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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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THE FRINGING REEFS OF MAGNETIC ISLAND:

BENTHIC BIOTA AND SEDIMENTATION

A BASELINE SURVEY

EXECUTIVE SUMMARY

Introduction

The Magnetic Quay development, at Nelly Bay on Magnetic Island, Queensland, is the first major development to impinge on marine environment around Magnetic Island. Insofar as the development may affect areas of the Great Barrier Reef Marine Park, it comes under the auspices of the Great Barrier Reef Marine Park Authority. The GBRMPA stipulated in 1988 that the construction of Magnetic Quay was conditional *inter alia* on the funding, by the developers, of baseline and environmental impact studies. This document is the report of the baseline study of the benthic biota and sedimentation on the fringing reefs along the south-east coast of Magnetic Island, including the reefs in Nelly Bay.

Methods

The baseline study was done between December 15, 1988 and February 23, 1989. Reefs were sampled in Picnic, Nelly, Geoffrey, Arthur, and Florence Bays. Within bays, fauna were sampled at 'stations' comprising two sites on the reef flat and two sites on the reef slope. Abundances of sessile biota (hard and soft corals, sponges, ascidians, and macroscopic algae) were estimated using four 20m fixed line intercept transects at each site. Sedimentation was measured using cylindrical sediment traps. Nine hundred corals of three genera were individually tagged and photographed as record of their condition prior to the commencement of the development. Algae were collected and weighed wet to estimate standing biomass of algae on the reefs.

Sampling sites were divided into those considered to be likely to be subject to any impact of the development and those expected to be immune from impact. All areas in Nelly Bay and those at the southern end of Geoffrey Bay (a total of six stations) were considered impact areas; six of the remaining stations were considered control areas, with the seventh (mid-way along Geoffrey Bay) being of uncertain status. Data were analysed by mixed-model analyses of variance and cluster analyses.

Results

Most corals were consistently significantly more abundant on reef slopes than on reef flats and algae were more abundant on flats than on slopes. Within reef flats, control and impact stations were generally similar, although two genera of corals (*Turbinaria* and *Montipora*) were more abundant at impact stations than at control stations. On the reef slopes, the designated impact stations differed significantly from the control stations in terms of percent coverage by corals and algae. Whilst some corals were more abundant at impact stations than at control stations, these were not rare species, and all were also relatively abundant at control stations. Several other corals were significantly more abundant at control stations than impact stations.

In general, overall coverage by corals was less on the reef slopes of impact stations than those of control stations. Within Nelly bay, coverage by most coral taxa was less at the northern end of the bay than at the southern end.

Six taxa were found almost exclusively in Nelly Bay, two algae and four corals. The algae were relatively abundant locally, but the four corals were extremely rare even within Nelly Bay. By contrast, 19 taxa were unique to control stations, five of them in reasonable abundances.

Sedimentation was greater in Nelly Bay than elsewhere, particularly on the reef slopes. Sedimentation was extremely labile, mostly dependent on prevailing weather conditions. On the reef slopes, rates of sedimentation were at times among the highest recorded for fringing coral reefs.

We also analysed the power of the sampling design used during the baseline study (and those suggested since) to detect, with reasonable certainty (90%), changes in abundances of corals during the development of Magnetic Quay. These analyses suggested that in the event of the development causing an environmental impact, we should be able to detect that impact if it resulted in changes in abundances as little as 20% or less for most groups of taxa analysed. We expect that effects of this magnitude would be detected whether such an impact affected Nelly Bay generally and the southern end of Geoffrey Bay, or was restricted to only the northern end of Nelly Bay.

Conclusions and Recommendations

We found no features of the biota of Nelly Bay that were unique among the reefs we surveyed. The greater abundances of some corals in Nelly Bay was not indicative of cause for special concern because those corals were also abundant in other (control) bays. Of all the stations surveyed, those at the north end of Nelly Bay were, with few exceptions, characterised by the lowest abundances of all taxa and, therefore, perhaps the least in need of special conservation measures.

We strongly recommend that the status of the biota be carefully monitored throughout construction and the early years of operation of Magnetic Quay. The GBRMPA is particularly concerned about the potential for enhanced sedimentation to deleteriously affect the corals in Nelly Bay during the construction phase. We stress that such effects will be minimised if every effort is made to avoid increasing natural sediment loads during calm weather. We have suggested the levels of sedimentation that, on the basis of the limited data available, should not be exceeded, but stress that these figures should be viewed as, at best, guestimates. Further baseline monitoring to improve the basis from which such recommendations are derived is strongly recommended.

ACKNOWLEDGEMENTS

This report reflects the efforts of many people. The majority of the field work was done by Robyn Cumming, Libby Moodie, Peter Stoutjesdijk, and Will Oxley. Tony Ayling, of Sea Research, led the field team and provided invaluable field support for the project. For their help with data entry and the tedious sorting of masses of algae, we thank Lou Dong Chung, Malcolm Choat, Cathy Lyon, and Stephanie Seddon. Karen Edyvane provided help with identification of algae and discussions about the baseline study. Ros Priest deserves special thanks for her tireless help with fieldwork, data entry and the production of figures.

We acknowledge the support and cooperation of the Great Barrier Reef Marine Park Authority, represented in this instance by Wendy Craik, John Gillies, and Peter McGinnity. Magnetic Keys Ltd, MacIntyre & Associates, and Linkon Pty. Ltd. also deserve thanks for their cooperation and their willingness to answer without hesitation all our questions about the proposed development.

The final design of this study and many of the issues discussed in this report benefitted greatly from the comments of numerous official and unofficial reviewers of the PER and design proposals. We have also benefited from discussions with Russ Babcock, John Collins, Terry Done, Vicki Harriot, David Hopley, Craig Mundy, Jamie Oliver, Mary Stafford-Smith, W. T. Williams, and Bette Willis. We thank them for their input. Provision of facilities and administrative services for this project were provided by James Cook University.

PREAMBLE

We have endeavoured to present the bulk of this report in relatively non technical language accessible to the general reader. Where we felt particular issues needed elaboration or the addition of technical details and procedural explanations, we have put such details into BOXES. In general the material in the boxes is not essential reading.

Details of analytical results have been relegated to appendices, as has a detailed review of the effects of sedimentation on corals. We also present a skeleton of what we would see as necessary for an impact assessment study of the environmental effects of the construction and operation of Magnetic Quay. In the table of contents, page numbers for figures and tables indicate the page immediately preceding the figure or table of interest.

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OVERVIEW

The development of Magnetic Quay is the first large scale commercial development to be undertaken on Magnetic Island that involves extensive modification of the marine environment. A major aspect of the development is the excavation of a 187 berth marina and access channel, and the construction of a large breakwater. These will impinge on a considerable area of the fringing reef adjacent to Bright Point, at the northern end of Nelly Bay.

This reef is included in the Great Barrier Reef Marine Park (Central Section). The progress of the development is therefore dependent upon the consent of the Great Barrier Reef Marine Park Authority, whose brief it is to ensure that such developments do not cause major impacts on the biota of the marine park. Accordingly, the GBRMPA has made construction provisional on the funding, by the developers, of detailed environmental monitoring of the fringing reef environments to assess whether the development of Magnetic Quay is likely to have any long-term adverse effects on those reefs. This document is the report of the baseline study of the fringing reefs along the south-east coast of Magnetic Island, including those in Nelly Bay where Magnetic Quay is to be built.

The fringing reefs of Arthur, Florence, Geoffrey, Nelly and Picnic Bays on Magnetic Island represent a diverse group of reef environments, supporting a rich assemblage of hard corals and other sessile taxa. The two strongest patterns in the distribution and composition of these assemblages were: A) Hard corals were more abundant and diverse on reef slopes than on reef flats at all bays; and B) reefs in Nelly Bay supported a different assemblage of corals than those at other Bays. Algae were more abundant on reef flats than on reef slopes and were slightly more abundant at the north end of Nelly Bay than elsewhere. We found no evidence of unique biotic features on the reefs at the north end of Nelly Bay that require special protection.

The organisms on these fringing reefs obviously thrive in the relatively turbid, high sediment conditions that are a feature of the coast of Magnetic Island. Sedimentation on the reefs during January and February 1989 was greater than that measured in most coral reef environments elsewhere in the world. The effects on the benthic biota of increasing rates of sedimentation beyond natural levels, however, is not well understood for any fringing reef environment. Suggested critical upper limits of tolerance of corals to sedimentation vary by an order of magnitude. The unequivocal statement of critical rates of sedimentation beyond which management action would be warranted is, therefore, difficult. We have recommended a set of values that should be seen only as first approximations, and should be subject to review in the light of the results of future fieldwork at Magnetic Island. We have also suggested a logical protocol for the sensible assessment of whether an impact has occurred at any time during the construction and operation of Magnetic Quay.

INTRODUCTION

Magnetic Island ($19^{o}9$'S, 146^{o} 50'E) is a large granitic island, $52km^2$ in area, 8km from the city of Townsville. Given its location and natural features, Magnetic Island is an increasingly important venue for recreational activities. The principal features in this context are beaches of relatively coarse granitic sand and the fringing reefs of the south-eastern shores. The fringing reefs comprise a series of bayhead reefs on the south-east coast of the island and a larger detached reef at its southern end (Hopley *et al*, 1983).

This report concerns the biological status of the fringing reefs of the south-eastern shore of the island. The most extensive and accessible reefs are those of Nelly and Geoffrey Bays. They comprise platforms of sediment with a biogenic framework and outer covering of corals and algae of varying thickness. The reefs extend seawards and are backfilled with sediment and coral debris. Examination of the structure of the reef platforms (Hopley *et al.*, 1983) suggests that these reefs have developed through an accumulation of non-biogenic sediments which has provided the foundation for assemblages of corals and algae. The reefs are exposed to the dominant south-easterly trade winds with relatively low wind speeds (Morrissey, 1980). Although the waters, especially those surrounding the southern reefs, are usually turbid, periods occur in which water clarity is such that underwater visibility reaches approximately 10m.

Since 1984, sections of these fringing reefs have been subject to marine park zoning conditions (Great Barrier Reef Marine Park Act, 1975). The most extensive fringing reef of the island, Geoffrey Bay, is now designated Marine National Park 'B' Zone and Florence Bay is designated Marine National Park 'A' Zone. The other fringing reefs discussed here (in Nelly, Arthur, and Picnic Bays) are zoned General Use 'A'.

The Magnetic Quay project comprises the development of resort and merchant facilities at the northern end of Nelly Bay and on Bright Point on the south-east side of the island (Fig. 1). The development also includes the construction of a 187 berth marina behind an extensive breakwater on the fringing reef and shoreward areas adjacent to Bright Point, at the northern end of Nelly Bay. This will require extensive excavation of the fringing reef at the north end of the bay. The excavation of the marina and construction of the breakwater will commence under terms of a provisional permit issued by the Great Barrier Reef Marine Park Authority consistent with the requirements of the Commonwealth Environmental Protection (Impact of Proposals) Act (1974).

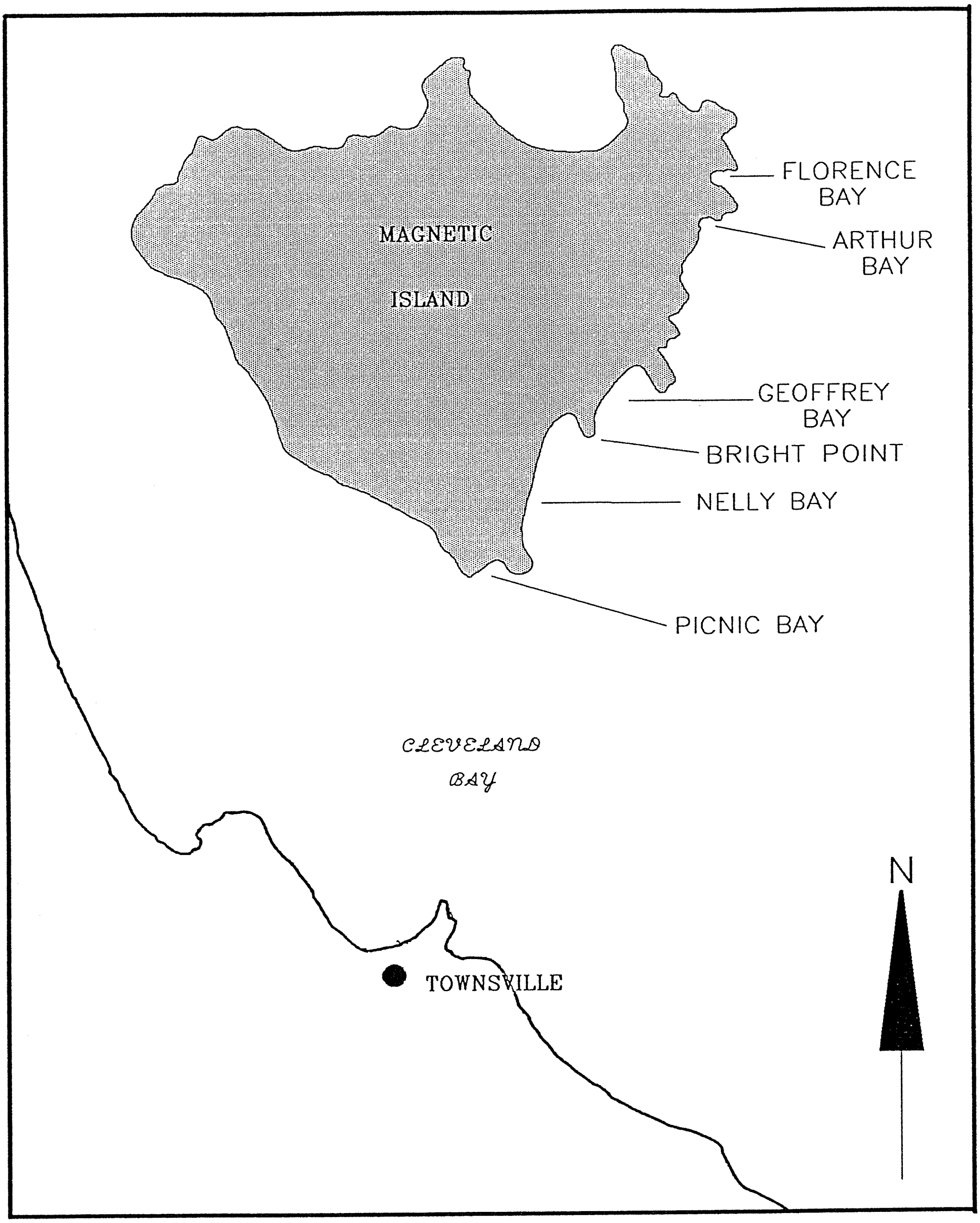


Figure 1

(A) Map (above) showing the location of Magnetic Island relative to Townsville and the locations of the bays sampled.

(B) Aerial photograph (next page) of the north end of Nelly Bay, Magnetic Island, showing the location of the proposed breakwaters and the area to be infilled (white lines). The reef flat inside the main wall will be excavated and an access channel will be excavated across the reef slope between the large and small breakwaters.

The permit conditions stipulate that the developers fund the survey of the marine environment at and adjacent to the site of the development to assess any impact on the fringing reef biota. The survey program involves a **baseline study** (Box 1; Green, 1979, pp. 68-73) of the fringing reef prior to the commencement of construction and an **impact assessment study** (Green, 1979, pp. 68-73) to be done during construction and to continue for up to three years after the commencement of commercial operations of Magnetic Quay. This document is a report of the baseline study of the fringing reef biological assemblages for the Magnetic Quay development.

BOX 1
SCOPE OF THE BASELINE STUDY

It must be recognised that baseline studies are descriptive by definition. They are not designed to, and therefore cannot, identify critical levels of impact or responses by organisms that might be used as triggers for management action. These data can only be provided by detailed and careful experimental studies that usually fall outside the scope (and budget) of a baseline study (see Choat, 1988).

What the baseline study does provide is a detailed description of the environment and biota prior to development. These data should be used for three purposes:

1) to examine whether there are any special characteristics of an area of potential or certain impact that warrant special conservation measures;

2) to compare with data collected during and after construction of the development to assess whether an impact has occurred;

3) as pilot data on which the impact assessment study can be designed to ensure an optimum balance between logistic and cost constraints and the ability to detect potential impacts of specified magnitude. The logical series of steps appropriate to assessing whether development is having some impact will be discussed later (Box 8).

Prior to the execution of this baseline study a document describing the design of the study was circulated for public review as part of the PER requirements (Table 1). The design was examined by members of the scientific community, including officers of the Great Barrier Reef Marine Park Authority. The major biological concern expressed by the reviewers was the potential impact of the development on the assemblages of corals on the fringing reefs. In particular, the potential effect on survivorship of corals of increased sedimentation and turbidity that could occur during the construction phase attracted considerable attention.

The emphasis of this baseline study largely reflects these concerns, and most effort has been directed towards assessing the status of coral assemblages and obtaining estimates of rates of sedimentation along the south-eastern fringing reefs of Magnetic Island. We have in places broadened the scope of the study and quantified the abundances of algae and some demersal fishes for future

SEQUENCE & TIMETABLE OF DESIGN REVIEW & CONTRACTUAL ARRANGEMENTS OF THE BASELINE STUDY

July | Aug | Sept | Oct | Nov | Dec | Jan | Feb | Mar

Design	Design Baseline Study	July
	Incorporate baseline study into PER	Aug
Design Review	Review Process of PER	Sept ▲- - - - - - - - - - -▲ Oct
	Briefing re. PER Review Comments GBRMPA/JCU	Oct
	Response to Comments	Nov
	Additional Design Requirements	Nov
Permits Finance & Contractural Arrangements	Discussion of Budget	Oct
	Acceptance of Budget	Nov
	Discussion & Review of Contract	Nov
	Issue of Conditional Permit	Dec
	Financial Guarantees	Dec
	Contract JCU/GBRMPA Accepted	Dec

Table 1

Timetable of major events of the baseline study.

SEQUENCE AND TIMETABLE OF FIELD ANALYSIS AND WRITING COMPONENTS OF THE BASELINE STUDY

Nov Dec Jan Feb Mar

Organisation Material & logistics

▲
Material for field survey, sediment traps & coral tags

Field Work

▲-------------▲
Transect Establishment

▲----▲
Sediment Trap Deployment

▲-----▲
Coral Tagging & Photography

▲----▲
Algal Collections

▲---▲
Profile diagrams & Nelly Bay Site examination

▲-------▲
Sediment Sampling

▲
Remeasuring Selected Line Transects

Analysis & Writing

▲---------▲
Data Entry

▲-----▲
Preliminary Analysis

▲---------▲
Main Analysis

▲---------▲
Writing & Report Preparation

Table 1 cont'd.

reference. The bulk of what follows, however, concerns the structure of coral assemblages and rates of sedimentation.

The central brief of the biological survey, therefore, was to identify patterns in the coral biota of the Magnetic Island fringing reefs and assess changes in these patterns attributable to the Magnetic Quay development. The baseline study was the initial phase in the survey and required the following features.

Firstly, the establishment of a series of study sites on the reefs and the description of their biotic characteristics was required. The sites had to be clearly identified so that the corals and associated biota could be measured consistently and repeatedly during the construction and operational phases of Magnetic Quay. They also had to be representative of the major habitats and topographic locations both adjacent to and distant from the area of development. Most importantly, the sites were deployed according to a design which will allow investigators to distinguish between the consequences of events unrelated to the development, such as natural events, and those attributable to the impact of the construction and/or operation of Magnetic Quay (Box 2, 3).

BOX 2
IMPACT ASSESSMENT

The unambiguous assessment of anthropogenic environmental impacts has two major requisites. One, that the places at which impact is anticipated be compared contemporarily with similar places that are not expected to be influenced by the cause of impact (control sites). Two, that the status of both impact and control sites prior to the impact occurring be documented as a reference point from which impact induced changes can be measured. Green (1979) suggested that single impact and control sites were satisfactory for such comparisons. Other authors have pointed out, however, that such a design provides insufficient grounds on which to assess unequivocally whether a change in the environment near a development was due to that development (Hurlbert, 1984; Millard, 1987; Millard & Lettenmaeir, 1985; Millard, Yearsley and Lettenmaeir, 1986). With only single control sites, the impact-control comparison is inherently confounded with potential natural variability between two random sites (Hurlbert, 1984; Sokal & Rohlf, 1981; Underwood, 1981). These authors have stressed the need to sample at more than one impact and control site to guard against making erroneous decisions about environmental impacts (Box 3).

In most instances, it is not possible to replicate impacts. Replicate sites of anticipated impact are, therefore, essentially sub-samples of a single treatment at one place and one time (Hurlbert, 1984; Stewart-Oaten, 1986). Nevertheless, replication of sites around an impact is essential to provide some estimates of variation and spatial extent of impact. Control sites, however, can be arbitrarily placed and legitimately considered replicate estimates of 'normal' environmental conditions over a range of areas believed to be similar to the place of development. Even when multiple control sites are compared with one or more impact sites, the inference of an impact from differences between impact and control sites is based only on correlation, but the probability of a significant result (i.e. inference that a significant impact has occurred) occurring by chance alone is far smaller when multiple control sites are sampled. These constraints have several implications for analysis of data and inference of an impact (Box 3).

BOX 3
TYPE I & TYPE II ERRORS

Clearly it is economically and politically desirable to minimise the chance of incorrectly asserting that an impact has occurred (a Type I error), but it is environmentally essential (and also economically and politically desirable) to also minimise the chance that a real impact goes unnoticed (Type II error) (Andrew & Mapstone, 1987; Bernstein & Zalinski, 1983; Rotenberry & Wiens, 1985; Toft & Shea, 1983;). Conceptually, the probability of making either error with respect to an impact of development is great when only single control and potential impact sites are sampled. This alone is ample justification for sampling several control sites. When comparing the average condition or change in condition over time at control sites with the impact sites, an assumption is implicit that the (single) source of impact has affected all impact sites. Given that such sites will likely not be similar in terms of their proximity to the development, this assumption may be incorrect and would then increase the likelihood of a Type II error. Thus, it is also desirable to compare each of the impact sites with the average of all control sites to ensure that localised impacts, at a scale smaller than that which encompasses all impact sites, might be detected. These comparisons are known *a priori* and any statistical procedures should recognise the advantages of making such planned comparisons. In this baseline study, we have sampled at several places of potential impact and several control locations to minimise, as far as logistic constraints would allow, the possibility of committing either Type I or Type II errors. The form of analyses used in this study and those recommended for the impact assessment programme will be discussed later.

Secondly, the deployment of arrays of sediment traps to estimate the natural rates of sedimentation on the fringing reefs was necessary. These traps were also arranged according to a design that allowed estimation of sedimentation in major habitats both near to and distant from the area of development.

Thirdly, a large number of coral colonies were individually tagged to allow the tracking of the condition and survivorship of known entities, from the baseline through the construction and operational phases of the project. Corals were tagged at a range of sites at varying distances from the development.

In this report we describe the patterns in abundances of benthic biota on the Magnetic Island fringing reefs and the natural rates of sedimentation on those reefs. On the basis of these results, we recommend a set of procedures for the impact assessment study that will allow the detection of relatively small impacts of the Magnetic Quay development on the fringing reef biota.

During the construction phase of the development, it is anticipated that any environmental disturbance will be manifested principally as changes in the pattern and rate of sedimentation. The design of the baseline and initial impact assessment studies reflects this likelihood. During the operational phase of the development, the influence of potentially enhanced levels of nutrients and pollutants is likely to be of greater concern. This possibility will be recognised in the design of the later stages of the impact assessment study. Programmes designed to assess these potential impacts on water quality will be designed and carried out by the Australian Centre for Tropical Freshwater Research in parallel with studies of impacts of development on benthic biota.

MATERIALS AND METHODS

SAMPLING DESIGN

The baseline study was designed to describe spatial patterns in the abundances of benthic sessile flora and fauna, and variation within and among reefs in five bays along the south-east coast of Magnetic Island. Preliminary surveys indicated that reefs along the south-east coast were qualitatively similar to each other but distinct from other reefs around Magnetic Island. Reefs around the north-western shore of Magnetic Island (Horseshoe Bay to Cockle Bay) were found to be mostly granite reefs or shallow mud-flats and were fundamentally different in physical and biological structure from the fringing reefs along the south-eastern side of the island. They were therefore considered inappropriate for consideration in the baseline and environmental impact studies for the Magnetic Quay development.

For the remainder of this document, 'station' will be used to refer to a tract of reef extending perpendicularly to the shoreline from the shallow reef crest to the outer edge of the reef slope and approximately 200m wide. Within each station, we haphazardly chose two sites within each of two depth strata (on the shallow reef flat; and deeper, on the reef slope). Replicate sampling units (transects, quadrats, sediment traps) were placed haphazardly within each site (Fig. 2). A total of 14 stations were sampled, allocated as shown in Figure 2.

The sampling design proposed originally (following review of the PER) was modified in four ways. Firstly, the fringing reefs at Florence Bay and Arthur Bay proved too small to support two complete stations, as originally proposed. Consequently, only one station was sampled at each bay (Fig. 2), and sites were well dispersed within the bays.

Secondly, the fringing reef in Picnic Bay was unlike those at the other bays and consisted only of a turbid, coral-poor reef flat area with little or no reef slope. The peninsular of reef extending from the southern end into the middle of the bay, however, was superficially similar to the fringing reefs in other bays and all sampling (two stations) in Picnic Bay was done on this reef (Fig. 2).

Thirdly, we have surveyed an extra station at the site of the proposed development (Nelly Bay station 0) to verify whether the area slated for excavation has any biological characteristics worthy of special attention (Fig. 2).

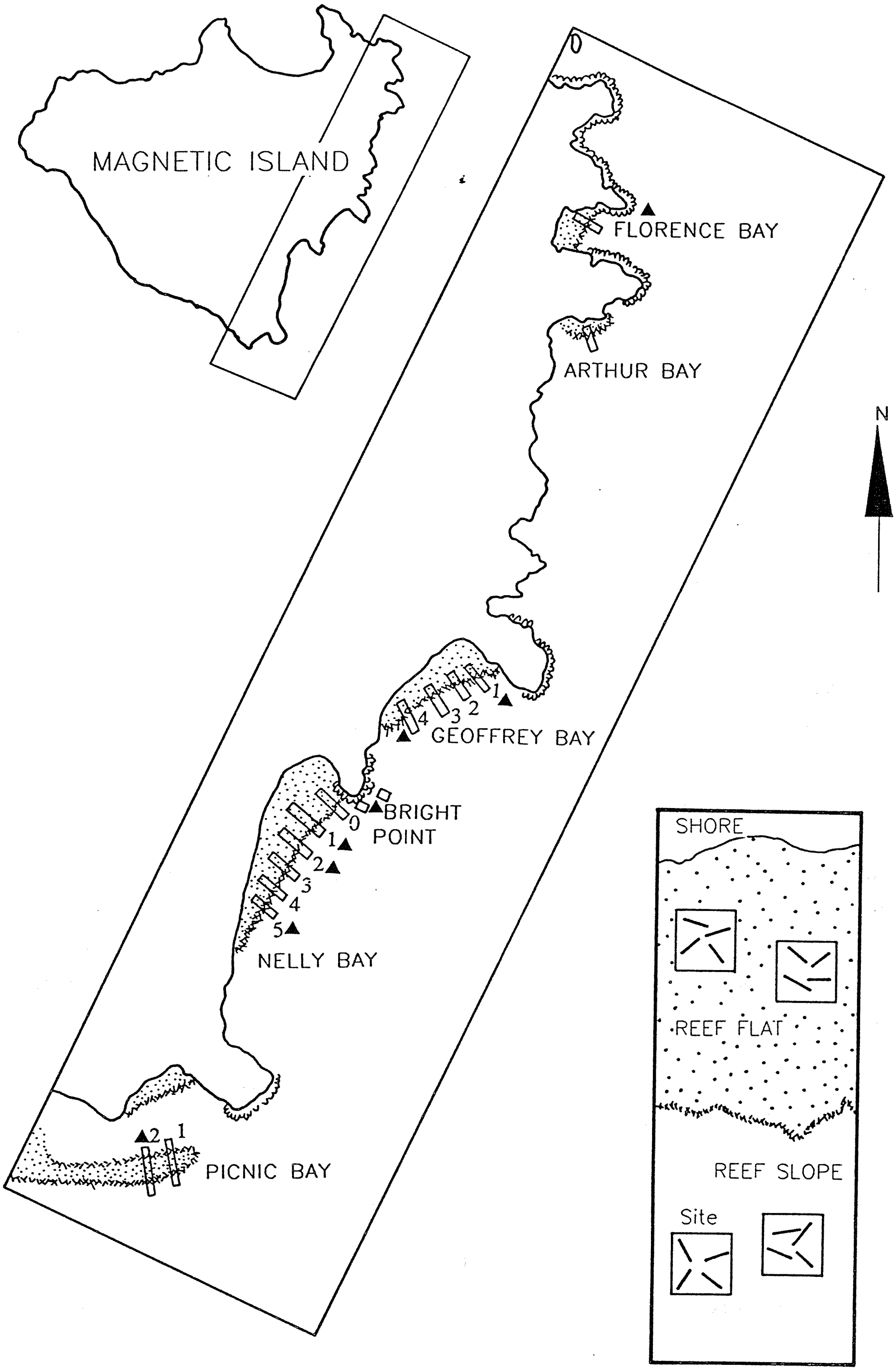


Figure 2

Detailed map of the bays sampled, showing the approximate locations of sampling stations. Numbers beside stations in Geoffrey, Nelly and Picnic are those used in the text in reference to these stations. Small open squares indicate the location of two sites at Bright Point. Triangles indicate the stations at which corals were tagged, sediment traps were deployed, and algae were collected (see text). The insert at lower right shows schematically the spatial arrangement of sites (squares) and transects (darker lines) at each station.

Finally, in both Nelly Bay (stations 0, 2, & 5) and Geoffrey Bay (stations 1 & 4), we surveyed pairs of transects oriented parallel with the shoreline at 50m intervals across the entire width of the reefs. These profiles provided a quantitative faunistic context within which to consider the data-set defined by the more structured sampling design. Water depths and times of sampling were also taken at each point across the reefs to allow approximate topographic profiles of the reefs to be drawn.

In summary, four stations were identified within Geoffrey Bay, and six were defined within Nelly Bay. Stations were equi-spaced along the reef in each bay. Two stations were surveyed at Picnic Bay but only a single station could be fitted onto the reefs at each of Arthur and Florence Bays. In addition, in accordance with specific requirements of the GBRMPA, benthic fauna and flora were sampled to the north of the proposed access channel for the marina. There was no effective reef crest between the channel and Bright Point, and so only deeper reef-slope sites were sampled to the north of the proposed access channel off Bright Point.

The above stations were chosen to represent areas of potential impact of the proposed development (impact stations) and areas expected to be free of impact (control stations). On the basis of preliminary hydrographic information (Parnell & van Woesik, 1988) and in view of their proximity to the proposed development, stations 1-5 in Nelly Bay (Fig. 2) and the southern station (4) in Geoffrey Bay were considered potential impact areas. These were the stations most likely to suffer any effects of the proposed development at the northern end of Nelly Bay. Note that station 0 in Nelly Bay will be dug up when construction begins.

The two stations nearer the north end of Geoffrey Bay (#1 & 2) and in the other three bays (Picnic Bay, Florence Bay, and Arthur Bay) were considered to be sufficiently hydrographically and geographically isolated from the area of development to have little likelihood of suffering any impact. These stations will be considered control stations against which the effects of development on reefs in Nelly Bay and Geoffrey Bay will be assessed.

Station number 3 in Geoffrey Bay (Fig. 2) was considered of uncertain status with respect to impact, and was sampled so that if an impact becomes evident at the southern end of Geoffrey Bay, the extent of that impact along Geoffrey Bay could be assessed against pre-existing conditions. Note that the sites off Bright Point are also likely to suffer any effects of development but do not fit into the general analytical framework of the rest of the sampling programme. Results from those sites will thus be compared to other stations after analysis.

FIELD WORK

BENTHIC FAUNA AND FLORA

Percentage Cover by Sessile Organisms

All of the above stations were sampled for cover by sessile fauna and flora using four replicate 20m line intercept transects at each site (i.e. 16 transects per station). Line transects were used in preference to belt transects because of the logistic impossibility of sampling with reasonable replication at a large number of sites using belt transects or large quadrats.

The location of each site was referenced to bearings on Magnetic Island and marked with a 1.4m star picket driven into the reef. The starting point of each transect was referenced to that picket by bearing and distance measurements, and the direction in which each transect ran from the starting point was also recorded. Each transect has been marked by 1.0m lengths of 2cm diameter reinforcing rod driven into the reef at five metre intervals. A numbered tag was attached to the first stake of each transect, and rough maps indicating the locations of transects at each site have also been drawn. These details will allow the unambiguous relocation of all 216 fixed transects. Relocation of sites and transects has proved reasonably easy in fair weather, usually taking no more than 15 minutes for experienced personnel. Note that the transects at station 0 in Nelly Bay and those surveyed for profile data were not marked.

Fibreglass tapes were used to measure the transects and the starting position and intervals under the tapes of all sessile organisms. From these data, we calculated estimates of percent coverage by each taxon on each transect. In all cases, organisms were identified to the lowest taxonomic level possible on the basis of field observations. Where pooling of lower taxa was necessary for analyses, such pooling was done after the data had been recorded in a data base and not in the field. Pooling of hard corals for analysis followed taxonomic affinities, as described by Veron (1986) and pooling proceeded until a group was represented in more than 50% of transects. In general pooling to at least family level was required because of low frequencies of occurrence of many species or genera. The frequencies with which all taxa occurred on reef slopes and reef crests were collated to provide distributional information that would otherwise have been obscured by pooling data on taxonomic grounds.

Some reviewers of the PER expressed concern that 20m line transects were too short to adequately sample the fauna of the reefs with sufficient precision for useful analysis. Analysis of data from the fringing reefs at Cape Tribulation indicated that increasing transect lengths from 20m to 30m improved precision little for most taxa relative to the increase in costs of surveying the longer transects. Transects of 30m length were surveyed at the beginning of this study (at Florence Bay) and data from the first 20m were compared to those from the whole 30m to verify whether this conclusion was appropriate for work on fringing reefs at Magnetic Island. At Magnetic Island, the length of transects that could be used was also partly restricted by the limited amount of reef present at several of the bays, and it was not considered feasible to sample with transects longer than 30m.

Biomass of Algae

Some reviewers and the GBRMPA expressed concern about the potential importance of overgrowth of corals by macro-algae whose growth might be enhanced by changes in nutrient conditions as a result of the development (Comments on the PER). There is a strong seasonal component to the growth of such algae, but it was nevertheless desirable to estimate the relative abundances of algae in all bays prior to the commencement of the development. Abundances of algae assessed by line-intercept techniques measured only the area of substratum covered by the basal holdfasts of upright species (principally *Sargassum* spp.) or that covered by foliose species. To estimate standing crop and species composition of algae, four 1m x 1m quadrats (Vakamoce, 1987) were haphazardly placed at each of several sites, and all macro algae collected within them. These samples were then sorted to genus and, where possible, to species, and each taxon was wet weighed. Samples of algae were not collected from all stations: collections were done at one station in each of Florence and Picnic Bays, two stations in Geoffrey Bay (1 & 4), three stations in Nelly Bay (1,2, & 5), and the sites off Bright Point (Fig. 2).

Tagged Corals

There was considerable emphasis by the GBRMPA and reviewers of the PER on the use of 'condition' of corals as an early indicator of deleterious effects of the proposed development on the biotic environment. Researchers at James Cook University, however, suggested that monitoring the reproductive condition of corals would be unlikely to provide an adequate or rapid assessment of physiological stress (Babcock, Oliver, pers. comm.). The initial research required to define a sound sampling programme to assess reproductive condition of corals, and the 1-3 month delay between collecting samples and obtaining useful data, would undermine the potential usefulness of this technique as an 'early warning system'.

