Executive Summary

The results for the first year of the Australian Institute of Marine Science Long-term Monitoring Program are presented. Approximately 34 reefs were surveyed for coral (and other benthic organisms), fish, water quality and crown-of-thorns starfish (COTS). An additional 53 reefs were also surveyed for COTS and estimated coral cover, while 60 additional reefs were sampled for water quality.

Broadscale surveys for COTS and coral cover using the manta tow technique, have been carried out over most of the Great Barrier Reef (GBR) since 1985. The results for 1992/93 indicate that active outbreaks on the GBR have continued to decline and that the previously described wave of southward propagating outbreaks has died out in the Whitsunday region. Only small outbreaks now exist in the far north and far south of the GBR.

Water quality variables were measured at 94 stations throughout the GBR. While there is an indication that there may be some seasonal and/or north south variation in the overall data set, formal statistical analysis was only possible for 2 sectors and 2 dates. These results showed that most variables varied significantly over a 4 month period, but that there were few significant differences between adjacent sectors. An analysis of 2 complete cross-shelf transects indicated that suspended solids and chlorophyll were much higher inshore and decreased towards the shelf edge, while nitrite showed the opposite trend.

The results for visual surveys of reef fish confirm the existence of community differences across the continental shelf and from north to south along the GBR. Some families and genera showed clear trends, either increasing or decreasing in abundance from inner-shelf reefs to outer-shelf reefs. Although significant differences were found among survey sectors, no obvious north-south trends in abundances were found. A comparison of the results from this study with those of previous surveys conducted at AIMS a decade ago demonstrated that fish abundances at the Capricorn Bunker reefs have changed substantially compared with other sectors.

Corals and other benthic organisms also exhibited some significant cross-shelf and north-south trends. Again the Capricorn Bunker reefs were distinguished by their low levels of hard and soft coral, and high levels of algae.

Overall, the most significant result from this first year of the Long-term Monitoring Program is that there is now an extensive set of base-line data which can be used to measure any future changes.

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Acknowledgments

We wish to thank the all the people who have, at various times, assisted the monitoring team in the collection and analysis of data. In particular we thank the captains and crews of the RV.Sirius and RV Harry Messel for their support during numerous field trips.

Jon Brodie, Steve Hillman and Brian Lassig from GBRMPA provided valuable and constructive criticism (and a management perspective) on the draft manuscript.

Christine Cansfield-Smith and Steve Clarke assisted with graphics and production.

This work was supported by the Great Barrier Reef Marine Park Authority, and the CRC Reef Research Centre.

1. Introduction

Background

In 1992 the Australian Institute of Marine Science (AIMS) initiated a comprehensive long-term monitoring program for the Great Barrier Reef (GBR) in conjunction with the great Barrier Reef Marine Park Authority (GBRMPA). Although there have been previous monitoring programs on the GBR covering a variety of spatial and temporal scales, the AIMS program represents the first attempt to monitor several important ecological variables on representative reefs over most of the GBR. The program has been set up with secure long-term government funding, and is therefore capable of accumulating long-term data sets over a large geographic scale. In 1993 the Long-term monitoring program was included as a task in the newly formed Cooperative Research Centre for Ecologically Sustainable Use of the Great Barrier Reef.

A detailed description of the AIMS Long-term Monitoring Program (LTMP), including rationale and objectives can be found in AIMS (1992 and in prep), however a brief summary of the program is included here as an introduction to this first annual report.

Objectives

The primary objectives of the Long-term Monitoring Program are to:

1. Monitor the status and trends in the distribution and abundance of reef biota and in water quality, on reefs in the GBR.
2. Provide environmental managers (and other decision makers) with information that is pertinent to managing the GBR according to the principals of Ecologically Sustainable Use.

As a monitoring program, the LTMP’s goal is to document change - i.e. where, how much, and what kind of changes take place in the study areas at 52 different reefs. The ideal is to resolve change at scales which will allow judgements to be made as to which changes are within normal, natural variability, and which are outside it.

Replication of monitoring effort within each reef provides a basis for assessing changes in the abundance of coral populations at four scales and fishes at three scales:

- groups of reefs with common cross-shelf and latitudinal position
- the whole “study area” (a linear section of reef margin 0.8-1 km in length)
- three permanently marked “sites” within each study area, each 250-300 m in length)
- (for coral) five permanently marked, 50 m long, linear “transects” within each site

For both corals and fish, the best basis for assessing ecologically significant change is to document the change at as many scales as methods, logistics and cost constraints allow. For corals, which don’t move, the minimum tractable scale is the “transect”, and for fish, which do move, it is the “site”.

Program Design

Measurement Variables

The Long-term Monitoring Program involves a suite of variables which are collected as part of 4 "tasks". These tasks, and the associated measurements are listed in Table 1.1.

Table 1.1. Summary of Measurement Variables for each of the LTMP tasks

Task	Description	Variables Measured
Broadscale Surveys	manta tow surveys around entire reef perimeter	crown-of-thorns starfish counts; estimates of coral cover; other incidental observations (e.g coral bleaching, *Drupella*, giant clams, reef aesthetics)
Water Quality	*in-situ* measurements and nutrient analysis of water samples at stations adjacent to reefs and in open water	temperature, salinity, nitrogen (total dissolved organic, total particulate, NH_4 NO_3, NO_2), phosphorous (PO_4, dissolved & particulate), silicate, suspended solids, chlorophyll
Benthos	video transects at selected sites on northern reef flanks	percentage cover of all identifiable sessile benthic organisms (with emphasis on coral identification)
Fish	visual surveys of fish at selected sites on northern reef flanks	counts of most mobile non-cryptic fish species

Sampling Design

Selection of reefs

A total of 52 reefs have been identified for annual measurements of all variables described in Table 1.2. The reefs were chosen to provide wide geographic spread throughout the GBR, and to encompass known variations in the composition of coral and fish communities (Done 1982, Williams 1982) and water quality (Furnas *et al.*1988, 1993). These variations are known (Done 1983, Williams 1991) to be greater across the GBR (distances of 50-200 km) than they are along its length (2000 km), reflecting gradients in water clarity and wave exposure, which are greater offshore than close to shore, and in plankton communities, which are more productive inshore.

