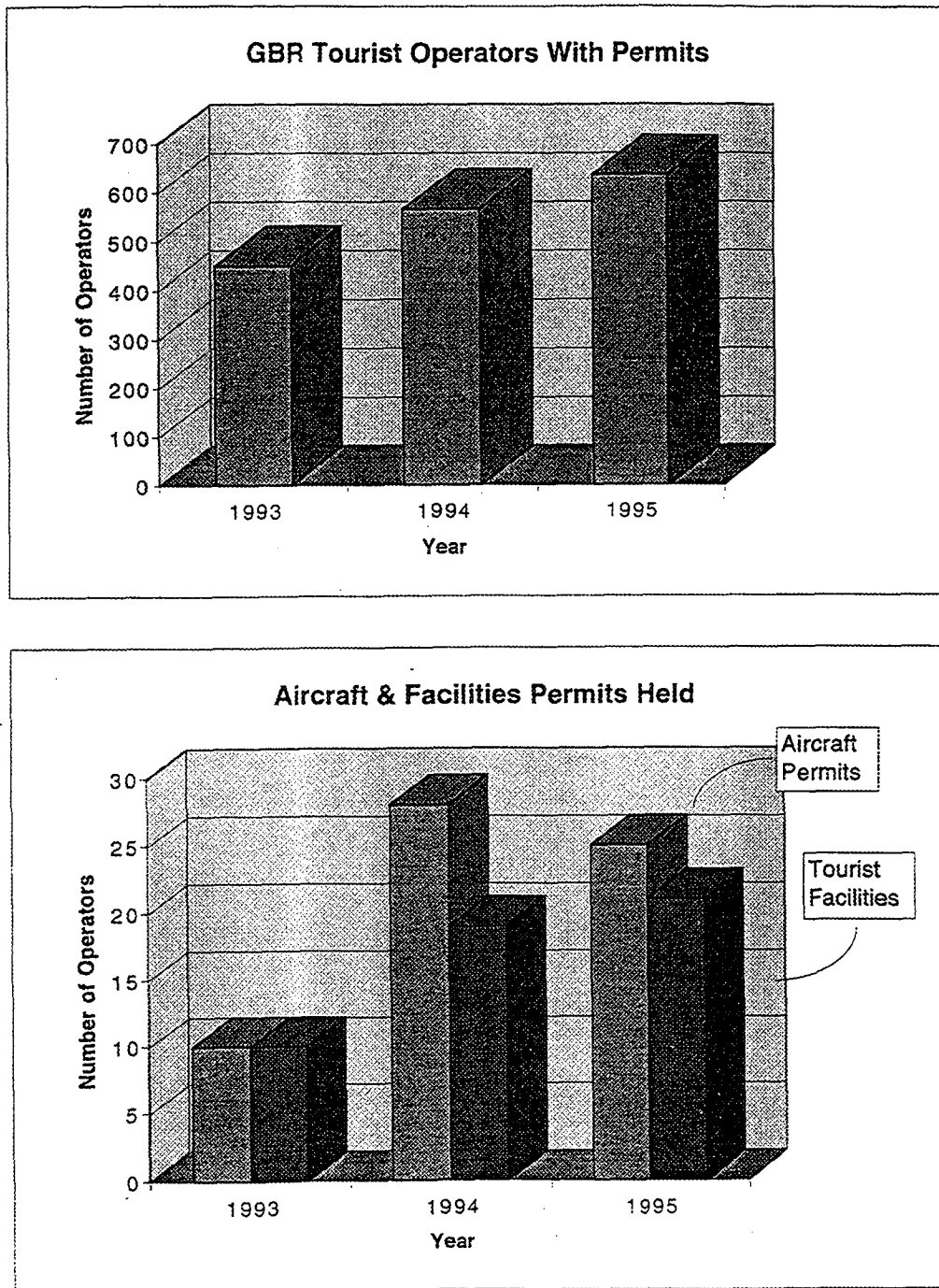


Figure 3. Tourism trends in the Great Barrier Reef Region

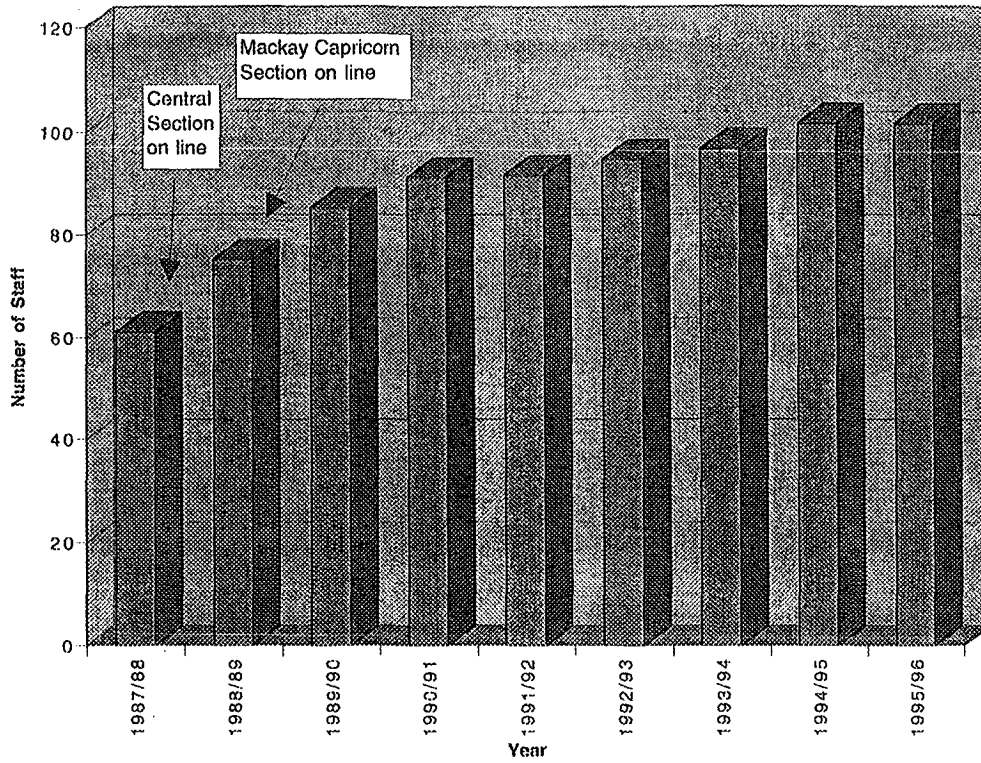


Figure 4. Day-to-day management staffing levels

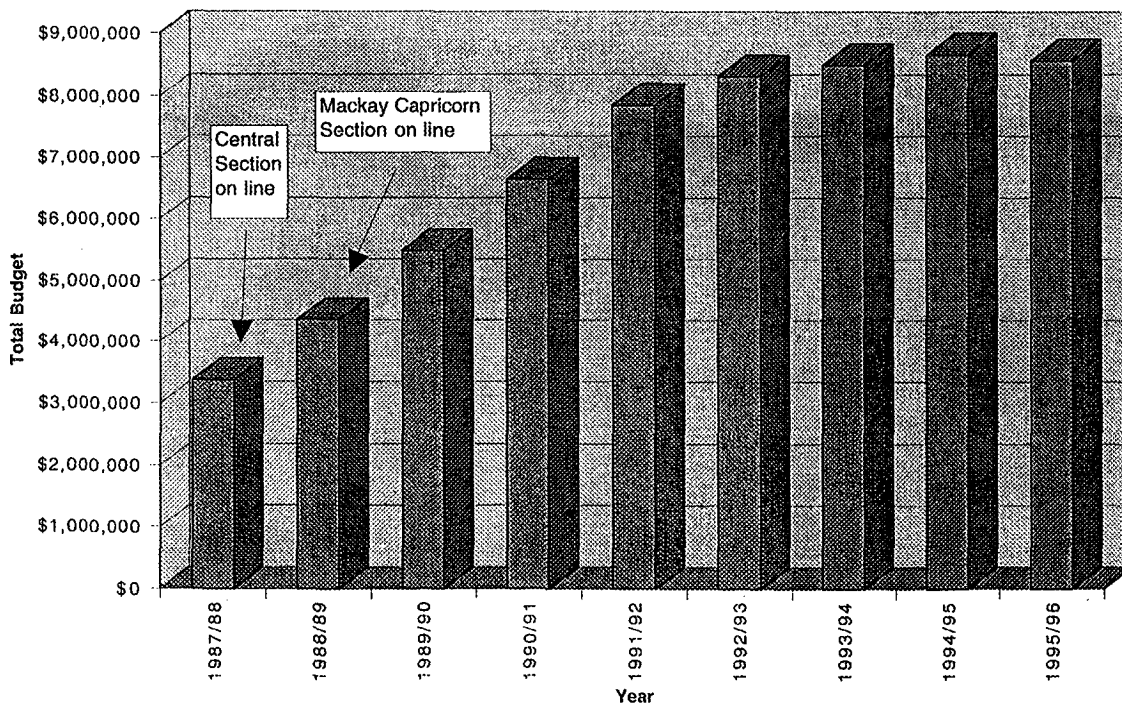


Figure 5. Day-to-day management budget trends. Source: Department of Environment

While such dedication will always be important, management can not rely on it alone. The future of the Great Barrier Reef World Heritage Area needs a lot more. Management is the responsibility of everyone and greater commitment from both the public and government will be necessary to continue to meet one of the world's greatest challenges for environmental management.