It has been suggested, however, that the visual assessment in the field of such characteristics as mucus production, bleaching, the presence of lesions, and death of parts of colonies would provide a logistically feasible and quickly presentable measure of the effects of the development on the physiological behaviour of corals (reviews of PER). Accordingly, we individually tagged a number of corals at each of several control and impact sites. Their behaviour/'condition' can thus be monitored during the development of Magnetic Quay.

Corals have been tagged at the same sites at which sediment traps were deployed and algae collected (Fig. 2). As originally proposed, 10 apparently healthy, intact colonies of each of three species were tagged at each site and each colony was photographed with its identifying tag and a linear scale visible in the photograph. A problem arose, however, in that we were unable to tag the same species at all sites. In particular, the coral fauna on the reef slopes was consistently different from that on the flats. Consequently we have tagged one set of species on all reef slope sites (*Turbinaria mesentarina, Montipora aequituberculata, and Acropora willisae*) and another, more disparate group on the reef flats. The above three genera are represented in the tagged corals on the reef flats, but to tag ten colonies in each we have had to include several species of each genus. Where possible, we have tagged on the flats at least some individuals of the species tagged on the reef slopes and in all cases where other species were tagged, their growth-form was similar to the above species.

During the development of Magnetic Quay, the corals near the development can be resurveyed at short intervals and any signs of physiological stress recorded. If these corals show signs of stress, corals at control sites also should be surveyed for similar signs of stress. Such assessment will be qualitative only. At longer intervals (e.g. 6-12 months) all (900) corals will be re-photographed and their status compared to that during the baseline study. Some quantitative analysis of changes in coral 'condition' will then be possible, for example comparisons of mean areal proportion of living tissue among stations, depths, sites and times.

Demersal Fish

There was no requirement in the brief for the baseline study to document the abundances of fish on the above reefs. We have, however, recorded the abundances of a few species of sedentary pomacentrid species that are closely associated with the substratum and might be expected to respond to long term changes in its composition. Fish were counted along 20m x 4m strip transects centred on the fixed line transects at most sites. Because of constraints of time, fish were not counted at either Florence or Arthur Bays and only two strip transects per site were surveyed at other stations. These data have been collated for future reference, but will not be presented in this report.

SEDIMENTATION

There are two main aspects of sediment transport and deposition which might affect corals:

1) turbidity of the water, and

2) benthic accumulation of sediment.

Enhanced turbidity will reduce light levels near the substratum on which corals grow, and sediment accumulation on the surfaces of corals may result in smothering of those corals. Entrainment of sediment near the substratum may also result in abrasion of corals.

As originally proposed, rates of sedimentation were measured adjacent to the area of development and at control sites using cylindrical sediment traps. Sediment traps were 50mm inside diameter and 150mm long (Fig. 3), and were fastened to vertical stakes (reinforcing rod, 1.2m long) such that the tops of the traps and stakes were 300mm above the substratum. Baffles were glued into each trap (Fig. 3) to reduce the re-suspension of sediments through turbulence in the traps and to exclude larger pomacentrid fish from nesting in the traps. The baffles did not prevent small blennies from nesting in the traps, however, and these fish may have excavated some sediments from the traps. Records were kept of the traps in which blennies were living to allow analysis of any relationship between occupation by blennies and amounts of sediment in traps.

Four sediment traps were deployed at each site at each of the seven stations where algae were collected and on the reef slope off Bright Point (Fig. 2). Traps were cleared at 7-10 day intervals on four occasions during the baseline study: January 19-21; January 29-30; February 6-7; and February 13-14, 1989. Collected sediments were dried and weighed in the laboratory.

Relation between Turbidity and Sedimentation

Measurements of sediment deposition in traps estimate rates at which sediments fall out of suspension and could accumulate on the surface of corals. Measurements of secchi depth and suspended solids in the water column provide information on water turbidity.

Secchi depth readings and measurements of suspended solids were obtained on two occasions (2 February 1989, and 9 February 1989) at sites where sediment traps were deployed. These estimates were used to examine the relationship between instantaneous measurements of turbidity of the water and weekly-averaged rates of sediment deposition in order to determine whether average rates of deposition of sediment could reliably be inferred from daily measurements of turbidity.

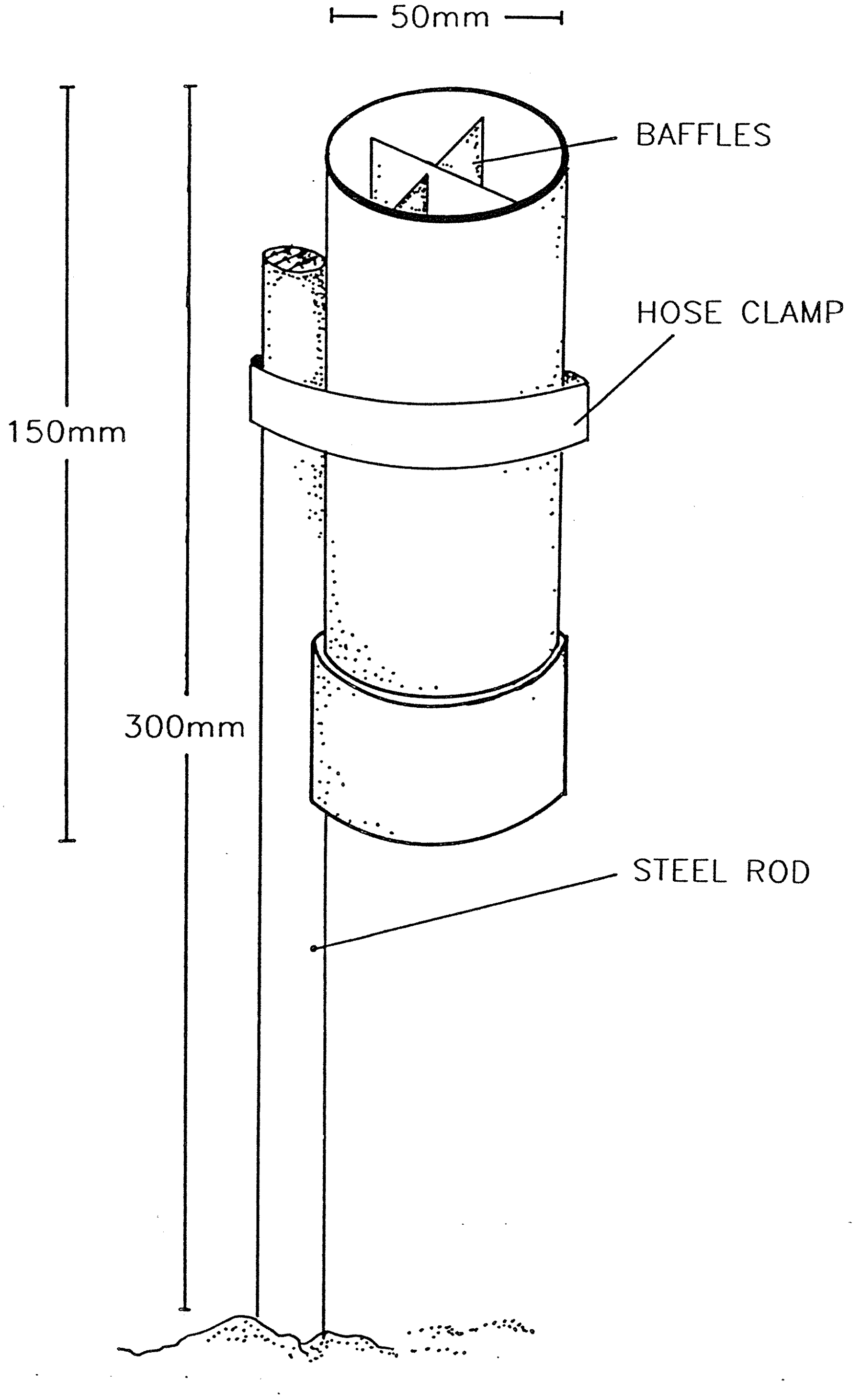


Figure 3

Diagram of a sediment trap. Note that the top of the support stake was below the top of the sediment trap, and baffles were placed in the traps to prevent resuspension of sediment and occupation of traps by pomacentrid fish. Baffles did not extend to the tops of the traps.

TIMETABLE

The baseline study commenced on 15/12/88, later than anticipated because of delays in obtaining ministerial approval for the GBRMPA to proceed with the contract. The timetable for the entire baseline is shown in Table 1.

ANALYSIS OF DATA

BENTHIC COVER

Multi-variate Descriptive Analyses

The main activity in the baseline study of benthic biota was the survey of line transects, which provided detailed and complex information about the biological structure of the fringing reefs. An important preliminary objective of the study was to determine the extent to which reefs at different localities or depths were characterised by common assemblages of benthic organisms.

As a first step in identifying patterns of structure and occurrence in the reef assemblages, we used exploratory analyses which grouped stations, habitats, sites, etc. on the basis of their shared biotic features. These analyses proved useful in two ways. Firstly, they provided a community-wide overview of the fringing reefs and their similarities and differences. Secondly, they verified whether our proposed structured sampling programme adequately represented the major natural patterns in assemblages of organisms on these reefs.

Naturally occurring patterns in the benthic communities of Florence, Arthur, Geoffrey, Nelly and Picnic bays and Bright Point were explored using cluster analysis. Two separate cluster analyses were performed, on the benthic transect data from all stations (a total of 58 sites, including those at station 0 in Nelly Bay) and on the reef profile data from Nelly and Geoffrey bays (five profiles with a total of 34 cross-reef sites at 50m intervals). Dendrograms generated by the cluster analyses highlighted natural groups based on biological similarity between sites.

The Euclidean Distance dissimilarity measure and Wards Incremental Sums of Squares fusion strategy, were employed for the cluster analyses, using the pattern analysis package PATN (Belbin, 1988). More information on dissimilarity measures and fusion strategies is included in Box 4.

BOX 4
CLUSTERING PROCEDURES

There are two stages involved in a cluster analysis. The first stage is the formation of a dissimilarity matrix from the raw data. This matrix is made up of coefficients of dissimilarity which evaluate the difference of each site from each other site.

The Euclidean Distance measure of dissimilarity was chosen for use with these data because it is symmetric and linear. The property of symmetry allows the common absence of a species between two sites, as well as its common presence, to be taken into account when making comparisons. The property of linearity means that the dissimilarity coefficient has the same value for the same difference at both high and low values in the raw data matrix. Euclidean Distance is therefore sensitive to the presence of rare species and the absence of common species, and all groups are considered equally, with dominant groups not given extra emphasis in the comparisons. These properties were considered desirable because the abundant taxa are not necessarily the best indicators of significant differences between communities.

Euclidean Distance is sensitive to large aberrant values and undue dominance may be given to large values unless the range of the data is reduced. Therefore a logarithmic transformation can be used prior to analysis.

The second stage in the clustering procedure involved the use of a hierarchical agglomerative fusion strategy to create groups based on the values in the dissimilarity matrix. The method used was Wards Incremental Sums of Squares, which is applicable to a Euclidean dissimilarity matrix (W.T. Williams, pers. comm.).

The benthic taxa were pooled into 19 broad categories as there were low frequencies of many species and genera. The categories were as follows: *Acropora willisae*, *Acropora spp.* (excluding *A. willisae*), *Montipora spp.*, Family Pocilloporidae, *Cyphastrea spp.*, *Favia spp.*, Family Faviidae (excluding *Cyphastrea spp.* and *Favia spp.*), *Goniopora spp.*, *Porites spp.*, *Turbinaria mesenterina*, *Turbinaria spp.* (excluding *T. mesenterina*), Family Fungiidae, Families Pectiniidae and Mussidae together, Families Siderastreidae and Agariciidae together, Soft Corals, Sponges, *Sargassum spp.*, *Lobophora sp.*, and Other Algae (excluding *Sargassum* and *Lobophora*,). Seagrasses, which were dominant on some inshore profile transects, were pooled with 'Other Algae'. The data were expressed in terms of percentage cover.

Univariate Analyses

The baseline sampling programme was designed so that variation could be logically partitioned among several sources. Univariate data sets were analysed by multi-factorial analyses of variance.

Given the uncertainty about the likely extent of any effects of the proposed development, however, a number of analytical models could be applied (Box 5; Table 2). The choice of analyses arises only because it cannot be known *a priori* how extensive any impact of development will be. That is, it cannot be known now whether any impact that might occur will affect only the station or stations very near to the development area, or will affect all of the stations nominated above as potential impact stations. The best analysis will be that which maximises the potential to detect effects of development at several scales.

These issues are discussed more fully in Box 5, but the most appropriate model for future impact assessment is model 4 (hereafter termed 'impact-control')in Table 2 (Box 5). We therefore analysed univariate data with this model so that the result of analyses of future data sets would be commensurate with the results of analyses of baseline data. This analysis comprises four factors: Habitat (Flat vs Slope; fixed), Treatment (control vs impact; fixed), Stations (6; fixed) nested within each Treatment, and sites (2; random) nested within each combination of the other factors. The design of this analysis is shown diagramatically in Figure 4.

Algal Biomass and Sedimentation

Algal biomass and sediment trap data were analyzed by four factor analyses of variance, similar to the impact-control analyses described above except that there were only three impact (Nelly 1 & 2 and Nelly 5 or Geoffrey 4) and three control stations (Picnic 1, Florence, & Geoffrey 1). Average rates of sedimentation at each site during weeks 2 and 3 were also related (by regression analysis) to secchi-disk readings and measurements of suspended solids and particulate matter collected from those sites by the Centre for Tropical Freshwater Research, which is responsible for the baseline studies of water quality.

For all analyses of variance, Type I error rates of 5% were considered acceptable unequivocally and effects suggested with error rates of 5-10% were considered worthy of note. Higher error rates were considered unacceptable and a 'non-significant' conclusion drawn. The most critical assumption of heteroscedasticity was tested by Cochran's test and data were transformed to alleviate heteroscedasticity and normalise variances where necessary. *A posteriori* tests for differences among more than two means in which significant differences had been detected by the analysis of variance

Model 1

SOURCE OF VARIATION	df_F	POWER
Habitat	1, 26	0.95
Station	12, 26	0.66
Site (Habitat, Station)	26,156	>0.99
Habitat*Station	12, 26	0.66

Model 2

SOURCE OF VARIATION	df_F	POWER
Habitat	1, 24	0.93
Location	5, 24	0.76
Station (Location)	6, 24	0.72
Site (Habitat, Location, Station)	24,144	>0.99
Habitat*Location	5, 24	0.76
Habitat*Station (Location)	6, 24	0.72

Model 3

SOURCE OF VARIATION	df_F	POWER
Habitat	1, 24	0.93
Treatment	2, 24	0.88
Station (Treatment)	9, 24	0.64
Site (Station, Treatment, Habitat)	24,144	>0.99
Habitat*Treatment	2, 24	0.88
Habitat*Station (Treatment)	9, 24	0.64

Model 4

SOURCE OF VARIATION	df_F	POWER
Habitat	1, 24	0.93
Treatment	1, 24	0.93
Station (Treatment)	10, 24	0.64
Site (Station, Treatment, Habitat)	24,144	>0.99
Habitat*Treatment	1, 24	0.93
Habitat*Station (Treatment)	10, 24	0.64

Table 2

Four analytical models (analyses of variance) under which the data could have been analysed. Habitat (reef flat vs reef slope), Treatment, Location, and Station are fixed effects and sites are random variables. In all models, the significance of sites as a source of variation would be tested against the residual variance, and all other terms would be tested against sites. Degrees of freedom for these F-ratios (df_F) are shown in the form numerator, denominator. The power of each test was calculated with Type I error set at 5% and an arbitrary effect size index (Cohen, 1977) of 0.7.

Model 1. All stations (13) are considered equal, with no distinction being made on the basis of likelihood of impact. Effects of development on specific stations would be assessed by a posteriori tests.

Model 2. Adjacent stations are considered together as a 'Location' effect. This has the effect of classifying as locations Arthur and Florence Bays (together), Picnic Bay, north and south ends of Geoffrey Bay, and north and south ends of Nelly Bay. Geoffrey Bay station 3 would be ignored. Exact differences among locations with respect to any effects of development would also need to be determined a posteriori.

Model 3. Three treatments are considered: High Impact (Nelly Bay stations 1, 2, & 3, and Geoffrey station 4); Intermediate likelihood of impact (Geoffrey stations 1 & 2, and Nelly 4 & 5); No Impact (Florence, Arthur, and Picnic stations 1 & 2). Geoffrey Bay station 3 would be ignored.

Model 4. Stations are divided equally between two treatments: control (Arthur, Florence, Geoffrey 1 & 2, and Picnic 1 & 2); and impact (Nelly 1-5, and Geoffrey 4).

In models 3 & 4, Geoffrey Bay station 3 is omitted because of its uncertain status with respect to the likely degree of impact. Its status would be examined a posteriori in the context of other results.

ANOVA MODEL FOR ANALYSES OF BENTHIC COVER

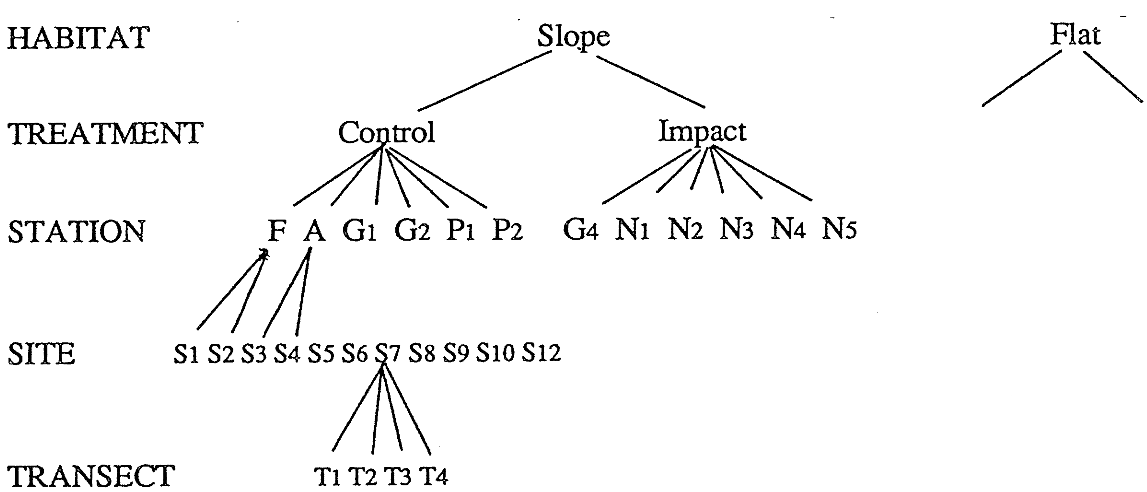


Figure 4
Tree diagram of Analysis of Variance models.

were Ryan's Test for multiple comparisons and Tukey's test for multiple pair-wise comparisons (Day & Quinn, 1988).

BOX 5
OPTIMUM ANALYSES FOR IMPACT ASSESSMENT

Uncertainty about the proper classification of stations with respect to likely impacts of the development complicates the design of analyses (see text). Four possible analytical designs are given in Table 2. The simplest model (model 1) is one in which all stations are compared in a single array, and comprises three factors: Habitats, Stations, and sites (H,S). The other three models are four-factor analyses: Habitat, Treatment, Station (T), site (H,T,S). Models 2 and 3 reflect two degrees of clustering stations according to suspected levels of exposure to impact. The potential level of impact is what defines the factor 'Treatment'. In model 4, all those stations expected to be vulnerable to impact are contrasted to those believed to be immune from any impact of development in a binary comparison (Table 2).

Habitat and treatment were clearly fixed effects and sites were clearly random. Arguments exist for considering stations as either fixed or random. We have defined stations to be fixed for two reasons: 1) they were deliberately chosen at specific locations to assess systematically the effects of the proposed development; and 2) because of the sizes of the reefs at Magnetic Island, the stations sampled represented a large proportion of the total number of such stations that could have been chosen. We are interested in the comparison of only those stations with respect to potential effects of development and not with a view to making general statements about stations elsewhere.

The fourth of the models in Table 2 has a number of advantages over the alternative possible analyses for these data. That is the analysis with the greatest power (Cohen, 1977; Winer, 1971), given any nominated effect of development, to detect that effect if it has an impact on all or most of the six potential impact stations. That is, the fourth design has the greatest power to detect a widespread impact. In the event of a small scale impact, however, the second design has slightly greater power to detect localised effects than other designs, including the fourth (Table 2). For example, if the development had an effect only on the station or stations immediately nearby, the second analysis would have slightly greater power to detect that effect than the others. As the extent of impact increases, however, and more stations are affected, so the balance of power favours model 3 and then model 4 (binary impact vs control).

As indicated in Table 2, the difference between the analyses in their power to detect a large scale effect is far greater than the difference in their power to detect a localised impact. On that basis, the fourth analysis 'impact vs control') is favoured. Further, it seems likely that a large scale impact is of far greater cause for concern than a localised impact, and this also urges the use of the fourth analysis. Finally, in the case of a binary comparison of impact and control treatments, the results of an analysis are always unambiguous. In assessing the localised effects of development (and also generalised effects under models 1 - 3), however, a significant result from the analysis of variance has to be resolved by *a posteriori* tests that are considerably less powerful than primary analyses of variance. In this case the appropriate comparisons are known *a priori* and should be conducted as planned comparisons of each suspected impact station with the average of the control stations. These comparisons will not be orthogonal (and will thus require an adjustment of the acceptable Type I error rates per comparison) but will provide unambiguous tests of an impact at each station. They are, however, less powerful than a binary comparison in the main analysis. Unplanned multiple comparisons are not appropriate in the assessment of localised impacts and the results of such tests may be ambiguous with respect to the impact of development at specific stations. We have used unplanned multiple comparisons in the baseline study, however, because we were mostly interested in detecting general patterns among stations rather than testing hypotheses postulated *a priori*.

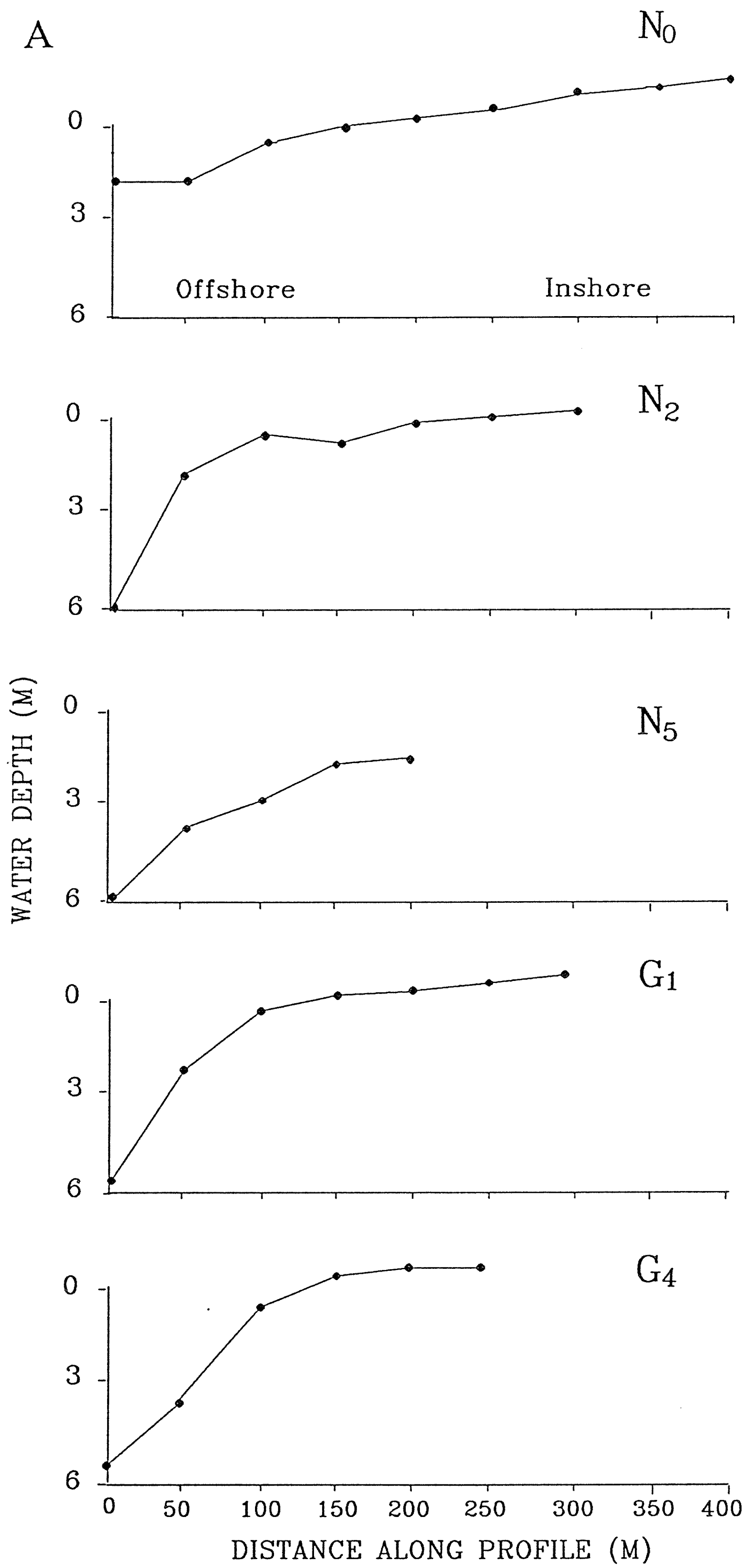


Figure 5

A: Topographic profiles (above) of the fringing reefs at stations 0, 2, and 5 in Nelly Bay and stations 1 and 4 in Geoffrey Bay. Depths are relative to Townsville port datum.

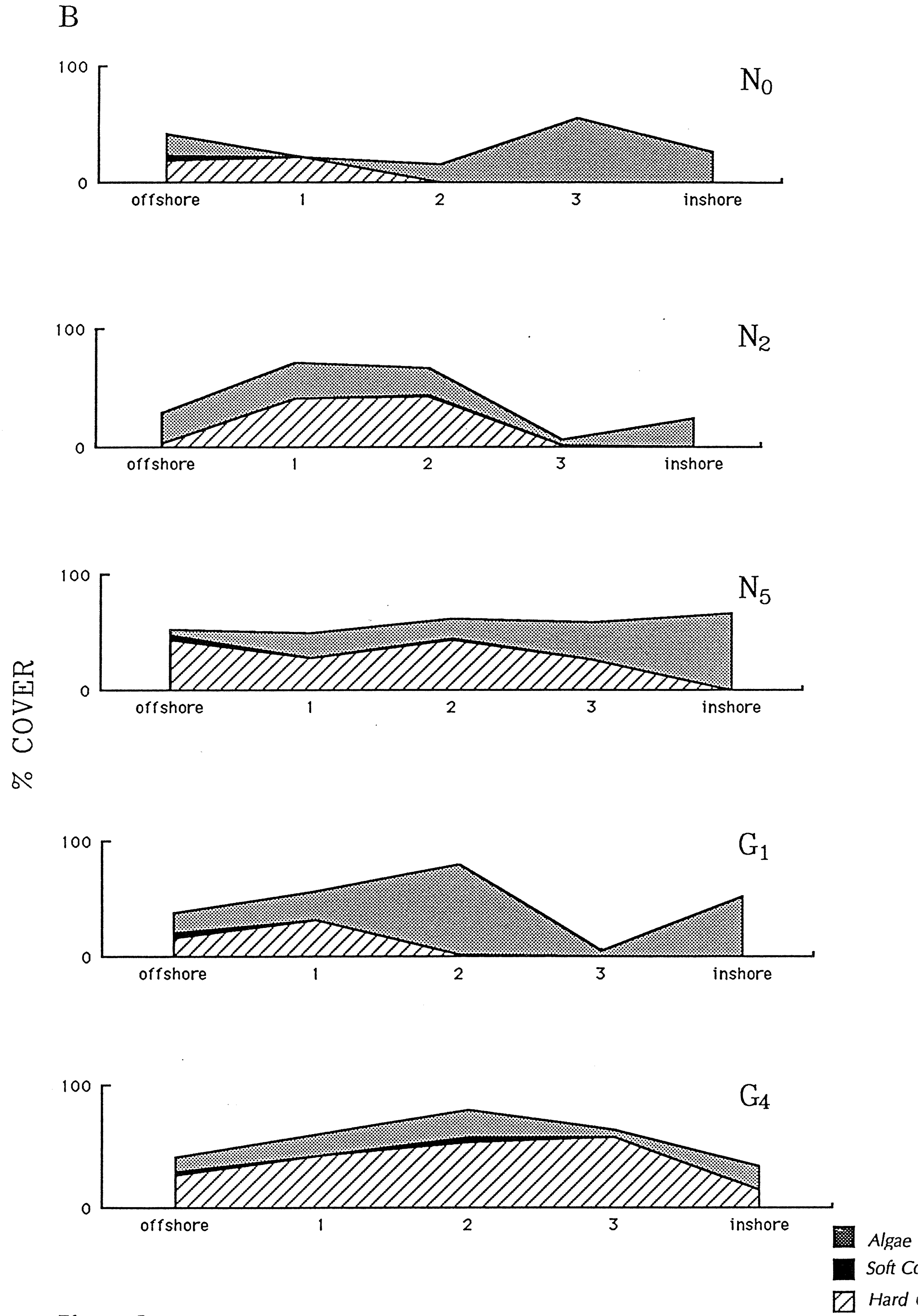


Figure 5
B: Abundances of algae, soft corals, and hard corals along the cross-reef profiles of stations 0, 2, and 5 in Nelly Bay and stations 1 and 4 in Geoffrey Bay.

RESULTS

BENTHIC FAUNA AND FLORA

TRANSECT LENGTH

No consistent increase in precision resulted from using 30m rather than 20m transects. Further, the cost (time) of surveying sufficient 30m transects to obtain a specified precision was generally greater than the cost of obtaining the same precision using 20m transects (Table 3). Transects longer than 30m could not be used at most of the sites sampled in this study because of the spatial constraints of the sampling design and the limitations of the areas of the reefs sampled. Finally, surveying transects of 30m rather than 20m length did not result in increased estimates of diversity. Consequently, 20m transects were used throughout the study.

The sessile taxa recorded during the baseline study are shown in Table 4, together with the number of transects or quadrats in which they were present on reef flats and reef flats. The significance of apparent differences in occurrence were tested by Chi-squared tests on the numbers of individual colonies recorded along all transects in each habitat.

STRUCTURE OF THE FRINGING REEFS: MULTI-VARIATE ANALYSES

The abundance of selected taxonomic groups at regular intervals across the fringing reefs of Nelly and Geoffrey Bays are shown in Figure 5. Also shown are topographies of those reefs. In general, it is clear that algae decline in abundance from the inshore, shallow areas to the offshore reef slopes, whilst most coral taxa show the revers trend. The patterns in the benthic assemblages are discussed more fully below.

Classification of Sites from Profile Surveys

The dendrogram generated by cluster analysis of the five profiles is shown in Figure 6 (A). The profile intervals were clustered into five groups. Table 5 shows the elements and taxonomic characteristics of each group.

GROUP	MEAN PRECISION		MEAN COST @ P=0.1	
	30m	20m	30m	20m
Acropora willisae	0.25	0.33	45.49	44.52
Montipora spp.	0.21	0.21	30.25	19.21
Families Acroporidae/ Pocilloporidae	0.52	0.53	177.27	119.46
Cyphastrea spp.	0.61	0.86	227.20	305.35
Family Faviidae	0.68	0.76	291.30	242.90
Porites spp.	0.61	0.67	270.77	201.14
Turbinaria spp.	0.59	0.65	244.11	187.74
Fungiid group	0.66	0.68	321.53	228.36
Soft Coral	0.55	0.60	188.08	168.59
Sponges	0.90	0.94	502.58	360.32
Sargassum spp.	0.44	0.51	134.38	140.16
Lobophora spp.	0.87	0.81	477.90	277.55
All Algae	0.43	0.52	132.95	143.34
Hard Coral	0.23	0.27	33.60	30.99

Table 3

Comparison of the mean precision of estimated abundances and the mean costs of estimating them for 30m and 20m line transects. A precision of 0.1 was used for several taxonomic groups. Mean costs and precisions were calculated from estimates for each of four sites in Florence Bay. Costs are indexed to the costs of surveying 20m transects: the survey of one 20m line transect would cost one unit; The survey of one 30m transect would cost 1.5 units. (A corollary of this costing is that the 'cost' figures for 20m transects are also the number of replicates needed to gain precision of 0.1).

Table 4

List of the taxa identified in all benthic line transects and collections of algae. Species marked at their left with an asterisk were pooled prior to any analyses. 'Pooled Groups' indicates the groups that were analysed by univariate analyses.

'Frequency' indicates the number of transects (out of 232) or algae quadrats (out of 120) in which each taxon or group was recorded. 'Flats vs Slopes' indicates results of Chi-square tests of differences in colony or patch number between reef slopes and flats.
Symbols.
*: $P < 0.05$; ns: $P > 0.1$; n/a: test not appropriate because less than 10 colonies or patches were found and so expected values for flats and slopes were less than 5.

