NEWSLETTER OF THE RESEARCH AND MONITORING SECTION

REEF RESEARCH

Great Barrier Reef Marine Park Authority

VOLUME 4 – No. 1 MARCH 1994

EDITORIAL

Just about everything you wanted to know about the Encore program is in this issue and COTS COMMS seems to have grown to its largest offering to date. We have still found room for lots of other good stuff and I would like, particularly, to thank Jim Higgs for his article on amateur fishing data. This data is the only reliable, long-term information on amateur reef fisher's catch and effort and is invaluable in assessing the impacts of fishing over the previous few decades. I join him in thanking the members of various fishing clubs who have made the information available and allowed his work to be carried out.

December's Reef Research provoked considerable interest by the media with regard to the article on scientific equipment that has been abandoned in various places around the reef. Unfortunately, virtually all the emotive media concentrated upon were the negative aspects of scientific endeavour and made little mention of the methods that were suggested to minimise impacts. It should be stressed that there is a need, under some circumstances, for hardware to be put in place for extended periods and there is no question that the Marine Park Authority recognises this need. Of more concern than possible adverse publicity was the suggestion that there might be uncontrolled removal of necessary hardware by members of the public. Reef Research would like to make it abundantly clear that such acts would be disastrous to the research and monitoring efforts that have taken place over many years and those that are planned into the future. 'What's out there' in this issue documents the efforts that are being made to rectify the situation and ensure that the Great Barrier Reef does not have unnecessary equipment attached to it. It should be noted that these initiatives were put in place independently of the Reef Research article and that the majority of the scientific community do act in a responsible and caring manner.

REEF RESEARCH is published quarterly by the Research and Monitoring Section of the Great Barrier Reef Marine Park Authority (GBRMPA).

Readers are invited to submit material for publication. Inclusion is the decision of the Editor. All contributions or inquiries should be addressed to:

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WHAT'S IN THIS ISSUE

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Beryl Dennis

Beryl has been with the Authority since October 1985 having spent the majority of her working life in private industry. Most of her time with the Authority has been spent with the Research and Monitoring Section and she is Personal Assistant to the Director of that Section. She is responsible for day-to-day administrative matters and has been responsible, amongst many other things, for the coordination of workshops particularly the Researcher Day which is held annually.

Trish Drury

Trish has been working for the Authority since July 1990 as an Adminstration Assistant. She is also Assistant Editor for the Research and Monitoring newsletter, *Reef Research*, and is responsible for organising the articles to be written, edited and passed to the production team for formating and final production. Trish is also responsible for preparing scientific reports for publication, providing word processing and general clerical assistance to the other members of staff.

CRC

Reef Research Centre

An unincorporated joint venture between:

Association of Marine Park Tourism Operators

Australian Institute of Marine Science

Great Barrier Reef Marine Park Authority

James Cook University

Department of Primary Industries

established under the

Cooperative Research Centres Program

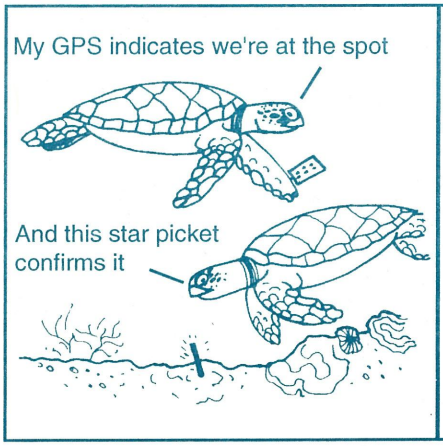
Chris Crossland

This column is aimed at providing further background, information, and updates on activities and products from the Cooperative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef (CRC: Reef Research Centre).

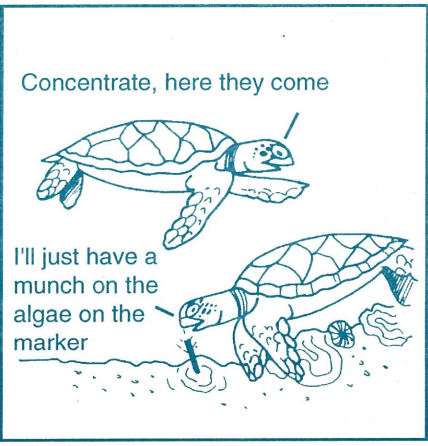
Issues Drive the Research

The research activities of the Centre outlined in the December 1993 issue of *Reef Research*, are all issues-driven. The Centre's purpose is to provide a firm scientific base on which management strategies and options can be developed and to provide direct information of use to industry in the ecologically sustainable development of the

Coralations



Monitoring Monitors



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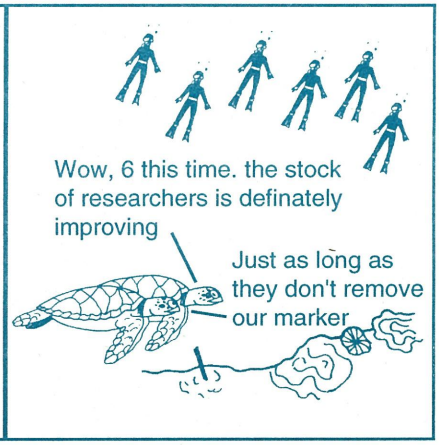

Great Barrier Reef. It will also look to application/evaluation through adaptive management strategies.

The identification of key issues provides a focus to achieve these purposes and the structure for the research direction and priorities. The present set of issues was identified by the user agencies (AMPTO, GBRMPA, DPI) initially during the development of the bid for the Centre, and then after consolidation at the commencement of the Centre in July 1993.

The broad shape of the research programs and the design and structure of the research tasks now being implemented were developed within the framework of the identified issues. The research tasks were designed through a process of consultation between the researchers and users/managers.

A total of 61 issues, identified by the tourism industry and environmental management agencies, has been incorporated into the Centre Operations Plan adopted in August 1993. Current research activities are addressing 43 of these issues which are summarised in table 1 'Summary of Key Issues'.

Issues before the Centre are kept under review by the Users Advisory Group which is now in the process of examining the linkage between the issues and research tasks to ensure that all the appropriate questions are being addressed and that the research results will be delivered in a form useful to the industry and management agencies.

Additional Research Tasks

Three new research tasks have been started, adding to the 25 tasks currently underway:

(a) The feasibility of constructing coral viewing platforms on underwater observatories by transplanting coral fragments - aimed at enhancing opportunity for visitor experience.

(b) The effects of natural and human disturbance on seabirds in the Swains reefs - this will draw upon Professor Hal Heatwole's 15-year data base.

(c) Risk analysis of a major oil spill in the Outer Route vs Inner Route of the Great Barrier Reef - work on behalf of GBRMPA and Caltex Australia Pty Ltd, contributing to a major Federal initiative looking at many aspects of shipping in the GBR Region.

Five more tasks are scheduled for start-up over the next quarter. A key element of these, and recently commenced activities, is work linking environmental and social science to address issues such as 'carrying capacity' and resource use conflicts - the latter will involve development of tools such as decision support systems.

Economic and socioeconomic factors are elements in the process of ESD - albeit factors which have achieved limited prominence in the recent ESD considerations in Australia. The Centre is looking at ways to incorporate appropriate elements of economic concepts and tools into the information needed to resolve issues.

Extension and Education Programs

An Extension Program strategy is being developed for commencement in the new financial year.

The Education Program is in its infancy and will rely heavily on the skills and research outcomes from the Centre and its joint venture agencies. We are currently finalising the selection and offer of six postgraduate awards and planning several courses for the immediate future.

The CRC will be sponsoring a course by Dr Brian McArdle, University of Auckland over the period 8 - 13 May 1994. The course will be relevant to the planning and design of aquatic monitoring and environmental impact work. Dr McArdle has an international reputation in this area and would be happy to 'build' a course and workshop regarding specific problems being encountered by workers in Australian tropical areas. For enquiries on the course please contact Prof JH Choat, Department of Marine Biology, James Cook University (Phone 077 81 4345).

For further information on the Centre please contact

Chris Crossland
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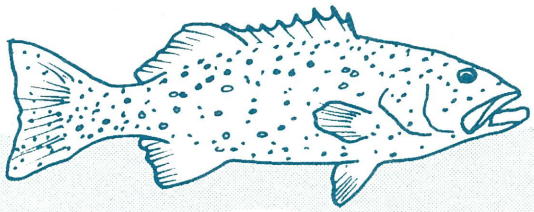
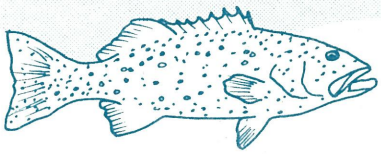
• Develop an understanding of major marine communities (especially coral, seagrass, finfishes) and the impacts of human use and natural events such as cyclones, major flood events and crown-of-thorns starfish.
• Quantify the nature and extent of the effects of major disturbances on the reef and develop a capacity to predict recovery from disturbances.
• Quantify inputs such as sediment, nutrients and chemical pollutants to the reef region from adjacent catchments and develop understanding of the role of terrestrial runoff on water quality and ecological processes in the Great Barrier Reef.
• Evaluate the effects of natural events/disturbances on the reef environment and implications for tourism sites.
• Develop and evaluate rehabilitation/remediation processes for sites; natural and managed.
• Provide a sound information base for the development of strategies for managing high use tourist areas and high use fishing areas; the strategies to provide a base for use throughout the Great Barrier Reef.
• Monitor and evaluate the maintenance of a broad range of quality visitor experiences and develop social impact assessment guidelines.
• Develop a sound information base and evaluation methods for establishment of optimum use levels ('carrying capacity') in ecological and social contexts.
• Quantify the effects of non-trawl fishing activities on demersal and pelagic fish stocks and determine impacts of fishing on non-target and target species and their habitats in the Great Barrier Reef Marine Park.
• Develop effective means of monitoring the distribution of fishing effort and catches by recreational fishers in the Great Barrier Reef Marine Park.
• Evaluate risks of pollution from shipping and transport activities.
• Develop guidelines for structures and assess the safety and design of reef-based tourist structures.
• Evaluate processes influencing groundwater and surface water quality and influence on reefal environments.

Table 1. Summary of key issues.

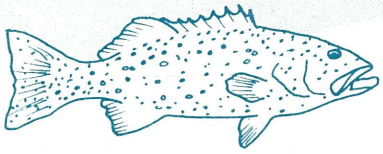
REEF FISH





AMATEURS PROVIDE PROFESSIONAL INFORMATION

Jim Higgs*



The Great Barrier Reef Marine Park Authority recreational demersal reef line fisheries database, or **REEF FISH** for short, is probably the most comprehensive source of information that is currently available detailing catch and effort information for the Queensland recreational reef line fishery.

Dr Wendy Craik was responsible for the original collection of information from amateur fishing clubs, charter operators and interested anglers in the late seventies. Ms Maria Zann-Shuster collected additional information in 1989 to update the data and began the tedious task of data entry while working as a consultant for GBRMPA. The author completed the data entry for the Townsville, Mackay and Rockhampton regions, some 700 hours of interpretation and entry of angler catch data and this information formed the basis of a Masters thesis (Higgs 1993).