The reefs were therefore selected within 6 of the 11 cross-shelf sectors (Figure 1.1) previously established for manta-tow surveys for crown-of-thorns starfish (Bainbridge *et al.*, 1994). Within each of these sectors (except the Capricorn Bunker sector), three or more reefs have been selected in each of the inshore, mid-shelf and outer-shelf regions (see maps and full listing in Appendix 1). Shelf position was determined by the position of the reef relative to the coast and continental slope with inner-shelf reefs closest to the coast, outer-shelf reefs bordering the continental slope and mid-shelf reefs between the two. In the Capricorn Bunker sector, there are no adjacent inshore or mid-shelf reefs, so only outer-shelf reefs have been selected.

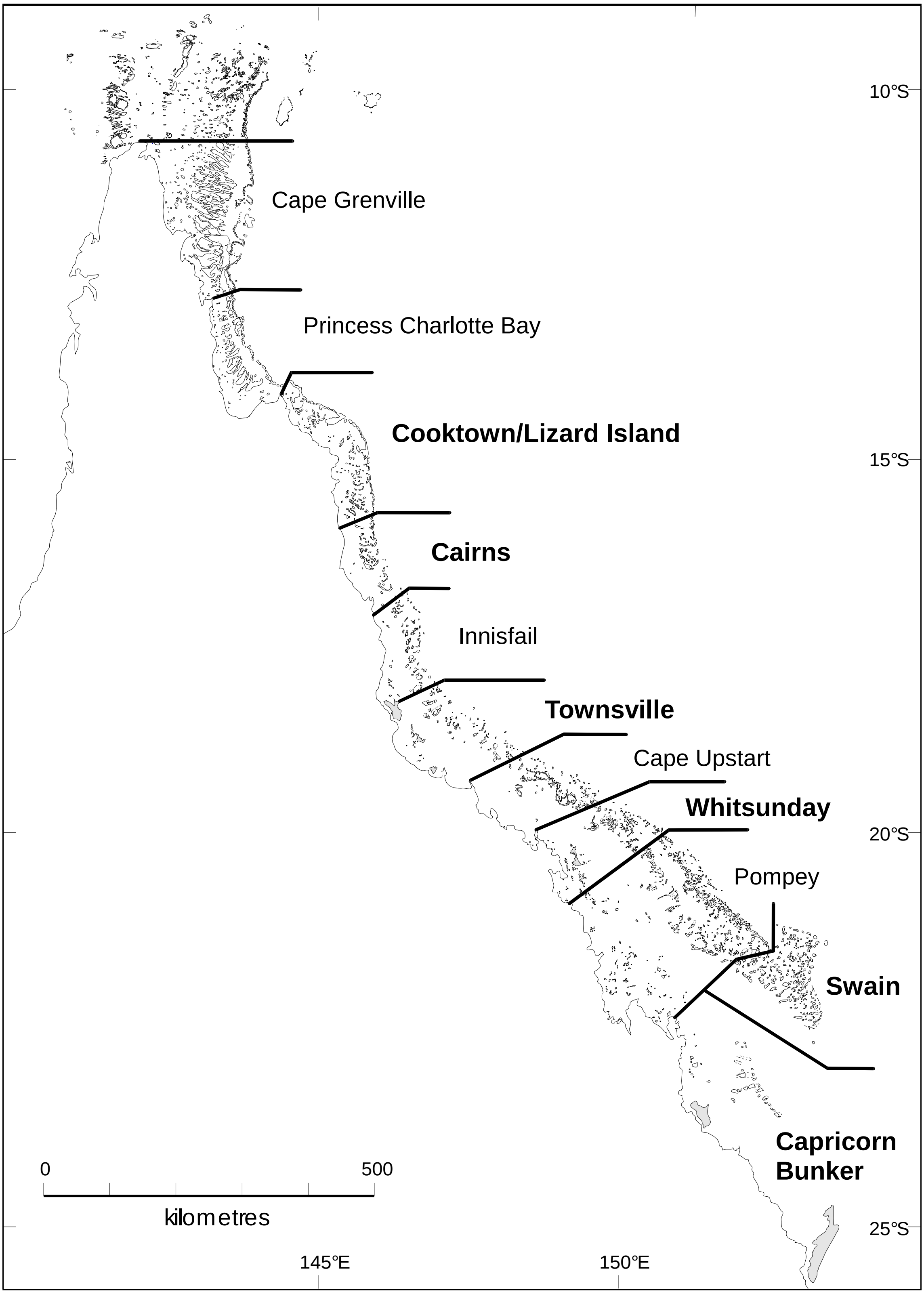


Figure 1.1 Map of the GBR showing sectors used in the monitoring program. All sectors are surveyed for broadscale surveys and water quality, but only those marked in bold are sampled for fish and benthos.

Because the establishment of sites on each reef requires additional time over and above that required for data collection, it was not possible to set up and survey all reefs in the first year. In total, 34 reefs were surveyed for benthos and water quality in 1992-93, and 33 for fish (one inshore reef could not be surveyed due to poor visibility). Only 32 of these reefs were surveyed by manta tow due to problems with low visibility at certain inshore reefs (Table 1.2). In addition to those reefs at which all variables are measured, additional reefs are surveyed each year using the manta tow technique. These extra reefs are selected from all 11 sectors. In 1992-93, fifty-three additional reefs were manta towed (Table 1.2). Additional water quality samples were also taken at a variety of locations away from reefs. These sites were chosen to compliment sampling being conducted by both AIMS and GBRMPA. A full tabulation of all reefs designated for surveys for different variables (including reefs not yet set-up) is presented in Appendix 1.2.

Table 1.2. List of reefs surveyed in the 92/93 sampling year. Reefs marked in bold were surveyed for all variables. Other reefs were surveyed by manta tow only. Where marked, reefs were not surveyed by manta tow (*) or for fish (†) due to poor visibility at the time of survey.