TAXON	FREQUENCY		FLATS vs SLOPES
	Flats	Slopes	
HARD CORALS			
Acropora spp.	0	2	n/a
Acropora aspera	19	14	ns
Acropora branching	12	5	*
Acropora carduus	0	3	n/a
Acropora clump	15	26	*
Acropora cytherea	10	16	ns
Acropora divaricata	6	16	*
Acropora elseyi	2	14	*
Acropora humilis	8	4	ns
Acropora hyacinthus	3	1	n/a
Acropora latistella	7	33	*
Acropora microphthalma	0	2	*
Acropora millepora	5	0	n/a
Acropora palifera	2	0	n/a
Acropora plate	8	18	*
Acropora staghorn	7	29	*
Acropora verweyi	2	7	ns
Acropora willisae	9	100	*
Acropora yongei	1	2	n/a
Astreopora spp.	0	5	n/a
Caulastrea spp.	0	1	n/a
Coeloseris spp.	0	1	n/a
Coscinaraea spp.	3	5	ns
Cyphastrea spp.	65	92	*
Echinopora lamellosa	0	5	n/a
Favia spp.	33	81	*
* *Favia favus*			
* *Favia maritima*			
* *Favia maxima*			
Favites spp.	12	43	*
Fungia spp.	2	8	*
Fungia concinna	0	5	n/a
Fungia danai	0	4	n/a
Fungia echinata	1	5	n/a
Fungia fungites	0	15	*
Fungia repanda	0	2	n/a
Fungia simplex	0	1	n/a
Galaxea spp.	15	42	*
Goniastrea spp.	48	29	*
* *Goniastrea aspera*			
* *Goniastrea favulus*			
* *Goniastrea palauensis*			
Goniopora spp.	10	58	*
Heliofungia actiniformis	0	8	n/a
Herpolitha spp.	0	6	n/a
Hydnophora spp.	3	33	*
Leptastrea spp.	18	13	*
Leptoseris spp.	1	1	n/a
Lobophyllia spp.	2	10	*
* *Lobophyllia corymbosa*			
* *Lobophyllia hemprichii*			

TAXON	FREQUENCY Flats	Slopes	FLATS vs SLOPES
HARD CORALS cont'd			
Merulina spp.	0	23	*
Montastrea spp.	0	12	*
Montipora spp.	94	108	*
Montipora digitata	18	0	*
Montipora stellata	1	15	*
Moseleya latistellata	2	10	*
Mycedium elephantotus	0	20	*
Oxypora/Echinophyllia spp.	0	30	*
Pachyseris speciosa	0	43	*
Pavona spp.	0	3	n/a
Pavona decussata	1	1	n/a
Pavona venosa	3	2	n/a
Pectinia spp.	0	20	*
Platygyra spp.	12	24	*
* *Platygyra daedalea*			
* *Platygyra pini*			
* *Platygyra sinensis*			
Plesiastrea versipora	1	0	n/a
Pocillopora damicornis	9	21	ns
Podabacia crustacea	0	14	*
Polyphyllia talpina	0	6	n/a
Porites spp.	81	69	*
Psammocora spp.	7	17	*
Psammocora contigua	13	4	*
Stylophora pistillata	0	21	*
Symphyllia spp.	1	11	*
Turbinaria spp.	21	24	*
* *Turbinaria bifrons*			
* *Turbinaria stellulata*			
Turbinaria mesenterina	52	96	*
Turbinaria peltata	3	18	*
Turbinaria reniformis	7	13	ns
SOFT CORALS			
Briarium sp.	32	31	ns
Lobophyton spp.	1	10	*
Sarcophyton spp.	4	56	*
Sinularia spp.	9	40	*
Other Soft Corals	0	7	*
ALGAE			
Caulerpa spp.	3	0	n/a
Ceratodictyon sp.	20	4	*
Halimeda spp.	5	1	*
Lobophora spp.	71	94	ns
Padina sp.	5	6	*
Sargassum spp.	112	100	*
Other Algae	34	62	*
OTHER GROUPS			
Anemones	1	1	n/a

TAXON	FREQUENCY Flats	Slopes	FLATS vs SLOPES
OTHER GROUPS cont'd			
Ascidians	0	1	n/a
Corynactus sp.	22	49	*
Diadema sp.	1	0	n/a
Dead Standing Coral	3	1	n/a
Gorgonians	0	4	n/a
Millepora sp.	1	3	n/a
Sand	28	48	*
Seagrass	1	2	ns
Seawhips	0	1	n/a
Sponges	19	95	*
Turpios sp.	2	7	ns
Zooanthids	0	4	ns
POOLED GROUPS			
Families Acroporidae/ Pocilloporidae	69	100	*
Acropora willisae	9	100	*
Cyphastrea spp.	65	92	*
Family Faviidae	73	106	*
Fungiid group	30	90	*
Lobophora spp.	71	94	ns
Montipora spp.	96	108	ns
Porites spp.	82	96	ns
Sargassum spp.	112	100	ns
Soft Corals	43	92	*
Sponges	19	95	*
Turbinaria spp.	63	102	*
Total Algae	112	117	ns
Total Hard Corals	111	120	ns
COLLECTED ALGAE AND SEAGRASS			
Amansia sp.	4	13	*
Amphiroa sp.	1	10	*
Ceratodictyon sp.	1	1	n/a
Cystoseira sp.	1	0	n/a
Eucheuma sp.	1	0	n/a
Gelidiopsis sp.	6	4	n/a
Halimeda sp.	1	0	n/a
Hormophysa sp.	9	2	*
Hypnea sp.	2	5	n/a
Lobophora spp.	17	41	*
Peysonnelia sp.	0	6	n/a
Sargassum bract./olig. var.	13	7	ns
Sargassum bracteolosum	37	15	*
Sargassum dichotoma	41	49	ns
Sargassum flataxis	20	7	*
Sargassum oligocystum	40	5	*
Sargassum polycystum	8	0	*
Turbinaria sp.	2	0	n/a
Zostera sp.	1	0	n/a

Classification of Profiles by Habitat

Figure 6 (A) shows two clearly separated clusters of groups, designated I and II. The two clusters indicate a distinction between inshore and offshore areas. Cluster I is comprised of three of the five groups and these contain mostly offshore sites (Table 5). However, the distinction is less clear than in the structured data set (see below) because group 1 also contains the three most inshore sites of Geoffrey Bay station 4, and is therefore represented by both offshore and inshore sites.

Cluster II includes two groups which are comprised predominantly of inshore sites, with the exception of one offshore site in group 4 (Table 5). Cluster I is characterized by moderate to high cover (5-40%) of *Montipora* and moderate to moderately high (5-20%) cover of *Sargassum*. Whilst only group 3 has all taxa present, the other two groups have the majority of taxonomic groups represented. Cluster II is characterized by low diversity, the majority of taxonomic groups being absent. The few hard coral taxa that are present occur in very low (0-1%) abundance.

Within Cluster I, groups 1 and 2 are the most similar (Fig. 6 (A)). They are characterised by a high (20-40%) cover of *Montipora,* moderately high (10-20%) cover of *Sargassum* and the absence of several taxonomic groups. They differ mainly in abundance of *Lobophora*. Group 3 is most typical of slope sites from all bays (see Table 6), with only moderate cover of *Montipora* and *Sargassum* and presence of all taxonomic groups.

Within Cluster II, the taxonomic composition of Group 5 is especially poor, with only three hard coral groups represented; *Montipora*, *Acropora* and *Cyphastrea*. This group represents sites located in large inshore seagrass beds, shown by the very high cover (40-60%) of the category 'Algae', which includes seagrasses. Group 4 is typical of flat sites from the analysis of sites from all bays (see Table 6), with moderately high cover of *Sargassum* and a low number of hard coral taxa, all with very low cover (0-1%).

Classification of Sites from all Bays

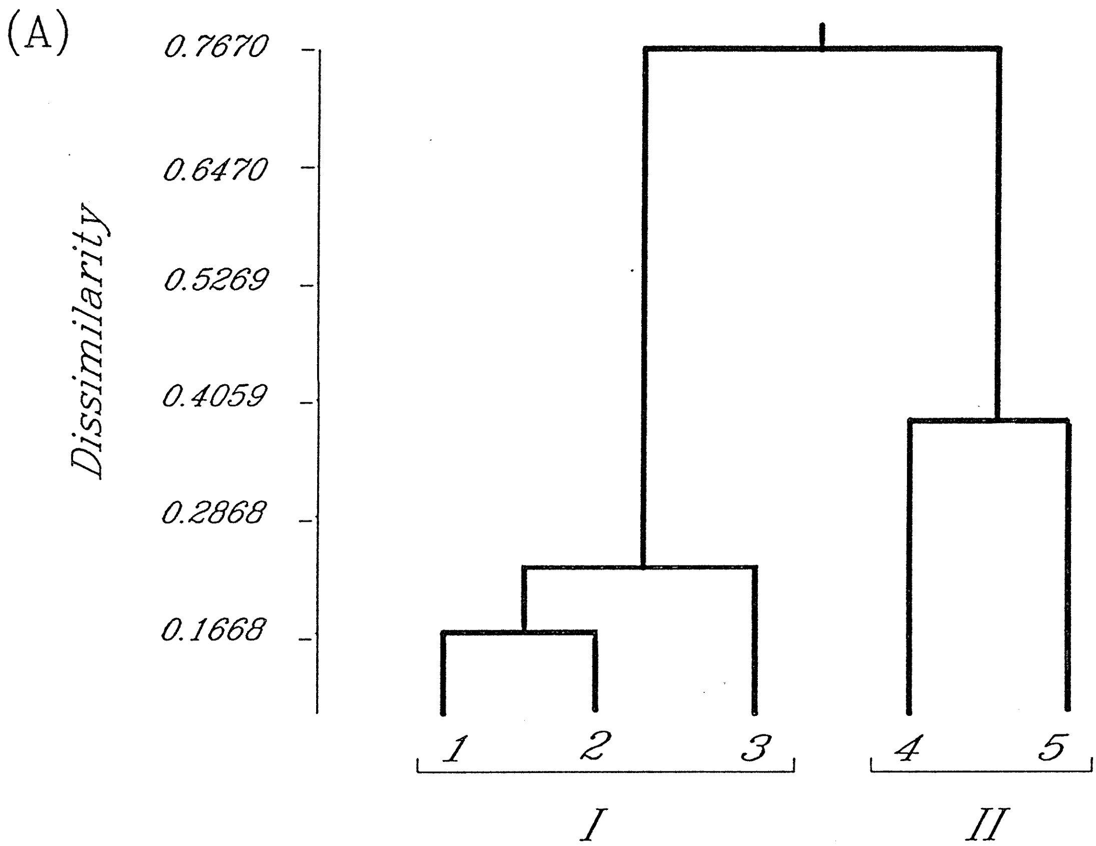
The dendrogram generated by cluster analysis of the 58 sites in the structured sampling programme is shown in Figure 6 (B). The sites were clustered into eight groups. Table 6 shows the elements and taxonomic characteristics of each group.

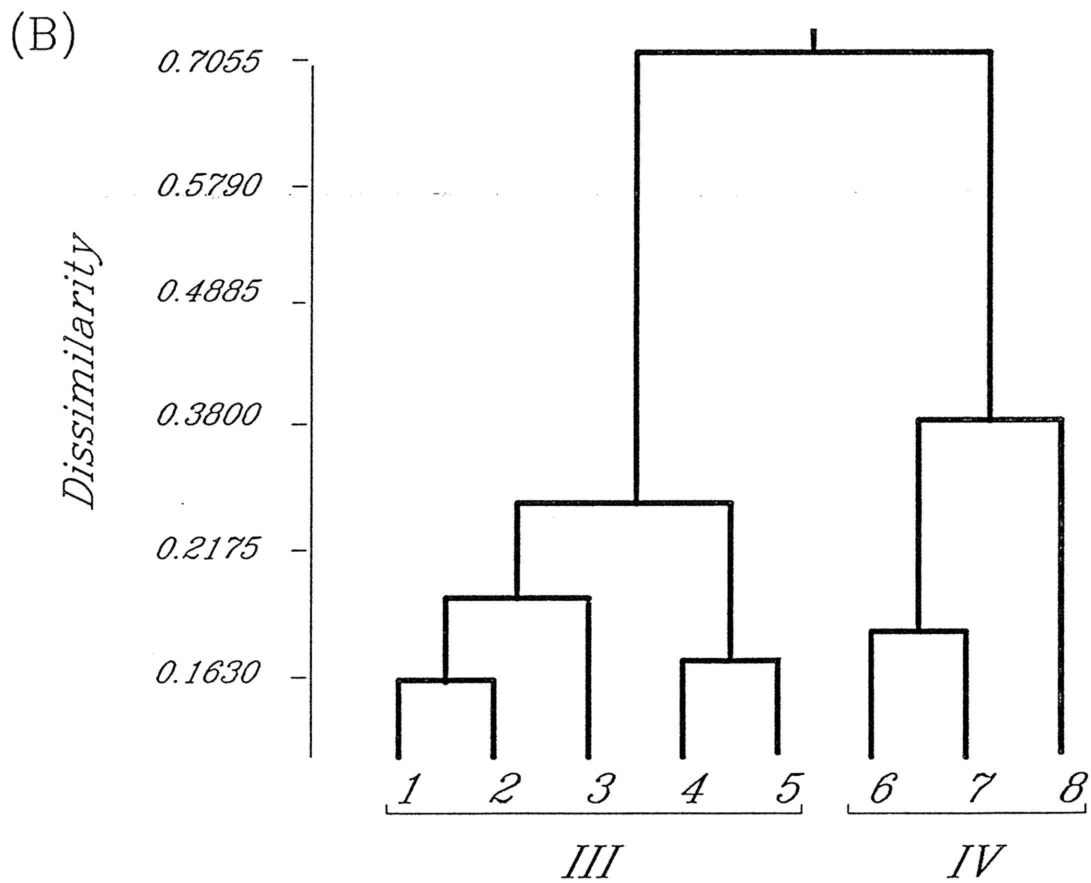
Figure 6

Dendrograms showing similarities among sites indicated by cluster analyses of abundance (percentage cover) data.

(A) Results of cluster analysis of profile data from Nelly and Geoffrey Bays;

(B) Results of cluster analyses of data from all bays. Roman numerals refer to major clusters cited in text. Arabic numbers refer to groups of sites with the characteristics described in Tables 5 (dendrogram A) and 6 (dendrogram B).


(A)
0.7670
0.6470
0.5269
0.4059
0.2868
0.1668
Dissimilarity
1
2
3
4
5
I
II


(B)
0.7055
0.5790
0.4885
0.3800
0.2175
0.1630
Dissimilarity
1
2
3
4
5
6
7
8
III
IV

GROUP	MEMBERS	CHARACTERISTICS
1 (7 sites)	Inlcudes all stations except Nelly Stn 2 Ranges from offshore Nelly Stn 0 to inshore Geoffrey Stn 4	High *Montipora* (20-40%) Mod. High *Sargassum* (10-20%) Several groups absent, all others very low (0-1%), except *Acropora* and algae (1-5%)
2 (5 sites)	Offshore only Nelly Stn 2,5 Geoffrey Stn 4	High *Montipora* (20-40%) Mod. High *Sargassum* (10-20%) Mod. *Lobophora* (5-10%) Several groups absent
3 (6 sites)	Offshore only Includes all stations	Moderate *Montipora* (5-10%) Moderate *Sargassum* (5-10%) All groups present (0-5%)
4 (8 sites)	Predominantly inshore Inshore Nelly Stn 0,2, Geoffrey Stn 1 Offshore Nelly Stn 2	Mod. High *Sargassum* (10-20%) Low Algae (1-5%) Majority of hard coral groups absent, those present very low (0-1%)
5 (7 sites)	All inshore Includes all stations except Geoffrey Stn 4	Very High Algae (40-60%) Low *Sargassum (1-5%)* Only *Montipora*, *Acropora*, *Cyphastrea* and sponges present, all very low (0-1%)

Table 5

Members and characteristics of groups of sites on the cross-reef profiles, grouped together with cluster analysis. Relationships between groups are shown in Figure 6 (A).

GROUP	MEMBERS	CHARACTERISTICS
1 (5 Sites)	SLOPES Only Geoffrey Stn 2,3 Picnic Stn 2 Florence	High *Acropora* (20-40%) Mod. *Montipora* (5-10%) All other taxonomic groups present, mostly less than 1%
2 (7 sites)	SLOPES Only Geoffrey Stn 1,2,3 Picnic Stn 1,2	Mod. High *Sargassum* (10-20%) All other groups present, mostly 1-5%
3 (3 sites)	SLOPES Only Geoffrey Stn 4 Arthur	High Family Siderastreidae and Family Agariciidae (20-40%) All other groups present (0-5%) Highest Family Fungiidae (1-5%)
4 (9 sites)	SLOPES Only Nelly Stn 2,3,4,5 Geoffrey Stn 4	Mod. High *Turbinaria mesenterina* (10-20%) All other groups present (0-5%)
5 (6 sites)	SLOPES Only Nelly Stn 0,1 Bright Pt.	Mod. *Turbinaria mesenterina* (5-10%) Mod. *Montipora* (5-10%) Mod. High *Sargassum* (10-20%) All other groups present (0-5%) except Family Fungiidae (0%)
6 (16 sites)	FLATS Only Nelly Stn 0,1,2,3 Geoffrey Stn 2,3,4 Picnic Stn 1 Florence	High *Sargassum* (20-40%) Mod. *Montipora* (5-10%) All other groups present, mostly 0-1%
7 (5 sites)	FLATS Only Nelly Stn 2 Geoffrey Stn 1,2 Picnic Stn 1	High *Sargassum* (20-40%) Other algae low (1-5%) All other groups either absent or very low (0-1%)
8 (7 sites)	FLATS Only Nelly Stn 3,4,5 Picnic Stn 2 Arthur	High *Sargassum* (20-40%) High *Lobophora* (20-40%) Mod. High *Montipora* (10-20%) Several groups absent All other groups low (0-5%)

Table 6

Members and characteristics of groups of sites in all bays, grouped together with cluster analysis. Data include all sites, except those on the cross-reef profiles. Relationships between groups are shown in Figure 6 (B).

Classification of Sites by Habitat

In Figure 6 (B) there are two clearly separated clusters of groups, designated III and IV. Cluster III is comprised of groups 1-5, which contain slope sites only, and cluster IV is comprised of groups 6-8, which contain flat sites only (Table 6). This indicates a distinct and general separation of reef slopes from reef flats on the basis of taxonomic composition.

The reef flat groups (cluster IV) are all characterized by high percentage cover (20-40%) of *Sargassum*, and *Montipora* is the only hard coral with greater than 5% cover (Table 6). Most other taxa have very low cover (0-1%), and in two of the three groups several hard coral groups are absent. The major differences between the groups is the abundance of *Montipora* and *Lobophora*. In contrast, four of the five reef slope groups comprising cluster III have moderate to high (5-40%) cover of a hard coral group, either *Acropora*, *Turbinaria mesenterina*, *Montipora* or Families Siderastreidae and Agariciidae. Group 2, however, has no single dominant hard coral but many taxa with low cover (1-5%), and moderately high (10-20%) cover of *Sargassum*. All taxonomic groups are represented, except Family Fungiidae in Group 5. Groups 4 and 5 form a separate sub-cluster within cluster III (Fig. 6 (B)), which is characterized by moderate to moderately high (5-20%) cover of *Turbinaria mesenterina*.

Classification of Sites by Bay

All of the Nelly Bay slope sites are clustered separately into groups 4 and 5 (Table 6), which appears in the dendrogram as a sub-cluster distinct from the other three groups of slope sites (Fig. 6 (B)). They are grouped with the Bright Point sites and one site at Geoffrey Bay station 4. The more southern stations in Nelly Bay (2,3,4,5) and one site at the southernmost station in Geoffrey Bay (station 4) are clustered together in group 4. The northernmost stations in Nelly Bay (0 and 1) and the Bright Point sites are clustered together in group 5. Together, the two groups form a unit which includes all slope sites except one (one slope site at Geoffrey Bay station 4) of the stations designated as potential impact areas. They are characterized by greater abundance of *Turbinaria mesenterina* than any of the other groups, with cover greater than 5% (Table 6). Members of group 5, at the northern end of Nelly Bay, have greater cover of *Montipora* and *Sargassum* and less *Turbinaria mesenterina* than members of group 4.

Reef slopes at the control stations, Geoffrey Bay stations 1 and 2, Picnic and Florence Bays, are not distinguished from each other in Cluster III (Table 6), implying overall similarity between reef slopes in the three bays. The Arthur Bay slope sites and the remaining Geoffrey Bay station 4 slope

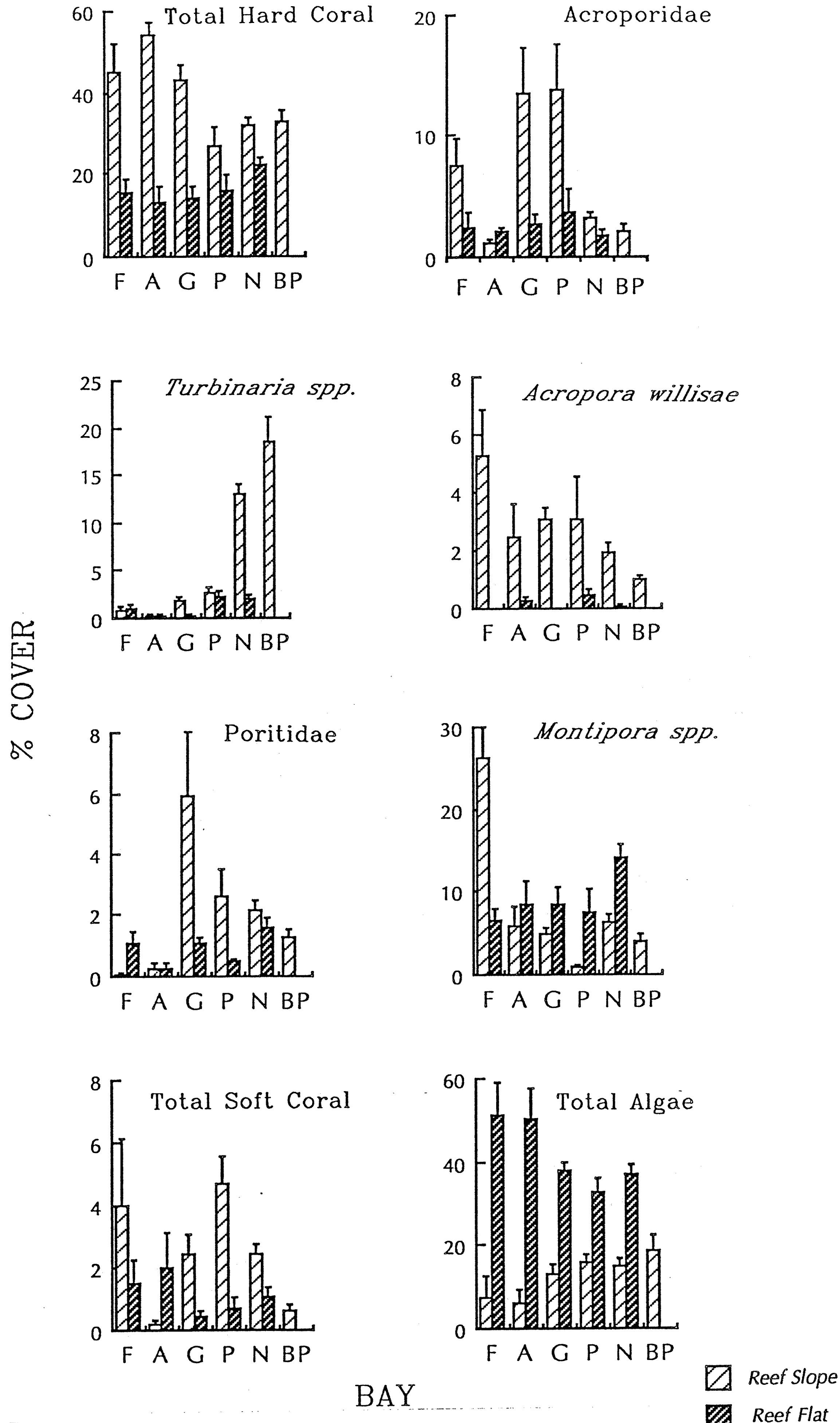


Figure 7

Histograms showing abundances of eight abundant taxonomic groups on the reef slopes and reef flats in Florence (F), Arthur (A), Geoffrey (G), Nelly (N), and Picnic (P) Bays and on the reef slope off Bright Point (BP). Data are the averages of all sites in each habitat in each bay. Error bars show standard errors.

site (group 3) form a distinct group which is separated from the others on the basis of high (20-40%) cover of the pooled Families Siderastreidae and Agariciidae.

In contrast to the slopes, there is no distinction between bays in the three groups containing flat sites (Table 6). The impact stations are not distinguished from the control stations. This implies that the reef flats of the five bays have quite similar benthic assemblages.

The cluster analysis indicates that Nelly Bay station 0, the site of the proposed development, is not unique in its taxonomic composition, as it is not grouped separately from the other stations (Table 6).

Summary

Both cluster analyses have shown distinctions between slope and flat sites on the basis of taxonomic composition of the benthic assemblages. In addition, the Nelly Bay and Bright Point reef slopes appear to be distinct from reef slopes of the other bays, particularly in relation to the abundance of *Turbinaria mesenterina*. In fact, all slope sites of the designated impact stations, except one at Geoffrey Bay station 4, are assembled together into two groups which form a separate sub-cluster. Further, these two groups divide Nelly Bay into northern and southern sections, with stations 0, 1 and Bright Point belonging to one group, and stations 2,3,4,5 and Geoffrey Bay station 4 belonging to the other group.

Geoffrey Bay station 4 seems to be a fairly atypical station, with one slope site grouping with Nelly Bay slopes and the other grouping with Arthur Bay slopes. From the profile analysis, the inshore section of this station appears to have more similarity to offshore areas of other stations. Geoffrey Bay station 4 is the only one of the five profile stations that does not have extensive seagrass beds at the most inshore sites.

ANALYSES OF ABUNDANCE

Percentage cover data for each taxonomic group of benthic flora and fauna were analyzed by four-factor analyses of variance as described above. The results of the impact vs control analyses (Model 4, Table 2) of the pooled groups are summarised in Table 7 (for details, see Appendix A). In almost all analyses, the greatest amount of variation was explained by variation among transects within sites, followed by variation between habitats or due to interactions involving habitat. Variation between sites, treatments or among stations within treatments was consistently small relative to other sources (Appendix A).

Source of variation	HAB	TREAT	STAT(T)	SITE(H,T,S)	H*T	H*S(T)
A.willisae	*	*	-	-	-	-
Cyphastrea	-	*	*	-	-	*
Montipora	*	*	*	*	*	*
Turbinaria	*	*	*	*	*	*
Acroporidae/ Pocillopora	*	*	?	*	-	?
Faviidae	*	*	-	*	-	*
Fungiid group	*	*	*	*	-	*
Poritidae	*	*	-	*	-	*
Hard Coral	*	-	*	*	*	-
Soft Coral	*	-	-	*	-	-
Sargassum	*	*	*	-	?	*
Lobophora	*	*	*	?	?	*
Total Algae	*	-	-	-	-	*
Sponges	*	-	*	-	*	*
Wet weight/ all algae	*	*	*	-	-	-

Table 7

Summary of analyses of variance results for percentage cover data and algae biomass data. All analyses were of the same form, but biomass of algae was measured at only a subset (3) of the six stations in each treatment. Terms in the analyses are given at the top of the table.

Abbreviations and Symbols.
'Hab': Slope vs Flat; 'Treat': Control vs Impact;
'Stat': comparison among stations within treatments.
*: $P_\alpha <= 0.05$; ?: $0.05 < P_\alpha < 0.1$; -: $P_\alpha >= 0.1$.

Comparisons of the station to be excavated (Nelly Bay station 0), and Geoffrey Bay station 3 with all other stations indicated that in no category was Nelly Bay station 0 exceptional and in need of particular attention with respect to the benthic biota (Figs. 7-14). Similarly, Geoffrey Bay station 3 was similar to other stations in Geoffrey Bay prior to the commencement of development. Nor were Bright Point sites distinctive from other reef slope sites (Fig. 7).

Hereafter, we will focus on the results of the impact vs control analyses. Although it is clear that no impact associated with Magnetic Quay could have occurred during the baseline study, we will continue to use the impact - control terminology to emphasise the relations of the stations sampled to the proposed development. To a large degree, the term 'treatments' (impact vs control) in these analyses represents a comparison between Nelly Bay and other fringing reefs along the south-east coast of Magnetic Island because five of the six stations of potential impact are within Nelly Bay. In that sense, the results of these analyses give some detailed indications of the extent to which Nelly Bay was different from other bays prior to the development of Magnetic Quay (also see results of cluster analyses).

HARD CORALS

All Hard Corals

When total coverage by hard corals was considered, significant differences were detected between habitats, among stations within each future treatment, and between some sites. The interaction between habitats and treatments was also significant (Table 7). This interaction arose because average coral cover on reef slopes at control stations (40.2%) did not differ significantly from that at impact stations (33.9%) but the reef flats at control stations (12.3%) had, on average, lower cover of hard corals than those at impact stations (23.3%; Fig. 8). Within both impact and control groups, coverage by hard corals was significantly greater on reef slopes than reef flats, the difference being greater at control stations than at impact stations (Fig. 8).

Within the impact stations, Geoffrey Bay station 4 had highest abundance of hard corals on average (38.7%), and within Nelly Bay there was a general decline in abundance along the bay from station 5 (35.4%) to station 1 (15.9%; Fig. 8). Coverage by hard corals was significantly lower at Nelly Bay stations 1 and 2 (15.9%, 17.5%) than at Geoffrey Bay station 4, but no other stations differed significantly.

There was no significant north-south trend in coverage of corals among control stations, but Arthur Bay (34.9%) had significantly higher coral cover than Picnic Bay station 1 (11.1%). No other

Figures 8-15

Figures 8-15 show analyses of variance results for abundances of fourteen taxonomic groups (see text). In all figures, the data are mean percentage cover and error bars indicate standard errors.

One plot format is common to all groups; others represent specific results of analyses for each group. The common format shows abundance against station for reef flats and reef slopes. This reflects the results of a habitat X station(treatment) interaction in the analyses of variance, but with the addition of data from those stations not included in the analyses (Geoffrey Bay station 3, Nelly Bay station 0, and Bright Point - see text).

In each plot, the stations are divided into the two 'treatment' categories: control stations (C) - Florence (F), Arthur (A), Geoffrey 1 (G_1) and 2 (G_2), Picnic 1 (P_1) and 2 (P_2)); and impact stations (I) - Geoffrey 4 (G_4), Nelly 1 (N_1), 2 (N_2), 3 (N_3), 4 (N_4), & 5 (N_5). A vertical dashed line indicates the division between the categories. Within each treatment, stations are arranged in north - south order. Geoffrey Bay station 3 is positioned between the control and impact stations because its status with respect to potential impact is not certain. Nelly Bay station 0 and Bright Point are distinguished from other impact stations because they represent special cases: station 0 is to be excavated; Bright Point has no reef slope.

Total Hard Coral

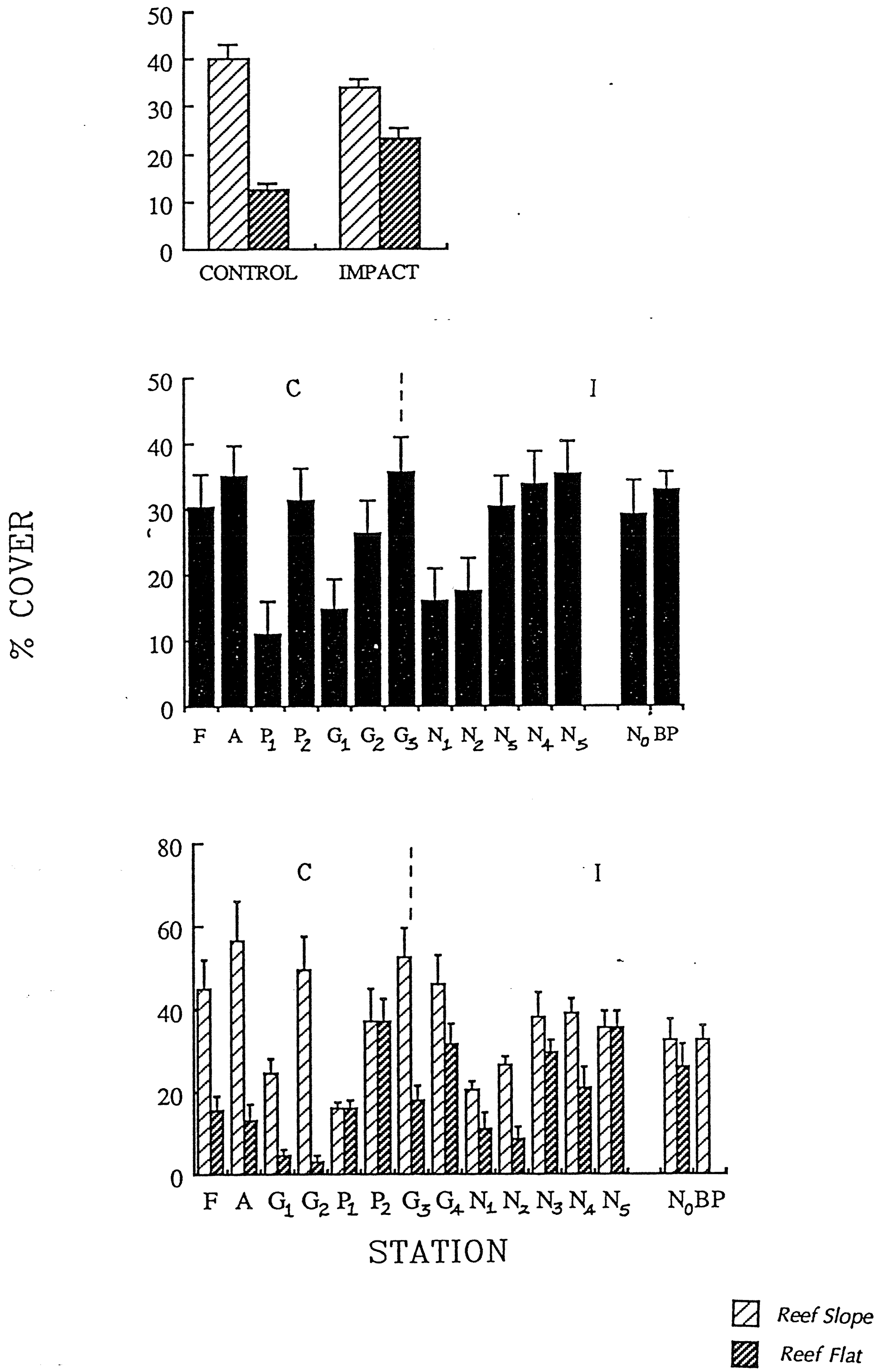


Figure 8: Total Hard Coral cover

differences were significant (Fig. 8). The range of cover among stations was similar in the impact (15.9 - 38.7%) and control stations (11.1 - 34.9%), equal to approximately 86% of the grand mean cover. It therefore seems likely that the two groups describe fairly similar sets of fringing reef conditions in terms of total cover by hard corals.

Acroporidae, Pocilloporidae

This group comprised all of the pocilloporids and all of the acroporids found during the baseline study except *Acropora willisae* and corals in the genus *Montipora*. *Acropora willisae* and *Montipora* sp. were analyzed separately (see below).

Percentage cover by this group was on average significantly greater at control stations (7.4%) than at impact stations (2.6%; Table 7; Fig. 9). Although cover was ranked greater on slopes than on flats at five of the six stations in each treatment, the difference was significant at only one station in each treatment: Geoffrey 2 (control) and Nelly 3 (Impact) (Fig. 9). No differences among stations on reef flats were significant in either treatment, and nor were differences among stations significant for the slopes of impact stations (Fig. 9). In the control group, Acroporids and pocilloporids were significantly more abundant on the slopes of Picnic Bay Station 2 and Geoffrey Bay station 2 than in Arthur Bay, but no other differences were significant (Fig. 9). Differences in cover among sites within treatment, station and habitat were significant in only three out of 48 cases. In summary, acroporids and pocilloporids tended to be less abundant over most of Nelly Bay than at other bays.

Acropora willisae

This species showed the simplest and most distinctive patterns in abundance of all groups of organisms considered. *Acropora willisae* was significantly more abundant on the reef slopes (2.6%) than on the reef flats (0.1%) and significantly more abundant at control stations (1.7%) than at impact stations (1.1%; Table 7; Fig. 9). Summed over all slope sites, 294 colonies or groups of colonies of *A. willisae* were found compared with a total of only 12 on all reef flats. There were no significant differences among stations within treatments or between sites (Table 8; Fig. 9).

Montipora sp.