REEF FISH provides sufficient information to calculate catch composition, species specific and total catch rates, and average weight of fish captured on amateur angling club trips operating within the Great Barrier Reef Region. The majority of amateur angling clubs keep records for competitive purposes which means that the accuracy of these records is generally very good. Catch information is usually recorded as the boat docks, eliminating the non-sample error that occurs when recall information is used to record details. The current extent of **REEF FISH** is 2400 individual trips, 1807 of which can be used to produce catch per unit effort information. A breakdown of the angler effort, total catch, and average weight of captured fish for trips that provided sufficient information to calculate catch per unit effort statistics is presented in table 1.

The analysis of **REEF FISH** by Higgs (1993) represents the first comprehensive regional comparison of the **REEF FISH** information since the earlier analysis in the late seventies (Craik 1979). The recent study involved a thorough examination of the information supplied from the Townsville region with an overview of catch rates and average fish weights for the whole Great Barrier Reef region.

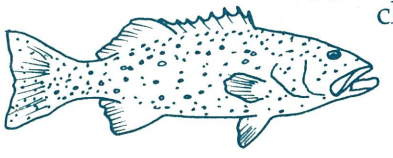
The additional years of information have

Table 1. Summary of the **REEF FISH** database records used by Higgs (1993)

REGION	NUMBER OF TRIPS	EFFORT IN ANGLER DAYS	TOTAL WEIGHT OF FISH (kg)	TOTAL NUMBER OF FISH CAPTURED
CAIRNS	349	8879	57303	21029
TOWNSVILLE	715	18463	233894	140940
MACKAY	172	4184	64117	42903
ROCKHAMPTON	571	10358	126291	130896
TOTAL	1807	41884	481605	335768

identified similar latitudinal patterns in catch rates (see figure 1) and average weight of captured fish (see figure 2) that were first reported by Craik (1979). Catch rates remained consistent for regions where constant sources of information (over 25 years in some cases) have been available (see figure 1). Analysis on a reefal scale for the Townsville region showed no obvious decline in catch rates that would suggest recruitment overfishing. Average fish weight in the Cairns, Mackay and Rockhampton regions display no signs of decline.

Average fish weight for the traditional coral trout/sweetlip emperor fishery in the Townsville region has decreased by approximately 1 kg from the high levels recorded in the early sixties. However, there is only a relatively small decrease in average weight of captured fish (0.24 kg) from the late sixties to the mid eighties. The decrease in average weight in the early to mid eighties may be 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 has increased rapidly since 1988. This corresponds to an increase in the percentage of lutjanids in the catch as suppliers of information change their fishing styles to include fishing deeper water for lutjanids.



Approximately 50 per cent of Cairns, and greater than 60 per cent of Townsville, Mackay and Rockhampton respondents to a boat ramp survey carried out, in 1990, as part of the Marine Park Authority's research program, reported declining catch rates (Blamey and Hundloe 1993). The differences in the sustained catch rates identified in the **REEF FISH** database and the declining catch rates identified in the Blamey and Hundloe study may be explained by several factors. Firstly, Blamey and Hundloe centred their work on the small boat fishery which concentrates its effort closer to shore. The data on which **REEF FISH** is based was generally collected from larger boats fishing on mid and outer-continental shelf reefs, 40-90 kilometres offshore. The declines in catch rates perceived by respondents to Blamey and Hundloe may represent real declines in the abundance of the inshore fish stocks. Problems associated with the use of recall surveys (see Thompson and Hubert 1990) may also have contributed to the decline reported in Blamey and Hundloe (1993).

Expansion of the **REEF FISH** database to include other fishing clubs has been hampered to a certain degree by the way in which management agencies and research institutions have independently tried to collect information from various fishing bodies. Considerable duplication has occurred and this has led to confusion

within some of the fishing clubs. This confusion has produced a resentment towards these institutions in many fishing clubs because they see the various groups as incompetent due to this duplication of data collection. One of the tasks of the CRC: Reef Research Centre: is *A review of the information needs from recreational fishing and boating activities and the design of sampling strategies to collect appropriate data* and it is hoped that this will lead to a streamlined approach to data collection from the recreational fisheries. This will reduce the amount of duplication that is currently occurring and may promote a healthier view of research and management agencies amongst recreational fishers.

REEF FISH and the commercial line fisheries logbook system provide an avenue for the users of the Marine Park to become more responsible for the management of the marine resources that they utilise by provision of timely and accurate information. Data bases composed of catch effort information are also a relatively cost effective way of monitoring the fisheries without extensive scientific surveys. Both commercial and recreational suppliers of information can be approached to investigate the accuracy of the records and to take biological samples of the catch. The ability for users of the marine resources to become more responsible for the management of these resources and the ability of researchers to utilise more cost effective research were both factors highlighted by the Industry Commission into cost recovery for managing fisheries (Industry Commission 1992).

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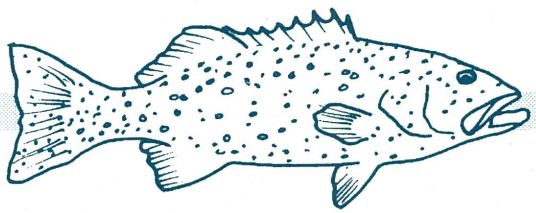


* Jim is employed half time by an Australian Research Council funded project investigating the age, growth and reproduction of smaller snappers, emperors, and groupers of the Great Barrier Reef. Recently he has been contracted to carry out tasks as a research officer, half time, for the CRC project titled *A review of the information needs from recreational fishing and boating activities and the design of sampling strategies to collect appropriate data.* His Master of Science thesis is currently undergoing external review.

Ed

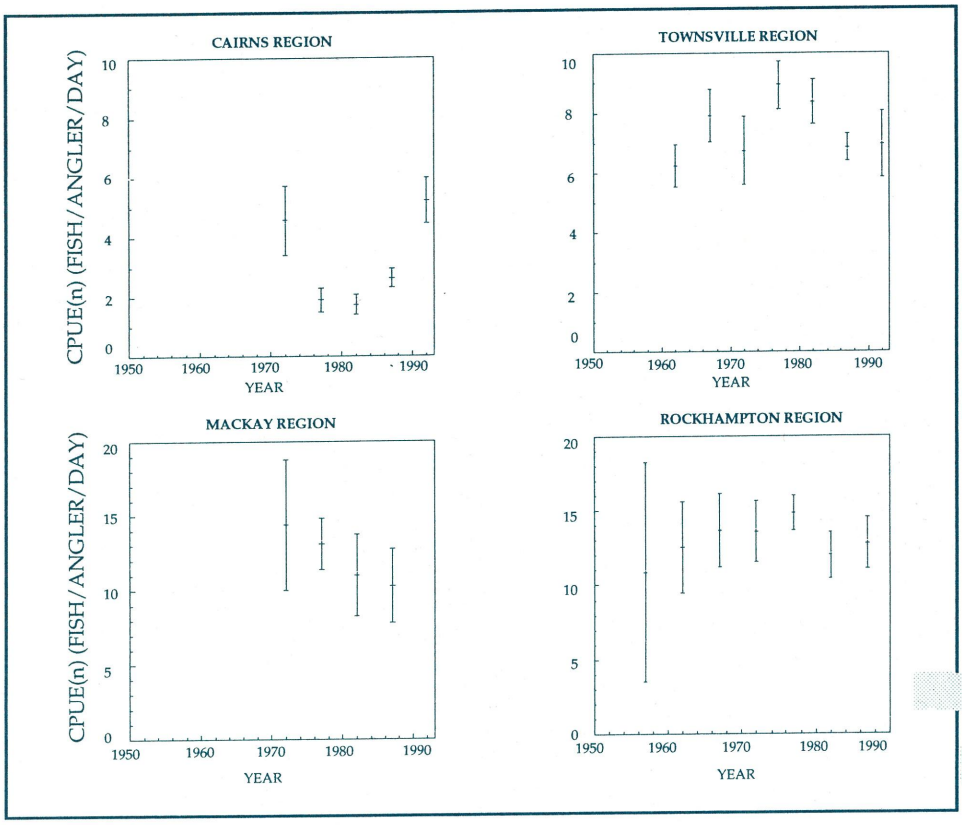


Figure 1. *Average catch rates for the Cairns, Townsville, Mackay and Rockhampton regions calculated over five year intervals (mean +/- 95% intervals)*

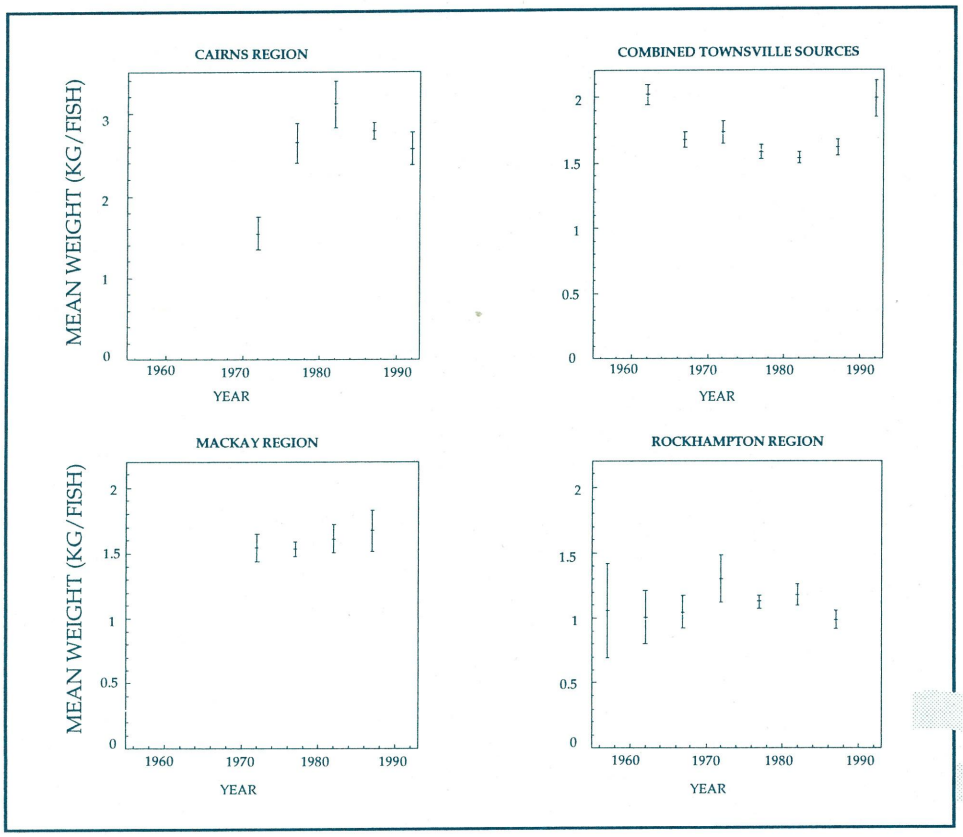


Figure 2. *Average weight of fish captured for Cairns, Townsville, Mackay and Rockhampton regions calculated over five year intervals (mean +/- 95% confidence intervals)*

Welcome to the second anniversary of the appearance of Slick Talk in *Reef Research*! It is hard to believe that two years have passed since this regular oil spill column first emerged from a recommendation of the third National Scientific Support Coordinators workshop in Perth in 1992. It is only fitting that here we report on the fourth Scientific Support Coordinators workshop that was held in Adelaide in October 1993.