	Shelf Position				
Sector	**Inner**		**Mid**		**Outer**
Cape Grenville	Curd Kay		Forbes Islands Sir Charles Hardy (1)&(2)		Lagoon 12-071
Princess Charlotte Bay	Osborne		13-063 13-124		Rodda Sand Bank No 8 Tydeman
Cooktown/Lizard Is	**Linnet** **Martin** Boulder	Coquet Is Egret Two Isles	**Macgillivray** Endeavour Helsdon	14-043 14-056 15-047	**Carter** **Yonge** Ribbon No. 9 Sand Bank No. 1
Cairns	**Green Is.** **Low Islets**		**Hastings** **Mackay** **Michaelmas** Morning Oyster (a)	Pixie Rudder Saxon Tongue (1)&(2) Undine	**St. Crispin** Agincourt No. 4 Ruby
Innisfail			Flora Normanby & Mabel		
Townsville	**Middle*†** **Pandora***		**Davies** **John Brewer**	Helix Little Broadhurst	**Dip** **Myrmidon**
Cape Upstart			Bowden Faith	Kangaroo (a)&(b) Stanley	Jaguar Viper
Whitsunday	**Hayman Is.** **Langford and Bird**		**19-138** **20-104** **Hardy**	Bait Napier	**19-159** **Hyde**
Pompey			Cannan Credlin		
Swain			**21-529** **Chinaman** **Gannet Cay** **Horseshoe** **Sanctuary** **Snake**	Central 22-144 22-112 22-118	
Capricorn Bunker					**Broomfield** **Lady Musgrave Is.** **One Tree Is.** **Wreck Is.**

Selection of sites and sampling units within reefs

For broadscale surveys, the entire reef perimeter is surveyed using the manta tow technique (Figure 1.2), while for water quality sampling, two sites approximately 500 m north and south of the reef are sampled twice about 48 hours apart. For both fish and benthos, three sites per reef are sampled. Sites are positioned in a similar habitat on each reef. The habitat selected is defined as the first stretch of continuous

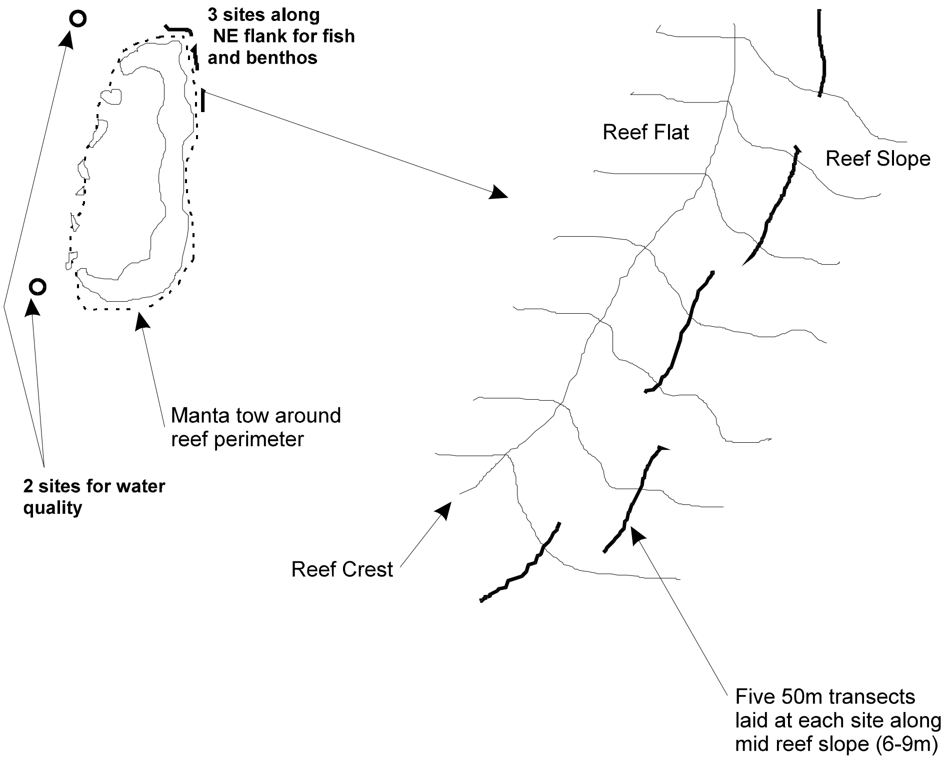


Figure 1.2. Arrangement of sampling effort on a typical reef.

reef with a less than vertical slope as one moves from the back reef zone in a clockwise direction towards the front of the reef. Typically this habitat is situated on the north-east flank of the reef. Sites are separated by at least 250 metres whenever the area of suitable habitat allows for this degree of spread. In situations where the reef is very small, the sites extend around the reef to the east and south-east flanks. There are five permanently marked 50 metre transects within each site. The transects run approximately parallel to the reef crest along the middle of the slope (generally at a depth between 6 and 9 metres). Transects are marked with a star picket at each end with sections of reinforcing rod at 10 metre intervals. In the first instance, transects were laid in a haphazard manner over hard substratum with distances between each transect varying between 10-40 m.

Limitations to the Present Design

Ideally, a monitoring program for the Great Barrier Reef should provide data which are representative at all scales. Because the GBR is not uniform, either among individual reefs or among habitats within a reef, an ideal monitoring program would involve replicate sampling within all combinations of reef and habitat type. Logistic and financial considerations make this impossible. The design described above is therefore a compromise which attempts to measure changes on reefs which are representative of most of the GBR (inshore, mid-shelf and outer-shelf reefs between Lizard Island and the Capricorn Bunkers), but within only one selected habitat (the middle reef slope in exposed to semi-exposed sites). Consequently the current design will not allow any firm conclusions to be drawn regarding long-term changes in other reef habitats, unless other studies demonstrate that there is a strong correlation in temporal variation between these habitats and the monitored sites. These studies will be conducted during the next few years.

For the sake of brevity, the term "reef" is used to describe information pertaining to "the study area at a reef". While it is axiomatic that a "whole reef" change in status will be reflected in a change in the study area, it does not necessarily follow that a change in the study area is representative of a change in the whole reef. The broadscale surveys of coral cover around the perimeter of each study reef do, however, provide a basis for assessing the broader extent of change within reef slopes. The manta board technique, which is analogous to a low-altitude flight over vegetation on land (Done *et al.* 1981), obviously cannot document the subtleties that the detailed work within the study areas can. Nor does it monitor deep reef areas or reef top areas. However, within the limits of available resources, the combination of detailed and synoptic monitoring provide a reasonable likelihood of detecting those major changes which might warrant some management or research response.