Patterns in the abundance of montiporids were complex, all terms in the analysis of variance being highly significant (Table 7). Percentage cover by *Montipora* sp. was similar on the reef flats (5.4%) and reef slopes (7.7%) averaged over all control stations, but at impact stations this genus was

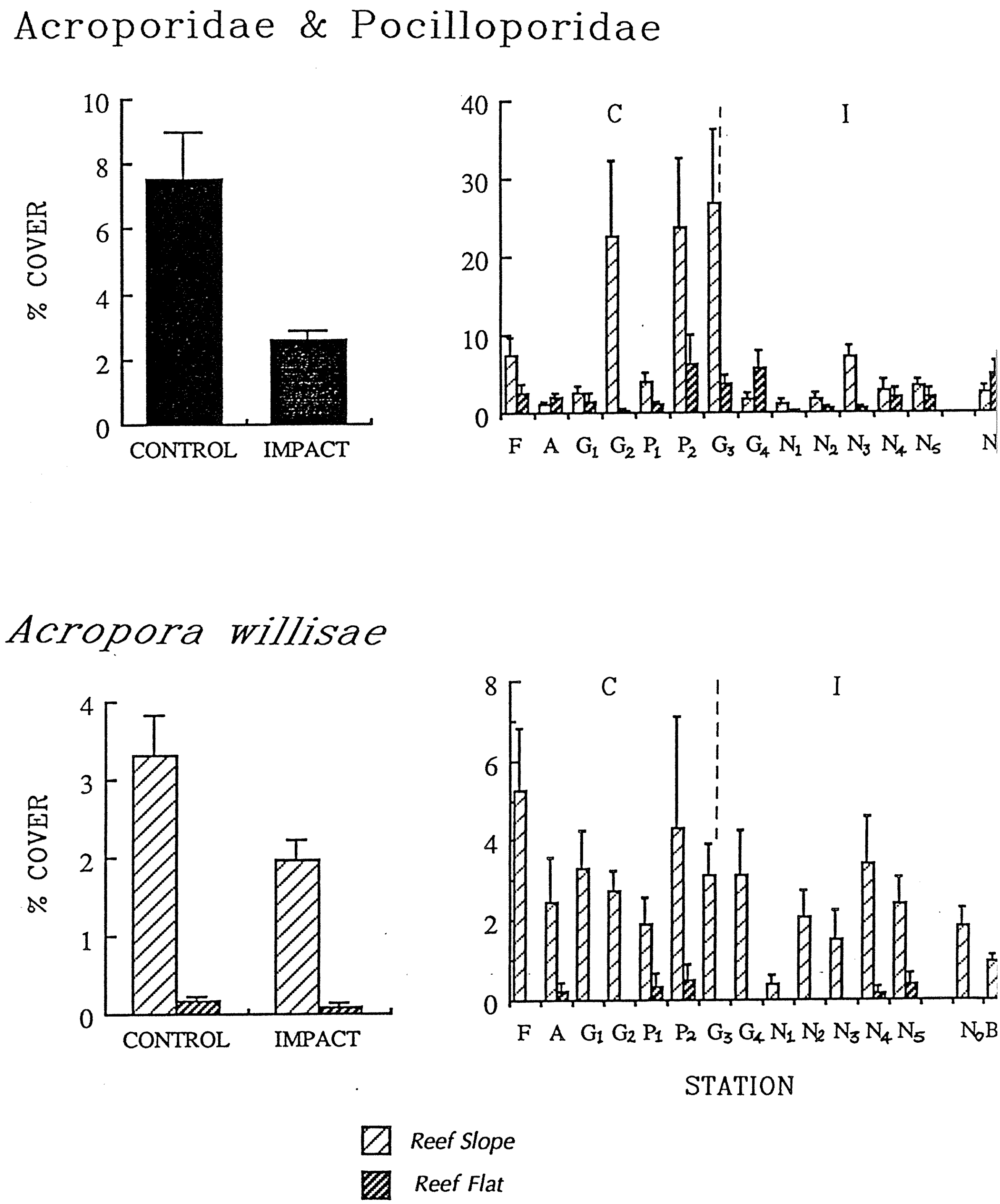


Figure 9: Family Acroporidae and Family Pocilloporidae (Top); *Acropora willisae* (Above)

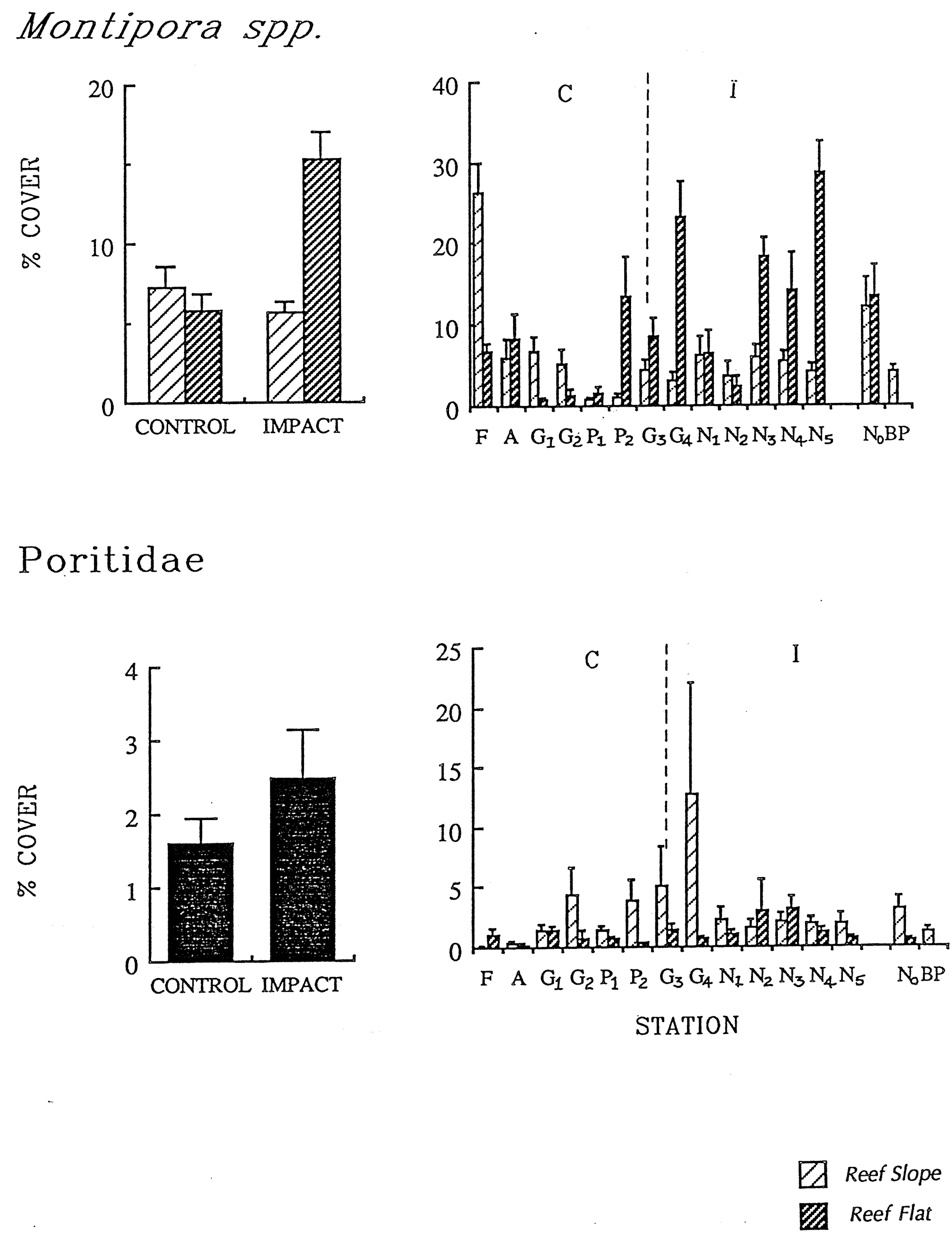


Figure 10: *Montipora* spp. (Top) and Family Poritidae (Above)

significantly more abundant on the reef flats (15.6%) than on the reef slopes (4.8%; Fig. 10). Whilst abundances of *Montipora* sp. were also significantly greater on the flats of impact stations than the flats of control stations, the reef slopes in the two treatments did not differ significantly (Fig. 10).

Stations within the control treatment were generally similar, except that *Montipora* sp. were significantly more abundant on the reef slope in Florence Bay than on either the reef slope or reef flat at all other stations Fig. 10). All Impact stations had similar abundances of *Montipora* sp. on their slopes but a complex array of differences with no clear pattern occurred among the reef flat at different stations (Fig. 10). Neighbouring sites differed on only two of 48 possible occasions. Overall, the most notable result was that the reef flat in Nelly Bay tended to have higher coverage by *Montipora* sp. than most other places sampled (Fig. 10).

Poritidae

Poritid corals were significantly more abundant at impact stations (2.5%) than control stations (1.6%; Table 7; Fig. 10). At two-thirds of the stations in each treatment, poritids were slightly more abundant on the reef slopes than on the reef flats (Fig. 10), but the difference was significant only at Geoffrey Bay station 4.

In neither treatment did the reef flats differ among stations, but differences among stations were significant on the slopes in both treatments. In impact stations, Nelly Bay stations 2 (1.6%) and 5 (1.9%) had significantly lower cover of poritids on their reef slopes than did Geoffrey Bay station 4 (12.8%). Among the control stations, the slope at Florence Bay (0.1%) had significantly lower cover than that at Geoffrey Bay station 2 (4.4%). There was no trend apparent among stations in either treatment for either habitat (Fig. 10). In only two cases did coverage by poritids differ significantly between adjacent sites.

Faviidae

All favid corals recorded were analyzed together, with the exception of species in the genus *Cyphastrea*. Favids were significantly more abundant on average at the impact stations (2.8% cover) than at the control stations (2.2% cover; Table 7; Fig. 11). Favids were also generally more abundant on reef slopes than reef flats, though the difference was not significant at all stations (Table 7; Fig. 11). Abundances of favids on reef slopes did not differ among stations within either treatment, nor did cover on reef flats differ significantly among control stations. Coverage on the flats did differ significantly, however, among stations within the impact treatment, but there was no systematic (e.g. north-south) trend in the differences (Fig. 11).

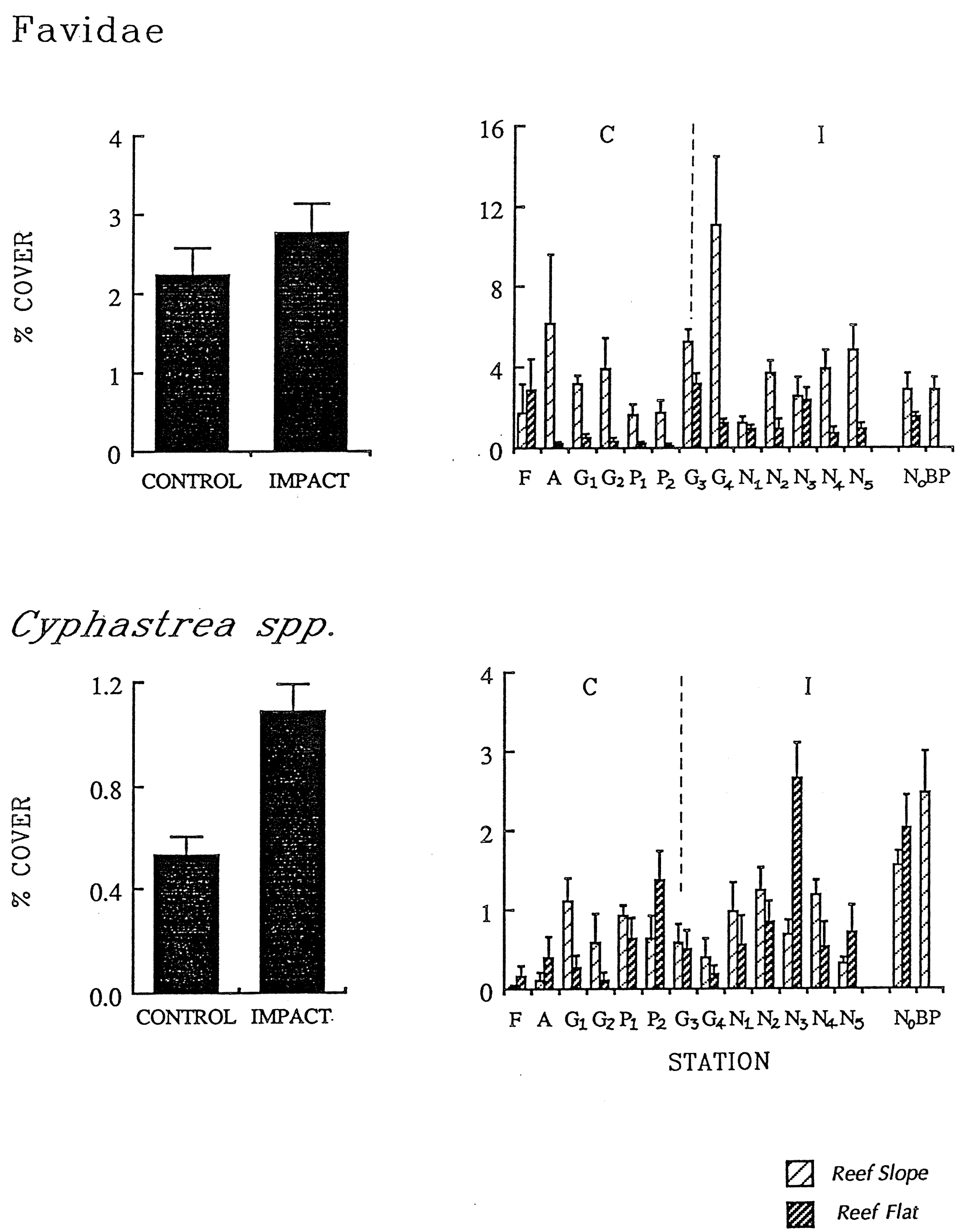


Figure 11: Family Faviidae (Top) and *Cyphastrea* spp. (Above)

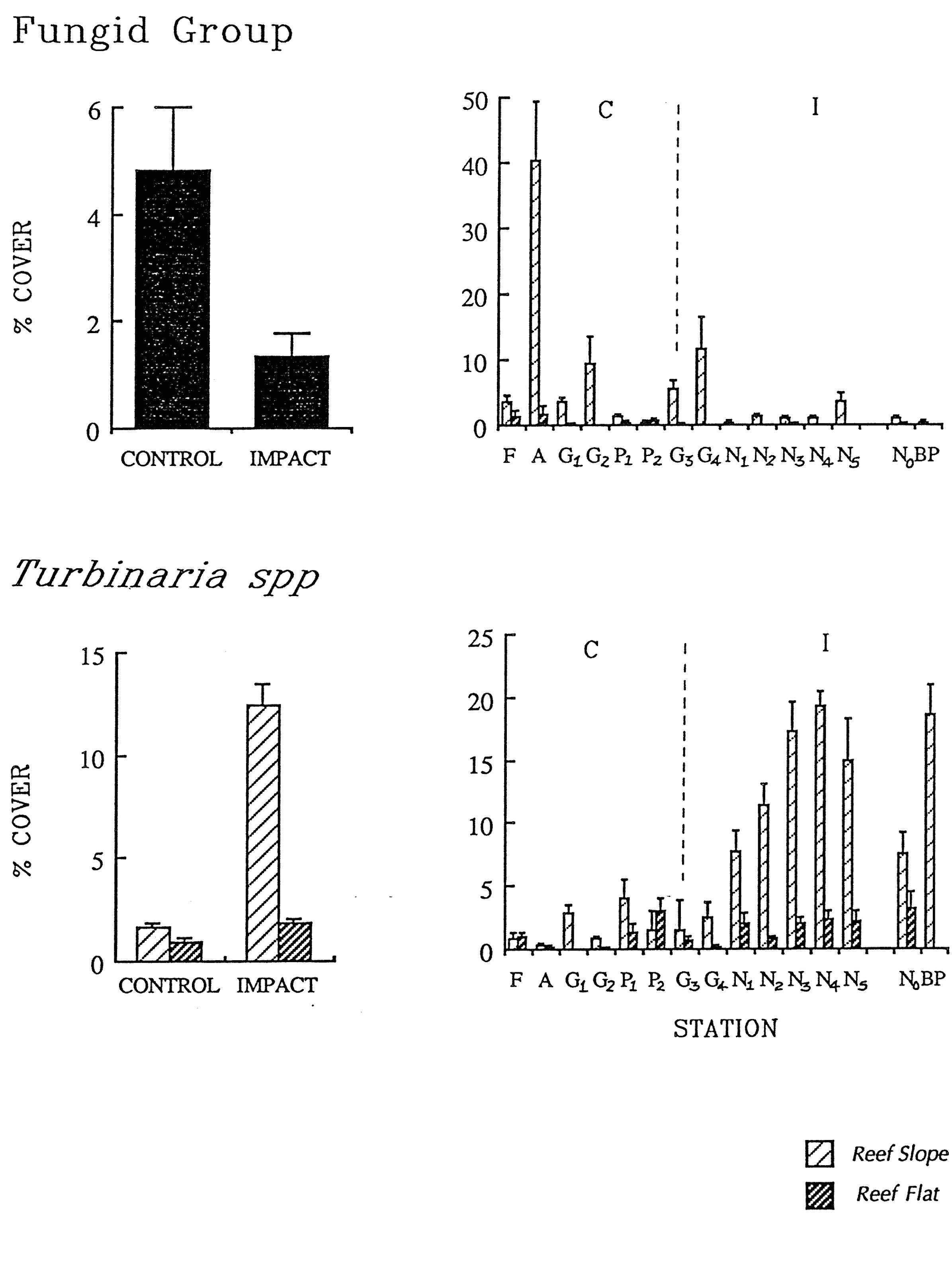


Figure 12: Families Fungiidae, Agariciidae, Mussidae, Pectinidae and Siderastreidae (Pooled, Top) and *Turbinaaria* spp. (Above)

Cyphastrea spp.

Colonies of *Cyphastrea* spp. were ubiquitous and abundant (184 colonies on flats vs 261 on slopes) but small, accounting for less than 1% of substrata at most sites (overall mean 0.7%). Nevertheless, these corals had significantly greater coverage at impact stations (0.9%) than at control stations (0.5%) (Table 7; Fig. 11). Differences in coverage between habitats were station specific (Table 7), and significant only at Nelly Bay station 3 (slope = 0.7%; flat = 2.7%). The coverage by *Cyphastrea* spp. on the flat at this station was unusually high and represented the only instance of a station differing from others in its treatment for either habitat (Nelly station 3 flat > reef flat all other stations).

Fungiidae, Agariciidae, Siderastreidae, Pectiniidae, and Mussidae

This composite group of corals were significantly more abundant at control stations (4.8%) than at impact stations (1.4%; Table 7; Fig. 12). Significant relations between habitats and among stations within treatments, however, were inter-dependent (Table 9; Fig. 12). Although at all stations these corals were apparently more abundant on reef slopes than on reef flats, the differences were significant only at Arthur Bay (40.4% vs 1.5%), Geoffrey Bay station 2 (9.2% vs 0%), and Geoffrey Bay station 4 (11.7% vs 0.1%). In the reef flat habitat, all stations were similar with respect to abundances of the above group, but differences among stations in both impact and control groups were evident on reef slopes (Fig. 12). These corals were significantly more common on the slopes at Arthur Bay than at all other control (and impact) stations, and more abundant at Geoffrey Bay station 2 than Picnic Bay station 2. Among the impact stations, Geoffrey Bay station 4 had greater coverage than Nelly Bay stations 1-4, but did not differ significantly from Nelly Bay station 5 (Fig. 12). The relevant general conclusion is that fungiids tended to be less abundant at Nelly Bay than elsewhere.

Turbinaria spp.

Like *Montipora* spp., *Turbinaria* spp. exhibited complex patterns of abundance (Table 7). Difference between treatments and among stations within treatment were dependent on habitat (Table 7). In both treatments and at 9 of the 12 stations, however, this genus was significantly more abundant on reef slopes than on reef flats (Fig. 12).

When only reef slopes were considered, *Turbinaria* spp. were significantly more abundant at impact stations (12.4%) than at control stations (1.7%). This was not the case, however, on reef flats (Fig. 12). Similarly, within neither treatment did significant differences occur among reef flats at

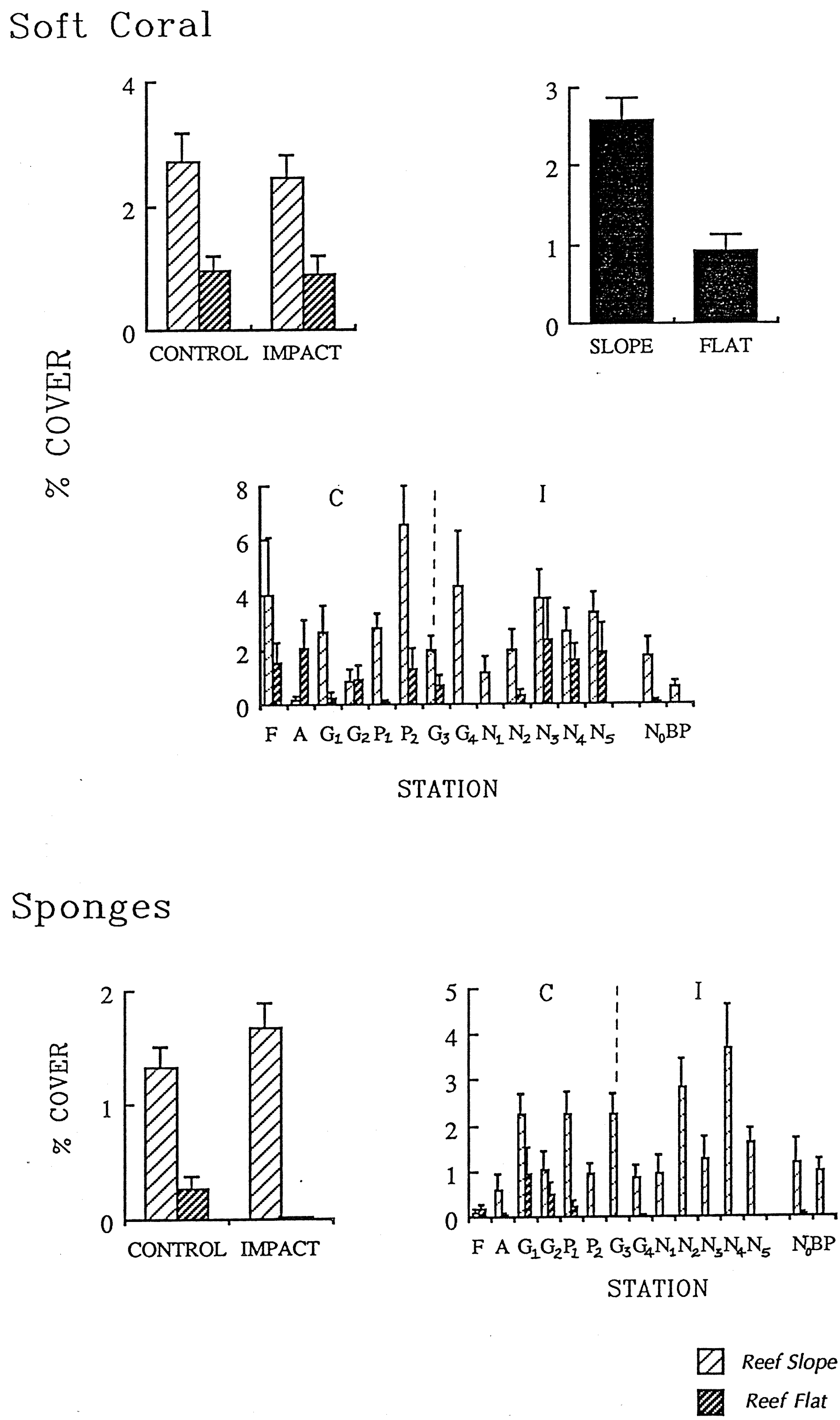


Figure 13: Soft Corals (Top) and Sponges (Above)

different stations (Fig. 12). On the reef slopes at control stations, coverage by *Turbinaria* spp. differed significantly between Arthur Bay (0.3%) and Picnic Bay station 1 (4.0%), but no other differences were significant. *Turbinaria* spp. were significantly less abundant on the reef slope at Geoffrey Bay station 4 (2.4%) than at all other impact stations (range: 7.6-19.3%), and Nelly Bay station 1 (7.8%) had less of the genus than Nelly Bay stations 3 (17.4%) and 4 (19.3%; Fig. 12). Differences between sites were significant in only two cases. In general, then, *Turbinaria* spp. tended to be more abundant on the slopes of Nelly Bay and southern Geoffrey Bay than elsewhere.

SOFT CORALS

Soft Corals were significantly more abundant overall on the reef slopes than on reef flats (Fig. 13). As for other taxa, abundances of soft corals differed significantly between sites in only two of the 24 pairs of sites. No other patterns in abundance were considered significant (Table 7).

SPONGES

Sponges were significantly more abundant on reef slopes than reef flats at both impact and control treatments, but the relation between treatments varied with habitat (Table 7; Fig. 13). Whilst coverage by sponges on reef flats in control and impact treatments could not be distinguished (Control = 0.3%; Impact = 0.01%), sponges were significantly more abundant on the slopes of impact stations (1.9%) than those of control stations (1.2%). Within treatments, abundances of sponges on reef flats did not differ significantly among stations. Although differences did occur among the slopes at different stations in each treatment, in neither treatment did those differences indicate any consistent north-south trend in abundance or any consistent differences among bays (Fig. 13).

PERCENTAGE COVER BY ALGAE

Although several species of algae were found during the baseline study (Table 4), only two genera (*Sargassum* spp. and *Lobophora* spp.) were present consistently enough and with sufficient abundance to be analyzed separately (see below). When all algae were pooled and analyzed, only two terms in the analysis were significant (Table 7). The difference in coverage by algae between habitats accounted for by far the greatest variation in the data (57%; Appendix 1). The interaction between habitats and stations within treatments was also significant, however, indicating that although there tended to be more algae on the reef flats (overall average = 39.6%) than the reef slopes (13.4%), the strength (though not the direction) of this relation differed among stations within treatments (Fig. 14). In neither habitat were there any significant differences among stations within treatments.

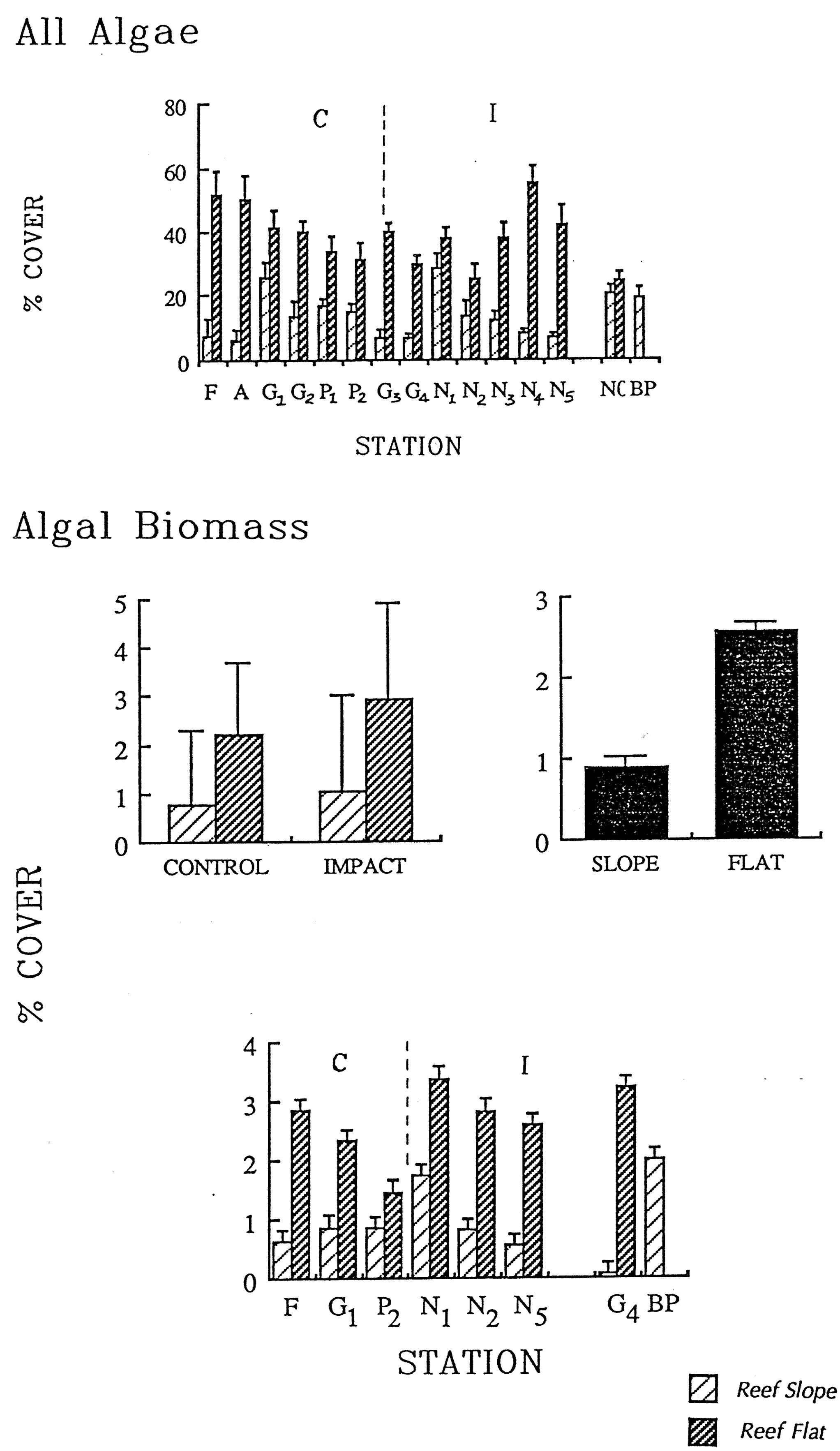


Figure 14: Total algal cover (Top) and total algal Biomass (Above)

Sargassum spp.

The pooled species of the genus *Sargassum* were significantly more abundant on reef flats than reef slopes in both impact (26.2% vs 6.0%) and control (34.8% vs 9.9%) treatments, but the relation between treatments was habitat dependent (Table 7; Fig. 15). Averaged over stations, *Sargassum* spp. were significantly more abundant on the reef slopes in the control treatment than those of impact treatment, but the abundances did not differ between the flats of the two treatments (Fig. 15). When stations within treatments were considered, these algae were in all cases at greater abundance on the reef flats than on the reef slopes (Fig. 15), but differences were not significant at Geoffrey Bay station 1, Picnic Bay station 2, and Nelly Bay stations 2 and 5. Although *Sargassum* spp. were noticeably more abundant at Nelly Bay station 1 than at other impact stations, no differences among stations in either habitat were considered significant (Fig. 15). The same was true among the flats of control stations, but on the slopes, *Sargassum* spp. were significantly more abundant at Florence Bay than at all stations in Geoffrey and Picnic Bays, and more abundant at Arthur Bay than at Picnic Bay station 2 (Fig. 15).

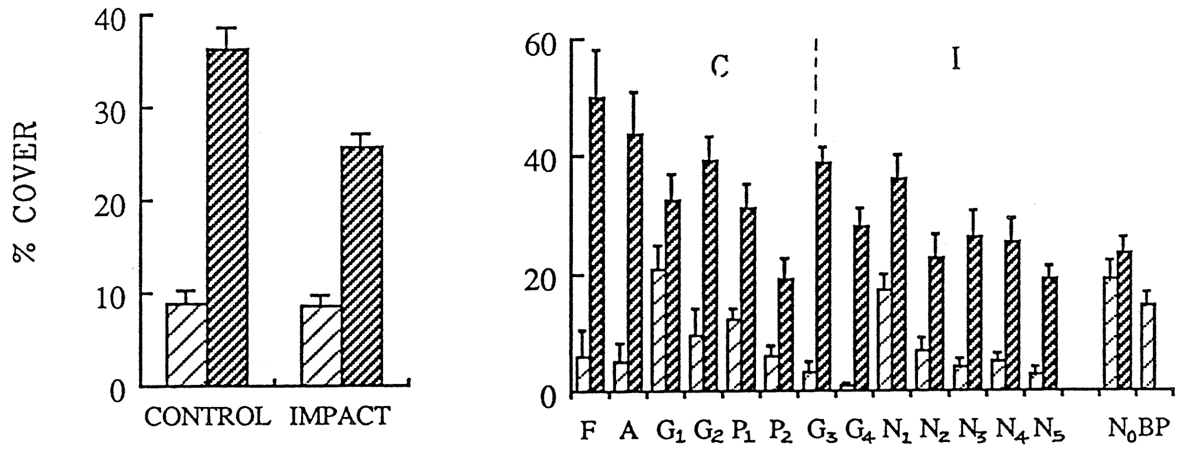
Lobophora spp.

Coverage by *Lobophora* spp. differed between habitats, but those differences varied with treatment and station within treatment (Table 7). Further, relations between treatments and among stations within treatments were both habitat specific (Table 7; Fig. 15).

Averaged over stations in the control treatment, *Lobophora* spp. were of similar abundance in both habitats (slope = 1.9% vs flat = 3.5%). In the impact treatment, however, this genus was significantly more abundant on the reef flat (10.7%) than on the reef slope (4.6%). The reef slopes of the treatments did not differ significantly with respect to coverage by *Lobophora* spp., but the algae were significantly more abundant on the flats of the impact treatment than in the control (Fig. 15).

In neither treatment did the reef slopes of stations differ in the percent coverage by *Lobophora* spp., but in both treatments differences occurred among the reef flats of stations (Fig. 15). In the impact treatment, *Lobophora* spp. were significantly more abundant on the reef flat at the south end of Nelly Bay (stations 4 & 5) than elsewhere, and coverage declined from south to north along Nelly bay and into Geoffrey Bay station 4 (Fig. 15). There was no similar gradation apparent on the flats of control stations, but there was greater cover by *Lobophora* spp. at Picnic Bay station 2 than at Geoffrey Bay stations 1 & 2 and Florence Bay (Fig. 15).

Sargassum spp.



Lobophora spp.

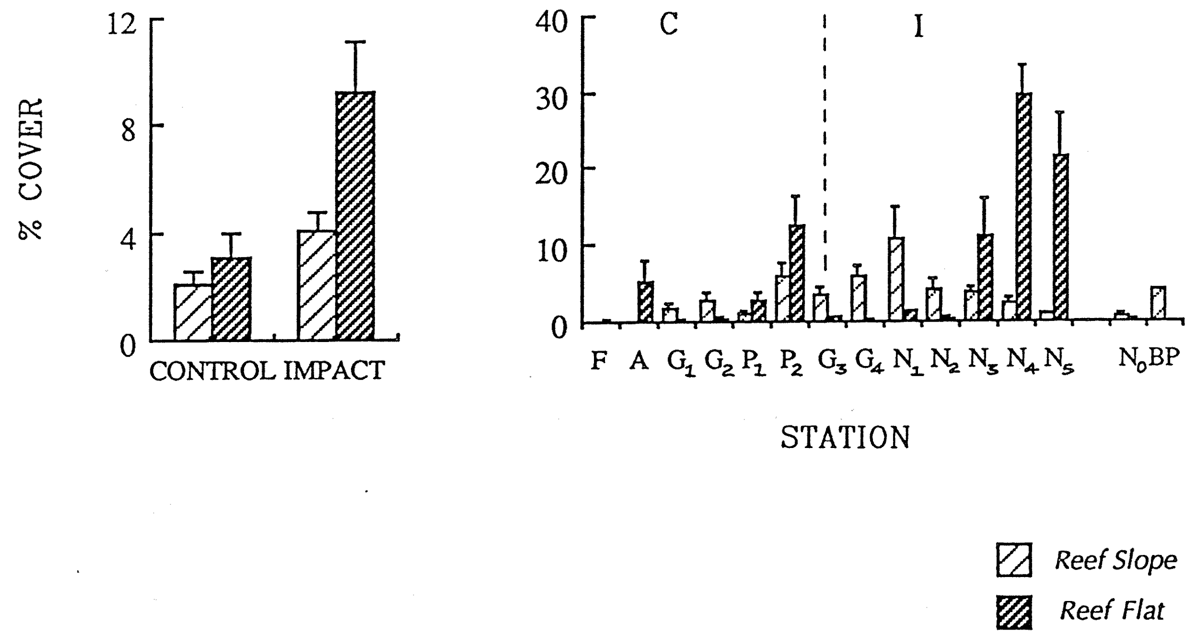


Figure 15: *Sargassum* spp. (Top) and *Lobophora* spp. (Above)

BIOMASS OF ALGAE

By far the most abundant algae by frequency of occurrence and biomass were the *Sargassum* spp., which accounted for over 85% of the biomass of algae in all quadrats. The patterns in total biomass were thus dictated by patterns in the biomass of the *Sargassums*. There was considerable variation in the species of *Sargassum* found in quadrats, and most species did not occur with sufficient frequency for individual analysis (Table 4). This was also true of the other algae identified (Table 4). In view of these characteristics, weights of all algae were pooled and only total biomass analysed.