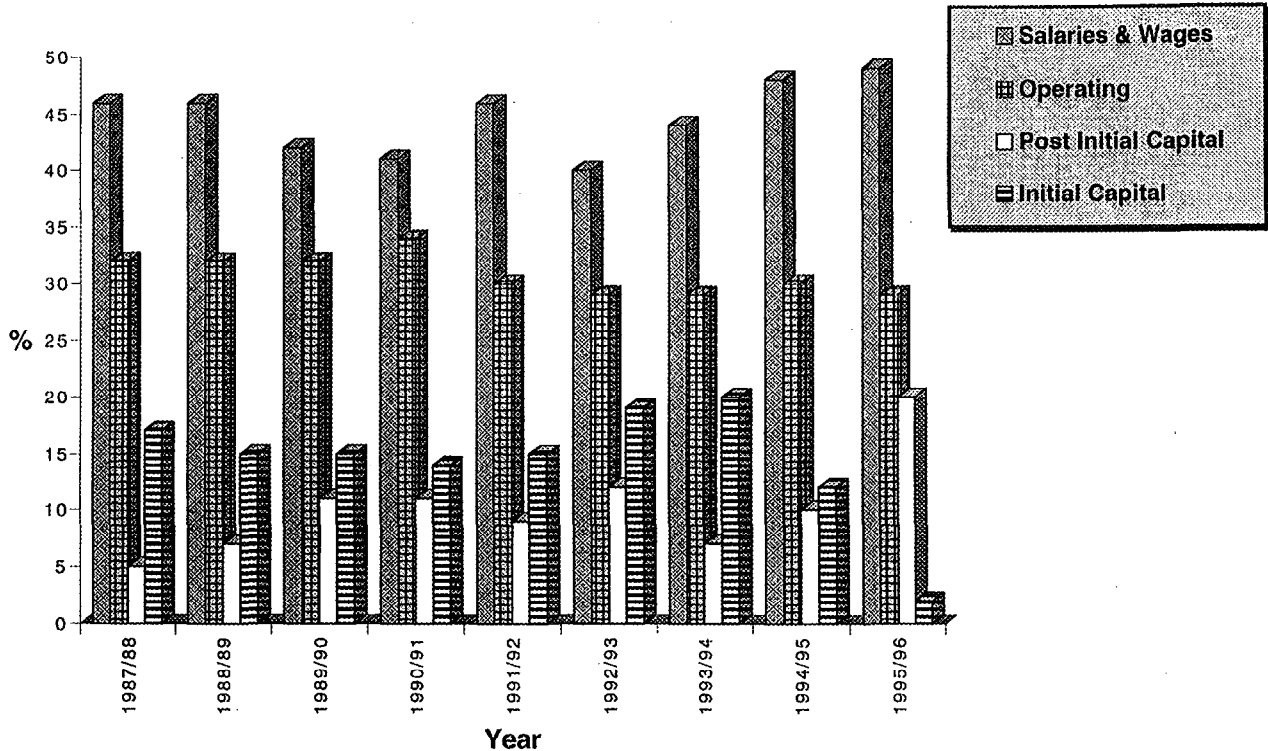


Figure 6. Day-to-day management budget breakdown (% of the total budget). Source: Department of Environment

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## Appendix 1

### Management Agreements for the Great Barrier Reef

#### The Emerald Agreement

The Prime Minister and Qld Premier agreed that as sections of the GBR were declared as part of the Great Barrier Reef Marine Park, then DDM would be undertaken by Queensland Government instrumentalities.

#### Day-to-day Management Agreement, Basis of Agreement and Deed of Agreement

These three documents provide the detailed basis for Commonwealth/State management relationships (the 'what is to be done by whom'). They should be read in conjunction with one another:

- the Basis of Agreement is the primary framework for these arrangements;
- the Day-to-Day Management Agreement largely confirms and elaborates on the Basis of Agreement; and
- the Deed of Agreement concerns the use and disposal of property.

#### Management Guidelines

Guidelines delineating principles and policies for the detailed management specifications and procedures for the day-to-day management of the GBR Marine Park. These guidelines include:

- Three-Year Rolling Program - a program developed for forward planning purposes covering administrative, operational and capital items that are proposed for implementation in the next three years; and
- Annual Program - developed from the 3YRP, the Annual Program outlines the activities and costs (a detailed breakdown of items of expenditure) for the coming financial year.

## **Appendix 2**

### **Day-to-day management activities undertaken by DoE staff for Marine Parks and Island National Parks (adapted from Perkins, unpubl.)**

#### **Administrative support and program/project co-ordination**

- Program co-ordination
  - 3YRPs
  - Annual Programs
  - contribute to Business Plans/Corporate Plans/Strategic Plans
  - Project management and supervision (incl external projects with DoE involvement)
  - Budgets and financial management
  - Reporting/external relationships
    - Forward Alerts
    - 6 month and annual reports
  - Personnel recruiting and management
- Plant & Equipment purchasing and management
  - Transport management
    - vessels and vehicles
- Training/staff development

#### **User Liaison and Management**

- User information and orientation
  - Signage
  - Information outlets/display boards
  - Information/orientation brochures; park guides
  - Counter and phone inquiries
- Interpretation and education
  - Interpretive brochures
  - Talks (educational and interpretive)
  - Audio visuals
  - Guided walks, activities etc.
  - Liaison with educational institutions
  - Visitor centre displays
- Extension and liaison
  - Liaison with commercial users
  - Training of tourist operators' staff
  - Public participation for planning
  - Liaison with Aboriginal and Torres Strait Islander communities
- Permits
  - Permit assessments (MP Permits and Commercial Activity Permits)
  - Permit issue (relates to issue of all types of permits including camping permits)
  - Permit compliance monitoring
  - Permit policy
    - Site supervision (for major developmental projects)
    - Management of traditional hunting (dugong/turtle)
- Surveillance and patrols
  - Aerial surveillance
  - Surface (vessel) patrols
    - Emergency response

- Law enforcement
  - Infringement detection/investigations
  - Interviews
  - Counselling
  - Collection/storage of evidence
  - Infringement reports
  - Court appearances/follow-up

### **Resource Protection and Management**

- Natural resource management
  - Site hardening
  - Site stabilisation/rehabilitation
  - Fire management (for hazard reduction or habitat manipulation)
  - Implementation of Special Management Areas (e.g. Replenishment Areas, Seasonal Closure Areas)
- Special species management
  - Problem species management, e.g. COTS, kangaroos at resorts
  - Endangered species management, e.g. Whales, Dugong (incl. stranding)
- Commercial species management, e.g. Coral Trout counts
- Feral animal control, e.g. trapping, shooting, poisoning
- Weed control/revegetation
- Natural resource research and monitoring
  - Natural resource surveys, e.g. vegetation mapping, photo monitoring
  - Species monitoring, e.g. seabirds, Torres Imperial Pigeons, reef fish
  - Key site monitoring
- Cultural resource management
  - Cultural resource surveys
  - Aboriginal and Islander cultural resources conservation/preservation
  - Maritime relics (conservation/preservation), e.g. lighthouse, grave sites
  - Historic shipwrecks conservation
- User management research and monitoring
  - Systematic recording
  - User surveys
  - Attitude surveys

### **Planning and Information Management**

- Management information systems
  - Maintain files
  - Develop and maintain data bases/inventories
    - natural resources
    - cultural resources
    - recreation resources/user inventory
  - Procure and use maps, air photos, library references, etc.
- Planning
  - Management planning (incl. complementary MP management plans)



- Resource and user management strategies, e.g. Cairns Offshore Strategy
  - Statements of Interim Management Intent and Conservation plans (legislative plans for geographical areas, biological resources)
  - Site plans/mooring plans/sign plans
  - Zoning
  - Strategic planning
  - Action Plans, e.g. Interpretive Plans, Fire Management Plans
  - Contingency planning, e.g. oil spills, wrecks, Asis, wildfire control
  - Public participation (formal and informal)
  - Forward planning of infrastructure and staffing needs
- Review of legislation (State and Commonwealth)

#### **Infrastructure Development and Maintenance**

- Visitor infrastructure development
  - Walking tracks/underwater trails
  - Signage
- Public facilities, e.g. toilets/camp grounds/picnic areas
  - Information centres/Interpretive centres
  - Moorings - installation and maintenance (non-commercial)
  - Zone demarcation
- Visitor infrastructure maintenance and servicing  
(All the visitor infrastructure listed above requires maintenance and periodic updating)
- Departmental infrastructure development (construction, leasing)
  - Offices
  - Barracks/staff accommodation
  - Workshops
  - Moorings/jetties
  - Workshops/storage sheds
- Departmental infrastructure maintenance  
(All Departmental infrastructure listed above needs maintenance and periodic updating)
- Non-Estate infrastructure management
  - Management guidelines/design standards (development and review), e.g. moorings, pontoons, jetties (commercial)
  - Infrastructure planning and design
    - Development planning/site surveys
    - Pre-design reports
    - Project management and supervision and consultancies (Architects)

# Legislation protecting the Great Barrier Reef World Heritage property?

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## Abstract

This paper reviews Australia's obligations under the World Heritage Convention and the current legislative regime in place in respect of the Great Barrier Reef World Heritage Property. In particular it looks, from a legal perspective, at the question of whether ecologically sustainable development of the property is compatible with its protection.

Under the Convention Australia's prime obligations in respect of listed properties are the protection, conservation, presentation and transmission of the features of those properties for which they were listed. Interpretation of the interaction of these obligations is problematic although it seems clear that protection of those values is the premier obligation to which the other obligations are subservient. It is argued that the Convention envisages that the property be used on an ecologically sustainable basis so long as that use is not at the expense of the world heritage features for which it was listed.

The legal framework covering the Great Barrier Reef World Heritage property is complex. Relevant Commonwealth and State statutes are reviewed in the light of the obligations identified. It is concluded that while some statutes are inadequate to ensure protection of the listed property, the *Great Barrier Reef Marine Park Act 1975*, subject to some minor but important amendments to clarify its objects, is well adapted to that end. The mainland coastal portion of the property is at present poorly protected and arguably most at risk. Those areas which are capable of being incorporated into the Marine Park should immediately be brought into the Marine Park.

It is also concluded that general principles contained in legislation relating to protection and management of world heritage areas do not necessarily resolve difficult management questions relating to specific developments and that regional planning with its main aim the protection world heritage values is essential.

## Introduction

The Great Barrier Reef World Heritage Area (the Property) co-incidentally has the same boundary as the area specified in Schedule 1 of the *Great Barrier Reef Marine Park Act 1975*. Schedule 1 of that Act, however, does not identify the boundary of the Great Barrier Reef Marine Park but rather provides a starting point from which the 'Great Barrier Reef Region' (the Region) is defined<sup>2</sup>; part or all of which may be incorporated into the Marine Park by Proclamation.<sup>3</sup> The Region is that area in Schedule 1 minus islands not owned by the Commonwealth and waters that were within the limits of the State of Queensland in 1901

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<sup>1</sup> This paper was prepared and given while the author was an employee of the Great Barrier Reef Marine Park Authority.

<sup>2</sup> Section 3 of the *Great Barrier Reef Marine Park Act 1975*.

<sup>3</sup> Section 31 of the *Great Barrier Reef Marine Park Act 1975*.

(internal waters, e.g. Hinchinbrook Channel).<sup>4</sup> Not all of the Region has been incorporated into the Marine Park.<sup>5</sup>

Thus the Marine Park covers most of the Region which covers most of the Great Barrier Reef World Heritage property. In summary the Great Barrier Reef Marine Park covers approximately 93 - 95% of the Property. Those parts not inside the Great Barrier Reef Marine Park include most of the islands of the Great Barrier Reef, some embayments and a few channels between the mainland and adjacent islands and some coastal subtidal areas – only the latter can be incorporated directly into the Marine Park.