Another limitation to the present design is that only one survey is carried out per year on each reef. This limited temporal replication may be particularly significant for measurements of fish abundance and water quality, which are known to vary considerably over periods of hours, days, weeks and months. Ongoing studies are investigating the magnitude of such variations and may be used to adjust sampling frequency or timing in the future.

Data storage and access

All data are stored in an ORACLE™ database on the AIMS computer system. Summaries of the data can be obtained using a custom graphical interface (ARMIS) on any Macintosh or PC compatible personal computer. A full description of the database and the ARMIS interface will be described elsewhere (Baker and Bainbridge, in prep). Anyone wishing to obtain access to the monitoring data should contact the LTMP Project Leader at AIMS.

Flexibility & review

Given the size and scope of the program, and its status as the first comprehensive, large-scale, long-term monitoring program in a coral reef region it is inevitable that there will need to be some modifications to the design of the program as a result of insights and experience obtained during the first years of sampling, and from specific methodological studies running concurrently with the monitoring program (see below). Some changes have already been made during the second year of the program and further changes are currently being considered. In addition the program is committed to undergoing a full external review every three years. While non-essential changes to the core design will be avoided wherever possible, so as to ensure the continuation of an unbroken and consistent data series, these periodic reviews aim to ensure that the program remains both scientifically rigorous and relevant to the needs of environmental managers.

Quality Control

In any long-term program, it is especially important that there is an ongoing system of quality control to ensure that the data are collected in a consistent and reliable manner, and that any errors associated with the data are identified and dealt with in an appropriate manner.

Errors in the data can be derived from several different sources: transcription errors; recording and instrumental error; observer bias and imprecision; measurement bias and imprecision; sampling bias and imprecision. AIMS has initiated an ongoing program to identify and document errors at all levels and, wherever possible, to eliminate these errors or to apply an appropriate correction factor.

Table 1.3. Dedicated studies on sources of error associated with various sampling and measurement methods

Task	Topic of Study	Status of Work (or reference)
Broad-scale Surveys	bias and precision of COTS counts bias and precision of coral cover estimates protocols for categorising reefs inter-observer variability/effects of training	Fernandes (1990), Fernandes *et al.* 1990), Moran & De'ath (1992) Fernandes (1991) Fernandes (1991) Miller (MSc - in review)
Coral & Benthos	comparison of line transect and video techniques sampling methods for analysis of benthic video tapes effects of transect placement and replication level on sampling error inter-observer variability/effects of training	Oxley (manuscript in prep) Christie & Mapstone (manuscript in prep) Davidson (MSc Thesis in prep) ongoing
Fish	inter-observer variability/effects of training temporal variability/sampling frequency	Thompson & Mapstone (in prep) Thompson & Mapstone (in prep)
Water Quality	temporal variability/sampling frequency	ongoing

Details of the quality control and training procedures aimed at identifying and eliminating errors associated with the program's four tasks can be found in the Standard Operating Procedure Manuals for the program (Bass and Miller, 1995;Christie and Neale, in prep; Devlin & Lourey, in prep; Halford and Thompson, 1994). In addition to these standard quality control and training procedures, a number of dedicated studies have been initiated to identify and quantify observer and sampling errors for various components of the program. These studies are listed in Table 1.3 and the results (where available) are briefly summarised in the relevant chapters of this report.

Purpose of this Report

This report summarises the results of the first year of the Long-term Monitoring Program. In most respects these results should be considered preliminary since the full number of survey reefs will not be established until the end of the second survey year. Thus no analysis of change through time is possible. Nevertheless, the summarised results from those reefs which have been surveyed do provide useful baseline information on the current status of each reef for environmental managers and other researchers. In addition, the results allow a preliminary comparison of reef groups organised according to sector and cross-shelf position. While this data set will be more comprehensive once all of the reefs have been set up and analysed, it still provides an early baseline of current patterns of cross-shelf and north-south variation in reef biota.

With the fish data, it has also been possible to compare the surveys with historical data, and to document patterns of both constancy and change over an interval of approximately 10 years.

2. Broadscale Surveys

J. Oliver, I. Miller, D. Bass, & G. De'ath

Introduction

Broadscale surveys of crown-of-thorns starfish (COTS) and coral cover have been conducted on the Great Barrier Reef since the mid 1980's, and the current AIMS Long-term Monitoring Program represents an extension of these early monitoring surveys. Although the results of the surveys for 1992-93 have already been published separately (Bainbridge *et al.*1994), the results are summarised here for the sake of completeness. This report also presents an update of the long-term trends in COTS activity last summarised by Moran *et al.* (1993).

In future years, the annual report for broadscale surveys, together with long-term trend data, will be incorporated into a single chapter of the annual report for the Long-term Monitoring Program. The format for the presentation of results is different to that of previous reports, and reflects feedback from GBRMPA on the most concise and effective mode of presentation for management purposes.

The overall objectives and design of the AIMS Long-term Monitoring Program have been described in Chapter 1. The primary objectives of the Broadscale Survey component of the program are to detect and monitor outbreaks of COTS on the Great Barrier Reef, and to monitor the primary effects and subsequent recovery of corals affected by COTS outbreaks and other large scale disturbances.

In this report we present the results of surveys on 85 reefs in 11 cross-shelf sectors running from Cape Grenville in the north, to the Capricorn Bunker group in the south. The overall results for the full survey period (1985-1993) are then examined in the light of these data.

Methods

Broadscale surveys are carried out using the manta tow technique, which has been described by Bass and Miller (1995) and English *et al.* (1994). The general sampling design is described in Chapter 1. For convenience, the key aspects of the methodology, sampling strategy and data analysis are summarised below.

Study sites

A total of 85 reefs were surveyed in 1992-93 (Table 1.2). The full list of reefs which will be regularly surveyed as part of the Long-term Monitoring Program can be found in Appendix 2.1.

Sampling techniques

Each reef is surveyed using two teams working in opposite directions around the perimeter. Each team consists of a boat driver and an observer who is towed behind the boat on a manta board. At 2 minute intervals the observer records information on several variables (see Table 2.1).

Table 2.1. Primary variables recorded during manta tows (see Moran *et al.* 1989) for more details.