Biomass of algae differed significantly between habitats, between impact and control stations, and among stations within impact and control areas (Table 7). There was on average greater biomass of algae on the reef flats (2.57 kg/m^2) than on the reef slopes (0.91 kg/m^2; Fig. 14), and more algae at impact stations (1.98 kg/m^2) than at control stations (1.50 kg/m^2). There were no significant differences among control stations (Florence Bay, Geoffrey Bay station 1, Picnic Bay station 2) when averaged over habitats, but in the impact group, Nelly Bay station 1 (2.56 kg/m^2) had greater biomass of algae than either station 2 (1.82 kg/m^2) or 5 (1.57 kg/m^2) in Nelly Bay (Fig. 14). Biomass of algae on the reef flat at Geoffrey Bay station 4 (3.22 kg/m^2) and on the reef slope off Bright Point (1.99 kg/m^2) was most similar to that at the stations in Nelly Bay (Fig. 14), but the reef slope at Geoffrey Bay station 4 (0.08 kg/m^2) was most similar to those at the control stations (Fig. 14).

Rates of Sedimentation

In the first three weeks of sampling, the presence of small blennid fish in sediment traps had no discernable effects on rates of sediment accumulation in traps on either reef slopes or reef flats at either impact or control stations (Analyses of Variance, $P > 0.2$ in all cases). In the fourth week of the study, however, the presence of fish was significantly inversely related to amounts of sediment in traps on the reef flats ($P = 0.015$), and possibly also on the reef slopes ($P = 0.086$). In both habitats, traps with resident fish contained approximately half as much sediment on average as traps without fish. The effect of fish was not treatment dependent, however, and thus unlikely to affect significantly conclusions about relative rates of sedimentation at control and impact stations.

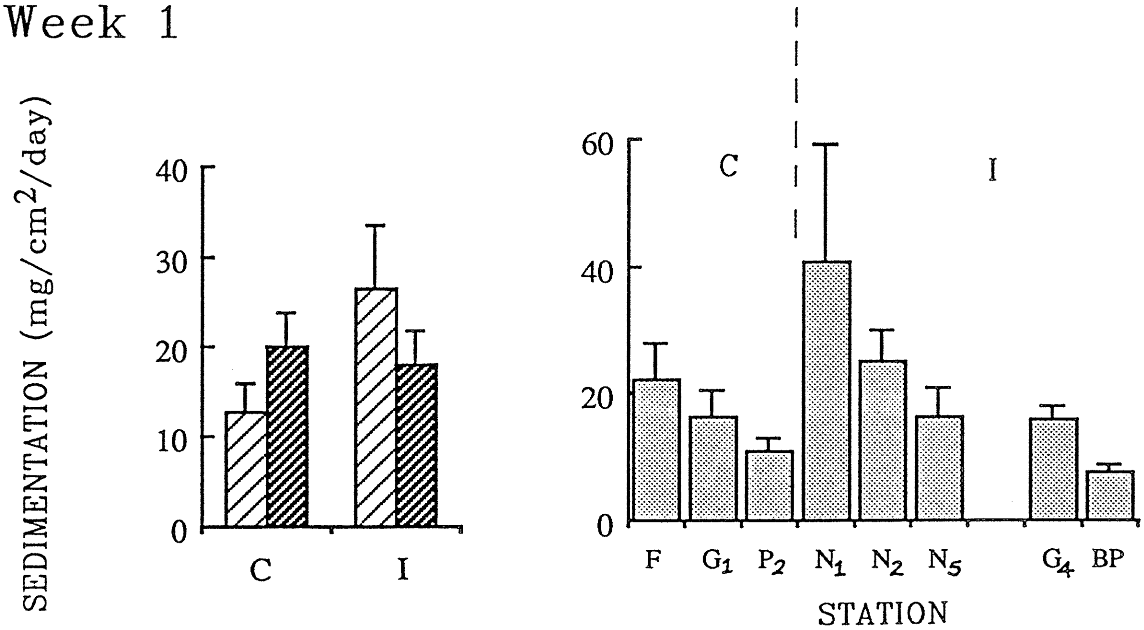
Rates of sedimentation along the south-east coast of Magnetic Island varied greatly during the baseline study. In general, variations in sedimentation reflected local weather and sea conditions, sedimentation being greater when winds and sea were stronger than in calm whether. Sedimentation ranged from less than 0.05g dry wt/trap/day (2.6mg/cm^2/day) to more than 7g/trap/day (356.6mg/cm^2/day). Sedimentation was greatest on the reef slope in Nelly Bay and at Bright Point (Fig. 16).

Source of variation	HAB	TREAT	STAT(T)	SITE(H,T,S)	H*T	H*S(T)
Week 1	-	*	?	-	*	-
Week 2	?	-	-	?	-	-
Week 3	*	*	?	-	*	-
Week 4	*	?	-	-	-	?

Table 8

Summary analysis of variance results for measurements of gross sedimentation for four weeks during January and February, 1989 (see text). All analyses were of the same form and abbreviations and symbols have the same meanings as in Table 7.

Week 1



Week 2

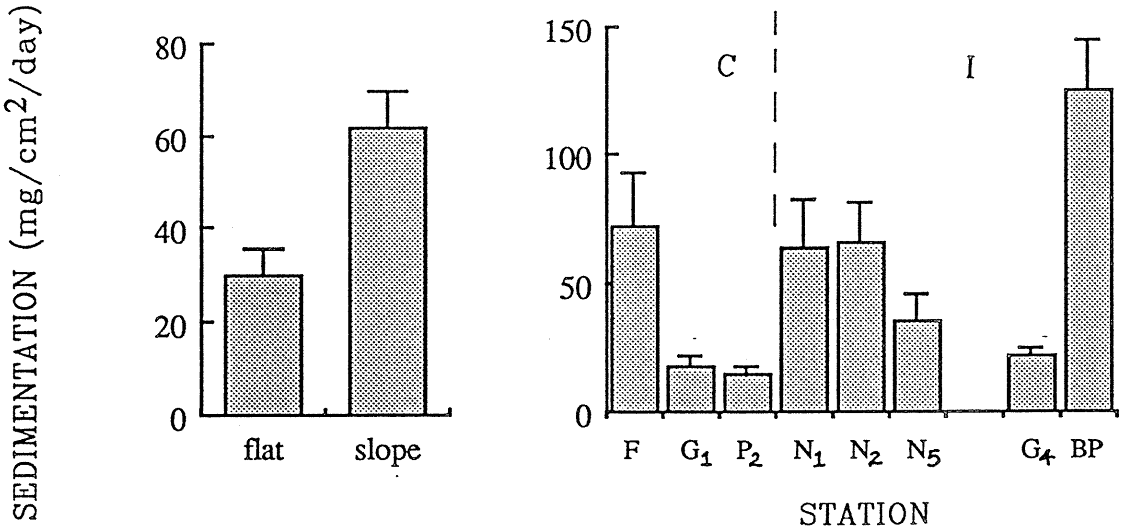
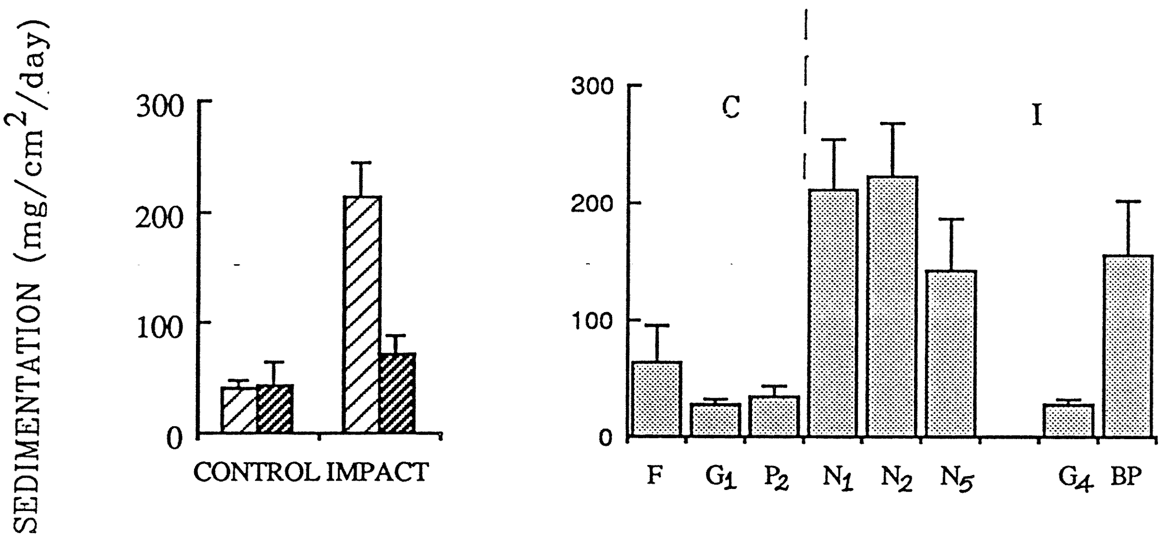


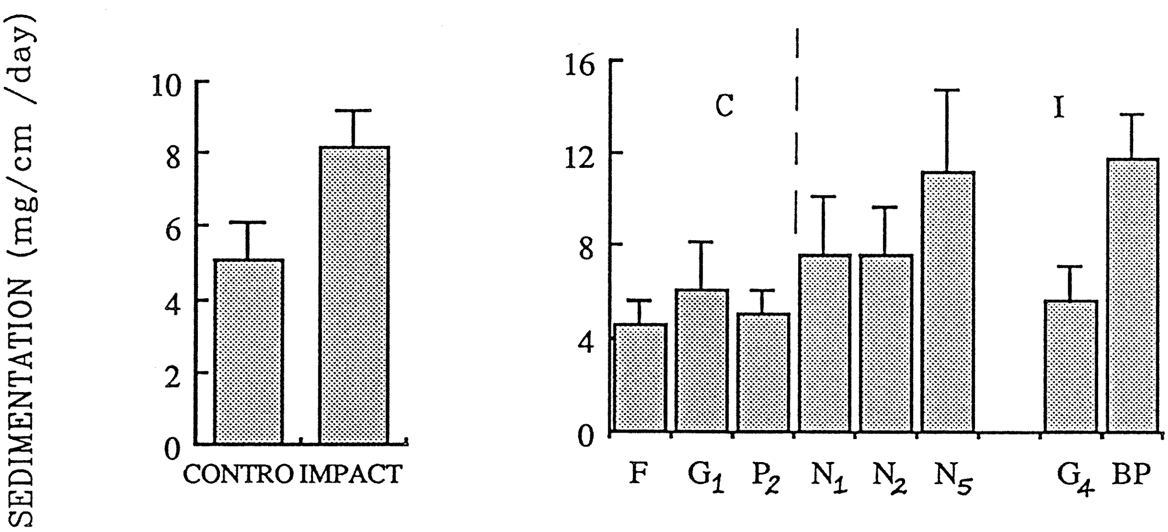
Figure 16

Analyses of variance results of aggregate sedimentation during each of four weeks at Bright Point and seven stations. The design and labels of these plots are the same as for figures 8-15, but with fewer stations involved.

Week 3


SEDIMENTATION (mg/cm²/day)
300
200
100
0
CONTROL IMPACT
300
200
100
0
C
I
F G1 P2 N1 N2 N5 G4 BP

Week 4


SEDIMENTATION (mg/cm /day)
10
8
6
4
2
0
CONTRO IMPACT
16
12
8
4
0
C
I
F G1 P2 N1 N2 N5 G4 BP

Between the 10th and 20th of January (week 1) and again between January 30 and February 7 (week 3), interactions between treatment and habitat were significant (Table 8; Appendix A for details). In both weeks rates of sedimentation were significantly greater on the reef slope at impact stations (Nelly Bay stations 1, 2, & 5) than on the reef slopes at control stations (Florence Bay, Geoffrey Bay station 1, & Picnic Bay station 2; week 1 - 26.5 vs 12.7mg/cm^2/day; week 3 - 230.3 vs 41.3mg/cm^2/day), but the two treatments did not differ significantly in sedimentation on the reef flats (Fig. 16; means: week 1 - 18.8mg/cm^2/day, week 3 - 57.3mg/cm^2/day).

Sedimentation was similar on reef slopes and reef flats in the control treatment, but averaged over the impact stations, reef slopes received significantly more sediment than reef flats (Fig. 16). In the same weeks, the analyses of variance indicated significant variation among stations within treatments (Table 8), but in only the later week could those differences be resolved by *a posteriori* tests. In that case, sedimentation at Nelly Bay station 5 was significantly less than at the other two impact stations, but did not differ significantly among control stations (Fig. 16). These two weeks represented both periods of high (week 3, overall mean = 114 mg/cm^2/day) and low (week 1, overall mean = 20 mg/cm^2/day) sedimentation, suggesting some consistency in the above patterns across a range of rates of sedimentation.

The patterns were only slightly different in the second and fourth weeks of the baseline. In the second week (intermediate sedimentation, overall mean = 44mg/cm^2/day), the only significant differences were between habitats (slope = 57.1mg/cm^2/day > flat = 32.6mg/cm^2/day; Fig. 16) and between some sites (in 2 of 24 pairs of sites). Although on both reef flats and reef slopes, more sediment collected in impact traps than control traps, the differences were not significant (Table 8).

In the fourth week of the baseline (very low sedimentation, overall mean = 6.6mg/cm^2/day), sedimentation in the impact treatment (9.4mg/cm^2/day), averaged over habitats and stations, was significantly greater than in the control treatment (3.8mg/cm^2/day). Differences between habitats were station-specific, and although reef slopes received more sediment than reef flats at most stations, differences were significant only at Nelly Bay stations 1 and 2. The only significant differences among stations within treatments occurred on the reef flat at impact stations (Nelly Bay station 5 > Nelly Bay stations 1 & 2; Fig. 16), the reverse of the pattern within Nelly Bay in week 3.

TRIP	X	Y	r	df	p
1	Trap	Secchi	-0.113	20	ns
	Trap	Surf Sol	-0.048	20	ns
	Secchi	Surf Sol	-0.678	20	p<0.01
2	Trap	Secchi	0.658	19	p<0.01
	Trap	Surf Sol	-0.382	29	p<0.05
	Trap	Bott Sol	-0.659	4	p<0.05
	Secchi	Surf Sol	-0.220	19	ns
	Secchi	Bott Sol	-0.881	4	p<0.05
	Surf Sol	Bott Sol	0.556	4	ns

Table 9

Results of analyses of correlation among secchi disk readings, concentrations of suspended solids and average rates of sedimentation for the third and fourth weekly samples (see Figure 17).
Trip 1:- 2 February 1989; Trip 2:- 9 February 1989.

In all weeks, sedimentation at Geoffrey Bay station 4 (south end of the bay) was most similar to stations in the control group, and usually considerably less than at the stations in Nelly Bay (Fig. 16). Conversely, except in week 1, rates of sedimentation off Bright Point were greater than on the reef slopes at most or all control stations and similar to those at the impact stations (in Nelly Bay) (Fig. 16). The tentative generalisation about patterns of sedimentation is, then, that Nelly Bay and Bright Point generally experience greater sediment deposition than the other stations sampled, particularly on the reef slopes.

Relation Between Turbidity and Sedimentation

On the first sampling occasion (week 3 above), secchi disk measurements were strongly related to amounts of suspended solids in surface waters (Table 9; Fig. 17). Rates of deposition in sediment traps, however, were not related to either secchi depth or suspended solids in surface waters (Table 9; Fig. 17). On the second occasion (week 4), secchi disk readings were not related linearly to measurements of surface suspended solids (Table 9; Fig. 17). Average rates of deposition in sediment traps, however, were strongly related to secchi disk readings ($r=0.658$, $P < 0.01$) and significantly related to suspended solids measured at the surface ($r=-0.382$, $P < 0.05$) (Table 9; Fig. 17). Both of these relationships were, however, counter-intuitive. It is clear that when summed over a week, the amount of sediment in traps near the bottom cannot be sensibly related to measurement of suspended solids or water clarity on any one day in that week.

In week 4, suspended solids were measured one metre above the substratum at seven of the reef slope sites. Due to the loss of two water samples, however, only five pairs of data were available for correlation. Secchi disk measurements and rates of deposition of sediment in traps from week 4 were correlated with the measurements of suspended sediment from the near bottom. The significance of this correlation, however, was clearly attributable to great leverage of a single outlier (Fig. 17). The amounts of suspended solids in surface waters were not related to concentrations of suspended solids near the substratum (Table 9; Fig. 17).

In general, there was considerable scatter around even highly significant relationships between measures of turbidity and rates of sedimentation. These results indicate that measurements of turbidity, such as secchi disk readings, are unlikely to be consistently reliable indicators of rates of sediment deposition near or on the substratum.

Figure 17:

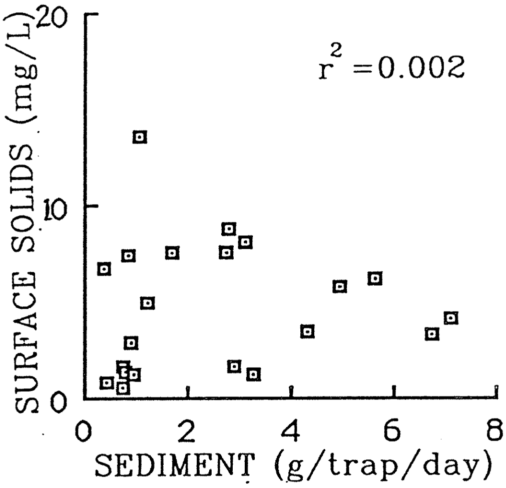
Relationships among secchi disk measurements (water clarity), surface and bottom solids (turbidity), and sedimentation. Surface and bottom solids are measurements of suspended solids taken from the surface and bottom respectively.

Week 3, January 30 - February 7, 1989

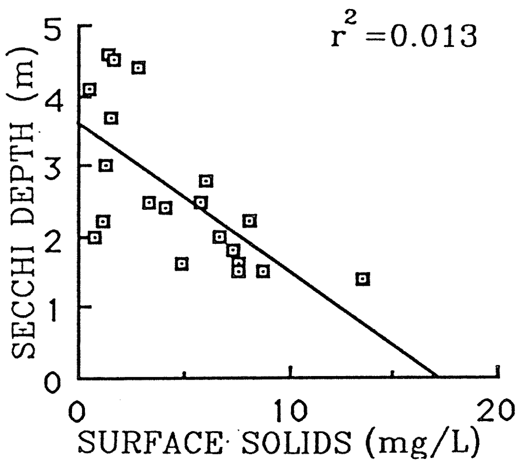
Week 4, February 7 - 14, 1989.

Water clarity and turbidity were measured on February 2 and February 9.

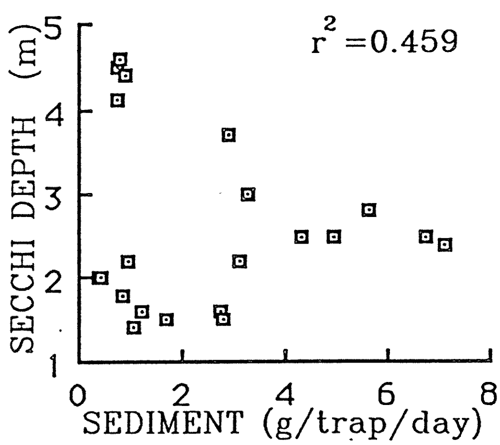
Week 3



$r^2 = 0.002$
SURFACE SOLIDS (mg/L)
SEDIMENT (g/trap/day)

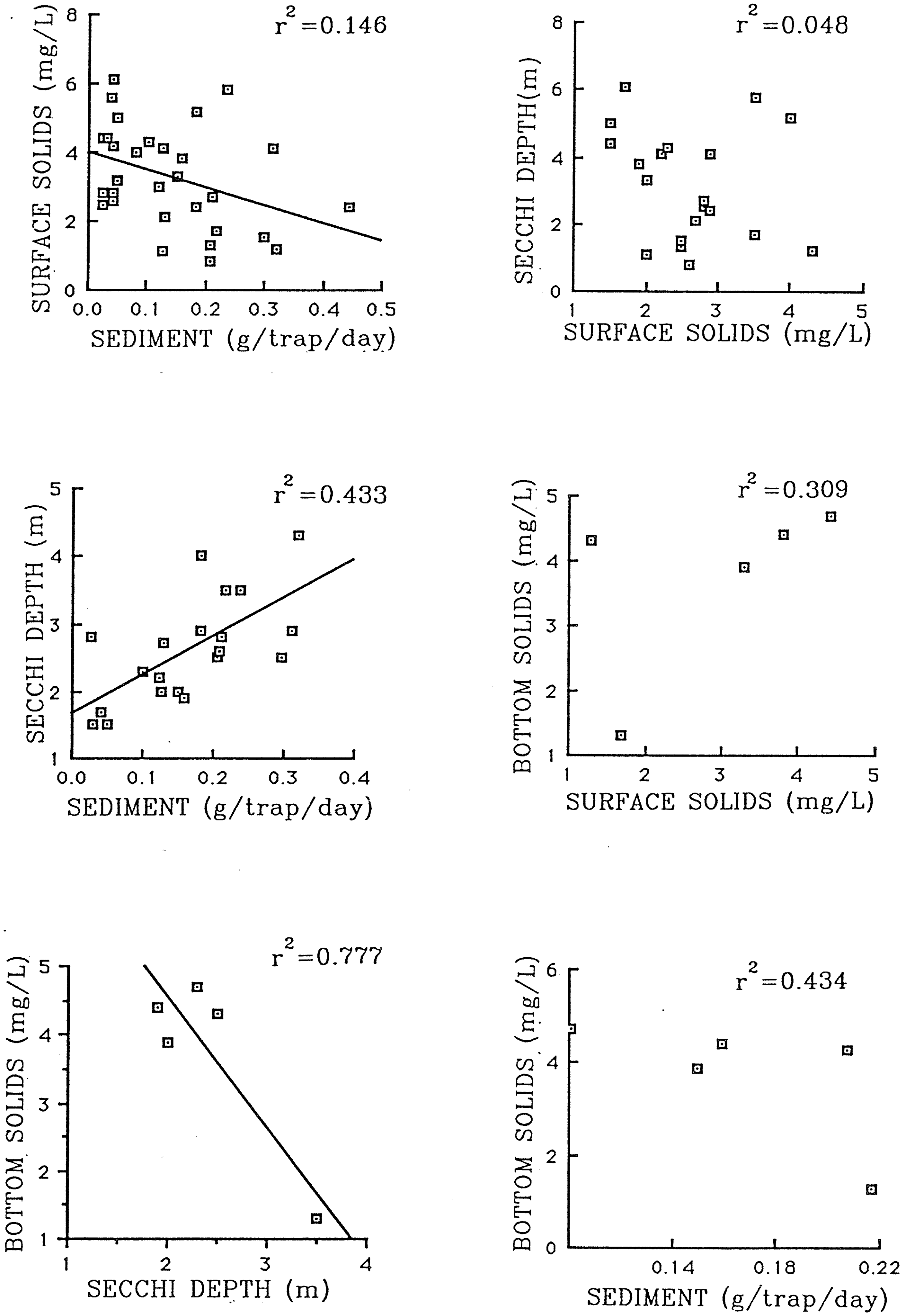


$r^2 = 0.013$
SECCHI DEPTH (m)
SURFACE SOLIDS (mg/L)



$r^2 = 0.459$
SECCHI DEPTH (m)
SEDIMENT (g/trap/day)

Week 4


$r^2 = 0.146$
SURFACE SOLIDS (mg/L)
SEDIMENT (g/trap/day)
$r^2 = 0.048$
SECCHI DEPTH(m)
SURFACE SOLIDS (mg/L)
$r^2 = 0.433$
SECCHI DEPTH (m)
SEDIMENT (g/trap/day)
$r^2 = 0.309$
BOTTOM SOLIDS (mg/L)
SURFACE SOLIDS (mg/L)
$r^2 = 0.777$
BOTTOM SOLIDS (mg/L)
SECCHI DEPTH (m)
$r^2 = 0.434$
BOTTOM SOLIDS (mg/L)
SEDIMENT (g/trap/day)

DISCUSSION

BENTHIC BIOTA

The fringing reefs off Magnetic Island clearly form a complex group, within which there are several striking patterns in the abundances of benthic flora and fauna. Most consistent were the distinctions between reef flats and reef slopes and between reefs in Nelly Bay (including Bright Point and the southern end of Geoffrey Bay) and all other bays. It is also clear, however, that there is considerable variation in these patterns among different groups of organisms. This is particularly the case at finer scales, such as patterns among stations within bays. It is clear that the reefs cannot be considered homogeneous with respect to biotic composition.

At no time in our study, however, was it apparent that the fringing reefs sampled were in any sense biotically unique or unusual, compared to fringing reefs along the coast north of Cape Tribulation for example. They are, however, the nearest fringing reefs to Townsville and they form a suite of habitats that are limited on Magnetic Island to the south east coast. For that reason alone, it is essential that the consequences of any large developments near these reefs are very carefully monitored.

The diversity among the fringing reefs of Magnetic Island has important implications for the assessment of any environmental impacts on them of the Magnetic Quay development. For most corals, the area of certain impact (i.e. the northern end of Nelly Bay) represents a low point in their abundance. Conversely, algae tend to be more abundant there than elsewhere. Given that the corals are of particular interest environmentally, and the algae are very abundant at most stations and form a labile component of the fringing reef communities, the area proposed for development is probably that at which damage to the aggregate of fringing reefs would be least.

It is of interest to note that the fringing reefs of Magnetic Island have been subject to a number of anthropogenic and natural disturbances over at least the past two decades. A particularly strong tropical cyclone (Althea) caused some damage to the reef biota, particularly on reef flats, in December 1971 (Collins, pers. comm). In 1973, there was an active quarrying operation on Bright Point, which would have been likely to increase rates of erosion of terrigenous sediments into the north end of Nelly Bay. Oliver (1985) reported considerable mortality of corals in Nelly and Geoffrey

Bays as a result of bleaching. The cause of bleaching was not known. The status of these reefs in 1988 suggests that they may be reasonably robust to periodic disturbance.

A second implication of the diversity among the fringing reefs on Magnetic island concerns the extent to which the reefs in Arthur, Florence, Picnic and Geoffrey bays reflect the biotic status of reefs in Nelly Bay. In particular, the use of these reefs as control reefs must be considered carefully. On one hand, it is important to note that our grouping of stations according to their geographic and hydrological proximity to the area of development corresponds very closely with the independent classification of stations by biotic similarity. The impact stations tend to form a distinct group from the control stations. This correspondence provides some circumstantial support for the logic we followed in classifying Geoffrey Bay station 4 together with Nelly Bay - *vis* because of the suggested hydrodynamic link between Nelly Bay and the south of Geoffrey Bay by a tidal eddy sweeping north around Bright Point (Parnell & van Woesik, 1988).

On the other hand, comparisons of abundances between impact and control stations for the purpose of impact assessment must be considered in the context of patterns that existed between these groups prior to the commencement of construction. The more complex the relations among stations *a priori*, the more difficult will be the assessment of whether an impact has occurred if that assessment is based on the analysis of patterns in abundances. The situation is exacerbated by the low power expected of tests based on raw abundance data (Box 6).

BOX 6
RESOLVING POWER OF STATISTICAL TESTS

The data from the baseline study were used to examine the statistical power of analyses to detect specified effects (such as differences in abundance or sedimentation between treatments, habitats, or stations). For all analyses of power, we followed the methods of Cohen (1977). Note that we were not examining *a posteriori* the power of the baseline analyses (in which there were many significant results, for which calculation of power has no meaning). Rather, we used estimates of variation from those analyses to predict the power of future analyses to detect specified differences.

In general, the power of analyses to detect differences in abundances of benthic organisms or rates of sedimentation will be poor, except for large effects - such as difference of 50% or 100% of the overall mean abundance (Table 10). This low power reflects the great inherent variability among replicate transects and among sites. Since the 'sites' term in all analyses is the denominator for F-tests of all other terms, and the numbers of levels of other factors is fixed, there are two ways to increase the power of tests for environmental impact. Either we can increase the number of sites sampled in each habitat at each station, or we could pool the variation among sites with the residual variation and test other terms against the pooled residual. The second alternative, however, is only valid if it is reasonably certain that sites do not constitute a significant source of variation (Winer, 1971; Sokal and Rohlf, 1981). This was not the case during the pilot study and is unlikely to change in the future. Hence, in Table 11, we show the numbers of sites that would have to be sampled in order to detect changes in abundances of benthic organisms equal to 25% and 50% of existing levels with equal probabilities of type I and Type II error (0.1).

	TEST 1 Effect Size			TEST 2 Effect Size	
	$\bar{G}$	$0.5\bar{G}$	$0.25\bar{G}$	$0.5\bar{G}$	$0.25\bar{G}$
GROUP					
Acropora willisae	0.84	0.39	0.17	0.19	0.12
Montipora spp.	0.70	0.30	0.15	0.16	0.11
Families Acroporidae/ Pocilloporidae	0.79	0.35	0.16	0.19	0.12
Cyphastrea spp.	0.67	0.28	0.14	0.16	0.11
Family Faviidae	0.83	0.37	0.17	0.19	0.12
Porites spp.	0.77	0.34	0.16	0.18	0.12
Turbinaria spp.	0.98	0.60	0.25	0.31	0.15
Fungiid group	0.62	0.26	0.14	0.15	0.11
Soft Coral	0.59	0.25	0.14	0.15	0.11
Sponges	0.63	0.26	0.14	0.15	0.11
Sargassum spp.	>0.99	0.69	0.29	0.38	0.16
Lobophora spp.	0.52	0.22	0.13	0.14	0.11
All Algae	>0.99	0.73	0.41	0.39	0.21
Hard Coral	0.96	0.54	0.26	0.27	0.14
SEDIMENTS					
Week 1	>0.99	0.53	0.22	0.35	0.16
Week 2	0.33	0.16	0.11	0.13	0.11
Week 3	0.87	0.41	0.19	0.27	0.14
Week 4	0.95	0.48	0.21	0.32	0.15
ALGAE - WET WEIGHT	>0.99	0.63	0.26	0.44	0.16

Table 10

Power of analyses to detect specified differences among levels of terms in the analysis of variance model used (model 4, Table 2). Power is shown for analyses of percentage cover of 14 groups of taxa, biomass of all algae and rates of sedimentation (for each of the four weeks of sampling). In each case, variation among sites was used in the calculation of power.

Power was calculated on the basis of a type I error rate of 10% and for the specified effect sizes. The effect sizes are expressed as the range over which means would be spread if they differed significantly. $\bar{G}$ is the grand mean of each group. Test 1 refers to tests of Habitat, Treatment and Habitat X Treatment effects as these all have F-ratios with the same power. Test 2 refers to tests of the effects of Station(Treatment) and Habitat X Station terms.

	$\bar{G}$	TEST 1 Effect Size 0.5$\bar{G}$	TEST 1 Effect Size 0.25$\bar{G}$	TEST 2 Effect Size 0.5$\bar{G}$	TEST 2 Effect Size 0.25$\bar{G}$
GROUP					
Acropora willisae	3	7	24	12	49
Montipora spp.	3	9	31	18	68
Families Acroporidae/ Pocilloporidae	3	8	28	14	56
Cyphastrea spp.	4	10	36	19	70
Family Faviidae	3	7	26	12	51
Porites spp.	3	8	30	14	59
Turbinaria spp.	2	4	12	7	23
Fungiid group	4	11	46	22	91
Soft Coral	4	12	50	22	100
Sponges	4	11	43	21	86
Sargassum spp.	2	3	10	6	18
Lobophora spp.	4	15	72	29	145
All Algae	2	3	6	6	11
Hard Coral	2	5	14	8	27
SEDIMENTS					
Week 1	2	5	14	6	21
Week 2	8	28	146	42	218
Week 3	3	6	21	9	30
Week 4	3	7	17	7	24
ALGAE - WET WEIGHT	2	4	11	5	16

Table 11

Numbers of sites that would have to be sampled to detect the indicated differences with a 90% certainty (power=0.9). Type I error was set to 10%, therefore Type I and Type II errors were weighted equally. Test 1 and Test 2 are as in Table 10, as are all other characteristics of the table.

ASSESSMENT OF IMPACT ON CORALS

The focus of interest in assessing the environmental impact on fringing reefs of the development of Magnetic Quay will be whether the development causes any noticeable decline in abundances of benthic biota, particularly hard corals. An impact of development would be signalled by decreases in the abundances of some or all corals at impact stations whilst abundances of those corals had not changed, or had changed in a different direction or by smaller amounts, at control stations. If no impact occurred, we would expect that changes in abundances would be the same, on average, at all sites, and unrelated to the patterns in absolute abundance among sites, stations etc. on any given occasion. The important point to note here is that it is the comparison of **changes** in abundance from one time to the next that is important.

The choice of fixed as opposed to random transects for this study provides a convenient solution to the problems of great variability in absolute abundance and low power of tests based on absolute abundance data. Fixed transects allow us to measure changes in abundances independently of patterns in absolute abundance, and to eliminate the effects of great spatial variability in abundance on analytical power. Since the same transects (and hence the same individual colonies) at each site will be surveyed on each occasion, changes in abundance can be measured with little error, certainly with far less error than had random transects been used. This is possible only because the corals are sessile and long lived relative to the intervals between repeated surveys.

Under these conditions, identification of changes in the corals attributable to an impact of development can be based on the measurement of changes in abundances of particular corals between resurveys of the same site. There are three sources of variation involved in this procedure. Firstly, there is the real, biological change in abundance resulting from processes such as growth, fragmentation, settlement, and death of corals. This is what we wish to measure and use to assess whether an impact has occurred. Secondly, there is variation attributable to errors in the measurement of abundance at any given time. Perceived changes in corals along a particular transect will reflect both these things. Variation due to errors of measurement, however, can be estimated by remeasuring the same transects at very short intervals, during which the corals along that transect would not have changed.

Finally, there is likely to be stochastic variation among transects, sites, etc. in the natural processes that cause change. This will result in real differences among transects or sites in the amount of change in corals that will occur over longer periods. Estimates of change in abundance at scales larger than transects (such as sites, stations, or groups of stations) will contain components of all three sources of variation. An impact would occur if the Magnetic Quay (or other) development systematically influenced the natural changes in abundance at the impact stations.

Following the resurvey of all transects during the construction and operational phases of Magnetic Quay, the differences between those data and the baseline data can be calculated. These differences will be the above estimates of the changes in abundances of corals along each transect. They will be independent of the patterns in absolute abundances among transects, sites, etc. If these 'difference data' are then divided by the abundances present during the baseline, the changes in abundance will be expressed as proportional change and will then also be independent of the abundance at each site.

Hypotheses about environmental impact (e.g. the specification of effect sizes) can now be conveniently stated and tested in terms of proportional change in abundance. For example, if it was stated that a decline in abundance of 20% that could be attributed to the development would be cause for management action, that criterion could be tested directly by comparison of proportional changes in abundance between impact and control stations. These tests are likely to have considerably greater power to detect environmental impacts than analyses of absolute abundances (Box 7).

If proportional change data were analysed, the sampling design that we used during the baseline would be sufficiently sensitive to detect relatively slight effects of the Magnetic Quay development at most scales. The detection of a 'critical' impact of, say, 20% change in abundance with 90% certainty would be a realistic proposition for most taxa (Table 12). Such changes would be very costly and difficult to detect with reasonable certainty, however, using absolute abundance data (Table 11). The analysis of differences is likely to provide a powerful method for detecting anthropogenic impacts on organisms such as corals.