The areas either left out of the Marine Park (parts of the Region) or not capable of being included in it (most islands and internal waters) represent significant habitats within the Property especially for dugong and turtle at the same time as being the most vulnerable to development and other forms of human induced impacts.

The Property was inscribed on the World Heritage List on 26 October 1981 as a place of outstanding natural heritage.

### **The World Heritage Convention**

The Convention for the Protection of the World Cultural and Natural Heritage<sup>6</sup> (the World Heritage Convention) relevantly provides as follows:

#### **I. DEFINITIONS OF THE CULTURAL AND NATURAL HERITAGE**

##### **Article 1**

For the purposes of this Convention, the following shall be considered as 'cultural heritage';  
.....

##### **Article 2**

For the purposes of this Convention, the following shall be considered as 'natural heritage':  
natural features consisting of physical and biological formations or groups of such formations, which are of outstanding universal value from the aesthetic or scientific point of view;  
geological and physiographical formations and precisely delineated areas which constitute the habitat of threatened species of animals and plants of outstanding universal value from the point of view of science or conservation;  
natural sites or precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty.

##### **Article 3**

It is for each State Party to this Convention to identify and delineate the different properties situated on its territory mentioned in Articles 1 and 2 above.

#### **II. NATIONAL PROTECTION AND INTERNATIONAL PROTECTION OF THE CULTURAL AND NATURAL HERITAGE**

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<sup>4</sup> Constitutional constraints prevent the direct incorporation of islands (not owned by the Commonwealth) and Queensland internal waters directly into the Marine Park.

<sup>5</sup> Areas around population centres and some proposed port developments were left out of the Great Barrier Reef Marine Park and its boundary in such places is often the coastal 5 km line.

<sup>6</sup> Adopted by the General Conference of the United Nations Educational, Scientific and Cultural and Organisation on 16 November 1972.

Article 4

Each State Party to this Convention recognises that the duty of ensuring the identification, protection, conservation, presentation and transmission to future generations of the cultural and natural heritage referred to in Articles 1 and 2 and situated on its territory, belongs primarily to that State. It will do all it can to this end, to the utmost of its own resources and, where appropriate, with any international assistance and co-operation, in particular, financial, artistic, scientific and technical, which it may be able to obtain.

Article 5

To ensure that effective and active measures are taken for the protection, conservation and presentation of the cultural and natural heritage situated on its territory, each State Party to this Convention shall endeavour, in so far as possible, and as appropriate for each country:

- (a) to adopt a general policy which aims to give the cultural and natural heritage a function in the life of the community and to integrate the protection of that heritage into comprehensive planning programs;
- (b) to set up within its territories, where such services do not exist, one or more services for the protection, conservation and presentation of the cultural and natural heritage with an appropriate staff and possessing the means to discharge their functions;
- (c) to develop scientific and technical studies and research and to work out such operating methods as will make the State capable of counteracting the dangers that threaten its cultural or natural heritage;
- (d) to take the appropriate legal, scientific, technical, administrative and financial measures necessary for the identification, protection, conservation, presentation and rehabilitation of this heritage; and
- (e) to foster the establishment or development of national or regional centres for training in the protection, conservation and presentation of the cultural and natural heritage and to encourage scientific research in this field.'

The primary obligations of Australia under the Convention in respect of a listed property which forms part of the natural heritage are given in Articles 4 and 5 of the Convention and can be summarised as the duty of ensuring the **protection, conservation, presentation and transmission to future generations** of the natural heritage and implementation of appropriate steps to achieve those ends.

The obligations are real and not merely hortatory. The majority of the High Court (Mason, Murphy, Brennan and Deane JJ, Gibbs CJ, Wilson and Dawson JJ dissenting) in *The Commonwealth v Tasmania* (the Tasmanian Dam Case) (1983) 158 CLR 1 held that the Convention imposed binding obligations on Australia with respect inter alia to the natural heritage situated upon its territory.<sup>7</sup> Mason J as he then was, for example, held in respect of the Western Tasmania World Heritage Property that the Convention requires Australia to establish 'a regime of control which will ensure protection and conservation of the property'.<sup>8</sup>

The obligations are not considered to be absolute since Article 5 uses such phrases as 'in so far as possible' and 'as appropriate for each country'.<sup>9</sup> Mason CJ and Brennan J (as he then was) in the Lemonthyme Forest Case held that the Convention permits the 'State in whose territory part of the world heritage is situated to take into account economic and other factors in deciding how it will discharge the duty imposed upon it by the Convention'.<sup>10</sup> While there are thus

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<sup>7</sup> *Richardson v Forestry Commission* (the Lemonthyme Forest Case) (1988) 164 CLR 261; See for example Mason C.J. and Brennan J at p. 289 and Wilson J at p. 298. Refer also to the State of Queensland and Anor v Commonwealth of Australia and Anor (1989) 167 CLR 232.

<sup>8</sup> at p. 138. See also Murphy J at p. 178, Brennan J at p. 224 and Deane J at pp. 262-263.

<sup>9</sup> See in particular Article 5(d).

<sup>10</sup> at pp. 286-287.

elements of discretion and value judgment as to how the obligations will be met<sup>11</sup> in exercising that discretion and judgement Australia must act in good faith.<sup>12</sup>

In the *State of Queensland and Anor v the Commonwealth of Australia and Anor* (the Wet Tropics Case) (1989) 167 CLR 232 the High Court held that once a property is included on the World Heritage List that fact is conclusive of the status of the property as a whole as world heritage. That is not to say that the level of protection to be provided to each and every part of a world heritage property or different properties should be the same. As indicated above the Convention recognises 'that each State, in giving effect to the obligations imposed by the Convention, with respect to the heritage situated on its territory will naturally have to take account of competing considerations, economic and otherwise'.<sup>13</sup>

In addition it is the 'features which give the property its outstanding universal value'<sup>14</sup> that are to be protected and conserved rather than the general environment of the area listed.<sup>15</sup> Thus not all damage to a listed property will constitute a breach of Australia's obligations under the Convention.<sup>16</sup>

The above view of the Convention is reflected in the *World Heritage Properties Conservation Act* 1983. This legislation is reactive and only applies to properties<sup>17</sup> in respect of which a Proclamation has been made by the Governor-General once he or she is satisfied that the property is being or is likely to be damaged or destroyed. It does not apply to World Heritage Properties in general.

Section 9 (in respect of persons), Section 10 (in respect of foreign corporations and trading corporations (formed within the limits of the Commonwealth)) and section 11 (acts in relation to Aboriginal sites) of the Act make it unlawful, without the consent of the Minister, for certain acts to be done in respect of a property to which the relevant Proclamation relates. The prescribed acts to which subsection 9(1) applies in respect of the three areas of Hinchinbrook Channel<sup>18</sup>, for example, includes 'constructing, establishing, maintaining or continuing to construct, establish or maintain:-

- (i) a breakwater; or
- (ii) a revetment; or
- (iii) any other substantial structure'.<sup>19</sup>

Section 9(1) does not apply to such an act on the prescribed property if the act is performed in a way that causes no damage to occur to the property or part of the property.<sup>20</sup> The consent of the Minister is therefore required under that section only if the act will damage the property. Thus the Act envisages the Minister granting permission to 'damage' the property in appropriate

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<sup>11</sup> See for example in the Tasmanian Dam Case, Mason J at p.132 and Brennan J at pp. 225 and 227.

<sup>12</sup> Article 26 of the Vienna Convention on the Law of Treaties.

<sup>13</sup> The Lemonthyme Forest Case; Mason C.J. and Brennan J at p. 290.

<sup>14</sup> The Tasmanian Dam Case; Brennan J. at p. 224.

<sup>15</sup> The Lemonthyme Forest Case; Gaudron J. at p. 347-348; the Tasmanian Dam Case; Mason J. at pp. 138 and 142; Brennan J. at pp. 224 and 238; Deane at p. 266. See also subsection 10(4) of the *Wet Tropics World Heritage Protection and Management Act* 1993 which provides that the Wet Tropics Management Authority must perform its functions in a way that is consistent with the protection of the natural heritage values of the wet tropics area.

<sup>16</sup> See for example the comment by Brennan J in the Tasmanian Dam Case at p. 238.

<sup>17</sup> The term is used here to refer to a listed property or part thereof but note the broader meaning in section 3A of the *World Heritage Properties Conservation Act* 1983.

<sup>18</sup> Schedule 2D of the World Heritage Properties Conservation Regulations.

<sup>19</sup> *ibid.*, Regulation 3F(2).

<sup>20</sup> *ibid.*, Regulation 3F(2).

circumstances. In granting permission pursuant to section 9 the Minister may only have regard to the protection, conservation and presentation of the property.<sup>21</sup>

In conclusion, in accordance with the decisions of the High Court and reflected in the structure of the Act the primary obligations under the Convention are, in my view, to protect, conserve, present and transmit to future generations those features or values of the property for which it was listed. In addition if the integrity of the property as a whole was threatened then it would be incumbent upon Australia to take steps to remove or abate that threat.<sup>22</sup>

### **Content of the obligations of protection, conservation, presentation and transmission to future generations of a listed Property**

The Convention as Murphy J indicated 'should be interpreted giving primacy to the ordinary meaning of its terms in their context and in the light of its object and purpose'.<sup>23</sup>

#### **Protection**

The Macquarie Dictionary<sup>24</sup> in this context defines 'protection' as 'preservation from injury or harm'. 'Preservation' in this context would appear to mean 'to keep safe from harm or injury; save'.<sup>25</sup> Thus, adopting the ordinary meaning of the word, the Convention at least requires Australia to keep safe from injury or harm those valuable features of the property for which it was listed. Concomitant with that aspect of the obligation is the requirement to keep safe from injury or harm the integrity or soundness of the property as a whole.

#### **Conservation**

The word 'conservation' has a number of meanings. The Macquarie Dictionary in this context defines conservation as 'preservation, especially of natural resources'.<sup>26</sup> If conservation is meant to imply 'preservation' then the phrase 'protection, conservation ...' in the Convention is somewhat tautological. In respect of monuments and other forms of cultural site it may be a term of art referring to the science of conservation as practiced by museum personnel etc. In that sense it would appear to require that the monument etc. be kept free from change or in a state of preservation.<sup>27</sup>

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<sup>21</sup> Note that in respect of consent given pursuant to sections 10 and 11 the Minister must have regard to all relevant matters. (refer, for example, to *Minister for Aboriginal Affairs v Peko-Wallsend Ltd.* (1986) 162 CLR 24).

<sup>22</sup> Refer to the majority judgement in the Wet Tropics Case.