Variable	Data Recorded	Categories
Number of COTS	number observed	
Size class of COTS	size class	juvenile, adult (>25cm)
Presences of feeding scars	abundance categories	absent, present, common
Live coral	estimated cover categories (scale of 0-5)	0 = 0% 1 = >0 - 10%
Dead coral	estimated cover categories (scale of 0-5)	2 = 11-30% 3 = 31-50%
Sand/rubble	estimated cover categories (scale of 0-5)	4 = 51-75% 5 = 76-100%
Visibility	distance categories (scale of 1-4)	1 = <6m 2 = 6-12m 3 = 12-18m 4 = >18m

Incidental data on reef aesthetics, giant clam sitings, and other phenomena are also recorded for the entire reef.

Data handling

All data are entered directly onto a computer in the field at the end of each day. The data are checked against filed records on return to the Institute before being transferred to the AIMS monitoring database. Preliminary data analysis is carried out to calculate the median number of COTS per reef and the number of COTS per tow for each reef. These derived variables are then used, in conjunction with other anecdotal reports, to classify each reef in terms of its outbreak status (Fernandes, 1991; Moran & De'ath, 1992). Reefs are assigned to one of three categories: Active Outbreak (AO); Recovering (RE); or No recent Outbreak (NO). For this report, live and dead coral cover have been back calculated to percentage cover by converting the score for each cover category to the midpoint of its respective range.

Results

Survey results for 1992-93

A total 273 COTS were observed on 27 of the 85 surveyed reefs. Only 3 reefs were found to have active outbreaks. Due to the substantial variation between sectors in numbers of COTS and other variables no further summaries are provided for the entire reef. When examined on a sector by sector basis (Table 2.1) it can be seen that while COTS were recorded in all sectors except the Pompey and the Capricon Bunker sectors, Active Outbreaks were confined to the Princess Charlotte Bay (Osborne Reef) and Swain sectors (Snake Reef, Gannet Cay). Recovering reefs predominate in the Townsville and Cape Upstart sectors, whereas the majority of reefs in other areas (except the Swain and Innisfail sectors) show no evidence of recent COTS activity. Highest mean coral cover was recorded in the Pompey (52%) and Cape Grenville (44%) sectors, while lowest cover was observed in the Innisfail (12%) and Townsville (14%) sectors. A detailed tabulation of the results for each surveyed reef is presented in Appendix 1.2. In general the results are consistent with a gradual decline in COTS outbreaks on the GBR following the wave of outbreaks between 1979-91.

Table 2.1. Summary of COTS activities for each sector in 1992-93

Sector	No. Reefs	No. COTS	No. COTS / Tow	% reefs with COTS	Mean coral Cover ±SEM	% AO reefs	% RE reefs	% NO reefs
CG	7	5	0.02	28	44.4±3.94	0	14.3	85.7
PCB	6	19	0.07	50	26.6±5.47	16.7	33.3	50.0
CL	16	9	0.03	25	23.4±2.52	0	37.5	62.5
CA	16	8	0.01	40	19.3±2.53	0	18.8	81.3
IN	2	2	0.02	50	12.4±2.15	0	50.0	50.0
TO	6	4	0.01	33	14.8±3.81	0	83.3	16.7
CU	7	3	0.01	28	15.3±2.46	0	57.1	42.9
WH	9	13	0.03	22	32.9±4.70	0	22.2	77.8
PO	2	0	0.00	0	52.1±2.18	0	50.0	50.0
SW	10	210	0.71	50	32.8±4.49	20	40.0	40.0
CB	4	0	0.00	0	21.1±2.13	0	0	100.0

Long-term trends 1985-1993

Although it is not possible to derive meaningful or reliable trends for the whole GBR, Figure 2.1 shows a synopsis of COTS status for each sector over the whole GBR. Detailed trends for each sector over the last decade are shown in Figures 2.2-2.12. It can be seen from Figure 2.1 that large numbers of outbreaks have only been observed in the central region of the GBR (Townsville, Cape Upstart and Whitsunday sectors) during the period of monitoring, and that there were successive 3 year lags in peak densities between Townsville and the 2 sectors to the south. For sectors between Cooktown and Innisfail, the majority of reefs have been recovering from COTS outbreaks which occurred prior to the initiation of the monitoring program. COTS activities in other sectors have generally been low throughout the monitoring period, although there have been persistent low level outbreaks in the Swain sector. More detailed results for each sector are presented below.