In addition we provide news on the use of National Plan oil spill resources to assist scientific research and monitoring on the Great Barrier Reef, and preview the intended development of an Oiled Wildlife Contingency Plan for Queensland.

With my recent move from GBRMPA to the Ports Corporation of Queensland, it has not been easy to keep pace with all oil spill developments around the country, and yet again I extend an invitation for practitioners in this field to submit articles and news items for inclusion in Slick Talk. Such material should be sent to my new business address, GPO Box 409, Brisbane Queensland 4001, fax 07 224 0734.

Fourth National Scientific Support Coordinators Workshop.

As part of its training and information exchange efforts under the National Plan to Combat Pollution of the Sea by Oil (the National Plan), the Australian Maritime Safety Authority (AMSA) funds and organises National workshops for oil spill Scientific Support Coordinators (SSCs) every eighteen months to two years.

The SSC workshops rotate to different States, with the relevant State oil spill agency usually providing supplementary funding and organisational support. The Commonwealth Environment Protection Agency (CEPA) also provides supplementary funding.

The last two SSC workshops have been held in States where recent oil spills provided opportunities to review local case studies. The third SSC workshop in Perth analysed the *Sanko Harvest* (14 February 1991) and *Kirki* (20 July 1991) spills, and the fourth SSC Workshop in Adelaide conducted a critique of the response mounted to the *Era* spill off Port Pirie (30 August 1992).

In addition to reviewing specific spills, the workshops also include updates from each of the State SSCs and presentations from government, industry and scientific experts on latest developments in the scientific and environmental arena of oil pollution. They also act as valuable training events, with table-top scenarios being exercised to test SSCs ability to provide the required support and advice to an overall spill response.

A significant feature of the Adelaide workshop was participation by overseas representatives from South-East Asia and several Pacific Island countries, supported by the International Maritime Organisation, the South Pacific Environment Program and AMSA.

Several speakers reviewed computerised oil spill trajectory models and coastal resource atlases, and it became obvious that there is a wide range of opinion on the utility of these tools. An interesting outcome of this section of the workshop was that participants were unable to identify a single oil spill in Australian history where an oil spill trajectory model has actually made a positive difference in preventing environmental damage from the spill.

Environmental managers from the offshore oil industry made some interesting presentations on recent industry activity. One significant event is the completion of the Australian

Petroleum Exploration Association's (APEA) review of the environmental impacts of the offshore oil industry. This review indicates that the offshore industry has an outstanding oil spill record, with 96 500 litres (from over 3 billion litres produced) of oil being spilt from exploration and production activities since the industry commenced operation in Australia in (approx.) 1966. Copies of the review can be purchased from APEA, phone 02 221 4899.

Another significant development in the offshore industry is an increasing requirement by some companies in Western Australia for environmental studies that they commission to be independently peer-reviewed and publishable in scientific journals. Such a requirement can only result in increased quality assurance and should be welcomed by environmental management agencies and the scientific community.

A primary objective of the workshop was to discuss development of National policies and guidelines on two important oil spill response issues that have not yet been properly addressed in Australia. These are post-spill damage assessment and monitoring, and the use of bioremediation.

These issues were intensively workshopped and allocated to particular SSCs to take away and develop draft documents. Once drafted these will be released for review and comment before submission to the National Plan Advisory Committee for acceptance, endorsement and implementation as the official National Plan policies and guidelines on post-spill damage assessment and monitoring and the use of bioremediation.

The workshop also included a field trip to the Port of Adelaide and a nearby mangrove wetland reserve to inspect the type of ecosystems impacted by the *Era* spill at Port Pirie.

Copies of the Proceedings of the Fourth National Scientific Support Coordinators Workshop will be available from AMSA. The date of availability will be reported in this column.

National Plan Resources Assist Barrier Reef Research

Under the National Plan, AMSA provides a variety of oil spill response equipment located at strategic resource centres around the country. While funded and owned by AMSA, the day-to-day maintenance and operation of this equipment is usually carried out by State marine agencies and/or port authorities.

In the case of Townsville in north Queensland, some National Plan equipment, including a 12 metre catamaran the *Chiton*, is maintained and operated by the Townsville Port Authority (TPA).

Throughout 1992 and 1993, the TPA undertook a variety of environmental studies and monitoring programs as part of major developmental dredging works and expansion of the port. These studies were undertaken jointly with the Great Barrier Reef Marine Park Authority (GBRMPA) and the Queensland Department of Environment and Heritage, and involved consultants Sinclair Knight, WBM Oceanics, Mapping and Monitoring Technology Pty Ltd and several departments at James Cook University of North Queensland.

The studies involved deployment of a large number of various pieces of monitoring equipment around Magnetic Island and throughout Cleveland Bay, and at control sites to the north of Townsville. A major factor in the success of such deployments is the availability of suitable work vessels capable of handling the equipment in often uncomfortable sea conditions.

The National Plan oil spill catamaran *Chiton*, with a large open work deck and hydraulic crane, is ideal for such work. On several occasions throughout the project GBRMPA approached TPA and AMSA for approval to use *Chiton* to deploy and retrieve monitoring equipment. Although totally unrelated to oil spill response, TPA and AMSA considered that using *Chiton* for this purpose would be a good opportunity to exercise the vessel, give the crew opportunity to practice operations at sea in sometimes less than ideal conditions and establish a good working relationship between TPA and GBRMPA staff at a field operations level, all of which would be of benefit should the *Chiton* be needed for response to real oil spills.

The *Chiton* proved invaluable during the monitoring program, and much thanks must go to TPA and AMSA for making the vessel and crew available.

Oiled Wildlife Plan for Queensland

While Queensland has fallen under the protection of the National Plan since its inception in the 1970s, and while the Great Barrier Reef has been covered by REEFPLAN since 1987, none of these plans include proper contingency arrangements for the rescue, handling and rehabilitation of oiled wildlife in the event of a spill.

Debate continues as to the effectiveness, necessity and value of rescuing and treating oiled wildlife during oil spills. There are many reports of oiled wildlife operations resulting in virtually no survival of oiled animals. This has caused a perception amongst many oil spill responders that the expense and effort involved is not worthwhile and that oiled wildlife should be accorded a low priority in the overall response, or addressed only for public relations value. However, an objective analysis of those spills where oiled wildlife operations have been a dismal failure, invariably reveals that either no or very poor contingency plans were in place and that the operations were implemented incompetently and in a climate of ignorance.

However, if proper preparations are made, including training of personnel in state-of-the-art techniques, and if oiled wildlife operations are conducted according to well exercised and supervised plans and procedures, a high degree of success can be achieved and the effort and expenditure can be most worthwhile. The Bird Rescue and Research Centre in the United States reports survival rates for properly treated oiled birds in excess of 70%, and similar positive results are also reported from South Africa and the United Kingdom where oiled wildlife procedures are well developed.

Under the National Plan, responsibility for the coordination of oiled wildlife operations in Queensland rests with the Queensland Department of Environment and Heritage (QDEH). In early 1990 GBRMPA held a workshop in Townsville on oiled seabirds, and this workshop identified the lack of a proper plan and the need for QDEH to develop one.

To date some of the QDEH Regional and District offices have developed their own local oiled wildlife plans, but there is no overall, coordinated and standardised approach for the whole State and the vast majority of the Queensland coast has no coverage at all.

QDEH have therefore undertaken to address this situation and in late February 1994 held an oiled wildlife training course for Marine Parks and National Parks rangers and other staff on Bribie Island, followed by a workshop to lay the basis for development of a State-wide plan.

The training course was conducted by the oiled wildlife response team from Taronga Park Zoo in Sydney. As the role of QDEH is to coordinate oiled wildlife operations, rather than conduct them in their entirety, the course was also attended by officers from the Royal Society for the Prevention of Cruelty to Animals (RSPCA), veterinarians and community wildlife care groups.

As part of development of the State-wide plan, QDEH will form regional response groups and conduct ongoing training courses at the local level.

An aspect of oiled wildlife operations that remains unresolved under the National Plan is the question of cost recovery. At present compensation and funding arrangements do not cover expenditure on oiled wildlife response, despite the fact that such operations are just as integral to an overall oil spill response as deployment of booms or spraying of dispersants. This is an issue that the recent review of the National Plan failed to address satisfactorily and one that the National Plan Advisory Committee needs to reconsider with input from the State SSCs.

Development of an oiled wildlife contingency plan for Queensland represents yet another step forward in the ongoing improvements to oil spill response arrangements that have been evident around the country since the review of the National Plan in 1993.

COTS COMMS

Dr Brian Lassig and Udo Engelhardt

We've reported on an apparent increase in the number of crown-of-thorns starfish on some reefs off Cairns and further north in the last two issues of COTS COMMS. The increase was based on reports from Reef users through the *COTSWATCH* Program (see next section). Recent analysis of the information collected through this scheme over the last few years and the results of 7 years of AIMS surveys (see Current COTS) shows that the increase in starfish numbers in parts of the northern GBR is **real**.

But before the panic button gets pushed, the newspaper headlines typeset and the COTS Program Coordinator besieged by bloodhounds, consider the densities of starfish being reported. During the peak of outbreaks on reefs off Townsville in the late 1980s, the AIMS manta tow surveys recorded averages of 200 to 300 COTS per reef, and around 4 starfish per 2-minute manta tow. The current average densities of starfish being reported on reefs off Cairns and further north are two orders of magnitude lower (i.e. 1/100th of outbreak densities). These are averages based on reefs within the particular Reef Sectors. On some individual reefs (e.g. Michaelmas Cay and Lizard Island) the COTS densities aren't too far from being called localised outbreaks.

We don't know whether or not the increase in starfish numbers represents the early stages of another major outbreak for the GBR. During the previous outbreak episodes there were no substantial monitoring programs in place that could have detected the increases currently being seen, so we don't know if outbreaks start with a bang or a gradual build up in starfish numbers. The only way we will get a clear picture of the dynamics of COTS on the Reef and the initiation of outbreaks is to maintain a close watch on the current situation.

RELAUNCH OF THE COTS - REEF USER SURVEY SCHEME (COTSWATCH)

A new and improved public participation program aimed at getting more Reef users actively involved in reporting COTS sightings was launched in November 1993. The new program continues the evolution of survey schemes that were spawned in 1982. Largely in response to comments made by previous contributors, we decided to introduce some fairly major and hopefully beneficial changes. COTSWATCHERS of the world report!

The survey form used for reporting on starfish sightings has been redesigned, making it more user-friendly and easier to complete. The number of questions on the form has also been reduced. An illustration of a mature crown-of-thorns starfish now assists Reef users in the positive identification of the species. There is also a warning in relation to the danger posed by the venomous spines of the starfish.