<sup>23</sup> Tasmanian Dam Case at p. 177 and Article 31(1) of the Vienna Convention on the Law of Treaties.

<sup>24</sup> The Macquarie Dictionary (1981) p. 1385.

<sup>25</sup> *ibid.*, at p. 1364.

<sup>26</sup> *ibid.*, at p. 403.

<sup>27</sup> In the preliminary draft of Article 4 (at the time numbered Article 3) the obligations were relevantly stated as: 'The States Parties to this Convention recognise that the duty of ensuring the protection, development and transmission to future generations of the property referred to in Article 2 situated on their territory is primarily theirs.' Similarly the introductory words of the draft Article 5 (then Article 3) stated in part: 'To ensure as effective a protection and as active a development as possible of all monuments, groups of buildings and sites on their territory ...'.

Brennan J in the Tasmanian Dam Case at p. 224 stated that after the United Kingdom objected to the use of the terms 'development' and 'active development' they were replaced with the word 'presentation'. He goes on to indicate that the French version of the Convention (which was not altered) uses the phrase 'mise en valeur' of which the drafting secretariat observed 'when applied to monuments, groups of buildings and sites, is taken to mean conserving and arranging them to bring out their potentialities to best advantage'. It would seem that the word 'conservation' was added to the English version at that stage as well. This should be checked.

The use of the word 'conservation' in the Convention, if it has the above meaning in respect of natural ecosystems, does not align with reality. Natural systems are in a constant state of change. Is it therefore appropriate to look to some other meaning of 'conservation' to ascertain the content of Australia's obligation of conservation of natural heritage properties?

The international community has adopted the following definition of 'conservation':-

'Conservation' is the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations (World Conservation Strategy (1980)).

Thus, in respect of ecosystems, 'conservation' developed internationally a highly anthropocentric meaning based chiefly on the concept of ecologically sustainable development.

Additionally the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area, a plan adopted by all levels of government and stakeholders, defines 'conservation' as the protection and maintenance of nature while allowing for its ecologically sustainable use. The *Nature Conservation Act 1992* (Qld) uses the same definition.

Conservation is not defined in the *Wet Tropics World Heritage Protection and Management Act 1993* (Qld), however, it is interesting to note that the Wet Tropics Management Authority must, subject to it maintaining the natural heritage values of the wet tropics area, 'as far as practicable perform its functions in a way that is consistent with the objectives and principles of the National Strategy<sup>28</sup> for Ecologically Sustainable Development' (s. 10(6)).

Is the concept of ecologically sustainable development compatible with the spirit of the Convention? Briefly, the main principles involved in achieving ecologically sustainable development are:

- the precautionary principle<sup>29</sup>;
- intergenerational equity;
- conservation of biological diversity; and
- improved valuation, pricing and incentive mechanisms.<sup>30</sup>

The application of these principles is likely to facilitate rather than hinder Australia's attempts to meet its obligations under the Convention.

It is therefore appropriate, in my view, to adopt the definition of conservation used in the *Nature Conservation Act* (Qld) which emphasises the protection of nature. That definition also accords with the thrust of Article 5(a) of the Convention, which states:

'To ensure that effective and active measures are taken for the protection, conservation and presentation of the cultural and natural heritage situated on its territory, each State Party to this Convention shall endeavour, in so far as possible, and as appropriate for each country:  
(a) to adopt a general policy which aims to give the cultural and natural heritage a function in the life of the community and to integrate the protection of that heritage into comprehensive planning programs;

.....'

While it is still a matter of some debate<sup>31</sup> it is arguable that the best protection of natural areas is afforded when local communities are both involved in and benefit from the management of the

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<sup>28</sup> Endorsed by the Council of Australian Governments on 7 December 1992.

<sup>29</sup> Refer to *Leach v Director-General of NPWS & Shoalhaven CC* (1994) ELR 060 and s 39Z(2) of the *Great Barrier Reef Marine Park Act 1975*.

<sup>30</sup> Refer to the Intergovernmental Agreement on the Environment.

natural areas. In other words where the relevant ecosystems are managed and used on an ecologically sustainable basis. This may have been the reason for the inclusion of Article 5(a) in the Convention.

Some commentators have argued that the only 'uses' to which a listed property may be put are activities associated with 'presentation' of the property. This view, with respect, misconstrues the Convention. The obligations to protect, conserve, present and transmit are positive obligations. The Convention does not identify what you may do with a property; it only requires (and not in an absolute manner) that whatever uses the property is put do not breach those obligations.

Thus, in my view, the Convention positively encourages ecologically sustainable development of listed properties so long as that use is consistent with the protection, presentation and transmission of the world heritage features for which the property was listed.

#### Presentation

Presentation in respect of cultural sites such as monuments seems to require that they are arranged 'to bring out their potentialities to best advantage'. The provision of lighting, access or amenities may thus be required.<sup>32</sup>

In respect of natural sites it would appear that opportunities for the appreciation of the outstanding universal value of the site must be provided. In respect of the Great Barrier Reef World Heritage Property this may include opportunities for tourist programs and appropriate tourist developments. However as Brennan J (as he then was) indicated, the protection and conservation of a property must not be sacrificed by presentation.<sup>33</sup>

#### Transmission to future generations

Transmission to future generations is a concept which is intimately connected with ecologically sustainable development (inter-generational equity as indicated above is a component of ESD) although in the sense used in the Convention it is not necessarily so. ESD conceptually allows for the transmission of world heritage features to future generations but is it sufficient? In my view it is not. A tourist venture which involves the construction of accommodation units may be an example of ESD yet it may adversely affect the world heritage values of a property because the units, for example, seriously impact on an important viewfield. Of course it all depends upon your interpretation of the ESD concept.

In addition it is the features for which the property was listed and the integrity of the property as a whole which must be transmitted to future generations. That is not to say that natural systems should not be allowed to change naturally<sup>34</sup>; rather human induced changes must be

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<sup>31</sup> For example in respect of elephant and mountain gorilla conservation.

<sup>32</sup> Brennan J in the Tasmanian Dam case at p. 224.

<sup>33</sup> *ibid.*, at p. 224.

<sup>34</sup> This is a personal statement of principle and there may be exceptions. It is not a principle which is readily discernible from the Convention. A natural site in the US was modified over the years by human intervention and the property (later listed) possessed a viewfield which was spectacular. It was recently said to be threatened by the effective rehabilitation efforts of its managers which caused the view to become obscured by the re-growth of trees (pers comm. Bugler, M). Such a site should perhaps be managed to ensure that the viewfield is maintained and thus the obligation of presentation met. More complex manipulation of ecosystems to maintain world heritage values, however, needs to be treated with caution from both philosophical and practical perspectives. The Convention should be recognised for its anthropocentric tendencies.



minimised so that world heritage values and the integrity of the ecosystem are not compromised.

### **Legislative protection of the Great Barrier Reef World Heritage Property**

#### Queensland legislation

The last six or so years has seen major changes to the environmental law landscape of Queensland. Table 1 briefly summarises some of the major legislative changes which have occurred during the period.

**Table 1.** Major 'new' initiatives in Queensland legislation relating to protection and use of the environment

<b>Name of Act/Bill</b>	<b>Major Topics Covered</b>
Local Government (Planning and Environment) Act 1990 and the State Development and Public Works Organisation Act 1971	They provide inter alia for impact assessment statements to be prepared in respect of certain developments. The latter Act is 'looser' in its requirements – refer to s 29
Queensland Heritage Act 1992	Conservation of cultural heritage – including aesthetic values
Nature Conservation Act 1992	Provides for an integrated and comprehensive approach to the conservation of nature
Wet Tropics World Heritage Protection and Management Act 1993	Provides for protection and management of the Wet Tropics World Heritage Property
Environmental Protection Act 1994	Regulates land based pollutant discharges into water, air and land
Fisheries Act 1994	Provides for management of fisheries on an ecologically sustainable basis.
Coastal Protection and Management Act 1995	Provides for better protection of coastal ecosystems by integrated planning, development of policies, and use of control districts (under review)
Transport Operations (Marine Pollution) Act 1995	Regulates operational discharges of pollutants from vessels - implements MARPOL
Planning and Environment Development Assessment Bill 1995	Implementation of an integrated development approvals scheme

All of the above legislation except perhaps the PEDDA Bill (which has been and may still be under review) in theory are capable of assisting in the protection of the Great Barrier Reef environment. Whether they do depends largely upon how the legislation is administered. Unfortunately Queensland legislation still provides little if any opportunity for public involvement in ensuring that the legislation is enforced. Nor is there any broad basis of merits review of government decisions affecting the environment. Where is the Queensland version of the Administrative Appeals Tribunal?

### The Wet Tropics Act

The Wet Tropics legislation while not applying to the GBR region allows for appropriate management of the adjacent coastal areas of the Wet Tropics World Heritage Property. Complementary integrated catchment management should therefore be possible. The legislation identifies the Convention's obligations imposed upon Australia<sup>35</sup> and requires the Wet Tropics Management Authority to perform its functions consistent with the protection of the natural heritage values of the area. It also has to implement ESD principles in its management but not at the expense of heritage values. Notwithstanding the directive nature of the legislation there is discretion as to both how it is interpreted and applied. The balance, however, has to be correct. The proposed resurrection of the Tully Millstream dam project located within the world heritage area is an example of how political and development imperatives rarely match conservation ideals. Such a development, in my view, would not have been consistent with the objectives of the Wet Tropics legislation or the Convention.

### Fisheries Act

The relatively new Fisheries Act is significantly better legislation than the Act it replaced. It provides inter alia for protection of fish habitats, aims at achieving ecologically sustainable fisheries and provides for opportunities for public consultation in respect of fisheries management. Notwithstanding its stated objects, generally speaking, there is little evidence<sup>36</sup> to suggest that any of the Great Barrier Reef fisheries are ecologically sustainable although the prawn trawl and the reef line fisheries may be economically sustainable.<sup>37</sup> Indeed trawling, in my view, is the single most directly damaging human activity in the GBR region yet it is not regulated to any significant extent under either the Fisheries Act or the Great Barrier Reef Marine Park Act.<sup>38</sup>

Two of the prime pieces of legislation for protecting the Great Barrier Reef environment are the *Marine Parks Act 1982* and the *Nature Conservation Act 1992*.

### Marine Parks Act (Qld)

There is legal uncertainty surrounding the position of the boundary of the Great Barrier Reef Marine Park.<sup>39</sup> The declaration of overlapping marine parks under Marine Parks Act (Qld) with complementary zoning plans and similar provisions<sup>40</sup> plays an important role in reducing the

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<sup>35</sup> Refer to paragraph 4 of the Preamble to the Act.