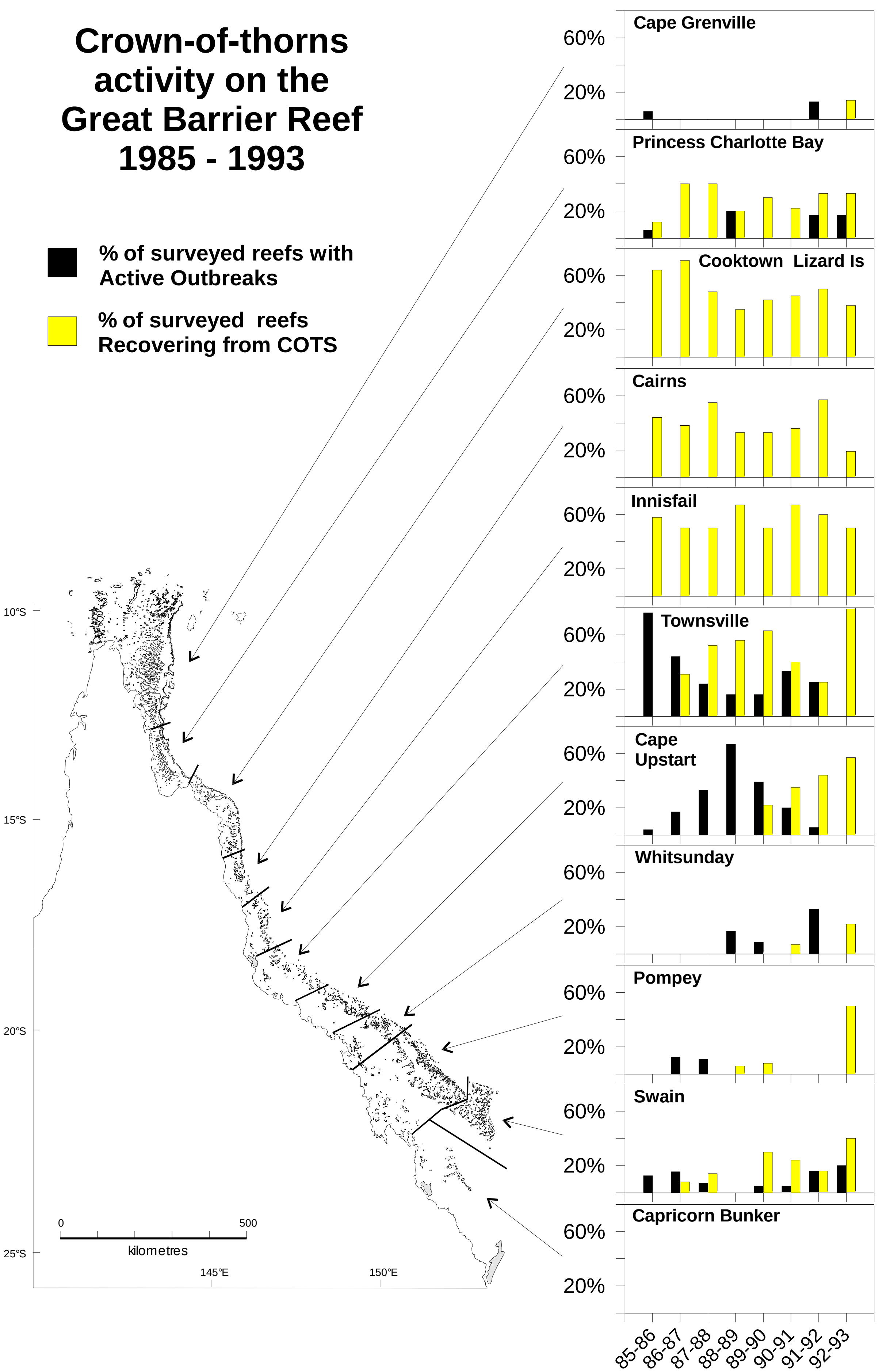


Figure 2.1. Summary results for COTS activity on the GBR between 1985-86 and 1992-93.

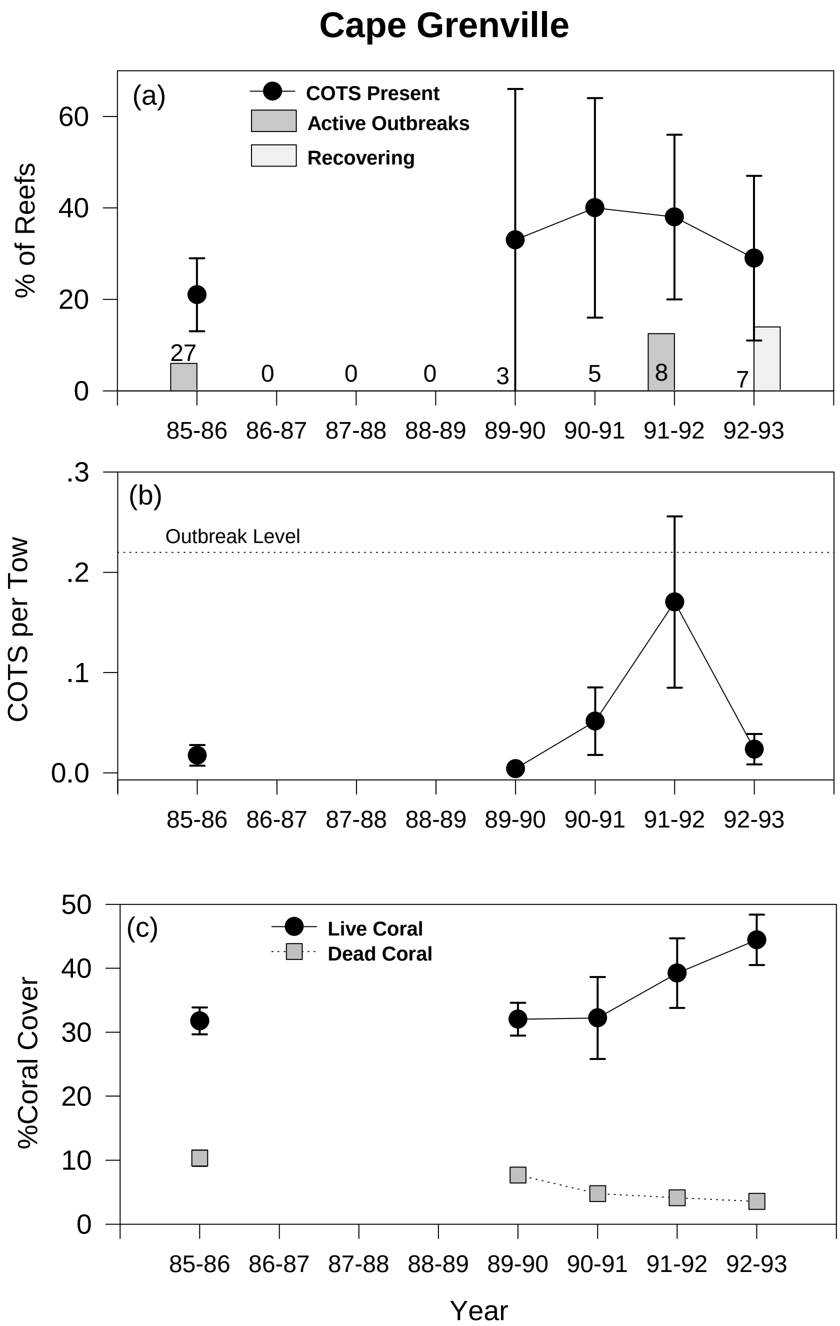


Figure 2.2. Broadscale survey results for the Cape Grenville sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Cape Grenville sector

The results for this sector are difficult to interpret due to small sample sizes and the lack of surveys during some years. Although COTS were recorded on some reefs during all surveys, only one reef (surveyed in 1991-92) had an active outbreak. Averaged over the entire sector, COTS densities were low for all years except 1991-92. Coral cover was moderately high (30-50%) and dead coral cover was low (<10%) for all surveys.