What hasn't changed is the emphasis on reporting 'zero-sightings' as well as actual sightings of starfish. Appropriate management action, i.e. giving permission to attempt local-scale controls, requires knowledge of both the past and present situations at any given reef. Also, our chances of detecting any real increase in the numbers of starfish over time rely very much on long-term records, including reports on both the presence and absence of COTS!

We have also attempted to address some other shortcomings of previous schemes - namely the insufficient feedback given to COTSWATCHERS. In the past, lack of time and resources often prevented us from maintaining an effective two-way flow of information between contributors to the scheme and ourselves. However, this is already changing. The new user survey scheme now provides added incentives to all contributors through a variety of new measures.

COTSWATCHERS will now:

- receive free information (i.e. brochures, booklets) on the latest research into the starfish phenomenon and on the Great Barrier Reef Marine Park in general;

  be acknowledged in *Reef Research* (starting with this issue; see below);

- be invited to attend regular slide presentations and updates on the current status of the starfish on the Reef. The aim is to conduct these presentations every six months in the major regional centres along the north Queensland coast.

Regular contributors to the scheme who provide information for extended periods of time may also receive additional tokens of our appreciation i.e. in the form of research publications, slides and maybe even a video tape (note that this doesn't mean that you'll score more brownie points by reporting more COTS!).

The earlier idea of conducting a quarterly prize draw has been abandoned in favour of the above reward system - ironically we were overcome by bureaucracy. Anyway, the new system of having incentives available to all contributors is more fair and equitable (and legal!).

Should you have further questions about this new scheme i.e. how to get involved, please do not hesitate to contact us directly. Survey forms are available from both GBRMPA in Townsville and most offices of the Queensland Department of Environment and Heritage (QDEH).

CURRENT COTS

Reflecting the unprecedented response from COTSWATCHERS, this section of COTS COMMS is divided into two parts - results of surveys by the Australian Institute of Marine Science (AIMS) and some of the growing number of reports of COTS through the Reef user survey scheme. Hopefully this will be an ongoing arrangement.

AIMS Surveys

Since the December issue of *Reef Research* the AIMS monitoring team has reported on surveys of reefs in the Cape Grenville, Princess Charlotte, Cooktown/Lizard Island, Townsville and Cape Upstart Sectors.

A total of 52 starfish were seen on the 30 reefs surveyed in the north (Cape Grenville, Princess Charlotte and Cooktown/Lizard Island Sectors) in December. Most of the COTS activity was in the Cooktown/Lizard Island Sector with 44 of the recorded starfish in this area. COTS were recorded on half of the 18 reefs surveyed but Lizard Island with 17 COTS and Forrester Reef with 10 COTS were the only reefs with substantial populations. These are not considered large enough to be classified as outbreaking, but there has clearly been an increase in the number of starfish seen on these reefs. None or 1 COTS were recorded on surveys of Lizard Island and Forrester Reef over the last 5 years (neither was surveyed last year).

Manta tow surveys were conducted on 6 reefs in the Townsville Sector and 5 reefs in the Cape Upstart Sector. SCUBA searches for COTS were also conducted on 5 reefs in the Townsville Sector. Single starfish were recorded on 4 of the 10 reefs surveyed by manta tow and none was recorded during the SCUBA searches.

Reef User Reports

During the period from November 1993 through to January 1994 we received a total of 63 completed survey forms from COTSWATCHERS, reporting on observations from a total of 139 sites spread over 43 different reefs. Table shows details of some of these reports. These statistics do not include the COTS seen and collected at Michaelmas Reef (see later).

A total of 728 COTS were seen on 78 sites. In contrast, 61 sites had no starfish present. We have often stressed the importance of getting 'zero-sightings' as well as actual starfish counts. It is very encouraging to see a relatively high number of zeros being returned.

From these observations, it would appear that current starfish activity is very much focussing on the Cairns to Lizard Island area with some notable 'hot spots' up north off Lockhart River.

Many thanks to all who have contributed. Your efforts are very much appreciated and we look forward to receiving many more completed forms in the future.

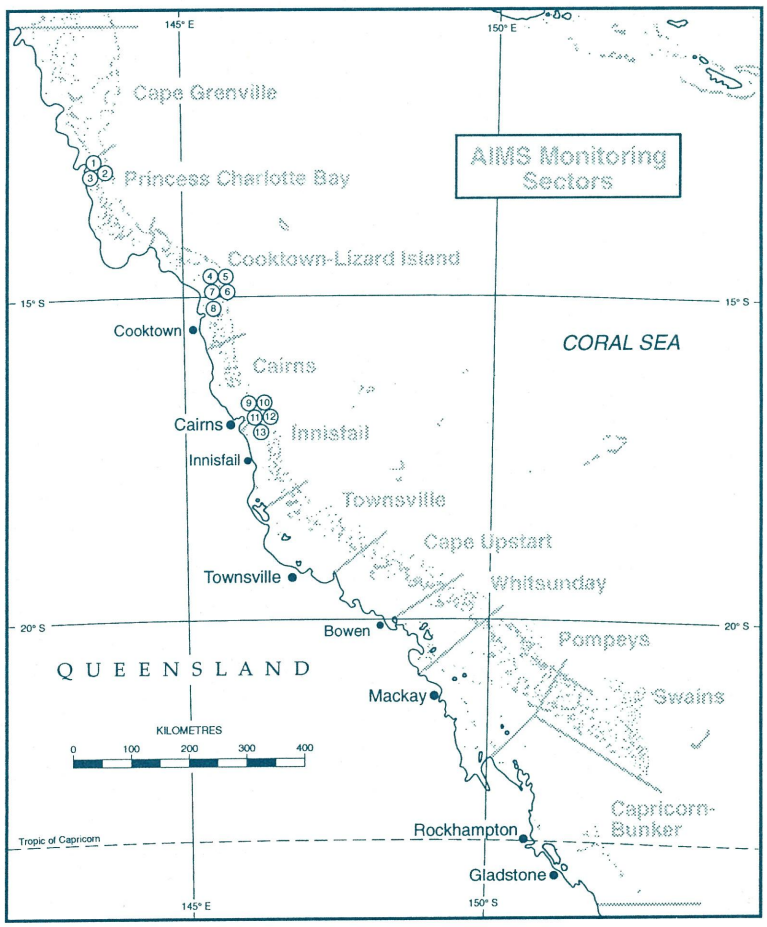


Table 1. The COTS 'Top Fifteen' reports (November 1993 - January 1994)

Reef Name / ID	No. of COTS	Observer
Michaelmas Reef	182	S Moon / Ocean Spirit Cruises
Sherrard Island Reef	61	F Muir / QDEH Cairns
Osborne Reef	52	F Muir / QDEH Cairns
Chapman Island Reef	48	F Muir / QDEH Cairns
Lizard Island Reef	28	T Ayukai / AIMS
Moore Reef	19	J Anderson / Cairns
Lizard Island Reef	18	L Vail & A Hogett / LIRS
High Rock	15	Mike Ball Watersports / Cairns
Milln Reef	9	G Svensson / Cairns
Briggs Reef	8	C Smith / Cairns
14-141	7	Mike Ball Watersports / Cairns
Ribbon Reef No 10	6	Mike Ball Watersports / Cairns
Milln Reef	6	A Van Welderen / Cairns
Flynn Reef	6	A Van Welderen / Cairns
Milln Reef	5	G Svensson / Cairns

In this issue we would like to acknowledge the recent efforts of the following COTSWATCHERS:

C Smith / Cairns; C Griffin / Greenwell Point; Mike Ball Watersports / Cairns; A Van Welderen / Cairns; L Newman / Port Douglas; A McColl / Cairns; Great Adventures Cruises / Cairns; L Vail & A Hogett / LIRS; S Moon & the staff of Ocean Spirit Cruises / Cairns; G Bennett / Cairns; Friendship Cruises / Mission Beach; T Ayukai / AIMS; J Anderson / Cairns; H Malcolm / GBRMPA; A Roelofs / QDPI Cairns; J Cruise, D Ball / all QDEH Airlie Beach; K Roach / Cairns; J Anderson / Cairns; R Vanstan / Cairns; S Singleton / Cairns; R Stuteley / Townsville; Great Diving Adventures / Cairns; G Svensson / Cairns; M Short, F Muir, G Kelly & D Devine / all QDEH Cairns; Port Douglas Dive Centre / Port Douglas.

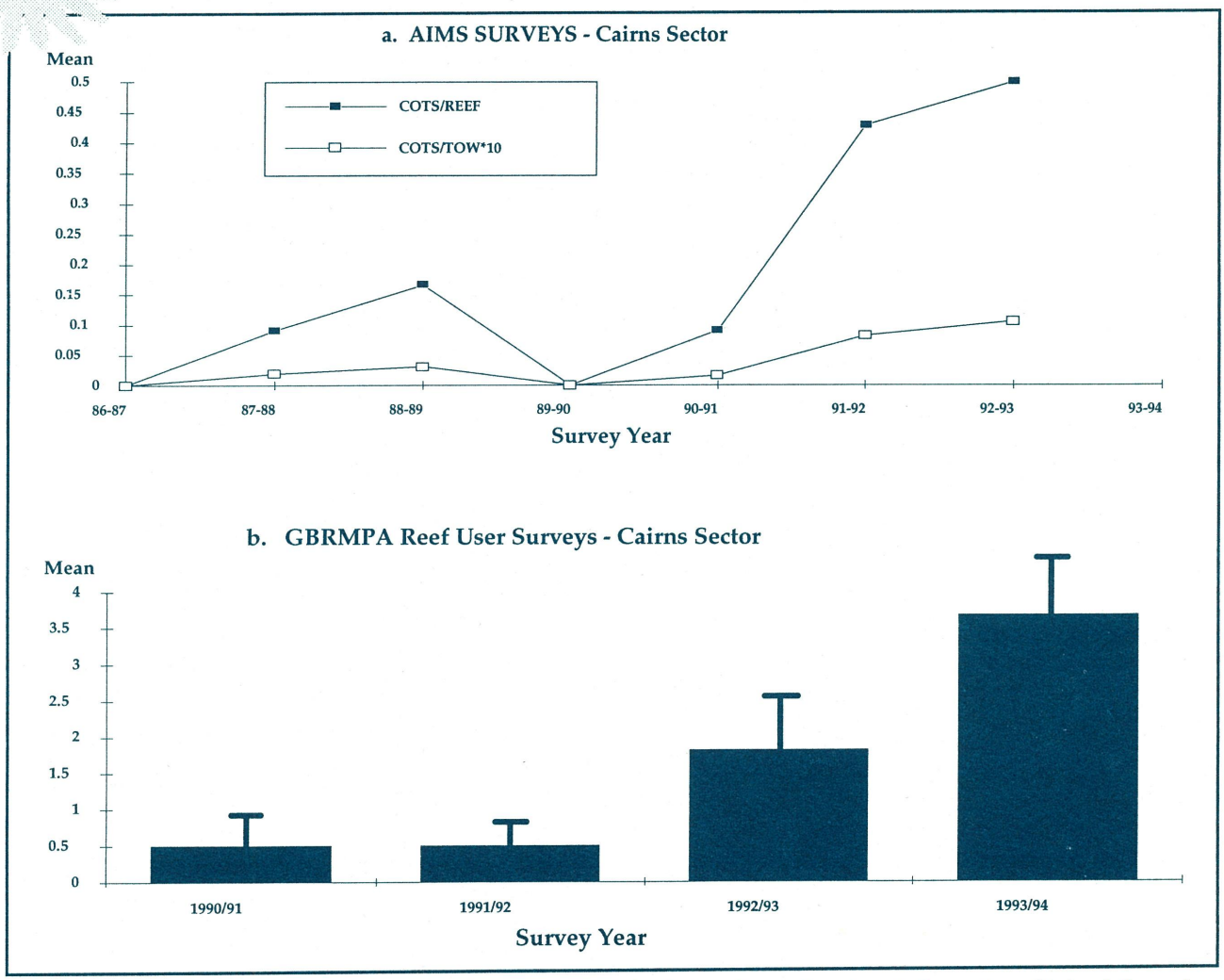
We have also completed some preliminary analyses of all the Reef User reports received since early 1990. Some very interesting trends have emerged for the Cairns Sector. Figure 1b shows the observed, increasing trend in the mean number of COTS per site as reported by Reef Users over the past 3 1/2 years. A similar trend is also apparent in the AIMS survey data for the same period (see figure 1a).