<sup>36</sup> A trawl experiment has been completed by CSIRO with the report expected at the end of the year and a large reef fisheries experiment is anticipated to commence in early 1997. This latter experiment will inter alia examine whether permanent reef closures are the best way to manage reef ecosystems.

<sup>37</sup> Catch per unit effort data which is available for the reef line fishery indicates perhaps that the fishery may be sustainable but this is more an indication of economic sustainability rather than sustainability of the reef ecosystem itself.

<sup>38</sup> This is because it is a significant export earning industry, people like prawns and the damage caused to the environment is hidden from view. Intuitively, the extent of damage to benthic organisms would appear to depend upon the nature of the species assemblages and the frequency and intensity of the trawling activities.

<sup>39</sup> Stemming chiefly from questions arising in respect of the meaning of 'low water' and the nature and extent of internal waters of Queensland which are not capable of inclusion in the GBRMP.

<sup>40</sup> Due to a variety of changes to GBRMP Act (see for example the amendments contained within the Environment, Sport and Territories Legislation Amendment Act 1995) the divergence between the two Acts has increased. The Qld Act is presently under going review.

significance of these boundary difficulties. The marine parks declared<sup>41</sup> under the State Act generally have effect only in respect of those parts of the Property in internal waters of Queensland (such as Hinchinbrook Channel) and intertidal areas (above mean low water) due to the operation of s. 109 of the Commonwealth Constitution.<sup>42</sup>

Like the Commonwealth equivalent the State marine park zoning plans require that persons wishing to undertake many activities within the marine parks (including dredging, construction of facilities and the conduct of tourist programs) require a permit from the Queensland Department of Environment.<sup>43</sup> In assessing applications for permits an assessment must be made in respect of the likely impact of the activity on the relevant marine park.

Depending upon the nature of the activity the impact assessment ranges from simple to complex. There are statutory criteria which must be taken into account in making the assessment.<sup>44</sup> Other relevant criteria also have to be taken into account. The criteria address conservation and amenity issues but do not cover the impact of a proposed activity upon the world heritage values of the Property. In any amendment of this Act this omission should be corrected since, in my view, it is unlikely that that criterion can be taken into account without statutory recognition<sup>45</sup> given the existing framework of the Act which is about marine parks per se.

In addition, other than in respect of an error of law<sup>46</sup>, permit decisions are not reviewable. This is a serious defect in Queensland administrative accountability processes. In application of the Act, the choice of the level of assessment is open to the exercise of discretion. Thus in respect of the channel components of the Port Hinchinbrook development (dredging, breakwall construction and mangrove clearance) it was decided that an EIS was unnecessary. In my view given the importance of the channel ecologically, its world heritage status, the level of public interest in the development and the lack of baseline information on channel processes a full and open EIS should have been required.

#### Nature Conservation Act

This Act provides inter alia for the establishment and on-going management of Queensland national parks, including island national parks within the Great Barrier Reef World Heritage Property. It also makes provision for the protection of native wildlife and its habitats.<sup>47</sup> The cardinal management principle under the Act is that national parks are to be managed 'to provide, to the greatest possible extent, for the permanent preservation of the area's natural condition ...'<sup>48</sup> The Act, in Division 5 also makes provision for the creation of world heritage management areas. The management areas are to be managed to:

- meet international obligations in relation to the area;
- protect the area's internationally-outstanding cultural and natural resources and its biological diversity; and

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<sup>41</sup> Cairns Marine Park, Townsville/Whitsunday Marine Park and the Mackay Capricorn Marine Park. A Cape York Marine Park is proposed.

<sup>42</sup> The GBRMP Act, in my view, covers the field in respect of at least marine park legislation; refer to *Ansett Transport Industries (Operations) Pty Ltd v Wardley* (1980) 142 CLR 237 which illustrates, albeit in respect of different legislation, the operation of the provision.

<sup>43</sup> This may change if the PED Act is put in place — QDoE would then become a concurrence agency.

<sup>44</sup> Marine Parks Regulation 9.

<sup>45</sup> Refer to the *Minister for Aboriginal Affairs v Peko-Wallsend Ltd.* (1986) 162 CLR 24.

<sup>46</sup> *Judicial Review Act* 1992 (Qld).

<sup>47</sup> For example turtle and dugong management plans have been under preparation for some considerable time.

<sup>48</sup> Section 17 of the *Nature Conservation Act* 1992.

- transmit the area's world heritage values to future generations.<sup>49</sup>

There is no area of the Great Barrier Reef World Heritage Property that has been declared a world heritage management area.

Conservation plans for 'world heritage' species such as turtle and dugong have been in preparation for a number of years. It is yet to be seen whether these plans will be useful in providing for better protection of these vulnerable and in some cases endangered species, however, present indications suggest that they will contain little more than motherhood statements.<sup>50</sup>

#### Coastal Protection and Management Act 1995

This legislation is about to be reviewed even though its efficacy in practice is yet to be determined. Unfortunately, even though a significant portion of Queensland coastline<sup>51</sup> has been listed under the Convention, this Act does not address the protection of the world heritage values of those listed parts of the coast. Indeed as indicated above the world heritage status of an area covered by this Act may be an irrelevant consideration under the Act.

#### Summary

The State legislation referred to above, while superior to previous legislation in terms of environmental protection<sup>52</sup>, still do not adequately address the protection of the world heritage values of the Great Barrier Reef World Heritage Property. Even the Wet Tropics legislation, which is not directly legally relevant to protection of the Great Barrier Reef should be amended to ensure that activities permitted in the Wet Tropics World Heritage Property and the management practices of the Wet Tropics Management Authority do not adversely affect the values of adjacent world heritage properties.

#### Commonwealth legislation

A range of Commonwealth legislation applies to the Property or parts thereof.

#### Endangered Species Protection Act

The Endangered Species Protection Act does not apply to the coastal waters of Queensland and thus a large portion (possibly as high as 70%) of the property is not covered by the Act<sup>53</sup>. Turtle species are listed under the Act but the dugong is presently not. Thus even though the southern GBR populations of dugong are endangered the Act has no application. In any case most dugong inhabit the relatively shallow and protected coastal waters.

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<sup>49</sup> *ibid.*, Section 25.

<sup>50</sup> Rather than tackling difficult issues such as further regulation of on-shore netting and the use of turtle excluder devices on trawl nets.

<sup>51</sup> And possibly more in future if the Cape York wilderness area is listed under the Convention.

<sup>52</sup> Yet still inadequate in respect of matters such as third party enforcement and standing, review rights based on merits review and consultative processes.

<sup>53</sup> Note however the regulation making power in s 175 in respect of implementing the international agreements listed in Schedule 4 of the Act.

**Table 2.** Some Commonwealth legislation applying to the Property

<b>Name of Act</b>	<b>Major Topics Covered</b>
Environment Protection (Sea Dumping) Act 1981	Implements the London Convention which regulates dumping and incineration at sea
Protection of the Sea (Pollution from Ships) Act 1983	Implements the MARPOL convention by regulating the discharge of operational waste from ships
Endangered Species Act 1992	Provides for protection of vulnerable and endangered species and ecosystems in Commonwealth controlled places and waters outside the coastal waters of the States (note also s 175)
Australia Heritage Commission Act 1975	Requires inter alia Cth. decision makers to assist in protecting places on the register of the national estate by seeking feasible and prudent alternatives to the taking of action which will adversely affect that place and when none exist minimising the impact of the action.
Whaling Act	Regulates the taking of whales and activities which interfere with whales and certain other marine mammals
World Heritage Properties Conservation Act 1983	Partially implements the Convention
Great Barrier Reef Marine Park Act 1975	Provides for the protection of that part of the GBR contained within its limits and possibly gives some protection to adjacent areas from activities within its limits
Fisheries Management Act 1991	Provides for the management of Cth fisheries and joint management of some fisheries in conjunction with State agencies
Native Title Act 1994	Provides inter alia for the recognition and protection of native title including over-riding in certain cases other legislation relating to the protection of endangered species (s. 211)

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World Heritage Properties Conservation Act

The Act does not allow for planning or management of world heritage properties.

The legislation is applied to world heritage properties<sup>54</sup> as a last resort where the world heritage values or the integrity of the property are under threat. Refer above to the brief comments on the Act.

Generally the Federal Government has been reticent to 'interfere' in issues such as land management which are seen as matters properly the responsibility of the State unless there is some real and distinct threat to a world heritage property or an area that may have such values.<sup>55</sup> This has been further institutionalised by the development of the Intergovernmental Agreement on the Environment (the IGAE) which entrenches a co-operative Federalism approach to management of environmental issues. Such an approach has significant benefits if the spirit of the agreement is implemented by the States. Unfortunately there are examples where, in my view, State Governments have not been committed to the spirit of the agreement.

The Port Hinchinbrook development is an example.<sup>56</sup> Here is a case where an exhaustive environmental impact assessment was essential to the making of an informed decision about the proposal yet it was never required by the Queensland Government. The Commonwealth Government intervened and the Act was applied to limited areas of the Property in the vicinity of Hinchinbrook Channel by Proclamation.

In my view one of the more significant impacts of the development is going to be on the viewfield of the Channel. The resort (other than the dredge channel and breakwall) is to be located above the low water mark and hence outside the Property yet it will have an effect on the Channel viewfield. The Act is deficient in that it inadequately protects viewfields or the scenic values of world heritage properties. This is because it is unlikely that damage to a viewfield will be seen by the courts as damage to the property as contemplated by the Act. In addition the viewfield on the boundary of a world heritage property is made up of property and non-property components. Thus properly enforced buffer zones around a property are essential. This is not to say that development should not occur adjacent to or even on the Property but rather that it has to be appropriate and not located in especially valuable portions of the property such as Hinchinbrook Channel. Regional planning is critical - not after but before such developments are approved<sup>57</sup>.

To clarify matters the Act should be amended to allow for the operation of the Environment Protection (Impact of Proposals) Act, to be triggered by the requirement for the Commonwealth Minister to give approval for proposed prescribed activities.

A further possible significant impact, in my view, of the proposed development is on dugong populations within areas around Hinchinbrook Island — both in the Proclaimed areas and outside them. These are generally likely to be indirect effects derived from subsequent increased use of the area.<sup>58</sup> While cumulative impacts may be taken into account under s. 13 by the Minister when deciding whether to give consent, not all of the impacts on the Property of the proposed development are covered in those decisions because the Proclaimed areas cover the immediate vicinity of the development but not more distant areas which might be affected by increased usage from the development.

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<sup>54</sup> And possibly potential world heritage properties.