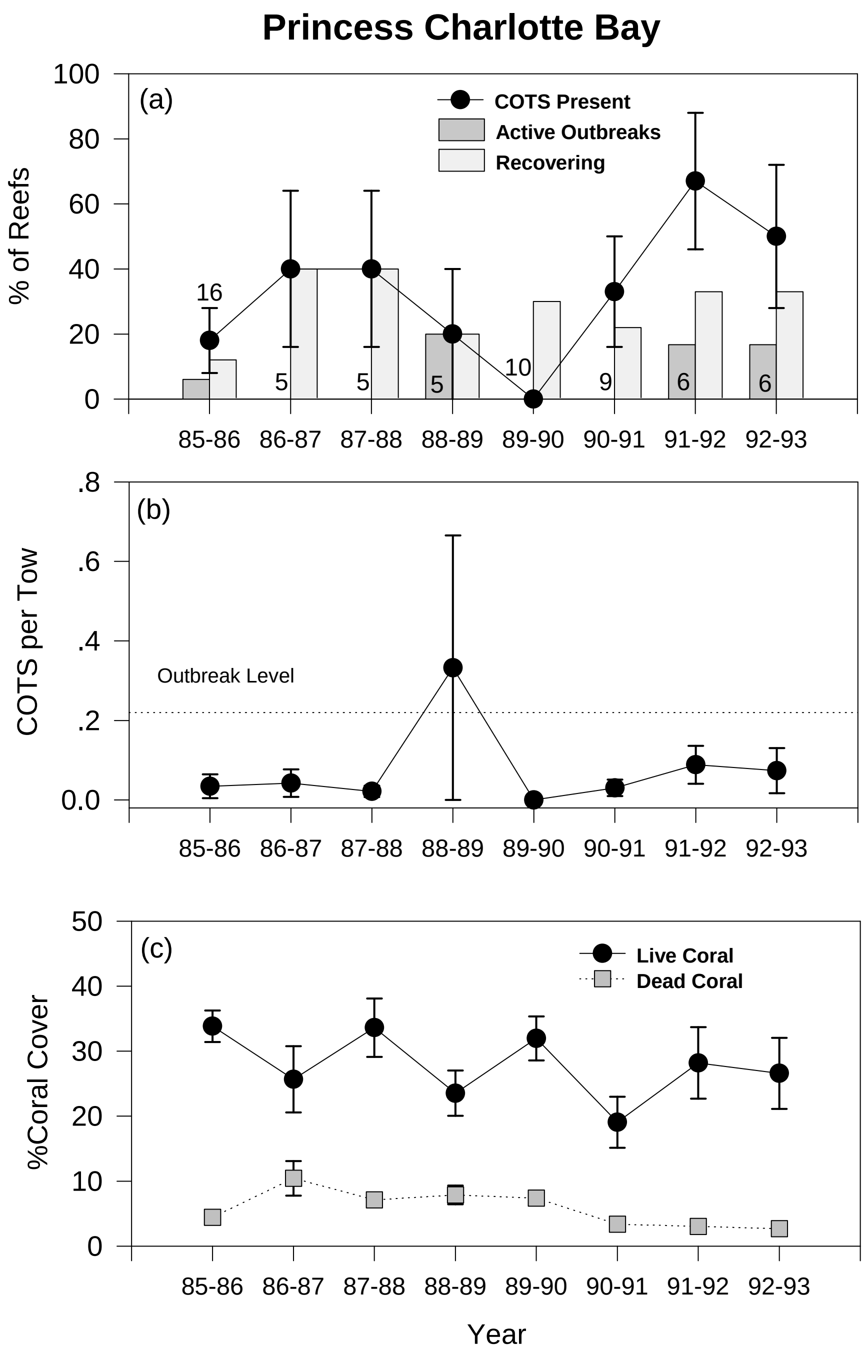


Figure 2.3. Broadscale survey results for the Princess Charlotte Bay sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Princess Charlotte Bay sector

COTS have been recorded on moderate numbers of reefs (~20-60%) in most survey years, and single outbreaks have been detected on three separate occasions. COTS densities have been low for all years except 1988-89. Live coral cover has been consistently fairly high (~20-35%), while dead coral cover has remained less than 10%.