The main constraint of analysing proportional changes in abundance is that change over only a single time interval can be analysed at once. In the assessment of environmental impact, however, this is acceptable since each 'treatment' condition (i.e. each survey during construction and operation of Magnetic Quay) should be compared to the single control - *vis* abundances present during the baseline. The questions of interest are 'has an impact occurred after six months of construction?', 'has an impact occurred after 12 months of construction?', etc. These questions constitute a series of separate paired before-after comparisons, appropriate to the analyses we have suggested.

GROUP	TEST 1		TEST 2	
	α,ß=0.05	α,ß=0.1	α,ß=0.05	α,ß=0.1
Total Hard Corals	13.2	11.0	17.5	15.8
Families Acroporidae/ Pocilloporidae	15.3	12.7	20.1	18.2
Acropora willisae	3.0	2.5	4.0	3.6
Montipora spp.	2.0	1.7	2.7	2.4
Family Poritidae	8.2	6.8	10.8	9.8
Family Faviidae	12.2	10.2	16.2	14.6
Cyphastrea spp.	3.0	2.5	4.0	3.6
Fungiid group	14.3	11.9	18.8	17.0
Turbinaria spp.	53.0	44.2	69.9	63.3
Soft Corals	1.4	1.2	1.9	1.7
Total Algae	66.2	55.2	87.4	79.1
Sargassum spp.	19.3	16.1	25.5	23.0
Lobophora sp.	49.8	41.5	65.7	59.5

Table 12

Effect sizes (differences among means) that would be detected when proportional changes in abundance were analyzed. Error variances (among sites) were estimated from repeated measures of transects over a one month interval (see Box 7). Effect sizes are shown for stated power of 90% (α,ß=0.1) and 95% (α,ß=0.05).

BOX 7
POWER OF ANALYSES OF PROPORTIONAL CHANGE IN ABUNDANCE

We resurveyed transects at two sites at Nelly Bay station 5 (one on the reef slope and one on the reef flat) shortly after the completion of field work for the baseline study to estimate the error of measurements inherent in repeated surveys of the same carefully marked transects. The repeated surveys were only four weeks apart, and it was considered unlikely that there would have been significant real changes in abundances of corals. Consequently, variation in estimates of cover for each transect between the two surveys would be attributable to only observer error and slight variation in the placement of the measuring tape. Using these estimates of within and between site variation in repeated measures of the same transects, we calculated the power-effect size characteristics of analysing proportional differences in abundances between two times when biological change was small (Table 12).

Some caveats are necessary, however. Firstly, we cannot be certain of the accuracy of our estimates of total variation in repeated survey among transects and sites. Our estimates of variation are likely to be predominantly comprised of variation due to errors of measurement. We have almost certainly underestimated the variations among sites and transects in natural changes in abundances that would occur over periods longer than one month. This would mean that the analyses of changes in abundance would be less powerful than predicted.

Counterbalancing this, is the fact that our errors of measurement were likely to be larger than normal for several reasons. Firstly, the transects were resurveyed in relatively rough, turbid conditions; rougher conditions than those in which transects would normally be surveyed. The considerable movement of the transect lines, and difficulty for divers to stay in one place above the lines during surveys, would have increased considerably the variation between original and repeated estimates of abundances. This effect would be important particularly for species with low abundances, such as the *Turbinaria* sp. and sponges at the sites we re-sampled. Secondly, we estimated within and between site variation from data from only two sites. It might be expected that these estimates would be considerably larger than those derived from averaging within and between site variation over all sites sampled, as would be the case when the complete set of transects was resurveyed. Finally, the two sites re-sampled were in different habitats. Our estimate of between site variation measurement error, therefore, would have included a component of between habitat variation in repeatability of surveys. This may have inflated the estimate of between site variance we used to calculate power.

If abundances of corals at adjacent sites change in fairly similar ways over the relatively short construction phase (18 months) of Magnetic Quay, we expect that we will be able to detect effect sizes at least as small than those given in Table 12 with the same power (0.9). Preliminary analysis of data from Cape Tribulation suggest that this is likely. It is possible, however, that natural change in abundances or any effects of development might be patchy at small scales, with corals in some transects or sites changing much more than others at adjacent transects or sites. This would have the effect of increasing variability in repeated measures within and/or among sites. Consequently, we would be not be able to detect differences in proportional change as small as those in Table 12 with power held at 0.9. We therefore suggest that the 'detectable effect sizes' in Table 12 form the basis for specifying initial criteria for management action and any improvement in sensitivity of our sampling be seen as an opportunity to review those criteria.

ASSESSMENT OF IMPACT ON ALGAE

Algae on the fringing reefs of Magnetic Island have been shown to have a strong seasonal component of growth and abundance (Vakamoce, 1987). Large changes in abundance and distribution of algae at most scales are expected over short periods. The plants present during the baseline, therefore, may not be present on all, or even most, subsequent sampling occasions. Even during the four weeks between the initial and repeated surveys of the sites in Nelly Bay, abundances of algae declined significantly. The rate of decline varied greatly between and within sites, however, indicating that the detection of moderate differences in changes in abundance between, say, impact and control stations would be difficult for these organisms (Table 12). Consequently, the analysis of differences proposed for the assessment of impact on corals may not be a powerful or appropriate method for analysis of impacts on algae.

Because many of the algae, in particular the *Sargassum* sp., are known to grow rapidly, it might be expected that variation in growth would be the most sensitive indicator of any effects on them of environmental perturbation over short periods (particularly changes in nutrient levels). We suggest, therefore, that during the construction and operation of Magnetic Quay, the growth (stipe elongation) of individually tagged *Sargassum* plants be recorded at regular intervals. These growth data would be amenable to analysis by analysis of variance similar to those used already, and would be likely to provide powerful tests of hypotheses about the effects of Magnetic Quay on the benthic algae.

It may also be necessary to monitor the status of adventitious turfing and filamentous algae that have the potential to over-grow live corals (Potts, 1977). Data on percentage cover by algae would be collected as a matter of course when the fixed line transects were being re-surveyed, and would be analysed to assess any gross changes in the patterns in abundances of algae from those described here. Biomass of algae should also be assessed, for the reasons outlined previously (materials and methods).

SEDIMENTATION

It was clear even during the limited period of the baseline study that the fringing reefs around Magnetic Island are subject to a relatively turbid, high sediment environment. Rates of sedimentation during only moderately rough seas were high compared to those measured at offshore reefs and fringing reefs in other parts of the world (Pastorok & Bilyard, 1985; but see Cortes and Risk, 1985 for details of extreme sedimentation - up to 1000mg/cm^2/day - on a Costa Rican fringing reef). Clearly, the organisms on these reefs are able to withstand at least short periods of high sediment movement. Cortes and Risk (1985) suggested that corals in Costa Rica were able to survive well under siltation rates of 300mg/cm^2/day.

It is likely, however, that these high rates of sedimentation can be tolerated only under the conditions that are likely to be their cause - that is, rough seas and great water movement. Under these conditions, it is unlikely that sediment would remain on the surfaces of corals for more than a few minutes, and accumulation of sediment and consequent physiological stress (and perhaps suffocation) of corals seems unlikely (T. Done, M. Stafford Smith, pers. com.). Equivalent rates of sedimentation were not recorded during calmer whether in the baseline study, and are probably unlikely under natural conditions when water movement is low. In calm whether, sediments are far more likely to remain on the surfaces of corals unless actively expelled by the organisms. It is under these conditions that increased sediment loads in the water column would be most likely to lead to accumulation of sediments on the surfaces of corals. These are the circumstances most likely to cause severe physiological stress and mortality of the corals. It is, therefore, critical that all care should be taken during the construction phase to minimise increased sediment loads over the fringing reef, particularly in calm weather.

Rates of sedimentation on the fringing reefs of Magnetic Island are clearly very labile and subject to very short term variation in weather and sea conditions. During the pilot study, there was no significant relationship on average between the amount of sediment in a trap on one occasion and the amount of sediment in that trap on subsequent occasions. Small scale spatial variability in sedimentation was apparently also very labile. Thus, although the same traps were used to collect sediments at exactly the same places on all occasions, we suggest that the resulting data were effectively independent from one occasion to the next. It would therefore be inappropriate to treat the analysis of sedimentation as an analysis of differences, as was suggested for coral abundance data.

The consequence of this is that we will have no choice but to arbitrarily evaluate the implications of any changes in patterns in sedimentation from those described in the baseline study. This will be particularly problematic because one of the most striking features of sedimentation during January-February 1989 was that Nelly Bay tended to have naturally considerably higher rates of sedimentation than the control stations, particularly on the reef slopes.

The potential for erroneously concluding that differences in sedimentation between Nelly Bay and control stations were cause for management action is great because of the limited period over which we have been able to assess the usual range of such differences. This problem would be alleviated considerably by the continuation of regular measurements of sedimentation in the period prior to the commencement of construction activities that might result in increased sediment loads in the water column. Such a programme would allow the calculation of an average difference in rates of sedimentation between the slopes of Nelly Bay and other Bays based on a greater range of seasonal and local whether conditions. The difference would be indexed to the average rates of sedimentation in the control bays so that data from both calm and rough periods could be sensibly and separately averaged. With these data in hand, a significant effect of the development would be deemed to have occurred if, during construction, sedimentation in the vicinity of Magnetic Quay or in Nelly Bay generally was greater than at the control stations by an amount greater than the 90% confidence limits of the mean difference prior to construction. On the basis of the results of the baseline study, we also recommend the ammendment of the programme of sampling sediments (Table 13).

We have been asked by the GBRMPA to provide recommended 'critical' rates of sedimentation on the reefs of Magnetic Island. In theory, these would be rates of sedimentation near the upper limits of the tolerance of the corals, and equal to or greater than rates that occur naturally. If these figures were exceeded because of construction activities, the GBRMPA would halt proceedings pending further investigation of the enhanced rates of sedimentation and their biological consequences. Such 'critical' levels, however, should not be the sole criterion for management action. The logical steps that should be followed in deciding whether the development has indeed had an impact are discussed in Box 8.

In view of the naturally greater rates of sedimentation in Nelly Bay, we have also recommended further sampling to better establish what can be considered the natural limits of such differences. At this time, we would suggest that an impact would be indicated if sedimentation on the reef flats of impact stations were significantly different from those on reef flats at control stations. Sedimentation on the reef slopes in Nelly Bay, however, was on average 2.6 times greater than that on reef slopes at the control sites. Because this relation was very variable, and we were able to sample for only four weeks, the (one-tailed) 90% confidence interval for the relation is 1.4. This would indicate that sedimentation on the slopes of Nelly Bay would have to be more than 4 times greater than that on the slopes of control stations before an effect of development could be inferred with reasonable certainty. This figure seems high, and we therefore reiterate the need for further sampling before construction operations are fully implemented.

If, on the basis of these criteria, it is decided that an impact has occurred (Box 8), the question of whether the enhanced sedimentation in Nelly Bay has exceeded critical levels must be answered. The answer will clearly be weather dependent. On the basis of rates of sedimentation recorded during the baseline, we suggest that in moderate to rough conditions (winds > 25 knots), sedimentation on the reef flat should not exceed 95mg/cm^2/day. On the reef slope, an upper limit of **average sedimentation at a station** of 254mg/cm^2/day would be cause for concern, although rates of sedimentation at single sites are likely to exceed this figure.

SOURCE OF VARIATION	MODEL 1		MODEL 2		MODEL 3		MODEL 4	
	df_F	Power	df_F	Power	df_F	Power	df_F	Power
Habitat	1	0.69	1	0.80	1	0.90	1	0.97
Treatment	1	0.69	1	0.80	1	0.90	1	0.97
Station (T)	4	0.49	6	0.55	4	0.77	6	0.83
Site (H,T,S)	12	>0.99	16	>0.99	24	>0.99	32	>0.99
Habitat*Treatment	1	0.69	1	0.80	1	0.90	1	0.97
Habitat*Station (T)	4	0.49	6	0.55	4	0.77	6	0.83

Table 13

Effects of varying the numbers of stations and sites sampled on the power of analyses of sediment data. For all models, power was calculated on the basis of a Type I error of 10% and an arbitrary effect size index (Cohen, 1977) of 0.6. Model 1 was used in the baseline study.

In Model 2, four stations would be sampled in each treatment but, as before, only two sites would be sampled in each habitat at each station. In Model 3, three stations would be sampled in each treatment and three (rather than two) sites would be sampled in each habitat at each station. Model 4 is the combination of Models 2 and 3, i.e. four stations per treatment, three sites per habitat in each station.

Because of the great increase in cost associated with model 4 (compared with model 1) and because 'Site' is the denominator in tests of all other effects, we suggest deploying only three sediment traps at each site rather than four. In this way, the cost of model 4 (the most powerful model) would be reduced to only a little more than that of the sampling design used in the baseline study (model 1). This is the strategy we would recommend for impact assessment studies, incorporating Geoffrey Bay station 4 into the impact assessment and either Arthur Bay or Picnic Bay station 1 as an additional station.

BOX 8
WHEN HAS AN IMPACT OCCURRED?

The following steps form a logical sequence of decisions which, to some extent, relegate the difficult question of 'critical' threshold levels of disturbance (e.g. sedimentation) to the end rather than the beginning of the impact assessment protocol. In many instances, this will probably mean that the question of critical levels never arises. This is so because the likely ecological importance of an impact needs to be assessed only after it has been demonstrated that a real effect of development is likely to have occurred.

We suggest the following sequence of steps in deciding whether a development is having an impact on natural processes (such as rates of sedimentation).

1. Is there a difference apparent between sites of potential impact and control sites? It is imperative that control sites be isolated from any effects of development and that they are sampled at the same time as impact sites. Initially, apparent differences would be assessed by simple comparisons of indicator variables by an on-site consultant.

2. Are apparent differences statistically significant and do they indicate a change in the relation between 'impact' and control sites from that which existed prior to the commencement of development? The natural relation between impact and control sites should have been established during a baseline study, completed before development commenced. If any perceived differences are asserted to be statistically significant, the Type I error rate must be specified and if perceived 'differences' are dismissed as not statistically significant, the Type II error rates must be estimated (Box 3). The latter requires the specification *a priori* of the magnitude of differences that could reasonably be expected to be detected over background (within-site) variation and the design of a sampling programme sufficient to detect such differences.

3. If a significant difference is detected in a variable likely to have adverse impact on the environment, 'reactive sampling' should be implemented immediately to estimate precisely the extent and magnitude of the effects of development and what variables (e.g. sedimentation, nitrogen concentrations, bacterial concentrations) are involved. Reactive sampling would entail complete and thorough sampling of the environment in all control and impact sites.

4. At this stage an interim decision would have to be made about the appropriate response to the impact - in particular, whether construction should be suspended. This decision need not be based on the absolute level of impact incurred, particularly where the consequences of such an impact are not certain. The environmentally conservative strategy would be to suspend construction pending the results of the reactive sampling or further investigation. With suspension of development, however, the impact may decrease or disappear, adding weight to the argument that the above difference was caused by the development, but also eliminating the possibility of verifying whether the impact had any chronic effects on the environment. To allow the development to continue 'pending further study' is to risk compounding any acute effects of the impact.

5. Assuming the potentially deleterious impact has been verified by reactive monitoring, is it likely to constitute an ecologically important effect - i.e. is it likely to result in a noticeable and important impact on the natural environment? This is when the questions of critical thresholds and environmental tolerances have to be addressed. It is also when longer term decisions about the continuation of the development have to be made.

Steps 1. - 4. can be taken without reference to critical levels of change and can be justified on the basis of information obtained from the baseline study, sampling design, statistical procedures, and conservation policy. Promoting the question of whether processes at the site of development exceed critical levels to the first step in impact assessment ignores the reasons for implementing baseline studies and control/impact comparisons. It also places the decision-makers in a more tenuous position when having to justify their decision to suspend, stop, or permit continued development than does the above set of procedures.

We stress that these figures are at best 'guestimates' because there is insufficient knowledge of the effects of specific rates of sedimentation on the health and survivorship of corals on Australian fringing reefs to provide definitive statements about critical thresholds. Suggestions from elsewhere of maximum rates of sedimentation that can be tolerated by corals range from 10mg/cm^2/day (Pastorok & Bilyard, 1985) to well over 500mg/cm^2/day (Cortes & Risk, 1985). These disparate figures highlight the likely dependence of tolerances of corals to sedimentation on local conditions, species, and acclimation of the corals to local conditions.

Instantaneous Measurements of Sedimentation

Except in rough weather, when sedimentation will be great, sediment traps will not adequately measure sediment deposition over short periods (1-2 days). Inferring average rates of sedimentation from instantaneous measures of other variables, however, is also unlikely to provide adequate estimates of sedimentation. We have shown that there are several difficulties with attempting to relate data from sediment traps to those from secchi depth and suspended solids. Sediment traps sample sediment deposition over 7-10 days, whereas turbidity measures are instantaneous. The sediment trap measurements are affected by varying weather conditions on days preceding and following those on which turbidity was measured. Clearly, more experimental work is necessary to establish whether there are short-term relations between turbidity and sedimentation. We therefore suggest that extreme caution is necessary if management decisions are to be based on inferences of rates of sedimentation from rapid, on site measurements of variables such as water clarity and turbidity.

SUMMARY

We have described the characteristics of the benthic biota on the fringing reefs along the south-east coast of Magnetic Island. The reefs are variable in structure at a variety of scales. Of particular interest with respect to the proposed development of Magnetic Quay, is the relatively clear distinction, on biological grounds, between Nelly Bay and the reefs Geoffrey, Arthur, Florence, and Picnic Bays, particular for reef slope biota. Although several taxa differ in abundance among the bays, reefs in Nelly Bay in general, and the northern end of Nelly Bay in particular, generally support a similar taxonomic assemblage of corals and algae as reefs in the other bays. It is unlikely, therefore, that ecologically significant features will be lost through excavation at the north end of Nelly Bay.

Several difficulties are likely to be encountered in the assessing of environmental impacts of the development of Magnetic Quay. These difficulties are not unique to this development, but their solution has not often been addressed. We devote considerable text to the discussion of possible

solutions and recommend several strategies to ensure that environmental impacts are assessed realistically. We provide an outline of an environmental impact assessment study that would achieve this aim (Appendix C).

On a procedural note, we would emphasise the necessity for the developers to minimise the output of sediment into Nelly Bay at all times. In particular, we emphasise that the consequences of any release of sediment are likely to be greatest when the weather is calm. It is under these circumstances, that sediment is most likely to accumulate on the corals and result in damage from smothering.

Finally, it is important to have established *a priori* a logical set of procedures which are to be used in determining whether an impact has occurred. Basing of such procedures on the singular relation of variation in environmental variables (such as sedimentation) to hypothesised 'critical thresholds' is logically and empirically flawed. In its place, we describe a set of five steps that will result in any conclusion of an impact being both justifiable and reasonably unlikely to be erroneous.

ADDENDUM: RESPONSE TO REVIEWERS' COMMENTS

Anova Models

The choice of analytical models for treatment of the data is essentially arbitrary within the constraint that the key questions of interest (i.e. has an impact occurred?) must be able to be answered. The four alternative models of analysis of variance discussed in this report represented different ways of addressing this question. All were based on the same data set, derived from the same set of transects sampled in the field. Under these circumstances, there seems little reason for choosing a less powerful analytical model over that recommended (model 4, Table 2, following p14), unless there were good reasons to dispute the classification of stations into impact and control groups.

For example, it might be argued that the stations should be classified as 'likely impact', 'possible impact', and 'control', and model 3 chosen accordingly. If it was suspected that an impact of development might affect the stations in this pattern, model three would undoubtedly have greater power to detect that pattern of impact (indicated by a significant Treatment effect) than model 4, in which such a pattern would be detected only by *a posteriori* analyses following a significant result for the Stations (Treatment) term (Table 2). This would also be the case for a pattern of impact which was a subset of the 'three treatment' model, such as an impact at 'likely impact' stations but no impact at the other two groups. The relative strengths of models 3 and 2 to detect impacts at smaller scales were discussed in Box 5.

An alternative strategy for assessing impacts of this kind, would be to subdivide the stations within each of the treatments in model 4 (impact vs control) into two specific categories. For example, the impact stations might be considered in terms of the group of stations very close to the development (Nelly Bay stations 1, 2, & 3) and at high risk, and those farther away from the construction area and at lower risk (Nelly Bay Stations 4 & 5 and Geoffrey Bay station 4). Similarly, control stations would be divided into those certain to be immune to potential effects of the development (Arthur, Florence, and Picnic Bays) and those about which there was some doubt as to their control status (Geoffrey Bay stations 1, 2, & 3 - see reviewers comments). This analysis would, then, incorporate a fifth factor 'Intensity' nested within treatments, each level of intensity being represented by three stations. The analytical design of this model is given in Table R1, together with

Table R1

Three analytical models (analyses of variance) under which the data could have been analysed. Habitat (reef flat vs reef slope), Treatment, Intensity, and Station are fixed effects and sites are random variables. In all models, the significance of sites as a source of variation would be tested against the residual variance, and all other terms would be tested against sites. Degrees of freedom for these F-ratios (df_F) are shown in the form numerator, denominator. The power of each test was calculated with Type I error set at 5% and an arbitrary effect size index (Cohen, 1977) of 0.7.

Model 3. Three treatments are considered: High Impact (Nelly Bay stations 1, 2, & 3, and Geoffrey station 4); Intermediate likelihood of impact (Geoffrey stations 1 & 2, and Nelly 4 & 5); No Impact (Florence, Arthur, and Picnic stations 1 & 2). Geoffrey Bay station 3 would be ignored.

Model 4. Stations are divided equally between two treatments: control (Arthur, Florence, Geoffrey 1 & 2, and Picnic 1 & 2); and impact (Nelly 1-5, and Geoffrey 4).

Modified Model 4. As for Model 4, except that stations are further divided into categories on the basis of potential 'Intensity' of impact: High (Nelly Bay Stations 1-3); Low (Nelly Bay Stations 4 & 5, Geoffrey Bay Station 4); Unlikely, but possible (Geoffrey Bay Stations 1-3); and zero (Arthur, Florence, and Picnic 1 or 2).

In models 3 & 4, Geoffrey Bay station 3 is omitted because of its uncertain status with respect to the classifications of likely degree of impact. Its status would be examined *a posteriori* in the context of other results. In the modified model 4, all of stations 1-3 in Geoffrey Bay are tentatively considered as controls, but the reservation is made that there is the potential for slight impact to occur as a result of their proximity to the development. One of the stations in Picnic Bay would be omitted from this model to balance the analysis.

Model 3

SOURCE OF VARIATION	df_F	POWER
Habitat	1, 24	0.93
Treatment	2, 24	0.88
Station (Treatment)	9, 24	0.64
Site (Station, Treatment, Habitat)	24,144	>0.99
Habitat*Treatment	2, 24	0.88
Habitat*Station (Treatment)	9, 24	0.64

Model 4

SOURCE OF VARIATION	df_F	POWER
Habitat	1, 24	0.93
Treatment	1, 24	0.93
Station (Treatment)	10, 24	0.64
Site (Station, Treatment, Habitat)	24,144	>0.99
Habitat*Treatment	1, 24	0.93
Habitat*Station (Treatment)	10, 24	0.64

Modified Model 4

SOURCE OF VARIATION	df_F	POWER
Habitat	1, 24	0.93
Treatment	1, 24	0.93
Intensity (Treatment)	2, 24	0.88
Station (Treatment, Intensity)	8, 24	0.67
Site (Station, Treatment, Habitat)	24,144	>0.99
Habitat*Treatment	1, 24	0.93
Habitat*Intensity (Treatment)	2, 24	0.88
Habitat*Station (Treatment, Intensity)	8, 24	0.67

the designs of Models 3 and 4 (from the report) for comparison. It is clear that the above model is perhaps the best compromise between models 3 and four, in that it retains good power to detect a widespread effect (like model 4) and also has good power to detect more localised impacts (similar to model 3).

The power of any test to detect a specified effect when more than two means are being compared depends explicitly on the real pattern of differences among those means. Throughout this report, all calculations of power, required numbers of sites, or detectable differences are based on the 'most detectable' arrangement of means, namely that where means within any sensible comparison are clustered into two groups with equal numbers of means in each group. As any suite of means becomes more heterogeneous - i.e. separated into increasing numbers of groups - so the power to detect a given effect will decrease. Viewed alternatively, as means become more dispersed, differences among them will have to be greater if the differences are to be detected with a specified (constant) power.

In the attached table (Table R2) we show the effect sizes that might be detected (see Box 7) if data on proportional changes in abundance were analysed under Model 3 and the revised model 4 described above. Two patterns of differences among means are considered - the 'best' and 'worst' cases (in terms of our ability to detect an effect) for the 'Treatment' and 'Treatment x Habitat' terms (model 3) and the 'Intensity' and 'Intensity x Habitat' terms in the revised model 4. The best case has already been discussed; the worst case is that where all except two means are not significantly different and the remaining two are different form this group, one being significantly larger than it and the other being smaller.

If, during the construction or operation of Magnetic Quay, it is suspected that an impact is occurring in a pattern similar to one of those outlined above, the baseline data and proportional change data could certainly be re-analysed by the appropriate model ANOVA. In the case of impact assessment, we suggest that the normally strict adherence to particular analyses to test particular hypotheses should be relaxed in the interests of ensuring that an impact is detected if it occurs.

Attributes of Reefs -

Analyses of Size-frequency Data and 'Runs'

Clearly the data from line transects were collected with analyses of growth and size-frequencies in mind. These were the reasons why we recorded both the position and size of all corals etc., rather than only recording cumulative cover by each taxon. We are now in a position to identify particular corals along each transect.

GROUP	MODEL 3 α,ß=0.1 BEST	MODEL 3 α,ß=0.1 WORST	NEW MODEL 4 α,ß=0.1 BEST	NEW MODEL 4 α,ß=0.1 WORST
Total Hard Corals	12.8	14.8	13.9	17.1
Families Acroporidae/ Pocilloporidae	14.8	17.0	16.0	19.7
Acropora willisae	3.0	3.4	3.2	3.9
Montipora spp.	2.0	2.2	2.1	2.6
Family Poritidae	7.9	9.2	8.6	10.6
Family Faviidae	11.8	13.7	12.9	15.8
Cyphastrea spp.	3.0	3.4	3.2	3.9
Fungiid group	13.8	15.9	15.0	18.4
Turbinaria spp.	51.2	59.2	55.7	68.2
Soft Corals	1.4	1.6	1.5	1.9
Total Algae	64.0	73.9	69.6	85.3
Sargassum spp.	18.6	21.5	20.3	24.8
Lobophora sp.	48.1	55.6	52.4	64.2

Table R2

Effect sizes (differences among means) that would be detected when proportional changes in abundance were analyzed by Model 3 ANOVA (Table 2) or the revised model 4 ANOVA Table R1). Error variances (among sites) were estimated from repeated measures of transects over a one month interval (see Box 7). Effect sizes are shown for stated power of 90% (α,ß=0.1) for the 'Treatment' and 'Treatment x Habitat' terms in the model 3 analysis and the 'Intensity' and 'Intensity x Habitat' terms in the latter model.

For model 3, the 'Best Case' (in terms of the ability to detect an effect) would occur when two of the three means were not significantly different and differed from the third; the 'Worst Case' would occur when all means differed significantly. For the other analysis, the best case (means split evenly into two groups) would result in a significant 'Treatment' effect, with effect size characteristics the same as for a significant Treatment effect under Model 4 (Table 12). The 'best' case above refers to that in which an impact occurred at only one set of three stations; the worst would be that in which two means were not significantly different and one of the other two was greater than that pair whilst the fourth was less than the pair.

Analyses of size-frequencies were neither required nor possible, however, within the limited time available for the analysis of data and preparation of the baseline report. Such analyses would be very time consumptive (and expensive), and meaningful only for the more abundant species. Further, the analytical procedures for comparing more than two size-frequency distributions are few, complex, and often indicate that differences among distributions occur but cannot specify which of several distributions differ(s) from which others. As a rule of thumb, size-frequencies should be based on at least thirty and preferably more than fifty individuals for comparative purposes. Thus, if analyses of size-frequencies were kept to simple pairwise comparisons between, say, habitats or treatments, analyses would be possible for only about 12-15 taxa, bearing in mind that pooling of taxa for such analyses would be inappropriate. If comparisons of size frequencies were required at finer scales (e.g. among stations), even fewer taxa could be analysed.

As the reviewers correctly suggest, impacts of the Magnetic Quay development might be manifest in forms other than mortality or gross changes in total abundances of corals. Biologically feasible scenarios in which the effect of development could cause a fundamental change in the size-structure of a population of corals without also affecting the percentage cover by those corals can be imagined. Such effects, however, would be more complex, (arguably) less likely, and more difficult to detect than the more obvious and likely impacts which led to changes in percentage cover and/or numerical abundances of corals. Although it was not a point of concern of the reviewers, it should also be noted that we did not analyse the numerical abundances of corals for the baseline report, other than by the simple Chi-Square tests described in Table 4 and Table R3 (below). Reasons for this were similar to those explained above: there was little time and we felt that the most important aspect of the corals to be considered, and that most likely to be simply affected by environmental perturbations, was percent coverage. Consequently, percentage cover data received top priority in the time allowed. We can, if required, analyse the other aspects of the data.

The suggestion that the data might be subjected to analyses of runs (sequences of coral/non coral being the example given) can also be done for existing and subsequent data. The usefulness of such analyses for impact assessment, however, is not clear to us. Analyses of runs test only for departures from randomness in a sequence of juxtaposed dichotomously categorised entities. Runs tests do not give quantitative, comparable estimates of the distribution of such entities: they can only indicate whether entities were arranged in random sequence or arranged non-randomly. The significance of a departure from randomness is not strictly a reflection of the magnitude of non-randomness. The significance refers only to the probability that the assertion of non-randomness is actually wrong (Type I error). If alterations to the dispersion of corals or of areas of non-living substratum are considered an important aspect of potential impact, then we would suggest calculating measures of dispersion and/or diversity for each transect or site and comparing these measures among stations in impact and control areas. These analyses can be further investigated if required.

Attributes of Reefs - *Quality of Reefs*

In accordance with the suggestions of the reviewers that qualitative visual impressions of the surveyed reefs might be useful, we have collated some recollections of the 'quality' of the reefs by the principal field workers (below). We suggest, however, that the usefulness of such impressions is dubious, given the difficulty of equating different peoples' assessments of aesthetic worth. It is not possible for us to now, over two months after the completion of fieldwork, assign 'ratings' (similar to those of manta tow surveys) to the sites we surveyed.

The suggestion that the baseline survey may not have covered enough ground to get an impression of the 'character of reefs' seems unfounded. In deploying fourteen stations on the south-eastern fringing reefs of Magnetic Island, we essentially covered over half of those reefs. A greater proportion was covered in Nelly Bay than elsewhere. Clearly in deploying the transects, tagging corals, swimming between sites, etc., the observers covered a great deal of area 'unofficially'. In so doing, they stood a very good chance of grasping the 'character of the reefs'. The summary of such impressions is given below.

The notion of 'resource assessment' was mentioned, but not elaborated, by one reviewer. We assume they meant biotic resources. We suggest that impressions about the biotic worth or aesthetic appeal of reefs such as those surveyed are very difficult to interpret. Such evaluations are inevitably conditioned by the observers experience. For example, one observer, accustomed to only mid-shelf, outer-shelf, and oceanic reefs, found the fringing reefs of Magnetic Island 'mediocre'. Another observer, with more experience of fringing reefs as well as other reefs, thought the reefs were very good examples of healthy, attractive fringing reefs.

Further, whilst there may be compelling social or aesthetic reasons for the preservation of all reefs around Magnetic Island, it is not within the brief of a baseline, biological survey to discuss those reasons. If it were found that there were important <u>biological</u> reasons for specific protection of the northern end of Nelly Bay, then they should certainly be emphasised in a baseline study such as this one.

The concern expressed about the status of rarer species on the fringing reefs of Magnetic Island pinpoints an important wider issue inherent in impact assessment in marine environments and relevant to the perceived objectives of the GBRMPA. The scale over which 'local' extinctions are likely to be important (indeed the meaning of 'local') is fundamentally different for most marine organisms than for terrestrial organisms. The life-histories and characteristics of dispersal of marine species mean that the status of a species is unlikely to be endangered by extinctions at scales of even tens or hundreds of square kilometres. This is certainly not the case for most terrestrial species, where entire habitat types may be limited to such areas. In this respect, the fringing reefs of magnetic island are likely to be almost inconsequential to the status of any of the species which inhabit them.

It is clear, however, that the brief of the Marine Park Authority has more to do with the preservation of such small scale areas because they are accessible and of social and aesthetic value than with the preservation of species pools. In this context, the importance of the rare species is essentially an arbitrary decision. The present status of ecology is such that the ecological importance of such species is essentially unknown. If the Authority sees as important the maintenance exactly of the existing character and species diversity of the reefs, or the need to protect the rare species because of their potential ecological importance, then the control of development and environmental impact must be very strict indeed. As the reviewers point out, this will also be expensive. If the GBRMPA sees its role as only ensuring that coral covered reefs are preserved, then the requirements of impact assessment and monitoring programmes become far less stringent. We return to this issue below (Sedimentation).

Qualitative Evaluation of Assemblages

In general, the field team does not recall any striking or outstanding examples of unusual or unique occurrences of any taxa. Clearly some taxa were more abundant in some places than others, but no reasonably abundant taxa were unique to only one or two stations. Rare species, by virtue of their rarity, were often seen at only one or two places, but never in very large amounts at those places. Observers noted the absence or extreme rarity from Nelly Bay of very large colonies of several species of coral that were present as large colonies in other bays. When asked to rate the bays by aesthetic appeal, all observers ranked them, in descending order, Florence and Arthur, Geoffrey, Nelly and Picnic. It was noted that the usually turbid conditions in Picnic Bay made it very difficult to get a good overall impression of the reef there.

Nelly Bay

Nelly Bay had obviously higher abundance of *Turbinaria*, particularly *T. mesenterina* but also *T. peltata* and *T. bifrons*, than other bays. This was so both on reef flats and reef slopes. Reef slopes in Nelly Bay differed in appearance form those of the other bays. Nelly Bay was characterised by the presence of large sandy areas, rather than the relatively continuous cover of coral, algae or at least consolidated substrata, that characterised the other bays. Station 0 (to be excavated) did not appear to be any different from the other stations, except perhaps in that it was more depauperate generally in terms of algae and coral. One had the impression that corals in Nelly Bay were generally smaller than the same species elsewhere.

Bright Point

The reef slope off Bright Point was noticeable for its similarity to reef slopes in Nelly Bay in terms of the abundance of *Turbinaria* spp. and patches of sand. The reef covered only a narrow margin at the base of the granite rocks. The substratum levelled off at about 5m into a sandy bottom with very little hard substratum.

Geoffrey Bay

The reef slopes in Geoffrey Bay were aesthetically very good, as were reef slopes in Arthur and Florence Bays. Coral cover and species diversity were high, and large and well established colonies were reasonably abundant. The flats were not particularly attractive or speciose, but this assessment applies to all flats in all bays. Perhaps the most conspicuous feature of Geoffrey Bay was that station 4 (at the southern end of the bay, near Bright Point) differed considerably from the other Geoffrey Bay stations. There were unusually large expanses of *Montipora digitata* on the reef flat and coral cover was very high on the reef slope. There were numerous large colonies of corals on the reef slope, particularly of *Goniopora* spp. and *Pachyseris* spp. In this respect, the slopes at Geoffrey Bay station 4 were similar to the reef slopes in Arthur Bay.