<sup>55</sup> *Richardson v Forestry Commission* (the Lémonthyme Forest Case) (1988) 164 CLR 261.

<sup>56</sup> Trinder, C. and Sparkes, S. (1995) Port Hinchinbrook and beyond — Background to the Controversy and the Great Barrier Reef Marine Park Authority's Role in Protection of World Heritage. Proceedings of Defending the Environment Conference, University of Adelaide 21-22 May 1995.

<sup>57</sup> A public notice was placed on 14 September 1996 in respect of a Hinchinbrook Channel Plan.

<sup>58</sup> For example increased boat strikes, increased disturbance and increased pollution from vessel based activities. Such impacts may be minimised by vessel routing and speed limit restrictions.

In conclusion the Act should at least be broadened to clarify the meaning of damage under the Act, clearly allow for an EIS to be required and provide a broader role for the corporations power in regulating or prohibiting activities of trading corporations etc. which may have a significant effect on a property.

#### Great Barrier Reef Marine Park Act

The object of the GBRMP Act is, in terms of modern drafting practice, particularly uninspiring and uninformative. Section 5 states that the:

'object of the Act is to make provision for and in relation to the establishment, control care and development of a marine park in the Great Barrier Reef Region'<sup>59</sup>.

However the zoning plan provisions of the Act further clarify the intent of Parliament as to the nature of the marine park to be put in place. Pursuant to subsection 32(7) of the Act the Great Barrier Reef Marine Park Authority (the Authority) is required, when preparing a zoning plan for the Marine Park, to have regard to certain matters. These matters are:

- (a) the **conservation** of the Great Barrier Reef;
- (b) the regulation of the use of the Marine Park so as to **protect** the Great Barrier Reef while allowing the reasonable use of the Great Barrier Reef Region;
- (c) the regulation of activities that exploit the resources of the Great Barrier Reef Region so as to **minimise the effect** of those activities on the Great Barrier Reef;
- (d) the reservation of some areas of the Great Barrier Reef for its **appreciation and enjoyment by the public**; and
- (e) the **preservation** of some areas of the Great Barrier Reef in its natural state undisturbed by man except for the purposes of scientific research'. (My emphasis)

It is interesting to note how closely the objects of zoning plans reflect Australia's obligations under the Convention<sup>60</sup>. Protection and conservation of the GBR are expressly identified as objectives. Presentation is clearly contemplated by the phrase 'for its appreciation and enjoyment by the public'. Transmission to future generations is implicit in paragraphs 32(7)(a), (b), (c) and (e) of the Act.

At present the GBRMP makes up between 93-95% of the world heritage property<sup>61</sup>. The Act is thus the single most important legislative instrument whose aim is to protect the Great Barrier Reef. Much of the other 5-7% falls within State marine or national parks.

The Authority is required to make<sup>62</sup> an assessment of the impact of many proposed activities before making a decision as to whether a permit to use or enter the Marine Park ought be granted<sup>63</sup>. In cases where the proposed activity is likely to affect the environment to a significant extent the applicant would be designated and the administrative procedures of the

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<sup>59</sup> Defined in s. 3.

<sup>60</sup> The Act came into force about two and a half years after the Convention came into being.

<sup>61</sup> At present further investigations are proceeding to determine if coastal areas omitted from the Marine Park should be included in it. These areas are not the internal waters of Queensland which cannot be included in the Marine Park but are rather areas left out to allow for 'unimpeded' port and other development potential. These areas have high conservation values and are important habitat for dugongs and turtles.

<sup>62</sup> Or have one made — regulation 26.

<sup>63</sup> There is a maximum penalty of \$20 000 for persons using or entering the Marine Park without a permit when one is required. Companies are liable to fines of up to five times this amount. The Authority or any person whose interests are affected (or would be affected) may seek an injunction to prevent or stop such an activity - section 38N of the Act.

*Environment Protection (Impact of Proposals) Act 1974* followed. In addition s. 30 of the *Australian Heritage Commission Act 1975* has application to Authority decision making<sup>64</sup>.

Amendments to the Act allow for the preparation of management plans for the Marine Park.<sup>65</sup> A new Part VB was added to the Act which provides for the making of management plans for areas, species or ecosystems within the Marine Park. Sections 39Y and 39Z provide as follows:

39Y. The objects of plans of management are as follows:

- (a) to ensure, for particular areas of the Marine Park in which the Authority considers that nature conservation values, cultural and heritage values, or scientific values, are, or may be threatened, that appropriate proposals are developed to reduce or eliminate the threats;
- (b) to ensure that species and ecological communities that are, or may become vulnerable or endangered are managed to enable their recovery and continued protection and conservation;
- (c) to ensure that activities within areas of the Marine Park are managed on the basis of ecologically sustainable use;
- (d) to provide a basis for managing the uses of a particular area of the Marine Park that may conflict with other uses of the area or with the values of the area;
- (e) to provide for the management of areas of the Marine Park in conjunction with community groups in circumstances where those groups have a special interest<sup>66</sup> in the areas concerned;
- (f) to enable people using the Marine Park to participate in a range of recreational activities.

39Z.(1) The Authority in preparing management plans must have regard to:

- (a) the protection of world heritage values of the Marine Park; and
- (b) the precautionary principle.

(2) In subsection (1):

'the precautionary principle' has the same meaning as in section 3.5.1 of the Intergovernmental Agreement on the Environment, a copy of which is set out in the Schedule to the National Environment Protection Council Act 1994.'

Thus the Authority in preparing management plans for areas, species and ecosystems within the Marine Park is required take into account the protection of the world heritage values of the Marine Park. In any case I am of the view that the Authority was already obliged to manage the Marine Park in a manner not inconsistent with the protection of world heritage values of the area. This view is derived from subsection 65(2) of the Act which states that:

'[t]his Act has effect subject to the obligations of Australia under international law, including obligations under any agreement between Australia and another country or countries'.

Thus not only is the Authority required to take into account the protection of world heritage values in making decision under the Act and regulations (for example permit decision) there is a positive obligation on it to manage the Marine Park in a manner which is conducive to Australia meeting those obligations.

Notwithstanding that it can be argued that the express object of the Act given in s. 5 needs refining and up-dating, the legislation is significantly stronger than most other environmental legislation in Australia in respect of protection of world heritage values. It also has two other significant advantages:

- (i) it is overarching and prevails over most other legislation;<sup>67</sup> and

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<sup>64</sup> In respect of permit decisions there is an internal review right capable of being exercised by a person affected by a decision (r. 22) and if still dissatisfied a right of appeal to the Administrative Appeals Tribunal. Third party injunctive relief is also available in certain circumstances (s. 38N).

<sup>65</sup> Amended by the Environment, Sport and Territories Legislation Amendment Act 1995 (No. 25 of 1995) which commenced on 6 April 1995.

<sup>66</sup> 'Special interest' includes native title interests (s. 39V).

<sup>67</sup> See subsection 66(6) for example.



- (ii) it covers a huge area<sup>68</sup> of diverse ecosystems.

The placement of further overarching legislation over it (and other Commonwealth environmental legislation), as has been suggested by a Departmental consultancy report, is both unnecessary and undesirable. Not only might it weaken the Great Barrier Reef Marine Park Act but it may also affect the independence of a world class independent statutory authority. The quest for national standards of protection is laudable but this should not be done at the expense of the integrated management approach presently existing in respect of the Marine Park.

The Great Barrier Reef Marine Park Act has some effect outside the Marine Park. The regulation making power under s. 66(2) inter alia allows for regulations to be made which 'regulate or prohibit acts (whether in the Marine Park or elsewhere) that may pollute water in a manner harmful to the animals and plants in the Marine Park'. Such regulation or prohibition of polluting activities outside the Marine Park may also co-incidentally protect parts of the Property outside the Marine Park<sup>69</sup>. If the polluting activity is not going to affect the Marine Park to a significant extent it may be difficult to justify passing regulations which in reality are designed to protect those areas outside the Marine Park rather than the Marine Park itself. In addition it is a requirement when assessing a permit application for the decision maker to take into account the likely effect of a proposed activity in the Marine Park on adjoining and adjacent areas.<sup>70</sup> For example it may be appropriate to refuse to grant a permit for access by a tourist program to some areas of the Marine Park because the noise and activity created will have a deleterious effect on birds breeding on an adjacent part of the Property (e.g. a national park island).

In respect of those parts of the GBR Region (as defined in s 3 of the Act) presently outside the Marine Park, I am of the view that those vulnerable and important areas should be immediately incorporated within the Marine Park.<sup>71</sup>

#### The other Commonwealth legislation

The other legislation identified above, except for the Native Title Act, contribute positively to the protection of the Great Barrier Reef environment although they individually duplicate (at least in part) what the GBRMP Act achieves in an integrated fashion. They also do not expressly protect and conserve the world heritage values of the property; they are single topic pieces of legislation in general.

Section 211 of the Native Title Act could give rise to concern in respect of its effect of overriding (in certain circumstances) legislative requirements for permission for the taking, for example, of endangered species. In general however Aboriginal people have been very concerned about the decline in turtle and dugong numbers on the reef, are self-regulating their take and are looking to government to reduce deaths from other sources such as commercial

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<sup>68</sup> It is about 350 000 sq km in size.

<sup>69</sup> See for example the Great Barrier Reef Marine Park (Prohibition of Drilling for Petroleum) Regulations.

<sup>70</sup> See for example r. 13AC(4)(f) of the Great Barrier Reef Marine Park Regulations

<sup>71</sup> In respect of those areas outside the Region (which cannot be incorporated into the marine park) but inside the Property, regulations could be made pursuant to s. 69 of the *National Parks and Wildlife Conservation Act 1975* to protect those world heritage values under threat (refer to the Schedule to the Act and the Tasmanian Dam case). Regulations could also be made with application inside the marine park under s. 69 but that, in my view, is neither desirable nor necessary. The Great Barrier Reef Marine Park Act should be amended to include a provision similar to s. 69 (relating specifically to implementation of the World Heritage Convention) which would have application to the whole of the Property not just the marine park.

fishing. Also, in the long term Aboriginal ownership of some marine areas may lead to enhanced protection of areas and species although this will depend upon carefully balancing issues of culture, conservation and economic independence.

#### Summary

The Great Barrier Reef Marine Park Act with its emphasis on integrated resource management and its concurrence with the aims of the Convention is, apart from some minor amendments to expressly indicate what it already provides in respect of protection of world heritage values, is entirely adequate to protect the great proportion of the world heritage property where it has application.