COTSREC'S COUNSEL

The Crown-of-thorns Starfish Research Committee (COTSREC), which provides advice to the Authority on COTS matters, met in November 1993 to review progress of the COTS program and to start thinking about directions for 1994/95. Progress reports prepared by researchers for the meeting showed that most of the currently supported projects are on track and there's an air of optimism surrounding the possible completion of a few long overdue reports.

The Committee made a total of 17 recommendations, mostly relating to operational matters and the preparation of information for the May 1994 meeting when the 1994/95 annual program will be considered. The highlights include:

- Preparation of review/discussion papers by COTSREC members and GBRMPA staff, including:
  - a discussion paper on the benefits of COTS research and spin-offs to other areas of reef research;
  - a discussion paper on possible links between water quality and COTS outbreaks; and
  - a review of the COTS program from 1989 to the present.
- Expansion of the terms of reference of COTSREC to include 'advise the Authority on the implications of research for management of the Great Barrier Reef Marine Park' *(this has been endorsed by the Authority).*
- The possibility of a risk-analysis study next year to ascertain likely socio-economic effects of another COTS outbreak on the GBR in the future. This work was done by Drs Tor Hundloe and John Parslow in the mid-1980s but there have been major increases in Reef-based activity since that time.
- Resurrection of the Geological Working Group (now chaired by Professor David Hopley of James Cook University following the retirement of Professor Don Kinsey from the Authority) to consider possible geological



Figures 1: *Recent trends in the mean numbers of COTS in the Cairns Sector based on information obtained through the AIMS broadscale surveys and GBRMPA's Reef User survey scheme (COTSWATCH). Note that the scales on the y-axes differ between plots.*

research (relating to incorporation of COTS skeletal elements in sediments) in the event of another outbreak.

- Revision to the Authority's policy on controlling COTS (see next item).

The next meeting is scheduled for 12-13 May.

LOCAL-SCALE CONTROLS AT MICHAELMAS REEF

Meanwhile out in the real world, in May 1993, staff on *Ocean Spirit* noted an increase in the numbers of COTS on some popular dive bommies at Michaelmas Reef (off Cairns). Mr Steve Moon, the General Manager of the Cairns-based *Ocean Spirit Cruises* expressed his concerns about the damage caused by the starfish and requested an urgent assessment of the situation. We were lucky enough to be able to enlist the help of both the AIMS Reef Monitoring Team and the Cairns Office of QDEH. In late June, some dedicated searches in the general area identified by the tourism operator revealed quite low numbers of starfish (13 and 3 respectively). However, there was more to come. Starfish numbers certainly built up over the following months and we requested a re-survey of the area in late October. This time, the AIMS team recorded 49 predominantly small COTS in a more extensive assessment of the southern end of Michaelmas Reef. In the meantime, the management of *Ocean Spirit Cruises* decided to apply for a permit to locally control the COTS. The Authority's long-standing policy of permitting local-scale controls in areas that are important to either science or tourism certainly applied in this case. Controls were finally initiated in November 1993, with the first effort yielding some 102 starfish over a two day period. An additional 20 starfish were collected the following week. A repeat effort in early January 1994 that concentrated on one of the previously cleared bommies resulted in a further 60 starfish being removed. This pattern of 'reinvasion' is consistent with the findings of past control efforts. None of the methods available

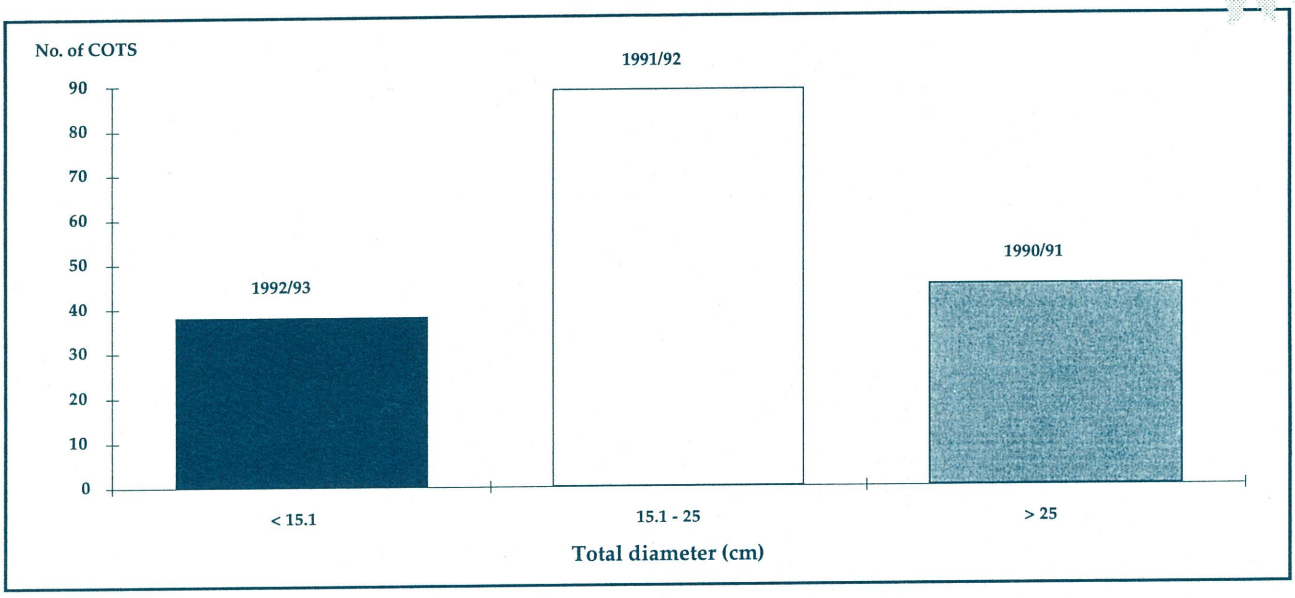


Figure 2: Size frequency histogram for total COTS collected at Michaelmas Reef (November 93 - January 94). Years given above individual columns refer to likely year of recruitment to the population.

today are anywhere near 100% effective. A number of starfish will always be missed, while other starfish migrate into cleared areas making it necessary to repeat controls at regular intervals. In this particular case, the chances of successfully protecting the popular dive sites in the area seem good, provided the current effort is being maintained.

Size-frequency information supplied to us by the operator clearly shows that at least three year classes were present in the area (see figure 2). There appears to have been a major recruitment some two years ago during the 1991/92 spawning season with somewhat smaller numbers of recruits in 1990/91 and 1992/93.

The situation at Michaelmas Reef highlights some important aspects of the COTS phenomenon on the Great Barrier Reef. Firstly, no one can afford to be complacent about this issue. The general conditions are again favourable for the starfish, particularly in the Cairns to Lizard Island Region. Coral cover in many areas is getting up to levels able to sustain larger populations of starfish. Furthermore, the normally inconspicuous juvenile COTS (< 15 cm) are now being seen on a number of reefs. This may well be an indication of things to come. It seems likely that a fair number of juveniles have successfully recruited to a series of reefs in this region. There is no reason to assume that Michaelmas Reef is unique in having a growing population of COTS. Results of surveys reported in CURRENT COTS suggest a fairly widespread increase in numbers on some reefs, but at this stage the numbers are well below outbreak levels.
All Reef users, including visitors, yachties, dive tourism operators as well as reef scientists need all be aware of the current situation. The potential importance of all the contributions to our Reef user survey scheme cannot be overstated.

GBRMPA LOCAL-SCALE CONTROLS RESEARCH

Dale and Kate Westwood's 'Research Vessel' *Banjora* continues her involvement in local-scale control trials at Bait Reef off the Whitsunday Islands.

The emphasis of our experimental trials has now shifted from identifying minimum dose levels of copper sulphate to finding and assessing more environmentally friendly alternatives.

Manual Controls

It has often been suggested that manual control methods such as removal by hand or cutting-up starfish underwater could be employed. We decided to trial two different ways of treating starfish - (i) cutting them into quarters and (ii) cutting their central disc open. Many starfish are well known for their ability to regenerate body parts following physical damage to their body. One of the aims of this experiment was to assess whether or not COTS could be killed using these rather severe physical treatments. Initially, the treatments were applied with the injured starfish subsequently being transferred to holding cages. The results were rather surprising. Some 16 days after the start of the experiment, some 73% of the total number of 'quarter-starfish' and 60% of the 'open-disc starfish' were still alive with no signs of wound infection or tissue decay. Logistics did not allow us continue to monitor their progress and the experiment had to be terminated. However, the fact that many starfish could survive these injuries

for extended periods of time has some important implications. There is a clear indication that even severe physical damage i.e. due to a predator or a diver's knife may not necessarily be lethal to the starfish. Our findings are similar to results obtained by Sweatman and Butler (unpublished report to GBRMPA) who recorded highly variable results after physically damaging COTS. They concluded that physical damage i.e. through predation, is only conclusively lethal if the whole starfish is removed. Up to 40% of adult COTS in some areas show evidence of having been attacked by predators.

Injection of alternative chemicals

We also conducted a small pilot study into the potential application of more environmentally friendly chemical compounds. A series of commonly available organic and inorganic compounds were trialed. A couple of fairly dilute acids did show some promise and further trials will need to be conducted in early 1994. At this stage, we are quite hopeful of being able to find a viable alternative to the use of saturated copper sulphate. Who knows, we might be able to present the good news in the next edition of *Reef Research.*

LATEST FINAL REPORTS

A number of GBRMPA / COTSREC funded research projects have recently been completed and copies of the final reports are now available from the Authority. However, as is often the case, these reports are rather large and bulky. If you are interested in obtaining a copy, please think about whether you require the full report or if a summary may be sufficient for your needs.