Florence Bay and Arthur Bay

All workers commented on the attractiveness of reef slopes in both bays. Large colonies of various species of corals were noticed, particularly in Arthur Bay. Particularly conspicuous were large colonies of *Pachyseris speciosa*, *Goniopora* spp., and *Galaxea* spp., but there were also large colonies of *Favia favus*, *Hydnophora* sp., and some *Acropora* spp. In this respect, the reef slope in Arthur Bay was similar to that at Geoffrey Bay Station 4.

Picnic Bay

Visibility seemed to be consistently worse in Picnic Bay than elsewhere. Generally, reefs in Picnic Bay were not very attractive. A couple of nice patches of coral were found, however, in which there was good cover and good diversity. There were some large beds of *Acropora aspera*.

All bays had very large stands of *Sargassum* spp. on the reef flats and varying amounts of the algae on the slopes. The *Sargassum* made working very difficult at times, especially at low tide, when it obscured almost all the substratum and made swimming almost impossible. It also made locating sites, transects and sediment traps very difficult.

Pooling of Taxa

The suggestion that organisms could have been, and perhaps should have been, pooled on other than taxonomic grounds (eg. morphology, sediment trapping potential, etc.) is acknowledged. Indeed, when it became clear that considerable pooling would be required for analyses, we considered this issue for some time. Our decision to pool on taxonomic grounds was basically a default choice. After discussions amongst ourselves and with colleagues familiar with coral biology, it was clear that insufficient ecological information was available for most species to justify pooling on ecological grounds. For example, the relative tolerance of sedimentation of most species is unknown and is unlikely to be related in any simple way to morphology. Further, morphological diversity within many species made pooling on morphological grounds very difficult for many of the corals we observed. In future surveys, we could, if required, record the 'life form' of each coral and pool corals accordingly for alternative analyses. Their is certainly considerable merit in doing so, but it will increase the cost of surveys considerably.

Status of Nelly Bay

The reviewers' criticisms of our statements that the northern end of Nelly Bay is not unique or in need of special conservation measures are appreciated. They are clearly correct in pointing out that there may be aspects of 'uniqueness' apparent at lower taxonomic levels than the grouped taxa we analysed.

It is not the case, however, that no distinctive characteristics would be recognised by analyses of pooled data. The fact that strong patterns in abundances of pooled taxa were repeatedly identified clearly demonstrates that even with pooled data, distinctive features of one station, habitat, treatment etc. can be, and indeed were, recognised.

The conclusion that Nelly Bay is not unique is clearly applicable only at the 'biological scale' of the groups of taxa we analysed. At those scales, Nelly Bay had significantly lower abundances of some coral groups and higher coverage by *Turbinaria* spp. (particularly *T. mesentarina*) and *Cyphastrea* spp. than did other bays. Its separation from other bays in cluster analyses (slopes only) reflects this pattern. Note, however, that the taxa that were more abundant in Nelly Bay than in other bays were not uncommon in those other bays - they were among the most abundant taxa overall.

The separation of the northern end of Nelly Bay (Stations 0 & 1) and Bright Point from reef slopes at other stations in Nelly Bay reflects the lower abundances of most groups at those stations than elsewhere. This separation occurred at a low level with only low dissimilarity between groups in the cluster analysis (Fig. 6). The characteristics that distinguished Nelly Bay from other bays were differences in abundances of generally abundant taxa, not the unique presence of some taxa or high abundances of most taxa. In that sense, Nelly bay was not considered special.

The point that analyses of frequencies of occurrence such as those in Table 4 (reef flats vs reef slopes) could be done for impact vs control stations is accepted. Accordingly, we present in Table R3 the number of transects along which each recorded taxon occurred in impact and control treatments, and Chi-square tests of differences in frequencies of occurrence between Impact and Control Stations.

For pooled taxa, *Cyphastrea*, the Favids, *Turbinaria* spp., poritids, and the alga *Lobophora* sp., all occurred significantly more often in impact than in control stations, but were abundant in both treatments. This is consistent with the analyses of percent coverage. All other grouped taxa had similar frequencies of occurrence in the two treatments, suggesting that difference in percent coverage by some of these groups reflected the impression that colonies were generally smaller in Nelly Bay than elsewhere.

When frequencies were compared between treatments for all taxa, the results were partly similar to those for pooled data. Ten coral taxa and two algae, total numbers of algae, and total corals were significantly more numerous at impact stations than at control stations. The coral taxa in this category were principally from the pooled groups discussed above. Fourteen coral taxa were significantly more numerous at control stations than at impact stations. For 25 taxa, differences between treatments were not significant and for the remainder there were too few colonies found for analysis.

Of those taxa sufficiently abundant for analysis, only two (the algae *Padina* sp. and *Halimeda* sp.) occurred exclusively, or nearly so, in Nelly Bay. By contrast, five taxa (four corals and the seagrasses) were almost totally restricted to control stations. Among those taxa too rare to analyse, four were unique to impact stations (3 to Geoffrey Bay station 4), and 14 were unique to control stations. Again, these results suggest that Nelly Bay is not a unique or special area. Indeed, the data and the impressions of the field workers suggest that of all the bays surveyed, Nelly, and perhaps Picnic, are those least worthy of special preservation.

Suitability of Control Stations

The *a priori* differences between the 'impact' and 'control' stations certainly complicate the assessment of environmental impact (p30). Ideally, the baseline would have revealed that all the reefs we sampled were essentially the same, in which case the control reefs could have been considered replicas of the impact reefs. This was demonstrably not the case. It is clear, however, that the control reefs we chose were the best available, comprising almost all other consolidated fringing reefs around Magnetic Island. Reviewers of the PER for the magnetic Quay development strongly counselled

Table R3

List of the taxa identified in all benthic line transects. Species marked on their left with an asterix were pooled prior to any analyses. 'Pooled Groups' indicates the groups that were analysed by univariate analyses.

'Frequency' indicates the number of transects (out of 120) in which each taxon or group was recorded. 'Control vs Impact' indicates results of Chi-square tests of differences in colony or patch number between control and impact areas.

Symbols.
*: $P < 0.05$; ns: $P > 0.1$; n/a: test not appropriate because less than 10 colonies or patches were found and so expected values for controls and impacts were less than 5.

against using data from fringing reefs near Cape Tribulation as representative of fringing reefs on Magnetic Island. The same is likely to be said of using fringing reefs on the Palm Islands or elsewhere as control sites, for good reason.

The differences among reefs means that any impact must be assessed in terms of the changes in the relations among control and impact reefs. If, for example, the reefs in Nelly Bay became increasingly dissimilar from the control reefs, then a deleterious effect of development on those reefs would be inferred. If, however, the differences between impact and control reefs decreased with time, a positive influence of development on abundances of biota should be inferred. With no impact, we would expect that the differences between impact and control reefs would remain essentially constant. In terms of the analyses of proportional changes in abundances along transects, these three alternatives would be indicated by, respectively: greater changes at control than at impact station; smaller changes at control stations; and equal changes in both treatments.

Assumptions of Proposed Analysis of Proportional Change

We concur entirely with the reviewers emphasis on the need to verify the assumptions of the proposed analyses of proportional changes in abundances (discussed in Box 7). The reviewers comments echo exactly our own reservations. Accordingly, we have proposed in the impact assessment study (revised version of Appendix three) to resurvey the line transects immediately prior to the commencement of construction. This survey will be at least 4-5 months after the baseline surveys and should provide reasonable, though not ideal, data by which the assumptions can be tested. The other avenue for testing the assumptions, though clearly not at Magnetic Island, is to completely analyse the data from Cape Tribulation collected over two years by Sea Research.

As the reviewer points out, such a resurvey will provide information that will verify what levels of difference in changes in abundances we will be able to detect with certainty. It will also verify whether there are any natural systematic differences in rates of change in abundances between impact and control stations. In the absence of such data, we will not know whether the biotic (and perhaps hydrodynamic) differences between Nelly Bay and other bays also extend to differences in rates of growth and mortality of corals. In the absence of such information, the rates of Type I and/or Type II error in impact assessment may be increased by unknown amounts. The situation is exactly analogous to needing baseline data of abundance before effects of development on abundance can be sensibly assessed. In the case of coral assemblages, however, it seems that analyses of differences in raw abundances are likely to be extremely insensitive to environmental impact. Analyses of differences in rates of change in abundances seem likely to be far more sensitive, but need to be indexed to knowledge of rates of change in abundance under natural conditions prior to development.

Sedimentation

Again the issue of critical levels has been raised by the GBRMPA. The stepwise logic (Box 8) for deciding whether an impact has occurred, irrespective of whether it is stated in the general or the particular, is the only logical and sensible way in which an impact can legitimately be separated from normal, background variation in, say, sedimentation. This is especially the case in instances where existing knowledge of the natural levels of a critical variable is poor or absent, which is definitely the case for the Magnetic Quay project.

We discussed the possible management responses (stop work vs allow work to continue) to the indication of an impact, and their consequences, because it would have been negligent not to. The decision about which reaction should be taken is clearly a difficult management decision. We have highlighted the issues, and the merits and problems of either strategy, but we cannot state which response should be made. We cannot make such recommendations because there are no empirical bases upon which to assert that a given impact (on sediments, nutrients, etc) will or will not detrimentally affect the corals. Such information simply does not exist.

If the GBRMPA is adamant that there be no impact of development on the fringing reefs (other than those to be excavated), then clearly any perceived changes in factors that might affect corals is cause for a stop work order. If, however, the GBRMPA is prepared to accept, and defend, that some loss of corals etc. might result from development, then it must state what level of change is tolerable. It might then also allow construction to proceed and insist on very close monitoring of the benthic biota to assess the extent to which changes in sediment regime (or nutrient levels) affect the biota. In this case, work would stop only when affects on the biota were confirmed. These are political and aesthetic decisions, not only ecological decisions. We applaud the reviewers' calls for resolution of these issues so that we, and other consultants, developers, etc., have a more readily identified set of guidelines within which to work.

The discussion of strategies was left open-ended also because, in the absence of sound knowledge of the effects of changed sediment regimes on corals, we can recommend only that if sedimentation (for example) is enhanced, its effects on corals will be determined only by subsequent surveys. In this sense, the procedure is largely exploratory (in a sense, a mensurative experiment) - it can, in 1989, be no other way. Without such exploratory work and some carefully designed experimental work, however, the difficulties will still be the same in 1999.

Clearly, in any impact assessment study it is important to minimise the times between an impact occurring, that impact being detected, and management action being instigated. We appreciate the GBRMPA's concern for 'quick and expeditious' detection of impacts. Simple methods (e.g. secchi disk readings) exist for the measurement of water clarity and could form the basis of immediate management decisions concerning any effects of the development on water clarity.

The data from the baseline study suggest, however, that there is no reliable relationship between immediate, short-term measurements of water clarity or turbidity and time-averaged sedimentation. We recommended that daily sedimentation be measured prior to construction and correlated with secchi disk readings on the same days at the same sites in the hope that such data would reveal a useful relationship that could form the basis of a quick and expeditious procedure for assessing potential impacts of the development on sedimentation. Without a good empirical relationship between water clarity and sedimentation, secchi disk measurements cannot be used reliably as indicators of sedimentation. If we do not find such a relation, then there is no choice but to accept the delays between impact, detection, and reaction inherent in the use of direct measurements of sedimentation as the principal quantitative means of impact assessment related to sedimentation. This situation would highlight the need to seek, by specific research programmes, alternative means of quick and expeditious measurement of rates of sedimentation.

We have already argued that the qualitative assessment of whether sediment is affecting corals is likely to be a useful immediate indicator of an impact. It is not usual for sediment to accumulate on the living tissues of corals. If the on-site observers observe corals near to the development every few days and at some stage notice a conspicuous increase in the amount of sediments resting on live corals and/or an increase in such things as lesions or bleaching of corals, then an impact might be suspected. In such an event, the observers should immediately survey corals at other impact and several control sites, particularly those farthest from Nelly Bay. If the phenomena are widespread at both impact and control sites, then it is unlikely to be a product of development. If, however, the phenomena are restricted to some or all impact stations, it is probable that they reflect an effect of the Magnetic Quay development and management action and detailed reactive monitoring would be appropriate.

Unfortunately, it is not known how long corals can tolerate being covered by small or large volumes of sediment. It has been suggested, however, that if the sediment is not being mobilised by water movement, smothering is likely to occur in a matter of hours rather than days. Accordingly, we re-stress the need to ensure that sediment loads are not enhanced during calm weather. In calm whether, it likely that we do **not** have 'a few days grace' in which to react to sediment accumulation on corals. With the same caveats as our suggested 'critical' rates of sedimentation in rough weather, we suggest that in very calm weather (wind speed < 10 knots):

1) sedimentation on the reef flats at impact stations should not exceed that on reef flats at control stations, or exceed 8 mg/cm^2/day; and

2) sedimentation on the reef slopes at impact stations should not exceed 1.5 times that on the reef slopes at control stations, or exceed 13 mg/cm^2/day.

In moderate weather (winds of 15-20 knots), sedimentation on the reef flats at impact stations should not significantly exceed that at control stations, or about 23 $mg/cm^2/day$. On reef slopes, sedimentation at impact stations in excess of twice that at control stations, or greater than 36 $mg/cm^2/day$, would be cause for management action.

As stated in the body of this report, these recommendations are based on a small data set - only four weeks of sampling. The value in continued measurement of sedimentation prior to construction is that the foundation for these recommendations would be considerably solidified. With only a small sample size, the estimates of variability in sedimentation on which our recommendations are based are poor. It follows that the recommendations are also dubious. With further sampling, both will be strengthened. This has real implications for both the GBRMPA and the developers. With the existing data, the potential exists to mistakenly argue that an impact has occurred (to the cost of the developers), or to let a real impact slip by undetected (to the cost of the environment and the GBRMPA). With more baseline information, these possibilities will be reduced, though of course they can never be eliminated. Both reviewers agreed with us on this point.

Answers to Specific Comments (not discussed above)

Transects on the reef profiles were the same lengths as elsewhere, 20m.

Data were log e transformed for cluster analyses

COMMENTS ON THE REPORT BY THE GBRMPA AND REVIEWERS

GREAT BARRIER REEF MARINE PARK AUTHORITY

Professor H. Choat
Department of Marine Biology
James Cook University
Townsville Qld 4810

Dear Professor Choat,

I refer to our recent discussions concerning the review of:

1) The Fringing Reefs of Magnetic Island: Benthic Biota and Sedimentation Study - a Baseline Survey by the Quantitative Ecology Division, Department of Marine Biology, James Cook University, and,

2) Magnetic Quay Water Quality and Sediment Baseline Study by the Australian Centre for Tropical Freshwater Research, James Cook University.

As a general comment, both reviewers and Authority staff have commented favourably on the benthic biota and sedimentation study. While the water quality study would appear to have met our requirements, the report appears to be in need of some revision. As you will be aware our main concern is the development of a feasible and quick reactive monitoring protocol for sedimentation.

Please find enclosed reviewers comments on the two reports (Attachment A refers). The reviewer's comments are to be addressed in finalising your baseline study reports and the impact assessment program for the proposed Magnetic Quay development at Nelly Bay, Magnetic Island. In particular the following points should be noted:

The Fringing Reefs of Magnetic Island: Benthic Biota and Sedimentation Study - a Baseline Survey by the Quantitative Ecology Division, Department of Marine Biology, James Cook University

a) Report Structure

An executive summary should be included in the report.

b) Anova Models

Using percent cover data, Model 4 Anova can detect a 20% change in most reef forming taxa (page 53 refers). However, what is not indicated is the percentage change that could be detected, if for various reasons, Model 4 is inapplicable.

c) Attributes

There is still considerable information in the data that could be analysed if time and resources permitted. Your comment is sought on the suggestion to examine size frequency and analysis of 'runs' after the assessment program is completed.

d) Evaluation of Nelly Bay Reef

The reviewer's comments regarding the demonstration of gross biological pattern (cluster analysis) using pooled taxonomic data, biotic uniqueness, rare species and resource evaluation should be noted. It would be useful if the aesthetic value of each of the different surveyed reefs and bays could be rated by the field survey personnel (for eg: using similar ratings to manta tow ratings). Similarly, trends or qualitative observations from the field survey team, which are not statistically verifiable should be noted and reported where possible.

Considering that discussions were held with reviewers prior to both the baseline field work and the report preparation I assume that species which are likely to be less tolerant of the projected increase in sediment loads or changes in water quality parameters were taken into account in your comments regarding comparison between bays etc. However it is suggested that this avenue be further examined as we discussed in our recent meeting.

e) Cluster Analysis

The designated impact stations are shown by cluster analysis to be biotically different from the controls (Figure 6B and Table 6 refers). How does this affect their suitability as controls?

f) Comparative Abundances

The critical issue for the interpretation of all future monitoring data is the assumption by the authors that if no impacts were to occur they would expect "... that changes in abundance would be the same, on average, at all sites, and unrelated to the patterns in absolute abundance among sites, stations etc. on any given occasion" (page 31, para 1 refers). The reviewer has suggested that verification of this assumption be obtained by resurveying all or some of the transects prior to the commencement of the construction activities. Your advice regarding this assumption and the suggested verification proposal would be welcomed. What additional information which may influence the design of the monitoring program would be provided?

g) Sedimentation Levels

The indicated figures for the upper limit of average sedimentation at a reef slope station (page 36 para 4 refers) are for wind speeds greater than 25 knots. What limits are envisaged for calm conditions? Given that sedimentation rates are averaged over a week or so from sediment trap data, if a reactive monitoring strategy required at least say 24 hours to provide sediment level results, could serious effects have already occurred (or do we have a day or two's grace).

h) Pooling of Taxa

The reviewers note that the pooling of taxa may combine inappropriate features and obscure certain changes resulting from the development. For example, the combination of species and species groups on taxonomic grounds may combine sediment susceptible forms with tolerant growth forms and thus obscure what may be a major effect on the former. Accordingly it is suggested that some scale of sediment trapping feature of morphology be recorded so that an analysis of treatment versus morphology could be examined.

i) Pre-construction Monitoring

"The potential for erroneously concluding that differences in sedimentation between Nelly Bay and control stations are cause for management action is great owing to the limited period over which the range of differences were assessed." In order to address this problem it is recommended that:

(1) continued regular measurements of sedimentation, and,

(2) further baseline work to establish whether there are short term relations between turbidity and sedimentation be undertaken in the period prior to the commencement of construction activities.

The critical question here is what additional information would be provided by such studies and how would we use it?

j) Reactive Monitoring Strategy

A rapid management response to any unforeseen sediment effects which occur during the construction phase of the proposed Magnetic Quay development is dependent upon the on site supervisor having some quick and expeditious measurement of suspended sediment which is indicative of physical or stressful effect on the corals.

While I appreciate the logic behind the 5 step process on which to basis a decision on when an impact has occurred, I am very concerned about the practicality of the procedures. Particularly, it seems to me that a decision to implement a "reactive sampling" procedure when a significant difference is detected in an environmental variable is likely to result in gross time delays in decisions about whether to halt construction or not. An observed characteristic of large construction projects is that they are very difficult to stop indeed and that such decisions have to be based on simple criteria if they are to be implemented by supervision personnel. Furthermore, the construction organisation itself prefers simple decision making procedures, preferably based on a single criterion, even if this sometimes leads to a decision being made to cease construction when more complex analyses might show that such cessation is unnecessary.

I believe that it is important to stress that the baseline study must provide guideline figures of certain sediment concentration or equivalent which would lead to certain management actions.

While I appreciate that the figures will be guidelines, it should be emphasised that they may be subject to modification during the course of the construction in the light of experience. I believe that it is better to approach this issue conservatively and relax the levels, if required, rather than go the other way. Accordingly, I would suggest that a flow or decision diagram be developed in conjunction with the Authority to assist both the developer and the on site supervisor in the use of the short-term, quick and expeditious reactive monitoring program.

While potential sedimentation is obviously the prime cause for concern during construction, are there any other parameters that we should be concerned about for the short-term, quick and expeditious reactive monitoring program.

PROPOSED MONITORING PROGRAMME

a) Sampling of Sediment Traps

How will the sampling of the sediment traps fit in with the short-term, quick and expeditious reactive monitoring program?

After 18 months of construction (end of 1991) I would have thought annual re-surveys would have been sufficient.

b) Experimental Study Payment by Developer

I am concerned about getting the developer to pay for the lipid investigation and the reproductive condition investigation given the experimental nature of these studies. While I agree that they are valuable studies the developer should be made aware of the likelihood of their producing useful information for impact assessment.

[Comments on 'Magnetic Quay Water Quality and Sediment Baseline Study by the Australian Centre for Tropical Freshwater Research, James Cook University' can be found in that report]

I look forward to our further discussions with you and your associates at the Authority's office at 2 p.m. 10 April 1989.

Yours sincerely,

Wendy Craik
Assistant Executive Officer
Research and Monitoring

cc Mr. J. Neal (Linkon Construction Pty Ltd)

REVIEWER 1

The fringing reefs of Magnetic Island: benthic biota and sedimentation. A baseline survey. A report to the Great Barrier Reef Marine Park Authority. Prepared by B.D. Mapstone, J.H. Choat, R.L. Cumming, and W.G. Oxley, Quantitative Ecology Division, Department of Marine Biology, James Cook University.

28 March 1989

This report describes results of a baseline study. The data collected are to be used as a reference against which the impact of the Magnetic Quay development will be measured - a procedure referred to as impact assessment. It uses the same data set to evaluate Nelly Bay Reef compared to other reefs on the SW side of Magnetic Island.

Baseline study for impact assessment

The study is among the best of its type ever done in the Great Barrier Reef Marine Park. In terms of the size of the data set and attention to sample design and statistical analysis, it has no peer. In terms of field work, it represents a major effort based on high levels of knowledge of coral reef benthos and a great deal of hard work. The report is well structured and clearly written. The data set and report provide a good baseline for future impact assessment.

Control versus Impact

An *a priori* declaration that Geoffrey 1, and 2 and controls is risky, as they may be impacted also. Since these sites comprise one third of the controls, it may be necessary to abandon the Model 4 ANOVA for a less powerful one. The authors are obviously in the best position to make such a judgement.

Attributes

Twenty metre line transects record information on small-scale spatial pattern, colony size-frequency, taxonomic composition and percentage cover. Using percent cover data, Model 4 ANOVA can detect 20% change in most reef forming taxa (page 53) using the existing transects. However, for minor injury and death of corals, size frequency and analysis of 'runs' (sequences of coral/non-coral, for example) may be even more sensitive. Such an analysis may be useful after the assessment program is completed.

Evaluation of Nelly Bay Reef

I don't consider the statements concerning levels of diversity and uniqueness of Nelly Bay reef and Nelly Bay station 0 are warranted on the basis of this data set. The report concluded (page v) that 'reefs in Nelly Bay supported a generally poorer assemblage of corals than those at other Bays' studied, and stated that 'we found no evidence of unique biotic features on the reefs at the north end of Nelly Bay that require special attention'. This analysis uses only coarse taxonomic data, usually pooled to generic or higher level. By pooling of taxonomic data, gross biological pattern has been demonstrated in site-group classifications. However it is misleading to say anything about 'biotic uniqueness' (page v) or otherwise of particular places. By the criterion of higher taxa, there is probably not a unique place on the entire GBR.

ANOVA-based monitoring requires precision and randomness. This study is exemplary in this regard. However resource evaluation is not an automatic byproduct of the sampling technique used here. Resource evaluation requires systematic broad scale searching. Short, haphazardly placed lines in regularly spaced stations will inevitably fail to capture a reef's total character, and to document that which is put at risk by a development.

Reefs should not be evaluated simply on percentage cover and diversity. If only objective criteria are acceptable, colony sizes and extent of monospecific stands (n.b. low diversity), at least, should be considered. If subjective criteria are acceptable, the aesthetic appeal of the place should be stated. It should not be necessary to play one bay off against others. There may be a very good case for preserving all the reefs on Magnetic Island.

Conclusion

The Quantitative Ecology Division has produced a good baseline data set which, with further sampling and complementary studies, should indicate the extent of impact of Magnetic Quay on live coral cover at Nelly Bay and elsewhere. As the report is couched entirely in terms of localised percentage coral cover and higher taxa, it is not possible for a reviewer to judge other reef values based on the benthos.

The GBRMPA should accept this report in its present form. With the completion of sampling and further analysis, it should form the basis of an important contribution to scientific literature on coral reef monitoring.

Specific comments

The following is a transcript of comments which occurred to me as I was reading.

p6. How long were the 'profile' line transects?

p8. Line transects are fine so long as they are informative and sensitive to change. Lines haphazardly placed on coral dominated areas are quite appropriate as t_0 so long as they intercept enough live coral.

p8. Pooling is fine to satisfy the criteria of ANOVA, but forfeits statements on biological uniqueness.

p11. It may be sufficient to do a frequency analysis based on numbers of colonies in injury categories, (including living and dead).

p13. Squared Euclidean Distance is swamped by dominant taxa. ED should be less so. Were the data log transformed?

p19. The designated impact stations are shown by cluster analysis to be biotically different from the controls. How does this affect their suitability as controls? This was raised but not resolved on p30.

p30, Box 6. Would it not have helped to stratify sampling into 'good' and 'poor' coral areas, and randomise sampling within good areas? This would decrease the 'inherent variability among replicate transects'. The whole thrust of the programme is to document change in existing coral communities, so it makes sense to select coral areas to start with. Reefs are patchy. Randomise within the patches you are interested in. See also p32 re fixed transects.

p35. Bravo comments on calm water risk.

p36. Taking this logic even further, the poorer the sample, the greater the latitude to allow sediment to impinge on the reefs.

p36. What abut guestimates for calm conditions?

p37. Box 8. Seems to be saying nothing concrete. Disadvantages of both suspension and continuation are given, and the whole business given the status of a huge uncontrollable experiment.

REVIEWER 2

The Fringing Reefs of Magnetic Island: Benthic Biota and Sedimentation - A Baseline Survey (Prepared by Mapstone, Choat, Cumming and Oxley).

28 March 1989

A. INTRODUCTION

A.1 With a few minor exceptions in the presentation of Figures and explanations in the text, this Baseline Survey appeared to be very well designed, and presented clearly. Indeed, many organisations carrying out impact studies in Australia and elsewhere could benefit by using a similar rigorous approach to their management problems.

The majority of my comments on the report are not on the design of the baseline survey, but rather on the interpretation and conclusions based on the results.

A.2 The terms of reference from the GBRMPA to Mapstone *et al.* for the Baseline Study are not clearly defined in the report. I am assuming, therefore, that the aims of the report were those given in Box 1 (page 2). Presumably a detailed monitoring proposal (with budget, reporting schedules, etc.) was not required to form part of this report.

In summary Box 1 indicates that the purpose of the data collected for the Baseline Study was threefold:

a) to examine whether there are any special characteristics of an area of potential or certain impact that warrant special conservation measures;

b) to compare with data collected during and after construction of the development to assess whether an impact has occurred;

c) as pilot data on which the impact assessment study can be designed to ensure an optimum balance between logistic and cost constraints and the ability to detect potential impacts of specified magnitude.

B. THE DEGREE TO WHICH THE AIMS OF THE BASELINE STUDY HAVE BEEN FULFILLED

B.1 a) Special characteristics of the area of potential or certain impact

B.1.1 Within the constraints of budget and time, the design of the Baseline Study tried to maximise the efficiency and usefulness of collected data. Analysis of these data should show with reasonable certainty whether the communities of corals and algae in the high risk regions are particularly unusual for the eastern seaboard of Magnetic Island.

B.1.2 The report states that analysis showed that there was no evidence of unique biotic features on the reefs at the north end of Nelly Bay that require special protection (p. v, para 3; p 19, para d). Whilst this may be evident to the authors from the raw data, I do not feel that this statement is particularly well supported by analyses or data presented in the report.

There are many criteria on which 'unique' or 'unusual' can be based in management studies. In this case, at the very least, the benthos should be examined on both the community and individual scales.

Firstly, I could find no discussion of the overall distributions of rare species. Therefore, it is not possible for the reader to judge whether or not these were represented in all bays, or which, if any, were located only on high risk reefs.

Secondly, the statement on p. 19, para 3, specifically discusses Nelly Bay station 0. It is "not unique in its taxonomic composition, as it is not grouped separately from the other stations". As I understand it, the cluster analyses were carried out on pooled groupings and again differences due to rare species may have been obscured. But, more importantly, in the analysis for reef slopes, Nelly Bay 0 is grouped with Nelly 1 and Bright Point, both of which would themselves fall in the high risk category. Furthermore, the nearest cluster to this high risk group comprises Nelly Bay sites 2-5 and Geoffrey Bay 4, which are, of course, themselves at risk.

I would suggest, therefore, that the evidence presented in the report does not support the interpretation that is presented by the authors. This is not to say that the interpretation is incorrect. The raw data may well show that rare species are dispersed among the Bays. The data presented in Table 4 examine the overall frequency of the taxa and their differences between the flat and slope habitats. This analysis could be extended to explore the differences between risk and control sites. Within the constraints of pooling, the reef flats do seem to have similar assemblages. However, should impact be extensive in the bay, some loss of the 'Nelly Bay reef slope' assemblage may be experienced.

B.1.3 The significance of the rare species should not be ignored. Our understanding of the tolerance of species to the high sediment loads of Australian fringing reefs is poor. It is possible that certain rare species are rare because they are at the limits of their stress tolerance, whether this be stress from the manifestly high sediment loads reported in the study or from some other source. If this is the case, slight or major increases in these stresses as a result of the development may lead to extinction of these rare species from the Bay, whilst having little effect on the more common species. At present the monitoring design predominantly concentrates on common species and pooled groups of species.

It would be very expensive to elaborate the design to examine suites of rare species. Nevertheless, there are a number of scientists available in Townsville whose input and experience could help to pinpoint a few species which are likely to be less tolerant of the projected increases in sediment loads or changes in water quality parameters. At present the tagged corals are common species. But rare species already occur at low abundance on some of the transects. If there are good a priori reasons for expecting a unidirectional change of, say, growth or survival of certain polyps, the number of required replicates in each treatment may turn out to be quite small. I feel that this avenue should, at the very least, be explored.

B.2 The second and third aims outlined in Box 1 will be considered together.

b) to compare with data collected during and after construction of the development to assess whether an impact has occurred

c) as pilot data on which the impact assessment study can be designed to ensure an optimum balance between logistic and cost constraints and the ability to detect potential impacts of specified magnitude

B.2.1 The approach to the design and collection of data has been well thought out and executed to provide a good database of information for future comparison. Furthermore, the data provide estimates of variability from which required sample sizes can be calculated.

B.2.2 The actual results, however, have some serious implications for the proposed monitoring program.

It is accepted that an adverse impact may ultimately manifest itself in an effect on the abundances of certain species. If these changes can be clearly attributed to the impact by comparison with control reefs there is a sound basis for 'reactive' management.

However, it seems to be clear that the Nelly Bay reefs plus Geoffrey Bay 4 (the 'impact' reefs) have a biotic composition that is different from other Bays (the 'control' reefs) (see p. v, para 3; Table 6;

p. 18, para 3; p. 19, para 4; etc.). In my view, the fact that the 'control' reefs cannot be considered to be the same as the 'impact' reefs has far more serious implications than discussed in the text (see pp. 30-32).

The authors argue (p. 31, para 1) that if no impact were to occur they would expect "that changes in abundances would be the same, on average, at all sites, and unrelated to the patterns in absolute abundance among sites, stations etc. on any given occasion ... it is the comparison of changes in abundance from one time to the next that is important". This is a critical assumption. All future statistical comparisons based on models discussed in the text will, necessarily, depend on the validity of this assumption. I know of no evidence for GBR fringing reefs which supports or refutes the authors' expectations (p. 31, para 1) but I personally could not accept this assumption on its face value.

This is such a critical issue for the interpretation of all future monitoring data, that some verification must be obtained. I would suggest that all or some of the transects be resurveyed prior to commencement of the construction activities. The details need to be determined within the requirements of the statistical procedure - however I expect that it would be inadequate to resurvey only once. Furthermore, if the time period prior to the resurvey is too short, the changes will be so small that it will be very easy to accept the assumption erroneously.

This will clearly raise practical problems both in cost and for the date of commencement of construction. On the other hand, the value of inferences from the monitoring program as it stands at present would be in great doubt. The benefits of a well thought-out statistical analysis of impact would be lost, and managers will be falling back on weak correlative data as in most of the studies reported in the literature. I feel that that would be a great waste and I would very strongly recommend that this verification be sought.

B.2.3 Moving on to another related point, the sedimentation data also showed a difference between the 'control' and 'impact' reefs. The authors state (p. 35, para 5) that there is considerable potential to "erroneously conclude that differences in sedimentation between Nelly Bay and control stations were cause for management action". I agree with their interpretation, and I would strongly support their recommendation to continue the regular measurements of sedimentation in the period prior to commencement of construction. To this end, funds should be released for this purpose without delay or any advantages will be lost.

C. GENERAL REMARKS

C.1 Critical level of sedimentation

This study reports a wide range of sedimentation rates over a period of only a few weeks (pp. 26-28). The upper limit of 356.6mg/cm^2/day is considerably higher than the maximum of 120mg/cm^2/day quoted in the previous PERs. The need for additional data over a wider range of conditions and seasons is very clear and has been stated above. The lack of long-term data on sedimentation and turbidity in Nelly Bay, is compounded by the lack of data on species sensitivities to sediment stress.

These facts emphasise the need to treat the critical levels quoted on p. 36, para 4 with extreme caution. It must be clear that the figures are for moderate to rough conditions. The critical levels for calmer waters are likely to be substantially lower. These values should be reviewed regularly as further data comes to light during the monitoring program.

C.2 Pooling of taxa

It should be emphasised that fairly extensive pooling of taxa has been adopted in the data analysis for the baseline study. This procedure has simplified the classification and description of the communities of Magnetic Island. However, if pooling is continued for the analysis of later monitoring data the procedure may combine inappropriate features and obscure certain changes resulting from the development. To some extent the practice of recording to the lowest identifiable taxon in the field will allow later manipulations. However it may be necessary to add certain other observations.

Increases in sedimentation and turbidity have both been highlighted as potential effects of the construction phase of the development. Whilst turbidity can be assumed to have any effect on the entire colony irrespective of morphology, the tolerance of a coral to sediment landing on its tissues can be highly dependent upon the local morphology. It is entirely possible that the combination of species and species groups on purely taxonomic grounds may combine susceptible with tolerant growth forms and thus obscure what may be a major effect on the former. For this reason it could be desirable to add some scale of morphology or rather 'sediment-trapping' features of morphology to the observations slate so that this possibility can be explored in an analysis of treatment vs morphology. This may well provide an earlier warning of stress or loss of coral cover than would be available from taxonomic groupings.

C.3 Tagged corals

Similar arguments apply to the fixed corals - local morphology and percentage of potentially vulnerable tissues would be important parameters to record as these are likely to be the first to suffer mortality from sedimentation. It would be useful to have further details of exactly what parameters of these tagged corals will be recorded and measured.

C.4 Guidelines

In both this report and earlier proposals and discussions, the authors have made commendable effort to tailor the study to their perceived view of management needs.

Has there been, at any stage, a detailed set of guidelines from the GBRMPA setting out the management priorities for this project? From my own management experience, it is clear to me that the ultimate emphasis of the monitoring program may be subtly or substantially altered depending upon the management priorities perceived by the GBRMPA. Before the consultants are asked to present the final monitoring program for review, I feel that it is necessary for the GBRMPA to draw up a detailed set of guidelines. Any monitoring will cost a great deal of money and a correct balance between protection of topographical, community and species diversities will depend upon the conservation priorities.