#### **The importance of the non-statutory management environment**

When words and phrases such as ecologically sustainable development, biological diversity, conservation, presentation and world heritage are used in legislation, notwithstanding whatever definitions can realistically be included they are sufficiently broad to allow discretion to managers in their approach to management of the relevant property (without their decisions being unreasonable in the *Wednesbury*<sup>72</sup> sense). It is the political climate within which managers work that is reflected in the nature and direction of the decisions made. Political in the broader sense of reflecting community and governmental values. Management of the Marine Park, with its diverse range of competing uses and values is both difficult and complex.

Protection of dugong is a good example of a difficult world heritage issue for managers, be they from State or Commonwealth agencies. In my view dugong is one of the features for which the Property was listed. From a conservation perspective they are a difficult species to manage being slow growing, have low fecundity and long gestation periods. They feed on seagrass beds which are vulnerable to impacts such as dredging, smothering from sediment caused by coastal development and altered nutrient levels from inappropriate farming practices. They are killed by boat strikes, being caught in fishing and shark nets and taken for food by Aboriginal and Torres Strait Islander people<sup>73</sup>. They are endangered world wide and the southern populations in the Property are rapidly declining. Fishing nets and habitat loss anecdotally appear to be the greatest threats to dugong in the southern portion of the Property. Yet there is a perhaps understandable reticence on the part of Government to control those activities because of the economic and social impacts that might cause. Further development in critical habitats such as in the Hinchinbrook Channel area are likely to hasten their decline in those areas due to direct and indirect long term effects. The Great Barrier Reef Marine Park Authority and particularly the Queensland Government will be judged on their ability to reverse this decline.

In terms of meeting Australia's obligations under the Convention it is arguable that any activity etc. which has a significant impact (as opposed to an insignificant impact) on world heritage values is unacceptable and should not be approved. Unless of course the activity can be managed in such a way as to reduce the impact to an acceptable level. Such an analysis of impacts for specific proposals should not only include construction impacts but also operational and cumulative impacts.

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<sup>72</sup> *Associated Provincial Picture Houses Ltd v Wednesbury Corporation* [1948] 1KB 223.

<sup>73</sup> Because of the importance of dugong as a food and cultural resource to indigenous people they have generally been most supportive of steps taken to further protect the species.

Finding the right balance between development and protection is essential. Continued piecemeal coastal development either on or adjacent to the Property<sup>74</sup> may not individually (unless they are in particularly special areas such as Hinchinbrook Channel) affect world heritage values. Collectively their cumulative impact will unless urgent regional planning is implemented. Hard decisions need to be made about the nature and extent of further development on and near the Property. Buffer zones for the Property should be included in this planning.

### **Conclusion**

Australia's prime obligations under the Convention in respect of listed properties are the protection, conservation, presentation and transmission of the features of the properties for which they were listed. Protection of these values is the premier obligation to which the other obligations are subservient. My view is that the Convention encourages the ecologically sustainable use of a property so long as that use is not at the expense of the world heritage features for which it was listed.

The State statutes protecting the Property are generally inadequate since while they provide some environmental protection, they do not expressly address protection of the world heritage values of the Property or part of the Property to which they apply. Queensland is likely to face continuing, complex and contentious management issues unless the Marine Parks Act (Qld) and the Coastal Protection and Management Act are both amended to include such express requirements.

Commonwealth legislation, other than the Great Barrier Reef Marine Park Act, are generally single subject matter statutes which do not provide for integrated management and protection of the Property. Nor do they, apart from the World Heritage Properties Conservation Act, expressly address the issue of protection of the world heritage values of the Property. The World Heritage Properties Conservation Act requires amending to enable better, more adequate protection of threatened properties.

It is also concluded that general principles contained in legislation relating to protection and management of world heritage areas do not necessarily resolve difficult management questions relating to specific developments and that appropriate regional planning is necessary. The question of the balance between protection and development is a political one but sight should not be lost of Australia's obligations under the Convention.

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<sup>74</sup> For example urban expansion in regional centres and new developments in areas including Keswick Island, Shute Harbour and Hinchinbrook Channel.

# Planning for the Great Barrier Reef Marine Park

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## Abstract

Planning for the Great Barrier Reef Marine Park is undertaken at a variety of scales and for a wide range of management issues. Plans currently in place: set strategic direction to coordinate management over the next twenty-five years by all agencies and stakeholders in the World Heritage Area; establish a zoning framework for the Park that regulates use of each area to achieve conservation and sustainable-use objectives; and establish specific strategies necessary to manage use at a number of the most intensively-used reefs. Plans currently being developed are: addressing the impacts of coastal land-use, intensive reef-based tourism, and private recreation at the regional level; identifying strategies for conserving threatened species; regulating damaging activities such as anchoring at a number of heavily used sites; addressing the contemporary, cultural, heritage and use values of indigenous peoples in the Far Northern section and at a number of other locations; are reviewing the adequacy of the representation of the various biological communities in the current protected areas strategy; and are assessing whether there is a need to introduce a wilderness strategy for the Park.

## Introduction

Planning for the conservation and reasonable use of the Great Barrier Reef began by defining the areas to be included in the Marine Park and arranging for their legal declaration. Historically, the Park was established in a number of sections which have since been combined or modified to the four Sections currently in place (see Fig. 1). The sequential approach of dealing with zoning for one section at a time made allowance for the complexity of the tasks involved in assessment of conservation values and management requirements over such large areas. Section boundaries were originally defined based on a combination of factors including:

- natural boundaries such as differences in oceanographic currents, reef types, fish communities etc.;
- intensity of human use, with the more intensively used areas having highest priority for initial inclusion; and
- consideration of existing administrative boundaries for state agencies and local government.

For a number of reasons some coastal waters, often associated with urban areas or ports etc., were not originally included in the Park. The Authority proposes to review this situation and it is likely that many of these areas will be incorporated over the next few years.

The Great Barrier Reef Marine Park is managed to provide for multiple use where this use can be managed to be consistent with the requirements for conservation of the Reef. The *Great Barrier Reef Marine Park Act 1975* (the Act) banned oil drilling and mining. Both activities were considered to be of too great a threat to the coral reefs. Management of the vast array of remaining activities is undertaken through a system of plans, including:

- World Heritage Area Strategic Plan;
- Marine Park Zoning Plans;
- Management Plans; and
- Special Management Areas.

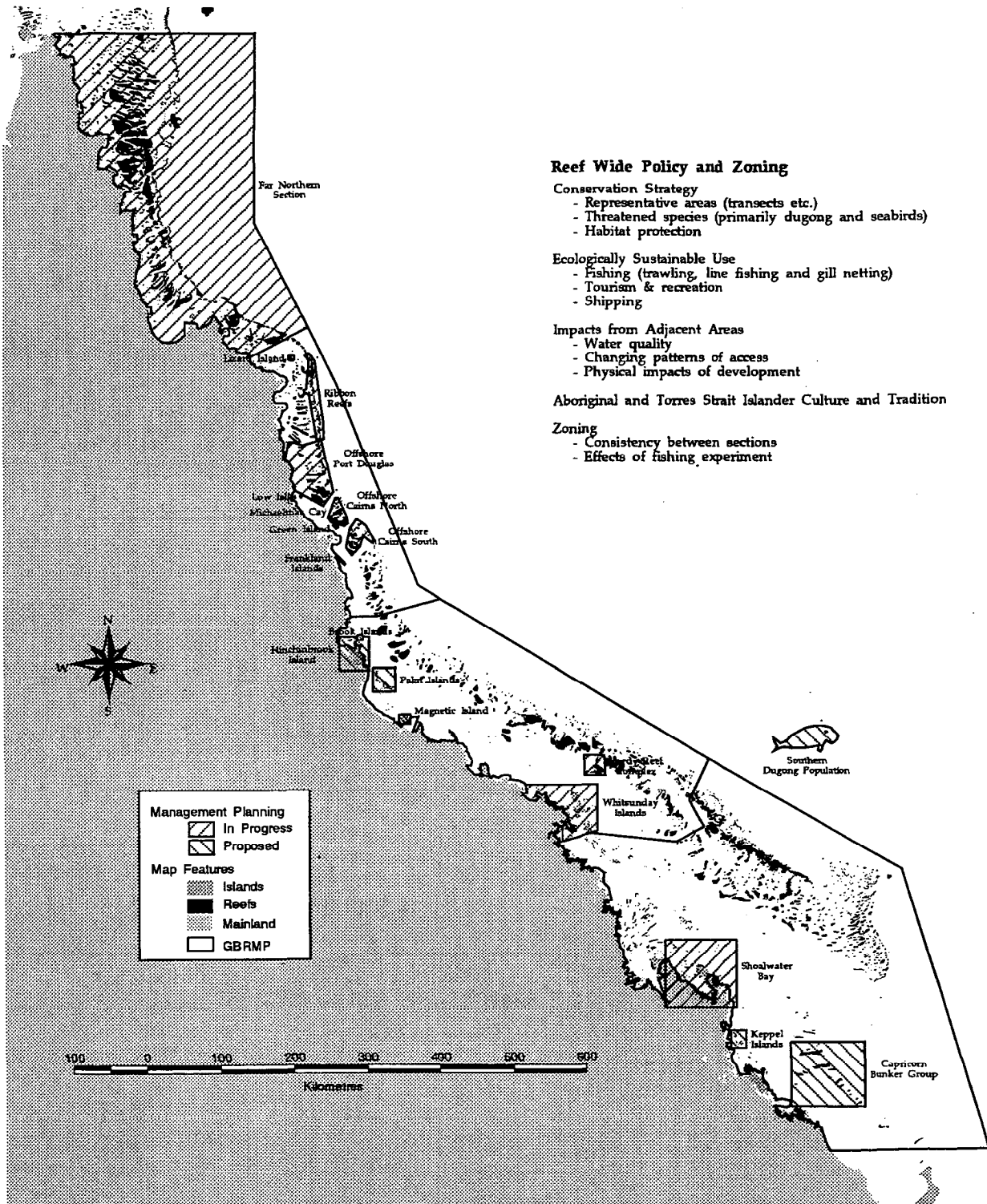


Figure 1. Management planning in the Great Barrier Reef Marine Park

**Strategic plan for the Great Barrier Reef World Heritage Area**

The aim of the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area is to achieve agreement between the various agencies and interest groups on the long-term management objectives and to focus the resources of all groups towards the most effective and efficient path for achieving those objectives.

In essence the Plan is a formula to achieve integrated planning and management by all relevant agencies and interest groups, recognising the different expertise and responsibilities of the various parties. Through this process longer-term problems, for example the need to reduce the inflow of nutrients from agricultural practices and sewage discharge into the Park, can be addressed. The five-year objectives established through the Strategic Plan will be the basis for each agency and group to derive their work programs for the next five years.