A preliminary study on the availability of dissolved organic matter to the nutrition of crown-of-thorns starfish larvae.

Tenshi Ayukai, Helen Sturmey and Lynn Swann, Australian Institute of Marine Science, Townsville

Based on his laboratory experiments John Lucas of James Cook University suggested that the availability of phytoplankton to the larvae of crown-of-thorns starfish (COTS) in Great Barrier Reef waters is usually too low to support their normal growth. In other words, the successful growth and recruitment of COTS larvae require exceptionally high phytoplankton concentrations caused by events like heavy terrestrial runoff. The results of in situ rearing experiments conducted by Randy Olson, however, have shown no evidence of starvation of COTS larvae under the low phytoplankton conditions common in Great Barrier Reef waters. The contrasting results of Lucas and Olson have raised some doubts about the traditional view that phytoplankton are the major nutritional source for COTS larvae.

It has been reported that marine invertebrate larvae derive a sizeable proportion of their nutrition from dissolved free amino acids (DFAA). Recent studies by Tenshi Ayukai and Ove Hoegh-Guldberg have confirmed that COTS larvae are capable of taking up DFAA, but at the same time have shown that DFAA, because of relatively low concentrations in the field, are unlikely to be the major nutritional source for COTS larvae. Their conclusions are, however, based on the DFAA data obtained in one snap-shot survey across the central Great Barrier Reef. At present, virtually no other data exist on the variability of DFAA concentrations in Great Barrier Reef waters.

In this project, water samples were collected (with the assistance of GBRMPA and Reef Biosearch, Port Douglas) for DFAA as well as total dissolved nitrogen (TDN) analysis at 5 stations between Port Douglas and Agincourt Reef over a 6 week period commencing 16 February 1993. DFAA concentrations observed were mostly very low, being below 0.1 micro mole l^{-1} except on three occasions. Such low DFAA concentrations are common in tropical and subtropical waters and are likely to reflect a close coupling between DFAA release and uptake in the water column. DFAA represent a very minor component of TDN (less than 1% of TDN) and no significant relationship was observed between these two parameters, rejecting the possibility of TDN concentrations being used as an index of the DFAA availability to COTS larvae.

Implications for science and management:

Because of the delay in delivery of sampling equipment the sampling was commenced well after the spawning season of COTS. The results presented in this report may, therefore, not allow to directly evaluate the importance of DFAA as the nutritional source for COTS larvae. However, DFAA concentrations measured are at least one order of magnitude lower than the compensating concentration of 1.8 micro mole l^{-1} for early stages of COTS larvae (bipinnaria) and 4.7 micro mole l^{-1} for later stages of COTS larvae (brachiolaria) reported by Ove Hoegh-Guldberg. At these levels the energy intake of COTS larvae from DFAA balances with the metabolic energy loss.

Reproductive biology of the crown-of-thorns starfish *Acanthaster planci*

R. C. Babcock and C. N. Mundy, Australian Institute of Marine Science

The crown-of-thorns starfish has a very high reproductive potential, achieving maturity rapidly, and producing very large numbers of eggs. Variability in reproductive success may have a considerable role in determining fluctuations in population size of *Acanthaster*.

The main objectives of this study were:

1. To determine the timing and extent of spawning;
2. To investigate the factors affecting fecundity and reproductive success;
3. To determine the effects of adult density on fertilisation success.

Both direct observations of spawning behaviour and studies of the gametogenic cycle of *Acanthaster* populations at Davies Reef indicate that spawning activity peaks in early December. The exact timing of reproductive events was not predictable, and spawnings were observed both day and night, and at various stages of the tide and times of the month. Spawning was observed until late January, but fewer starfish participated in these spawning events, and those that did were likely to have released fewer gametes than starfish spawning earlier in the season. Laboratory studies showed that eggs spawned after December had reduced levels of fertilisation, and more importantly, embryos were markedly less likely to develop successfully. The probable influence of these combined factors should be considered when assessing the potential role of seasonal factors, such as terrestrial runoff, on *Acanthaster* populations.

The large number of gametes released by individual *Acanthaster* allow populations of this animal to maintain high levels of fertilisation even when separated by considerable distances. Fertilisation was still measurable even when spawning animals were separated by up to 100 metres. In natural populations the majority of eggs are likely to be fertilised by animals which are located some distance from each other. Mathematical models of sperm diffusion and fertilisation rates have been applied to our results and have provided the ability to predict fertilisation levels for starfish separated by varying distances. These models will form the basis for future modelling that will allow estimation of minimum population densities able to initiate outbreaks. Results indicate that at outbreak densities fertilisation rates are likely to be high but that at lower densities fertilisation rates will be lower unless starfish aggregate for spawning.

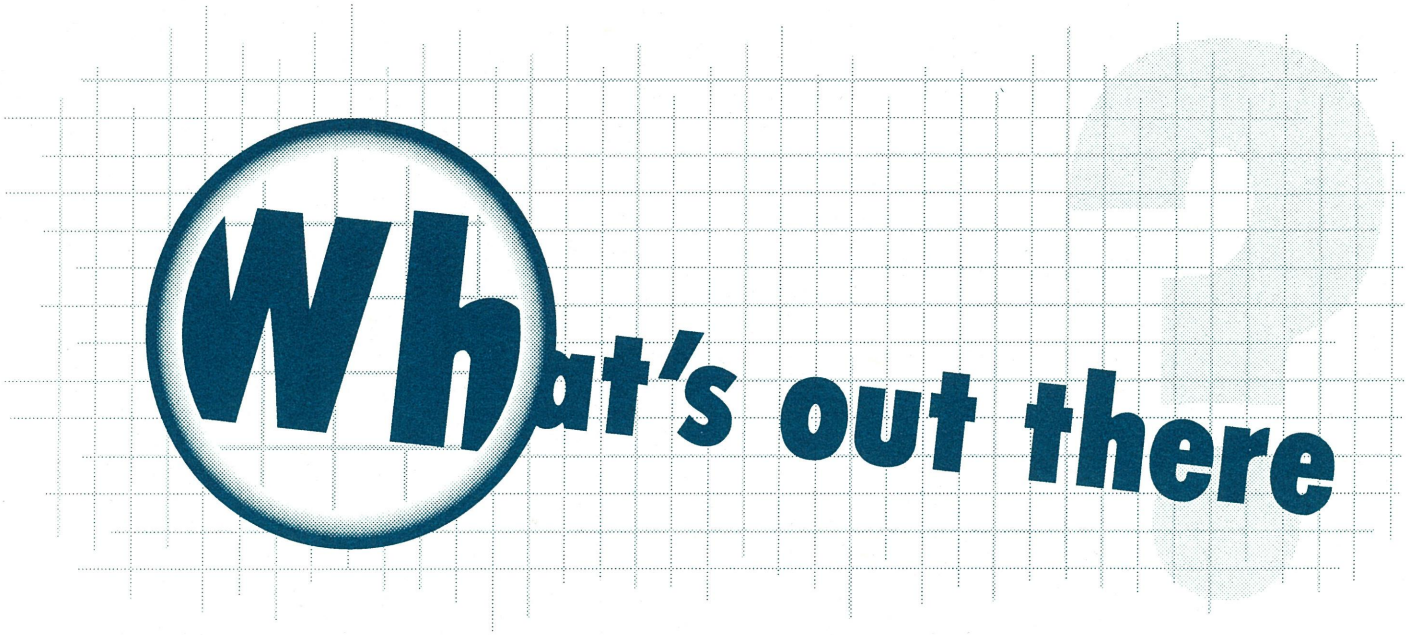
The temperatures and water currents of the Great Barrier Reef during crown-of-thorns starfish outbreaks since 1966

Dr Kerry Black (ed.), Victorian Institute of Marine Sciences

This study aimed to rigorously define the water currents and other physical oceanographic parameters that existed during the known history of COTS outbreaks on the Great Barrier Reef. The collection of measured oceanographic data obtained was used to hindcast currents in the central GBR since 1965. These data will also provide a basis for more exact testing of hypotheses related to larval dispersal and the location of COTS 'hot spots'.

The average sea surface temperatures along the GBR during the spawning season of the crown-of-thorns starfish (*Acanthaster planci*) were determined. Averaged over 30 years, the variation in temperature along the Reef between latitude 27 ^{o}S to 11 ^{o}S was from 25 ^{o}C to 29 ^{o}C. Laboratory measurements have indicated that larvae survive in temperatures from 24 to 30 ^{o}C, with maximum survival at 28 ^{o}C in sea water at salinities of 35 parts per thousand. The optimum temperature of 28 ^{o}C occurs at 16 ^{o}S. This latitude was previously identified by Moran et al. (1992) as the epicentre of initial starfish outbreaks. A suite of linear models was developed to allow low frequency along-shelf currents to be specified using readily available meteorological and oceanographic forcing data. These models reflect our understanding of regional hydrodynamics. They were calibrated using current meter data obtained from a transect across the central GBR in 1985 and validated using data from similar deployments in 1987 and 1990. Using as inputs coastal sea levels or, when available, offshore sea level differences, they can precisely predict currents over time spans of up to 25 years. The predicted currents are being used to drive advective models of COTS larvae dispersal and set boundary conditions for more complex numerical hydrodynamic current simulation models.

Analyses of hindcast coastal currents have revealed that self-seeding of the natal reef (or natal region) during periods of slow currents may be a critical factor causing primary outbreaks of COTS on the GBR. The dates of initial recruitment for primary outbreaks coincided with years when currents were slow throughout the pelagic dispersal phase. Slow currents result in high local retention of larvae with a corresponding potential for abnormally high natal recruitment. Secondary outbreaks at downstream reefs were also identified. However, the latter could not explain notable exceptions in the inter-annual outbreak migration along the GBR and the cause of initial infestations.



Scientific Hardware in the Sea - What's Happening

Hamish Malcolm

This follows on from the article ' What's Still Out There' - *Reef Research*, December 1993.

That article was targetted at researchers and as such did not stress the importance (well known to practitioners) of hardware used in scientific field studies, or that most of the equipment in the Marine Park is still being used by researchers. Considerable media comment ensued as a result of the article and focussed on the 'junk' aspect of research. Unfortunately, the other aspects of the article about how not to leave a mess received little mention. My concern was primarily with that hardware which was no longer serving a purpose, and to emphasise the importance of budgeting both time and money for demobilisation, prior to starting a field study.

This article is about the positive side: the ongoing efforts of the marine scientific community to remove hardware which is no longer being used, and to keep track of that which is.

Rod Forbes from the Marine Biology Department at James Cook University of North Queensland (JCU) is undertaking an audit of the hardware in Geoffrey Bay, Magnetic Island. This audit commenced in October 1993 and the locating phase should be completed when Rod gets a week underwater with good visibility. Once Rod has located all the hardware in Geoffrey Bay he will be in touch with researchers to determine what is still being used. It would be a great help to Rod if researchers with equipment in Geoffrey Bay could let him know the status and location of their gear. This will save him having to chase people down. Once the hardware still in use has been identified, the rest will be removed.