For example, is the overall conservation priority to protect the hard coral cover of the Nelly Bay reefs? Or is it to protect the species diversity? How important is it to prevent extinction of the rare species? Are there other, more important, management considerations which have not so far been considered in the design of the monitoring? What level of impact is considered unacceptable and therefore what level of impact is the monitoring program supposed to detect? (The authors suggest 20%: ecologically this could be viewed as a large impact - is this level of destruction acceptable to the GBRMPA, especially in view of the fact that further damage is likely to have occurred before this is reported for 'reactive' management to take place.)

These questions may not be easy to answer but an attempt should be made to establish the best strategy, so that the monitoring program can be tailored to its needs. These guidelines could be drawn up at a meeting of the GBRMPA, scientists, and other consultants, and should set out clearly the aims of the monitoring program.

C.5 The emphasis on statistics

The approach taken by the authors to maximise their ability to make statistical rather than 'guestimated' inferences from impact assessment data, is highly commendable and regrettably rare.

However, the importance of qualitative observations made by their field team must not be ignored in reports to the GBRMPA. There is such a strong emphasis on statistics in this report that it becomes slightly indigestible. It would be a great loss if trends or qualitative observations became obscured simply because they are not statistically verifiable. In many management scenarios funds are insufficient to examine all possible parameters and it is often these unquantified factors which point to areas requiring urgent 'reactive' verification. For this reason, the authors should be encouraged to report on these more qualitative findings - interpretation may be more significant to the wider audience of experienced managers in GBRMPA. If necessary the statistical integrity of the major reports could be maintained by instigating a series of regular informal reports.

C.6 Details of report presentation

C.6.1 Executive summaries

I felt that this was a report that was very well written and presented. However, neither the overview, nor the summary provided details of all the critical points which were discussed in the text. For a document of this complexity and magnitude, and particularly when its readership extends to non-biologists/statisticians, a comprehensive 6-8 page summary would be of enormous benefit.

This kind of summary is designed to stand on its own, and can be distributed as such. The sections cover all topics, but are greatly condensed. Thus it would precis the report under all the following headings plus any others of relevance:

BACKGROUND
  Commissioning Body
  General terms of reference
  General overview with history.
AIMS
METHODS (brief overview)
KEY RESULTS AND THEIR IMPLICATIONS
KEY RECOMMENDATIONS (with caveats)
FUTURE MONITORING PROGRAM (if relevant, including summary budget)
etc.
etc.

C.6.2 Publication of report

Reviewers are requested by the GBRMPA to make recommendations on the publication of reviewed reports.

As discussed above, I am unhappy about some of the interpretations made in this report. In certain cases (section B.1.2) this may be because the relevant data is in existence but not included in the report. If so, these analyses should be included. Modifications based on comments on the assumption discussed in section B.2.2 should be considered.

Secondly, it would be helpful to have fuller captions on many of the Figures and Tables, and for legends to be repeated. To have to find legends on previous Tables and Figures which do not have page numbers is tedious (e.g. Table 8).

I wasted much time trying to sort out the profile sampling. How long were the transects? (see page 7). Figures 5A and 5B would have benefited from a more detailed caption.

With modifications based on the points above, I would definitely recommend that the report be published. It is refreshing to read a management report that has such a sound scientific foundation and which bases its design on rigorous statistical concepts without losing sight of management goals. I hope it will be an inspiration to others.

APPENDICES

APPENDIX A:
4 FACTOR ANALYSES OF VARIANCE

FACTOR	SOURCE OF VARIATION	FIXED/ RANDOM	DENOMINATOR
A	HABITAT	F	D(ABC)
B	TREATMENT	F	D(ABC)
C	STATION	F	D(ABC)
D	SITE	R	RESIDUAL
	A*B		D(ABC)
	A*C(B)		D(ABC)

SOURCE OF		FAVIIDAE			ACROPORIDAE AND POCILLOPORIDAE		
VARIATION	df	F	P	%v	F	P	%v
(A)HABITAT	1	35.905	.000	26.4	19.539	.000	16.4
(B)TREATMENT	1	7.759	.010	05.4	6.747	.016	05.1
(C)STATION(B)	10	1.188	.346	00.6	2.146	.061	06.1
(D)SITE(ABC)	24	1.836	.016	08.4	1.781	.021	09.3
AB	1	0.001	.971	00.0	2.326	.140	02.3
AC(B)	10	2.068	.070	19.8	2.226	.053	13.1
RESIDUAL	144			39.6			47.7

SOURCE OF		*Acropora willisae*			*Montipora*		
VARIATION	df	F	P	%v	F	P	%v
(A)HABITAT	1	156.440	.000	55.1	9.180	.006	04.7
(B)TREATMENT	1	4.200	.052	01.0	6.810	.015	03.3
(C)STATION(B)	10	1.597	.168	00.9	4.451	.001	11.8
(D)SITE(ABC)	24	0.833	.690	00.0	2.318	.001	7.8
AB	1	1.866	.185	00.5	21.900	.000	23.8
AC(B)	10	1.752	.126	02.4	4.686	.001	25.2
RESIDUAL	144			39.9			23.6

SOURCE OF		PORITIDAE			FUNGIIDAE		
VARIATION	df	F	P	%v	F	P	%v
(A)HABITAT	1	6.988	.014	05.8	61.736	.000	31.9
(B)TREATMENT	1	7.899	.010	06.6	9.806	.005	04.6
(C)STATION(B)	10	1.428	.227	02.5	4.682	.001	11.6
(D)SITE(ABC)	24	1.539	.064	08.1	2.401	.001	07.4
AB	1	0.061	.807	0	1.871	.184	01.0
AC(B)	10	2.453	.035	16.9	4.544	.001	22.4
RESIDUAL	144			60.2			21.0

SOURCE OF		*Turbinaria*			*Cyphastrea*		
VARIATION	df	F	P	%v	F	P	%v
(A)HABITAT	1	87.137	.000	24.3	0.026	.872	0.0
(B)TREATMENT	1	74.841	.000	20.8	7.361	.012	5.0
(C)STATION(B)	10	6.630	.000	09.6	3.961	.003	13.9
(D)SITE(ABC)	24	2.032	.006	03.5	1.408	.113	4.3
AB	1	41.317	.000	22.8	0.542	.469	0.0
AC(B)	10	2.649	.025	5.6	3.617	.005	24.6
RESIDUAL	144			13.4			52.3

SOURCE OF VARIATION	df	HARD CORALS F	P	%v	SOFT CORALS F	P	%v
(A)HABITAT	1	46.131	.000	33.4	18.300	.000	19.4
(B)TREATMENT	1	1.855	.186	0.6	0.125	.727	0.0
(C)STATION(B)	10	3.907	.003	12.9	1.705	.137	17.3
(D)SITE(ABC)	24	2.559	.000	10.8	2.571	.000	16.0
AB	1	7.361	.012	9.4	0.071	.792	0.0
AC(B)	10	1.570	.176	5.1	1.446	.220	6.0
RESIDUAL	144			27.8			41.4

SOURCE OF VARIATION	df	*Sargassum* F	P	%v	*Lobophora* F	P	%v
(A)HABITAT	1	201.096	.000	56.7	11.734	.002	5.0
(B)TREATMENT	1	17.323	.000	4.6	19.614	.002	8.8
(C)STATION(B)	10	3.720	.004	4.6	5.074	.001	11.5
(D)SITE(ABC)	24	1.111	.340	0.7	1.592	.050	4.2
AB	1	3.171	.088	1.2	4.053	.055	2.9
AC(B)	10	3.236	.009	7.6	7.959	.000	39.3
RESIDUAL	144			24.5			28.4

SOURCE OF VARIATION	df	ALL ALGAE F	P	%v	SPONGES F	P	%v
(A)HABITAT	1	155.450	.000	57.4	76.275	.000	33.6
(B)TREATMENT	1	1.381	.252	0.1	1.454	.240	0.2
(C)STATION(B)	10	1.892	.097	2.0	4.369	.002	9.0
(D)SITE(ABC)	24	1.347	.145	2.3	1.191	.260	1.7
AB	1	0.230	.636	0.0	9.907	.004	7.9
AC(B)	10	3.629	.005	11.7	3.173	.010	11.6
RESIDUAL	144			26.5			35.9

SOURCE OF VARIATION	df	WET WEIGHT ALL ALGAE F	P	SEDIMENTS WEEK ONE F	P
(A)HABITAT	1	108.998	.000	0.259	.620
(B)TREATMENT	1	9.360	.010	6.793	.023
(C)STATION(B)	10	4.653	.017	2.612	.089
(D)SITE(ABC)	24	0.434	.942	0.441	.941
AB	1	2.168	.167	13.688	.003
AC(B)	10	2.350	.113	2.470	.101
RESIDUAL	144				

SOURCE OF VARIATION	SEDIMENTS WEEK TWO df	F	P	SEDIMENTS WEEK THREE F	P
(A)HABITAT	1	3.194	.099	41.811	.000
(B)TREATMENT	1	2.076	.175	96.413	.000
(C)STATION(B)	10	2.368	.111	3.229	.051
(D)SITE(ABC)	24	1.663	.094	0.368	.970
AB	1	0.472	.505	42.979	.000
AC(B)	10	0.372	.824	2.016	.156
RESIDUAL	144				

SOURCE OF VARIATION	SEDIMENTS WEEK FOUR df	F	P
(A)HABITAT	1	14.568	.003
(B)TREATMENT	1	3.787	.076
(C)STATION(B)	10	0.686	.615
(D)SITE(ABC)	24	1.552	.126
AB	1	0.708	.417
AC(B)	10	3.001	.062
RESIDUAL	144		

APPENDIX B:

EFFECTS OF SEDIMENTATION ON CORALS WITH PARTICULAR REFERENCE TO FRINGING REEFS.

I. INTRODUCTION

The geomorphological process of coral reef development relies heavily on the transport and deposition of sediments. Sedimentation of calcified algae and animal fragments plays a major role in contributing to reef construction (Cribb, 1981).

It has been proposed by Hopley *et al.* (1983) that the majority of fringing reefs in North Queensland may have developed over unconsolidated sediments rather than over any kind of rock platform; a situation that has only once previously been described. Fringing reefs, by virtue of their environment, are prone to regular episodes of sedimentation from additional sources, such as terrestrial run-off. These sediments are often re-suspended, during and following wind and wave action, resulting in low light levels due to turbidity. Whilst many coral reefs have been observed growing in an apparently "healthy" state in these fringing reef areas (Marshall and Orr, 1931; Roy and Smith, 1971), severe siltation (up to 1100 mg/cm^2 /day) has been shown to result in damage and destruction to reefs (Cortes and Risk, 1985).

Before discussing the general effects of sediment on coral communities it is important to distinguish fringing reef systems from other open water reefal environments where levels of sedimentation are very low. Data presented by Pastorok and Bilyard (1985) (Table A:1) when compared with data collected from Magnetic Island (this document) and Cape Tribulation (Hoyal, 1986) express this point well. The level of sedimentation at which Pastorok and Bilyard (1985) suggest an impact that is "severe to catastrophic" lies well below the average levels of sedimentation recorded on Magnetic Island (44 mg/cm^2 /day; week two collection) and Cape Tribulation (South section 86 mg/cm^2 /day) yet these reefs support flourishing reef communities (Ayling and Ayling, 1987; this report). Clearly information from these differing reef environments are of little value as bench marks for fringing reef environments.

Localized damage to coral reef communities could be expected to result from human activity such as dredging, filling and mining (Dodge and Vaisnys, 1977; Bak, 1978; Sheppard, 1982; Gabrie *et al.*, 1985). The objective of a sampling programme which examines the effects of such activities is to determine the extent of change that results in the impact area compared with appropriate "control" areas that are not affected by the impact. Prior to the design of such a sampling scheme it is necessary to have some knowledge of the effects of sediments on coral reef biota to enable any damage caused to the community to be assessed in an objective manner.

In order to provide the rationale for the sampling design used in our baseline programme, and proposed for the future impact assessment study, the effects of sediment on corals and the methods used by corals to reject sediments will be reviewed. Details of previous human induced sediment impacts and their effects on coral communities will be presented. This review will focus on corals because of their sensitivity to environmental change and because corals are an integral part of reef communities.

SEDIMENTATION RATE mg/cm² /day	DEGREE OF IMPACT
1 - 10	**Slight to moderate** Decreased abundance Altered growth forms Decreased growth rates Possible reductions in recruitment Possible reductions in numbers of species
10 - 50	**Moderate to severe** Greatly decreased abundance Greatly decreased growth rates Predominance of altered growth forms Reduced recruitment Decreased numbers of species Possible invasions of opportunistic species
> 50	**Severe to catastrophic** Severely decreased abundance Severe degradation of communities Most species excluded Many colonies die Recruitment severely reduced Regeneration slowed or stopped Invasion by opportunistic species

Table A:1. Estimated degree of impact of various sedimentation rates on coral communities (from Pastorok and Bilyard, 1985).

II. METHODS OF MEASURING SEDIMENTATION.

A wide variety of methods have been used to quantify the amount of suspended and settling sediment in the water column. These range from snap-shutting Nansen bottles to simple dishes of known surface area placed on the substratum. Each method has a number of biases and is subject to various sources of error. The relative merits of sediment collectors have been reviewed in the literature (e.g. Gardner, 1980). These studies generally conclude that the most efficient way of quantifying sediment (in terms of accuracy of estimating the concentration of sediment for a given effort), is by using a cylindrical tube with a height to width ratio of between two and three. Even traps designed in this manner are inefficient under certain hydrodynamic conditions. Hoyal (1986) noted that in areas of high wave action or current velocity, vortex action may lift sediment out of the traps or in some cases wash the actual trap away. Several studies of sedimentation on inshore fringing reefs involved using sediment traps that are within these suggested parameters (Kelly, 1982; Hoyal, 1986). However there are certain biological problems in the use of bare cylindrical traps. Hoyal (1986) reported that traps left in position for a number of months often became "home" to a variety of marine invertebrates and fish including worms, hermit crabs and small pomacentrid fish. These animals often removed any sediment from the traps. In addition the traps quickly became fouled by algae which obviously affected the sediment collecting efficiency. Willis (1987) overcame this second problem by painting traps with an anti-fouling paint.

Gardner (1980) found that baffles in sediment traps help to decrease the size of turbulent eddies and rate of mixing within a trap. These baffles are also useful in keeping out the previously mentioned fish and invertebrates. Kelly (1982) used both anti-fouling paint and baffles in her sediment traps and these appeared successful in combatting the biological problems of fouling and habitation. The baffles were also useful in improving the efficiency of the trap.

Gardner (1985) has determined that the tilt of a sediment trap has an effect on its collecting efficiency. Preferential settlement of particles smaller than 63 μm may be experienced if the trap tilt is greater than 30° in a downstream direction (Gardner, 1985). It has also been calculated that replicate traps should be placed at least three diameters apart if they are to be used at the same level (Gardner, 1980) otherwise flow interference is likely to alter their efficiency. Cortes and Risk (1985) demonstrated an inverse relationship between height of trap above substrate and increasing sedimentation.

In summary, past work indicates that a sediment trap should have the following characteristics:

1) They should be cylindrical with a height to width ratio of between two and three.
2) Traps should be anti-fouled to inhibit growth of fouling organisms.
3) Traps should contain removable baffles.
4) Traps should be positioned in an upright position.
5) Replicate traps that are at the same level should be at least three diameters apart or flow interference is likely to alter their efficiency.
6) Collections of sediment from traps should be made on a regular basis to minimise problems of fouling and habitation by animals.
7) Traps should be placed at a standardised height above the substrate

Measurements of sedimentation calculated from sediment trap data can only be used for comparisons between areas, and not as estimates of actual rates of sedimentation onto corals. This is because the traps are artificial structures subject to differing hydrodynamics when compared with coral colonies and open to biases that are not readily quantifiable. In addition sediment accumulating inside traps is less likely to be resuspended than sediments on the substrate (Gardner, 1980).

III. EFFECTS OF SEDIMENTS ON CORAL COMMUNITIES.

There are two main effects of sedimentation on coral communities:

-smothering of corals
-reduced light levels

A. Smothering

Early studies, by Marshall and Orr (1931), on the ability of corals to reject sediment found that they were able to remove coarse and fine sediments from their living surfaces. The factors controlling sediment removal were considered to be colony morphology and mucus production. Hubbard and Pocock (1972) have ranked various coral species according to their sediment rejection capabilities for different sized sediments. They found that silt (the smallest sediment class used) was the only size removed effectively by all the species tested.

Removal of sediment by corals requires energy. Coral respiration rates have been shown to increase significantly during "vigorous" sediment-cleansing activities (Dallmayer *et al.*, 1982). This energy might otherwise have been used for food capture, growth, skeletal repair or reproduction (Dodge and Vaisnys, 1977). In addition, Dallmayer *et al.* (1982) suggests that sediment on corals may interfere with the feeding process of corals.

Hoyal (1986) suggests that corals are unable to survive more than a few hours of burial. However the data available on the effects of lower levels of sedimentation, both lethal and sublethal are scant. Words such as high, severe and extensive do little to describe the quantitative nature of sedimentation.

B. Reduced light levels

Light levels decrease exponentially with depth (Dunstan, 1982) and, as corals contain algal symbionts which require certain levels of light to photosynthesize, represent one of the major determinants of coral zonation (Done, 1983). Sediment loading in the water column causes a reduction in light intensity by scattering light rays. Studies by Rogers (1979); Weber and White (1976); and Goreau (1964) have demonstrated the controlling factor of light on coral growth. Rogers (1979) showed experimentally that the detrimental effects on corals of light reduction caused by sedimentation were greater than the effects of the sediment itself. Several authors have clearly demonstrated a relationship between suspended sediment levels and the reduction of coral growth (Dodge *et al.*, 1974; Cortes and Risk, 1985). Note however that suspended sediment levels do not necessarily relate to the amount of sediment actually falling onto corals (Cortes and Risk, 1985; as found by this study). Cortes and Risk (1985) discuss a shallow reef environment combined with strong currents and high wave action resulting in suspended sediment passing over the corals but not settling out.

IV. CONFOUNDING FACTORS IN SEDIMENT EFFECTS.

The effects of sedimentation on coral communities may sometimes be confounded with other environmental factors. Where the suspended sediment is due to terrestrial input, low salinity waters may coincide with high sedimentation input. Goreau (1964) reported extensive bleaching of corals as a result of flood rains accompanying a cyclone in Jamaica. Huge quantities of sediment were released onto the reefs off eastern Jamaica. However, the accompanying freshwater run-off, rather than the sediment, was implicated in the resultant damage to coral communities. Evidence put forward to substantiate these claims included 1) the zone of bleaching always cut horizontally across reef communities without regard to topography or ecology, 2) the depth of bleaching was greatest where the thickness of the fresh water layer was greatest, and 3) bleaching was restricted to surface layers whereas sediment shading would be expected to affect deeper zones rather than shallower zones. Oliver (1985) describes widespread bleaching occurring over hundreds of kilometres on the GBR and therefore suggests that locally varying parameters such as salinity or turbidity are unlikely to be causative agents. Szmant-Froelich *et al.* (1981) reported that suspended sediment levels of 100 ppm over six weeks resulting from drilling had an adverse effect on reef corals. However, the drilling mud was contaminated with large quantities of oil which may have played a significant role in the damage to the corals. Bak and Elgershuizen (1976) did not find any difference in the rejection mechanisms used by corals to remove oil-sand particles compared with clean sediments. They suggest that the water-soluble fraction of oils may be more harmful than physical contact of corals with oil-sediment particles. More recent work by Kendall *et al.* (1983) comparing drilling mud with equivalent quantities of Kaolin (to produce equivalent turbidities) suggests that the toxins in drilling mud do have an effect over and above that of turbidity and smothering.

V. PHYSICAL FACTORS INFLUENCING DISTRIBUTION OF SEDIMENT WITH CONSIDERATION OF PARTICLE SIZE

Sediment particle size and water velocity determines the length of time that sediments spend in suspension. Very fine sediments are easily transported and remain in suspension for extended time periods. The ability for sediments to remain in suspension and to later be re-suspended is reduced as sediment size increases. Heavy sediments are more likely to remain on the surface of coral colonies or to "roll off" the colony, whilst fine sediments are more likely to flow past or be re-suspended.

Whilst strong currents will assist in the removal of sediments from corals the abrasive characteristics of sand and other coarse sediments, when transported by currents, can inhibit the growth of corals (Johannes,1975; Loya, 1976; Rogers, 1983).

Clearly the prevailing hydrodynamic conditions affect the extent of sediment distribution. Tidal range and periodicity, wind strength and direction, swell and wave action, and episodic storms all result in some form of water movement. It is interesting to quote data from Hubbard (1986) on the movements of sediments during storm periods. He reports that one third to one half of the sediment moved annually at St. Croix can be transported during only 14 days of stormy weather. These data emphasize the importance of not drawing potentially erroneous conclusions from data collected over short time periods.

VI. METHODS OF SEDIMENT REJECTION.

The morphology of the coral skeleton has an obvious effect on how a colony deals with sediments (Schumacher, 1977; Logan, 1988). In addition corals may show a behaviourial response to clear themselves of sediment (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976). The relative importance of this behaviourial response is in contention (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976), however it is agreed that corals may remove sediments using a variety of methods (Schumacher, 1977; Fisk, 1981; Coffroth, 1985; Logan, 1988). The four methods generally identified are as follows:

1) use of tentacles to brush particles aside
2) transportation of sediment using ciliary action
3) entrapment of sediment with mucus streams that are then removed by water movement
4) particles pushed out of the way by distension of polyps as a result of water uptake.

The method used may be dictated by the size of the sediment particles (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976; Lasker, 1980).

VII. MEASURABLE RESPONSES OF CORALS TO INCREASED SEDIMENTATION.

Coral species show different levels of tolerance to siltation (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976; Chansang, 1988). Mayor (in Bak and Elgershuizen, 1976) reports that large polyps are more effective in the rejection of accumulated sediments, although the details of his studies are not clear. Stafford-Smith (pers. comm. March 1989), however, has observed that several small polyped species ,*Montipora, Porites and Cyphastrea* appear very sediment tolerant.

A. Death

The most obvious response to an observer of the effect of sediment on a coral colony is the death of part or all of the colony. Willis (1987) studied *Turbinaria messenterina* in Nelly Bay, Magnetic Island and suggests that the convoluted form of this species copes with sedimentation by sacrificing the lower portions of the colony. However, she agrees that other conclusions for the death of these lower portions are equally plausible.

Smothering of a coral for periods longer than one or two days results in the death of the coral (Edmonson, 1928 in Endean, 1973). This occurs when the amount of sediment deposited on the colony is greater than the amount it is capable of rejecting.

B.Reduction in growth

Coral growth has been shown to be reduced as a result of sedimentation (Aller and Dodge, 1974). Bak (1978) described the immediate effects of suspended sediment during dredging activities in Curacao. He recorded a dramatic change in the environmental conditions on the reef, including reduction of light levels to less than 1% surface illumination at a depth of 12-13 m. Readings such as these are normally confined to much deeper waters (> 40 m, van der Hoek *et al.*, in Bak, 1978). In addition, with the notable exception of live corals, the entire substratum was covered with more than a 1cm thick layer of sediment. Bak (1978) noted that the plating colonies of *Porites astreoides* were the only corals unable to reject the sediment. Partial or total death of these colonies occurred. Calcification rates for several corals were recorded. The short period of stress on these corals (one month) resulted in an immediate reduction of approximately 33% in calcification rates and rates remained affected for more than one month. Bak (1978) hypothesized that decreased light levels and increased energy expenditure in removing sediment were the causal factors of reduced coral growth rates. He suggested that, as corals do not rely heavily on a planktonic food source, the effect of sediment on feeding would not have significantly affected growth.

Patterns of annual banding in massive corals have been used to estimate the impact of sedimentation over long time periods (Dodge and Vaisnys, 1977; Dodge *et al.*, 1974). However, Wellington and Glynn (1983) state that interpretations of such data are difficult as the factors responsible for banding patterns are poorly understood and yet to be fully elucidated. Nonetheless, in an analysis of growth patterns of corals in Bermuda, where extensive dredging has occurred, Dodge and Vaisnys (1977) noted a distinct decrease in the growth rates of corals in the area of the dredging. They then died. For some of these corals the decline observed was over a longer period of time than the actual dredging. Corals sampled from a control area were unaffected. Dodge and Vaisnys (1977) suggest that even if the high levels of sedimentation and turbidity experienced during a dredging event do not immediately kill the coral communities, the higher sedimentation and turbidity following the event may create such stressful conditions that the corals eventually die.

Long term growth studies of *Montastrea annularis* colonies in a sediment-affected area suggested that the sediment was responsible for a reduction in growth rates, although this was not demonstrated conclusively (Hudson, 1981; Hudson *et al.*, 1982).

None of these data described above have been collected from Australian fringing reefs. In contrast to these results, Isdale (1981) used x-radiographic studies to show that *Porites* on inshore fringing reefs of Queensland (including Magnetic Island) had higher mean annual growth rates compared with offshore reefs of the region.

C. Reproductive Biology

Of all life functions reproduction usually has the narrowest tolerance to stress (Kinne, 1963; Gerking, 1980). A long term study of reproduction in fish has determined that inhibition of reproduction occurs before any detrimental effects can be detected by histopathological examination or measurements of growth (Gerking, 1980). Kojis and Quinn (1984) suggest reproduction in hermatypic corals shows the same early response to stress and that coral fecundity can be a sensitive indicator of sublethal stress in reef environments.

Continued measurement on the development of eggs and sperm would provide some indication into the long term effects of sedimentation on coral recruitment. Studies of this kind may also reveal that levels of sedimentation, previously thought to be harmless to adults, may, in fact, have a significant effect on the reproductive processes of corals.

D. Other methods to determine Stress

Stimpson (1987) presented evidence to suggest that shallow water corals use lipids as an energy reserve and that these levels may be reduced under lowered light levels. Current research at James Cook University is extending this research in an attempt to determine whether stress of corals may be expressed by a reduction in their lipid reserves (S. Seddon, pers. comm.).

Johannes (1975) suggests that corals may be at their lowest levels of tolerance for oxygen under normal circumstances in some environments and that the depletion of oxygen by suspended sediment may constitute a significant stress.

E. Behaviourial responses

There are several behaviourial responses of corals which may be used as indicators of stress, such as:

1) messenterial filament extrusion
2) mucus production
3) sediment shedding.

However these responses are not unique to sediment damage (Brown and Howard, 1985). These responses may be useful in general descriptions of a corals condition, observed externally.

VIII. SUMMARY

It is clear from the examination of previous work that the effects of increased sedimentation on corals in a reef environment will vary according to the severity, type and duration of the sedimentation. Arguments and data concerning tolerance thresholds of coral to sedimentation are location specific. The effects on individual species are related to the morphology and sediment rejection capabilities of that species. The data available to date do not allow quantification of levels of sedimentation and the resulting response of corals. Any event needs to be examined individually to determine accurately the effects of increased sedimentation on a coral community. Death, growth, and reproductive output can be assessed quantitatively. New techniques examining physiological signs of stress in corals may soon be used to provide detailed measure of chronic stress.

APPENDIX C

PROPOSED IMPACT ASSESSMENT PROGRAM

Phase 1 The Construction Phase: May 1989-1990

Phase 2 The Post-Construction Phase: June 1990-November 1991

Phase 3 Breakwater Monitoring Phase: December 1991-1996

The impact assessment program is designed to cover three stages of the Magnetic Quay development. The first is the construction phase and will be of 12 months duration. This will cover the assessment of impacts which occur during the actual construction of the marina and will focus on environmental impacts attributable to the disturbance of excavating the site and emplacement of breakwaters. We will investigate possible short term, acute effects and also potential low level effects that may have long term chronic implications. Some deployment of sediment traps and tagging of corals will be necessary before the expected commencement date of construction in May 1989.

The second will be a post-construction phase involving monitoring of benthic organisms for a period of 18 months following the completion of the marina and breakwaters. This phase will commence only after all marine construction has ceased, and will be designed to assess longer term and more subtle disturbances associated with the development. Any further construction, such as re-dredging the channel or marina, would require additional impact assessment studies.

The third phase will involve longer term (5 years) monitoring of the breakwater and marina to establish patterns of growth of benthic organisms on these artificial structures, and recolonization of the disturbed bottom areas.

The impact assessment program must also incorporate an element of reactive monitoring to respond to unexpected events, changes in the construction plan, or a perceived environmental impact (Box 8). Events such as the influence of unexpected weather changes or modifications to the dredging or transport of material removed from the marina basin and channel would require special attention.

MEASUREMENTS AND OBSERVATIONS TO BE CARRIED OUT THROUGHOUT THE CONSTRUCTION PHASE: MAY 1989 TO MAY 1990

Major resurveys will be carried out at intervals of four months during the construction phase.

1) Patterns in Abundances of Benthic Organisms

a) The 216 fixed line transects will be resurveyed at intervals of 4, 8 and 12 months from May 1989. The initial resurvey will incorporate all stations to provide an estimate of the spatial pattern of change. Estimates of the power of our sampling designs indicate that the number of transects used in the pilot study, and their allocation among sites and stations, is sufficient to detect reasonably small proportional changes in abundances of benthic organisms with good power. For most of the important reef forming taxa, it is expected that repeated surveys of fixed line transects with the level of replication employed in the pilot study will allow us to detect changes of 20% or less in coral abundance. This level of sensitivity is manifestly adequate for the impact assessment program.

In later surveys, it may be possible to reduce the number of stations or bays sampled. This will depend on our assessment of the spatial pattern and magnitude of environmental impacts and on the resolving power of our tests over longer periods (Box 7).

b) There will be a short-term (1 week) re-survey of a selected series of stations in Nelly Bay and Geoffrey Bay to estimate measurement errors inherent in resurvey of the fixed transects. It is anticipated that 2 stations in each bay will be resurveyed. This will be done at the beginning of the survey in September - October, 1989.

2) Estimates of growth, mortality and 'condition' in tagged organisms

a) The corals tagged during the baseline study will be resurveyed at the 4, 8, and 12 month intervals to estimate the extent of mortality, physical damage, and lesions or bleached areas. A photographic record of all these corals is available from Feb. 1989. All corals will be re-photographed at the 8 month survey.

b) A reduced suite of tagged and untagged corals from a number of reef slope sites will be monitored for lipid levels using a modification of the method of Stimson (1987). The method is presently being tested and extended as an honours project at James Cook University, and will be developed in collaboration with Dr. V. Harriott. Ten individuals of *Montipora aequituberculata* will be selected from each of three stations at Nelly Bay, two at Geoffrey Bay, one at Bright Point and one each at Picnic and Florence Bays. Samples might also be taken from tagged populations of *Acropora willisae*, particularly in the event of any enhancement of turbidity or sedimentation attributable to the development of Magnetic Quay. Samples for analysis of lipids will be taken in May/June and September.

c) Also in May/June and September, samples will be taken to assess reproductive condition in the above suite of corals. *Turbinaria mesenterina* will also be sampled for analysis of reproductive condition. The sampling program will be designed to assess differences within and between colonies, and between stations in both control and impact areas. Samples will be decalcified and examined histologically. Estimates of necessary numbers of replicates to detect specified levels of change in lipid and reproductive estimates with reasonable power will be obtained from the honours project at James Cook University. Estimates of lipid levels and reproductive activity will be used to assess 'condition' in corals. Much of the work will be done in the period between May and November to estimate the immediate effects of construction on the 'condition' of these corals.

d) The growth of large macroscopic algae will be investigated by a tagging programme. Twenty plants of either *Sargassum dichotoma, S. oligocystum,* or *S. bracteolosum* will be individually tagged at each site in 3 stations in each of Nelly Bay and Geoffrey Bay, and at one station in each of Arthur and Florence Bays. Plants will be tagged in late spring 1989, and the mortality and growth (elongation rate, stipe dimensions) of whole plants will be monitored until May 1990. This element of the monitoring plan will be designed to investigate the possible influence of potential nutrient enhancement during and following construction on plant growth. Increases in growth of macroalgae may influence corals. The strong seasonal component of *Sargassum* occurrence and growth will determine the timing of this study.

3) Estimates of standing crops of algae

a) Collections of macroscopic algae to estimate biomass will be repeated at the same stations used in the pilot study. These will be made in February 1990 to estimate whether algae cover and biomass at impact and control sites differ by more than they did in February 1989.

b) Cover of adventitious, filamentous, and turfing algae over tagged corals and line transect areas will also be assessed. These estimates will be added to the survey to identify whether differences occur between impact and control stations in the extent of overgrowth of corals by these algae.

4) Estimates of spatial patterns in sedimentation

a) The pilot study provided a basis for redesigning the deployment of sediment traps (Table 13). It is proposed that sediment traps be deployed at an additional control station at either Arthur or Picnic Bay. The number of sites monitored at each station will be increased to three, with three traps at each site. This will enhance considerably the power to resolve small to moderate differences between impact and control stations (Table 13). These traps will be sampled at regular intervals during the construction period.

b) In addition, extra sediment traps will be placed adjacent to the immediate impact area and extending from this area into Nelly Bay in the south and through Bright Point into Geoffrey Bay in the north. This will allow us to detect local scale patterns of enhanced sedimentation from the impact site and examine whether the characteristics of the sediment are being modified by terrigenous input.

c) Tagged corals along the same gradient (impact site to Nelly and to Geoffrey Bay) will be regularly examined to determine the area and thickness of sediment retained on the coral surface over short time periods. Comparisons of sedimentation in adjacent sediment traps will be made at the same time. Sediment weight and grain size will be measured.

Some disturbance of the fixed transect markers is already apparent. It is anticipated that a number of stakes will have to be replaced because of human interference and natural disturbance.

MEASUREMENT AND OBSERVATIONS TO BE MADE DURING THE POST-CONSTRUCTION PHASE

This period will commence at the completion of the marina and breakwater complex and continue for 18 months. Major re-surveys will be carried out at 6 monthly intervals after the completion of construction activities.

1) Patterns in Abundances of Benthic Organisms.

a) Benthic organisms will be re-surveyed along all fixed line transects on each occasion. Special attention on the possibility of algal overgrowth of corals.

b) On the basis of earlier (construction stage) studies, we will implement a sampling programme to detect any changes in the abundance of adventitious algae and possible overgrowth of corals attributable to Magnetic Quay.

2) Estimates of growth, mortality and condition in tagged organisms.

a) Tagged corals will be resurveyed to measure mortality, physical change, lesions and bleached areas over the same three intervals. We will also re-photograph all tagged corals the 12 month sampling interval.

b) Depending on the results of studies during the construction stage of Magnetic Quay, it may be necessary to continue monitoring lipid levels and reproductive status of corals and growth of algae.

3) Sedimentation

A decision concerning the continued monitoring of sedimentation patterns will be made on the basis of the outcome of the construction stage study. Any re-dredging of the channel or marina, or leaching of material from the shore, will require reactive sampling of sedimentation.

4) Colonisation of Breakwater and Channel

We will establish permanent sites on the breakwater and in the access channel. Fixed belt transects will be established expressly for the detection of recruiting and recolonizing hard corals, soft corals and algae on new structures and into disturbed areas. The transects will be deployed along the seaward face of the breakwater to detect the spatial pattern and depth gradients of colonization. In the channel, belt transects will run perpendicular to the channel axis to measure recolonization of sessile fauna at all depths on the walls of the channel. Re-dredging of the channel site will necessitate additional monitoring.

MEASUREMENT AND OBSERVATIONS TO BE MADE DURING THE BREAKWATER MONITORING PHASE

The sites on the breakwater and channel will be monitored initially at 6 monthly intervals (3 years) and then annually for a total of five years. This will provide a basis for establishing the sequence of coral colonization of the breakwater. A minimum of 20 permanent belt transects on the breakwater wall is anticipated. Transects will be monitored photographically.

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