### **Zoning plans**

Zoning is the spatial partitioning of an area into a variety of uses to meet the overall objectives of conservation with reasonable use.

The Great Barrier Reef Marine Park Act sets out the objects which are to be considered in developing a zoning plan. They are:

- (a) the conservation of the Great Barrier Reef;
- (b) the regulation of use of the Great Barrier Reef so as to protect the Great Barrier Reef while allowing for the reasonable use of the Great Barrier Reef Region;
- (c) the regulation of activities that exploit the resources of the Great Barrier Reef Region so as to minimise the effect of those activities on the Great Barrier Reef;
- (d) the reservation of some areas of the Great Barrier Reef for its appreciation and enjoyment by the public; and
- (e) the preservation of some areas of the Great Barrier Reef in its natural state undisturbed by man except for the purposes of scientific research.

Policy guidance is also given in drawing up the plan. For example:

- (a) the zoning plan should be as practicable as possible;
- (b) the plan should minimise regulation of and interference in human activities, consistent with the goal of the Marine Park Authority; and
- (c) as far as practicable the following policy guidelines should be applied:
  - single zoning should surround areas with a consistent geographic description;
  - samples of areas representative the various habitats and biological communities found in the Park should be kept free from extractive activity;
  - plans drawn up under Commonwealth and State Queensland Marine Parks legislation should complement each other; and
  - the pattern of zones should avoid a sudden transition from highly protected areas to areas of relatively little protection.

Some of the features of zoning currently in place include:

- establishment of 'representative areas' of protected habitats as flora and fauna refuges and scientific reference areas;
- protection of sensitive habitats from activities that threaten them (e.g. trawl fishing is precluded from coral reef and seagrass communities);
- separation of conflicting uses (e.g. scientific research zones exclude commercial and recreational fishing);
- maintenance of areas of the Reef as marine national parks, free from fishing and collecting, for appreciation and enjoyment by the general public; and
- permit provision for individual activities that may have significant environmental impacts.

Zoning of all existing sections was completed in 1988. The Authority currently has a policy of reviewing each zoning plan every five years or so. Reviews have been completed for the Capricornia, Cairns and Cormorant Pass Sections and a review is currently underway for the Far Northern section.

The zoning process used by the Authority has been widely publicised and is now utilised as a basis for planning marine protected areas in a number of locations around the world.

### **Management plans**

Management plans establish strategies for management of individual reefs and islands, or for groups of islands and reefs. Management plans complement zoning plans by addressing issues specific to the area in greater detail than can be accommodated in the broader-reaching zoning provisions. Management plan provisions may be more but not less restrictive than the relevant zoning plan.

Management plans drafted to date have addressed:

- the conflicts between nature conservation and tourism use at Michaelmas Reef, Green Island and Lady Musgrave Island; and
- appropriate levels and types of use at Low Isles, a site of significance for conservation of the heritage-listed lighthouse, a very long history of intensive research and high demand as a tourism destination.

Management plans are currently in preparation addressing conservation issues including anchor damage and protection of bird rookeries, cultural heritage protection, and tourism and coastal development impacts in the Whitsundays Islands and reefs offshore from Cairns. Management planning is also being undertaken in Shoalwater Bay to ensure long-term protection of the very important conservation and Defence training area.

### **Special management areas**

Special Management Areas (SMAs) may be prepared for a bay or part of a reef to implement controls that may be necessary specifically at a site. Currently emphasis is being given to introducing mooring and anchoring strategies for heavily used sites. Previously SMAs have also been used at high profile tourism sites to protect fish stocks.

### **Future directions**

By the end of 1996 the Authority should have completed the current management planning projects and the review of the Far Northern section Zoning Plan. It is also anticipated that work will have been completed to amend the existing zoning plans as necessary to introduce a major experiment investing the effects of line fishing. Over the next few years it is anticipated that the 'establishment phase' will have been fine tuned and completed. This will involve reviews to:

- achieve consistency of provisions between all zoning plans; and
- incorporate and zone coastal waters of the Region that are not currently part of the Park.

Significant changes to the historic planning approach are presently being considered. The aim is to break off the shackles of the section by section zoning approach, which while essential in the establishment phase of the Park, is now constraining the ability to deal with Park-wide issues in a more strategic manner. The future is never certain, but is likely to include:

- a need to more adequately address management needs associated with indigenous peoples contemporary use and traditional association with the Park;
- a continuing need for tactical planning to address issues as they develop in high usage areas such as Cairns and the Whitsundays;
- strategy plans that address major issues such as dugong and turtle conservation, effects of fishing, maintenance of water quality, growth in recreational and tourism use with zoning plans and regulations amended as required on a Park-wide basis most probably; and

- increased emphasis on integrated planning with other agencies to address in-Park issues such as fishing and tourism, and off-Park issues such as coastal development and downstream effects of agriculture.



**Appendix 1**  
**Great Barrier Reef Marine Park Summary of Planning to Date**

**Strategic Plan for the Great Barrier Reef World Heritage Area**

The Strategic Plan is an agreement between the various agencies and interest groups on the long-term management objectives for management of the World Heritage Area. Through this Plan longer-term problems, for example the need to reduce the inflow of nutrients from agricultural practices and sewage discharge into the Park, can be addressed. The plan was endorsed by all stakeholders and released by the Prime Minister in the early part of 1994.

**Zoning Plans**

Zoning Plans have been prepared for all four sections with the original Capricornia (now part of the Mackay/Capricorn section) and Cairns plans having been reviewed. Work on review of zoning plans halted during the preparation of the World Heritage Strategic Plan, and there is now a ten to twelve year lag between finalisation of each plan and commencement of the review. Review of the Far Northern section began in late 1993 and is expected to be completed in 1997. Consideration of Aboriginal and Torres Strait Islander rights and needs, review of the adequacy of the current system of highly protected areas and development of a wilderness strategy and major focuses for the Far Northern section review and will establish precedents for other areas of the Park.

**Management Plans**

*Michaelmas Reef Management Plan*

Prepared jointly by the Authority and Queensland Department of Environment (QDoE), this plan addresses the potential conflicts of intensive tourism use at a site of regional significance for nesting sea birds. The plan was approved in 1986.

*Lady Musgrave Reef and Island Management Plan*

Lady Musgrave reef and island are located in the Capricorn/Bunker group at the southern end of the Great Barrier Reef. Lady Musgrave Island is an important turtle and bird-nesting site, it is also popular as a recreational camping and tourism location. The reef is one of the best known all weather anchorages, popular for fishing boats and cruising yachts. The plan for this area was prepared jointly by the Authority and QDoE and was approved in 1989.

*Low Isles Management Plan*

Completed during 1993, the Low Isles Management Plan establishes a framework for management of this very important reef and island complex. Low Isles is significant because of its diversity of reef and mangrove habitats, the presence of a light house listed on the register of Australian Heritage properties, a history of intensive research dating back to 1928, and a high demand for tourism and recreation. An interesting feature of Low Isles management is the establishment of the Low Isles Preservation Society, a local community group who voluntarily take an active role in management.

*Whitsundays National and Marine Parks Management Plan*

A draft plan was released for this area in October 1993 and covers marine and national parks in the area. The Whitsundays has very high conservation values, but is also an important growth

area for island, reef and coastal tourism development. The major focus of the plan is protection of fringing reefs and sensitive coastal sites. Several user conflicts of overcrowding and noisy activities such as waterskiing in 'quiet anchorages' are also being addressed.

#### *Offshore Cairns*

The Cairns area has been the fastest growing tourism area in Australia for the past ten years or so. Plans are currently being developed to ensure public access is adequately provided for at approximately thirty reefs. These plans will ensure that cumulative impacts associated with intensive tourism, such as anchor damage and displacement of other users, are appropriately addressed. The plans will identify sites that are suitable for intensive tourism and maintain appropriate levels and types of use at other reefs as well as implementing measures necessary to preserve unique conservation or cultural values.

#### *Shoalwater Bay*

Shoalwater Bay is a coastal area in the Mackay/Capricorn section. This area has very high conservation values and is the site of a Defence Force training facility. A Commonwealth Commission of Inquiry recently recommended exclusion of sandmining from the area and the development of a strategic plan for the area to protect the World Heritage values. Cabinet accepted the recommendations and allocated funds to the Authority to commence planning in January 1995.

#### *Special Management Areas*

Zoning plans provide for small areas of the Reef to be specifically managed for the purposes of conservation, undisturbed scientific research, appreciation by the public or public safety. These provisions have been widely used throughout the park to:

- protect areas immediately adjacent to tourist operations from fishing and collecting; and
- protect reef areas from anchor damage by banning anchoring, generally in combination with the installation of public moorings.

#### *Replenishment Area*

Zoning plans provide for temporary closure of selected high-use reefs to fishing, with the aim of allowing fish stocks to replenish. Replenishment closures have been used sparingly with a closure applied at Bolt Reef in the Capricorn Bunker Group and more recently at Bramble Reef in the Central section. In both cases the closures were subject to intensive monitoring. Management of Bramble Reef was overseen by an advisory group of local stakeholders.

#### *Turtle and Dugong Strategy*

The Turtle and Dugong Strategy has been prepared to address conservation of dugong and turtle throughout the Marine Park. The strategy was released following Ministerial Council endorsement during the early part of 1994. Implementation of the strategy is to be coordinated by a working group comprising researchers, representatives of fishing and traditional hunting groups and other relevant management agencies.

Appendix 2  
Great Barrier Reef Marine Park Planning Program as at July 1996

Plan	First Public Participation	Second Public Participation	Plan Finalised
Far Northern Review <sup>1</sup>	completed	early 1997	mid-1997
Effects of Fishing Zoning Amendments <sup>2,3</sup>	completed	July 1996	December 1996
Cairns Section Management Plans	completed	February 1997	July 1997
Low Isles Management Plan	completed	February 1997	July 1997
Whitsundays Management Plan	completed	February 1997	July 1997
Shoalwater Bay Strategic Plan	completed	September 1996	Late 1997
Dugong Plan	completed	September 1996	December 1996

<sup>1</sup> While re-zoning will be completed in this period, this program will require the preparation of management plans, with the first two commencing in 1996 but others being developed in later years, to implement more localised management measures - particularly those associated with Aboriginal cultural interests.

<sup>2</sup> Originally included a program to achieve more consistent zoning provisions between sections, however this aspect has been delayed and will hopefully commence during 1997.

<sup>3</sup> Future zoning amendments will implement the outcomes of a review of the current system of representative areas, the review will be undertaken over two years and is currently planned to commence in late 1996.