Orpheus Island is another intensively used research site and clean-ups are held in Pioneer Bay approximately every two years to remove derelict hardware. These clean-ups have involved dive teams including the Navy and the Army, and the JCU dive club. The next clean-up of Pioneer Bay is intended for sometime in the first half of 1994 using the Army dive team. Project sites are recorded on a map at the Orpheus Island Research Station to keep track of where hardware is deployed.

At the Heron Island Research Station (HIRS), researchers have to draw a map of their project site along with a list of how much

gear is emplaced, what it consists of, how long it will be there and how it could affect other researchers at that location. All researchers deploying equipment are required to label their hardware with identification and their Marine Parks permit number. When a research project has ended, the researcher has to remove the associated hardware. Actual sites are not visited by HIRS staff to ensure everything is removed, but they observe that the amount of gear pulled out adds up to that put in. Problems occur when long-term projects lose funding and the researcher cannot come back to maintain or remove the hardware. The cost and effort of removal then falls to the Research Station.

At the Lizard Island Research Station every piece of equipment that goes into the water is listed under the project to which it belongs. In addition all equipment is identifiable through the use of compulsory Research Station identification (ID) tags. These tags were previously made of plastic but are now being replaced by stainless steel washers with the ID number punched into the steel. It is anticipated that the stainless steel tags will last longer and enable ongoing identification at long-term project sites. Long-term projects can involve hardware staying in the water for years or even decades.

The managers at Lizard Island have a proprietary and responsible attitude to their area which ensures that hardware is removed after it is finished with. Woe betide any researcher who hasn't planned for demobilisation.
The researcher in charge of a project is responsible for the removal of the hardware belonging to that project when the field work is completed and the hardware is marked off the list as it is removed. There are presently only two lots of unclaimed hardware around Lizard Island and these will soon be removed.

The Australian Institute of Marine Science (AIMS) keeps log records and cruise reports which detail the equipment that has been emplaced or removed. One program which has involved considerable amounts of hardware being emplaced in the water is the Long-Term Monitoring Program. This has required the establishment of a large number of permanently marked sites to monitor changes in coral reef communities along the length and breadth of the Great Barrier Reef. Long-term programs such as this can require the hardware being left in the water for the duration of its life, which, for a star picket, may be 5 to 10 years. Maintenance of these site markers will be through replacement when needed, with the old marker being removed from the sea.

Normal protocol with students now working through AIMS is to stick with the few reefs that are commonly used by researchers and to remove hardware once the project has finished. It is the feeling at AIMS that work practices have improved over the last 20 years with better environmental consideration.

A Code of Practice regarding use of scientific equipment in the Marine Park is being jointly developed by the Great Barrier Reef Marine Park Authority and the CRC: Reef Research Centre. If any researcher wants input into that, please send Ray Berkelmans, (Research and Monitoring Section GBRMPA) your ideas.

Notwithstanding the above, there is discarded gear in the Marine Park and it is only through continued efforts by responsible scientists that it will be removed when appropriate and not allowed to increase in future.

ENCORE: THE RESEARCH PROGRAM

Andy Steven

In vol 2: 1 of *Reef Research* I gave a general outline of a major experimental initiative into the the effects of nutrint enrichment on coral reef organisms. Dubbed ENCORE (Enrichment of Nutrients on COral Reefs Experiment) this experiment is designed to quantify the fate of nitrogen and phosphorus within a coral reef, and assess their impacts on a variety of coral reef organisms. Coordinated by the Authority, 30 scientists from 8 Australian organisations are undertaking research encompassing cellular through to community level responses. In this article I will summarise the studies being undertaken and some of the expected outcomes of this research.

DESIGN

Research priorities are structured as 4 interlocking research programs, each addressing different aspects of coral reef response to nutrient enrichment (see table 1), and together forming a cohesive framework to integrate individual research efforts (see table 2). Program 1 investigates organism level responses to nutrient enrichment, and program 2 the consequences of these changes on population and community structure and function. Program 3 examines processes that regulate the supply of nutrients and how they may determine community level responses. Program 4 synthesises the previous 3 programs to develop a model for predicting the effects of nutrients on reefs, and tests the utility of some parameters as indicators of nutrient stress.

GBRMPA called for proposals from interested Australian scientists to undertake projects which address one or more of these research priorities. A number of international scientists were also contacted in the hope that they would be able to obtain grants to join the program. Currently there are 20 projects, 16 of which are being funded partly or wholly by GBRMPA (see table 2).

Program 1: Organism Level Responses

This program sets the context of the overall research program by firstly detailing the characteristics of nutrient uptake by algae, coral and other invertebrate organisms. Secondly it examines the metabolic, histopathological and structural responses of these organisms to increased nutrient supply. Parameters include nutrient uptake,

photosynthesis, respiration, metabolic products, growth, reproduction and nutritional status.

Algal Responses

Four projects (see table 2; 1, 2, 10 and 14) undertake aspects of algal response to increased nutrient supply. By necessity there is some overlap between parameters that are arbitrarily considered organism responses and those that are population/community responses. Three types of algae are being investigated: epilithic algal communities (EAC), coralline algae, and macroalgae.

Numerous studies have indicated that the EAC - a microscopic layer of small algae on all dead limestone surfaces and kept at this stage of colonisation by intense grazing - is the major source of food for the grazing food chains on a coral reef. Thus the EAC will be a major focus of attention for these studies, using as a substrate either dead *Porites* coral blocks or terracotta tiles. Caged and uncaged blocks will quantify the effects of grazing. Parameters include uptake measurements of nutrients, primary productivity and biomass, C:N:P ratios and alkaline phosphatase activity.

Macroalgae respond rapidly to nutrient enrichment, resulting in the overgrowth and shading of surrounding corals. Similar parameters as for the EAC are being measured on the same tiles and dead *Porites* blocks as the EAC, and also for one species, *Laurencia intricata*, in specially developed incubation chambers. Coralline algae contribute to the overall accretion of the reef by calcification, and its maintenance by cementing and consolidating the reef matrix. Photorespiration, growth and calcification are being measured using rhodoliths of *Lithothamnion kotchyanum*.

Coral and Clam Studies

Studies focus on four species of coral with demonstrable differences in sensitivity, morphology, polyp size and life history strategies. Six projects (table 2; 3, 4, 5, 6, 7 and 14) are being undertaken to examine a range of biochemical and physiological parameters. Previous studies on hermatypic corals and clams have indicated that a range of biochemical parameters are affected within a short time when exposed to a change in the nutrient environment. They may, therefore, be good indicators of higher availability of nutrients within the environment. Changes in metabolism, density of the symbiotic zooxanthellae and chlorophyll concentration per cell have been observed in previous studies. Parameters monitored include; nutrient uptake characteristics of inorganic and organic nutrients, photosynthesis and respiration, C:N:P ratios and ^{14}C and ^{18}O ratios.

Changes in the calcification pattern under conditions of nutrient enrichment are also apparent for corals and clams. Increases and decreases in the linear extension, decreases in skeletal density and misshapen aragonite structure have been documented. Various measures of calcification are being undertaken including linear extension, buoyant weight and instantaneous rates. Skeletal structure and ultrastructure are examined for disruptions, and strontium/magnesium ratios are also determined as an indicator of a changed nutrient regime.

Reproduction, a critical feature of any study of scleractinian coral communities, appears to have a poor tolerance to stress. However, little is known of the effects of elevated nutrients as a stress on coral reproduction. Changes in gametogenesis, spawning behaviour and timing, fecundity, fertilisation rates, larval development and settlement success are being monitored.

Program 2: Population and Community Responses

Effects occurring at the individual level are often inter-related, and the sum of these effects may be expressed at the population level. Reduced rates of growth, fecundity, and egg viability will reduce competitive ability and limit population production.

These effects on populations may in turn have repercussions on community structure and function. Changes of dominant or key species can be expected to affect community attributes such as species richness, niche breadth and overlap, the impact of predators and the partitioning of energy flow.

Algal and Coral population dynamics

Algae typically overgrow and out compete corals under conditions of nutrient enrichment. Coral and algae population dynamics and their interaction are being investigated in four projects (see table 2; 1, 10, 11 and 12). Parameters include settlement, abundance, and growth as well as the competitive interactions of algae, coral and other fauna.

Stereoscopic photography and video-monitoring is being used to record the growth and condition of individual corals and algae plates as well as the gross changes in benthic composition of the micro-atolls. Another project is examining interactions between hard corals, soft corals, sponges and algae, which have been placed together on panels, to see whether fertilisation changes competitive dominance.

Fish Studies

The ecology of herbivorous fishes in and adjacent to the experimental microatolls is being studied to quantify changes as a result of nutrient enrichment (see table 2; 9). For pomacentrid fishes (*Pomacentrus wardi*), territory area, feeding rate, defence rate and coral density are being monitored. For roving scarids and acanthurids density and size distribution changes will be quantified. Spawning of *P. wardi* is being monitored since fecundity is a good measure of fitness and it may be possible to detect changes in response to nutrient enrichment.

Infauna Studies

Abundant meiofauna in reef sediments consume much of primary production *in situ* resulting in generally low net community productivity. There have been few studies of tropical infauna responses to nutrient enrichment, in contrast to temperate systems where rapid changes in infaunal populations have been used as indicators of eutrophication.

Samples are collected from specified sediment areas for analysis of changes in population dynamics of infauna (see table 2; 13).

Community Productivity and Calcification

The original Kinsey and Domm (Kinsey and Domm 1974) experiment estimated a 25% increase in community production and a 50% decrease in calcification. Using similar techniques as the original experiment the major aim of these studies (see table 2; 14) is to determine whether N or P enrichment, or both, cause these changes. These results will then be compared with the measurements of primary production and calcification of individual coralline algae and corals.

Bioerosion Experiments

Bioerosion occurs extensively on coral reefs and is caused by the excavation and destruction of $CaCO_3$ substrates by organisms that bore and graze. Nutrient enhancement has been postulated to increase rates of bioerosion. Experimental substrates made of dead *Porites* coral, and a variety of other $CaCO_3$ substrates, have been exposed within the study microatolls. Changes in microborer substrates, rates of erosion and accretion on coral blocks and changes in polychaetes are being investigated.

Program 3: Integrative Processes

Research into the pathways and mechanisms of supply and retention of nutrients within coral reef systems is needed to assess the resilience of reefs to changes in water quality. Much remains to be done to relate fluxes between reef components to fluxes between the sediments and the water column. The relationships between dissolved and adsorbed sediment nutrients and dissolved water column nutrients needs to be assessed so that the relative contribution to nutrient

enrichment can be determined. The role of biological processes such as grazing and bacterial remineralisation in regulating the uptake and response of nutrients is important to quantify. Although the relative importance of abiotic and biotic processes in reef cycling is open to debate, both types of factors undoubtedly play a role.

Water Column Studies

Water column measurements of dissolved inorganic nutrients (PO_4, NH_4, NO_3) are being monitored with the objectives of determining what nutrient concentrations are being achieved, and determining whether the uptake time of the released nutrients changes through time (see table 2; 16). These measurements are obtained concurrently with community productivity and calcification estimates at spring low-tides near the middle of the day. Temperature salinity and light are recorded continuously with dataloggers. Measurements of dissolved free amino acids and organic carbon will be used to estimate organic pools of nutrients (see table 2; 19). Changes in the levels of dimethyl sulphide, widely used in temperate systems as an indicator of stress, are being measured and tested as a possible assay for reef environments (see table 2; 20).

Sediment Studies

Carbonate sediments containing both adsorbed and interstitial nutrients represent a significant sink/source. Nutrient pore water concentrations and sorbed nutrients are being measured in the sediment areas (see table 2; 17). Combined with the water column studies this information will be integrated to estimate total inorganic nutrient pools and flux rates between sediment and the water column.

Nitrogen fixation is an important component of nutrient cycling within coral reef ecosystems. Nitrogen fixation of heterotrophic bacteria, within the sediment and cyanobacterial mats, as well as epilithic cyanobacteria and those associated with macroalgae will be assayed to determine the flux of atmospherically derived nitrogen into the micro-atolls (see table 2; 18).

Pelagic Studies

Changes in phytoplankton are difficult to quantify because any increase in biomass over the period that the micro-atolls are moated is flushed away once the tide rises. Chlorophyll analysis and radio-tracer studies will be used to estimate productivity (Table 2; 14, 6).

Microbial Responses

Bacteria can act as potent agents of nutrient regeneration, carbon metabolism and secondary production. For example, bacteria may mineralise approximately 50% of the organic carbon fixed by phytoplankton. As a result of these activities dissolved and dead organic matter, mostly unusable by other organisms, is introduced into the metabolism of an ecosystem via grazing invertebrate consumers. Since the microbial loop is important for recycling carbon and nitrogen in the sediments on coral reefs it is important to monitor this aspect. Bacterial populations and productivity are being assayed at various stages throughout the project.

Fish Grazing and Caging Studies

The intense cropping activities of herbivores explains the paradox of low gross primary productivity, but high net productivity, observed on coral reefs. These activities represent a significant source of remineralisation of bioavailable nutrients. Indirectly, grazing enhances the recruitment of crustose coralline algae and reef building corals. Limited nutrient fertilisation may cause an increase in primary production of the fertilised microatolls, but it is not expected that this will cause any increase in the standing crop of algae, as was noted in the original Kinsey experiment. Grazing pressure from vagile fish is expected to be high enough at all times to reduce the standing crop of algae to natural levels.

To quantify this effect on the standing crop of algae, cages are placed over substratum and settlement plates to exclude grazers (see

table 2; 1, 10). While this will in no way mimic the effect of fertilising a significant proportion of a reef, it will give an indication of the relative effects of grazing in the different nutrient treatments. In addition, the studies of herbivorous fish (see table 2; 9) will yield information on the grazing patterns in the various treatments.

Light Reduction Studies

Eutrophication results not only in increased nutrient availability, but can lead to a reduced light environment caused directly by increased turbidity from sedimentation, and indirectly from increased phytoplankton concentrations, or overgrowth of macroalgae. The metabolic and physiological responses of corals in a reduced ambient light environment are being investigated within the micro-atolls (see table 2; 14)

Program 4: Modelling nutrient enrichment effects

Defining techniques which can predict when a reef is stressed is critical to the effective management of coral reefs. A controlled manipulative experiment such as ENCORE provides an ideal opportunity to validate a number of these techniques and assess their utility as management tools. Parameters which have potential include biochemical compounds, colour, growth and reproduction. Such parameters may provide an early warning in a situation where water quality is deteriorating and at a stage when damage to the organism or population is preventable.

A number of scientific and management models will be developed from the research programs. Process models will initially be developed to describe the key processes occurring including exchange and recycling, primary production rates and biomass change. Integrated models will be derived by integrating the process models to describe the interaction of relevant physical and biological processes. They will be reiteratively developed to provide predictive capabilities for the effects of nutrient loads. As such they will form primary level tools with which managers can assess appropriate management options.

OUTCOMES

The ENCORE Project will have four major outcomes:

1. **Scientific Database and A Basic Model**

The information from ENCORE will provide a scientific basis for developing appropriate water quality management strategies in coral reef environments, and may well identify a number of sub-lethal indicators of nutrient stress. The experiment is unique in the world as it is being undertaken before the effects of eutrophication have been clearly demonstrated on the Great Barrier Reef. This puts Australia in a strong position to develop sound management strategies, as well as providing a firm understanding of the fundamental principles of how coral reef systems function. Few other countries have the research base, or the facilities, to mount such a large and coordinated project.

2. **Scientific and Management Education**

In all, 8 Ph.D. students are already being trained in various aspects of the ENCORE project. In addition it is intended to conduct a number of scientific workshops on key areas of the project - respirometry of algae and corals, coral calcification, fertilisation design, microbial processes and management of nutrient inputs in coral reefs.

3. **Basis for Further Studies**

The site for the ENCORE project was chosen because of the unique set of features and history of One Tree Reef which make the experiment logistically possible. However, from the experience gained, it should be possible to contemplate similar experiments in other more difficult environments. It is planned to repeat the experiment at an inshore reef, where the effects of increased sediment loads are difficult to distinquish from those due solely to nutrient enrichment. With a better knowledge of sub-lethal indicators of nutrient stress, programs can be designed to assess the health of coral reefs both within Australia and, hopefully, in other countries.

4. Management of Coral Reefs

Outcomes 1, 2 and 3 will have important contributions to make to the management of coral reefs throughout the world at a time when they are exposed to increasing anthropogenic activities, including nutrients. In particular, it should allow the development of management models for use in the prediction of the impacts of nutrients on coral reefs. ENCORE will inevitably attract a large amount of international interest at a time when many coral reefs are threatened in South-East Asia and the Pacific Rim. Scientifically based management policies on issues of water quality are clearly dependent on studies such as ENCORE.

References

Kinsey, D. W. & Domm, A. (1974). Effects of fertilisation on a coral reef environment - primary production studies. *Proceedings of the second International Symposium on Coral Reefs*, Great Barrier Reef Committee, Brisbane. 1: 49-66.

1 ORGANISM RESPONSES	
ALGAE	**CORALS & CLAMS**
• Nutrient uptake • Productivity in epilithic algal communities • Productivity in macroalgae • Algal biomonitors of nutrient enrichment • C:N:P ratios of all algae • Alkaline phosphatase activity in macroalgae • Productivity and calcification in coralline algae	• Nutrient uptake • Productivity/respiration responses • Growth and biomass accumulation • Calcification & structural maintenance • Fecundity & gametogenisis • Histopathological and ultrastructural changes • C:N:P ratios • Secondary metabolites and other bio-markers • Behavioural responses
2 POPULATION & NET COMMUNITY RESPONSES	
POPULATION	**NET COMMUNITY**
• Algal settlement and community development • Coral recruitment & settlement • Interactions between settlement of algae, corals and other fauna, • Coral and algal population dynamics • Herbivorous fish population dynamics • Sediment infauna changes	• Net productivity/respiration • Net calcification/bioerosion • Gross benthic community changes • Net nitrogen fixation
3 REGULATING & REMINERALISATION PROCESSES	
BIOGENIC	**EXOGENOUS**
• Piscivorous and macro-invertebrate grazing rates • Bacterial and microbial remineralisation • Nitrogen fixation • Fluxes of dissolved organic matter	• Inorganic nutrient fluxes • Sediment remineralisation • Light attenuation • Effect of high light and UV-B radiation
4 PREDICTION & INDICATORS OF STRESS	
SCIENCE	**MANAGEMENT**
• Nutrient limitation models • Nutrient recycling models	• Sub-lethal stress indicators • Predictive assimilative capacity models

Table 1. *ENCORE Research Program Priorities*

1 **A.W.D. Larkum & K. Koop (SU)**: *The role of nitrogen and phosphorus in the growth of epilithic and coralline algae on a coral reef.*
2 **E. Drew (AIMS) & B. Dennison (UQ):** *The role of nitrogen and phosphorus in the growth of macroalgae on a coral reef.*
3 **D. Yellowlees (JCU), O. Hoegh-Guldberg (SU) & M. Johnson (UT)**: *The effect of enhanced ammonium and phosphate levels on a range of biological, physiological and biochemical parameters in corals and clams.*
4 **O. Hoegh-Guldberg (SU):** *The effect of nutrient enrichment on the energetics and growth of reef-building corals.*
5 **P. Harrison & S. Ward (USC):** *Effects of experimentally elevated nutrient levels on gametogenesis, fecundity and reproductive success in corals.*
6 **P. Harrison & D. Bucher (USC):** *Effects of experimentally elevated nutrient levels on coral tissue structure.*
7 **C. Wilkinson & S. Seddon (AIMS):** *In situ productivity of corals.*
8 **J. Coll, S. Duquesne & T. Tentori:** *Soft corals as indicators of a changed nutrient regime.*
9 **D. Booth (AIMS):** *Response of resident and transient herbivorous fishes to nutrient enrichment on microatolls in One Tree Lagoon.*
10 **C. Johnson & P. Fugelli (UQ):** *Effect of eutrophication on settlement and recruitment of corals, turf algae and crustose coralline algae on coral reefs.*
11 **R. McGill & A.D.L. Steven (GBRMPA):** *Photomonitoring and community responses to eutrophication.*
12 **J. Coll, S. Duquesne and T. Tentori (UCQ)**: *Effects of nutrients on competitive interactions between benthic organisms.*
13 **K. Koop (SU):** *Responses of benthic infauna populations to nutrient enrichment.*
14 **A.D.L Steven & D.W. Kinsey (GBRMPA):** *The effect of nutrient enrichment on net coral reef calcification.*
15 **P. Hutchings (Australian Museum) & B. Kiene (J.W. Goethe University):** *The impact of increased nutrients on rates and agents of bioerosion.*
16 **K. Koop & A.W.D. Larkum (SU):** *Temporal and spatial variability of selected water column parameters in the microatolls of ENCORE.*
17 **B. Dennison & J. Udy (UQ):** *Nutrient content of GBR sediments: Effect of water column nutrient enrichments.*
18 **J. O'Neil & D. Capone (University of Maryland):** *Effect of nutrient enrichment on nitrogen fixation in coral reef atolls.*
19 **O. Hoegh-Guldberg (SU):** *Effect of elevated nitrogen and phosphorus on the dynamics of dissolved free amino acids (DFAA) on microatolls.*
20 **G. Jones, A. Broadbent & M. Curran (JCU):** *Dimethyl sulphide as an indicator of stress.*

Table 2. *Summary of ENCORE research projects.* ***Institution abbreviations:*** *AIMS = Australian Institute of Marine Science; GBRMPA = Great Barrier Reef Marine Park Authority; JCU = James Cook University; SCU = Southern Cross University; SU = Sydney University; UCQ = University of Central Queensland; UQ = University of Queensland.*