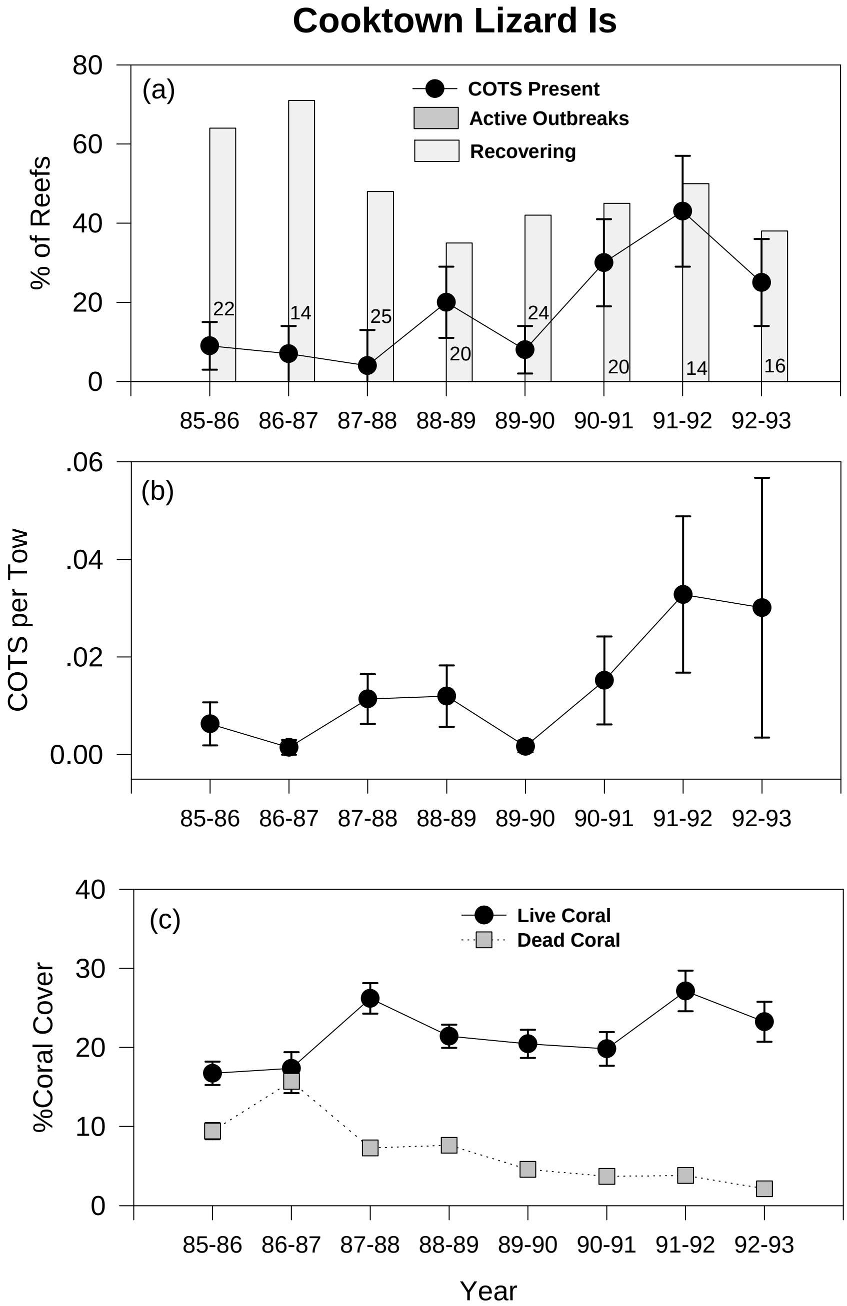


Figure 2.4. Broadscale survey results for the Cooktown - Lizard sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Cooktown/Lizard Island sector

During the initial years of the program, the reefs in this sector were characterised by very low numbers of starfish on just a few reefs. No outbreaks have been observed, although some reefs are known to have experienced outbreaks prior to the commencement of monitoring. The majority of reefs were classified as Recovering in every year. In the past 3 years, there has been an increase in starfish densities on a slightly higher proportion of reefs, however current densities are still very low compared to sectors experiencing or recovering from recent outbreaks (e.g. Townsville).

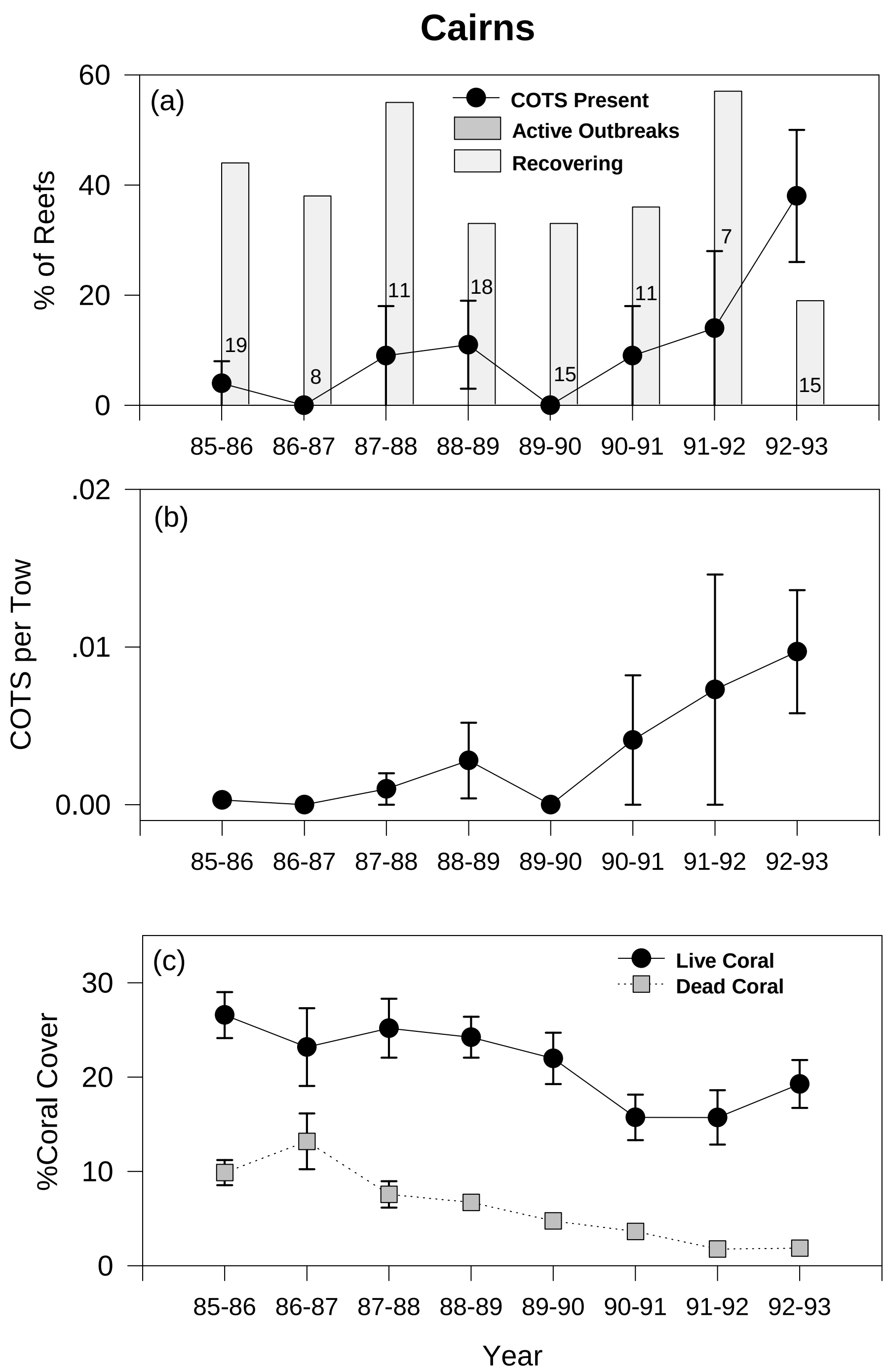


Figure 2.5. Broadscale survey results for the Cairns sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Cairns sector

Although there were several outbreaks in the years preceding the initiation of the COTS monitoring program, very few COTS have been observed in this sector and no outbreaks have been detected. However, in the most recent 2-3 surveys there has been a slight increase in the overall density of COTS. Current COTS densities (~0.01 COTS/tow) are well below minimum outbreak levels of 0.22 COTS/tow. Live coral in this sector has decreased slightly but not consistently over the last seven years, while dead standing coral has shown a more consistent decrease from a maximum of 13% in 1986-87 to ~2% in the latest survey.

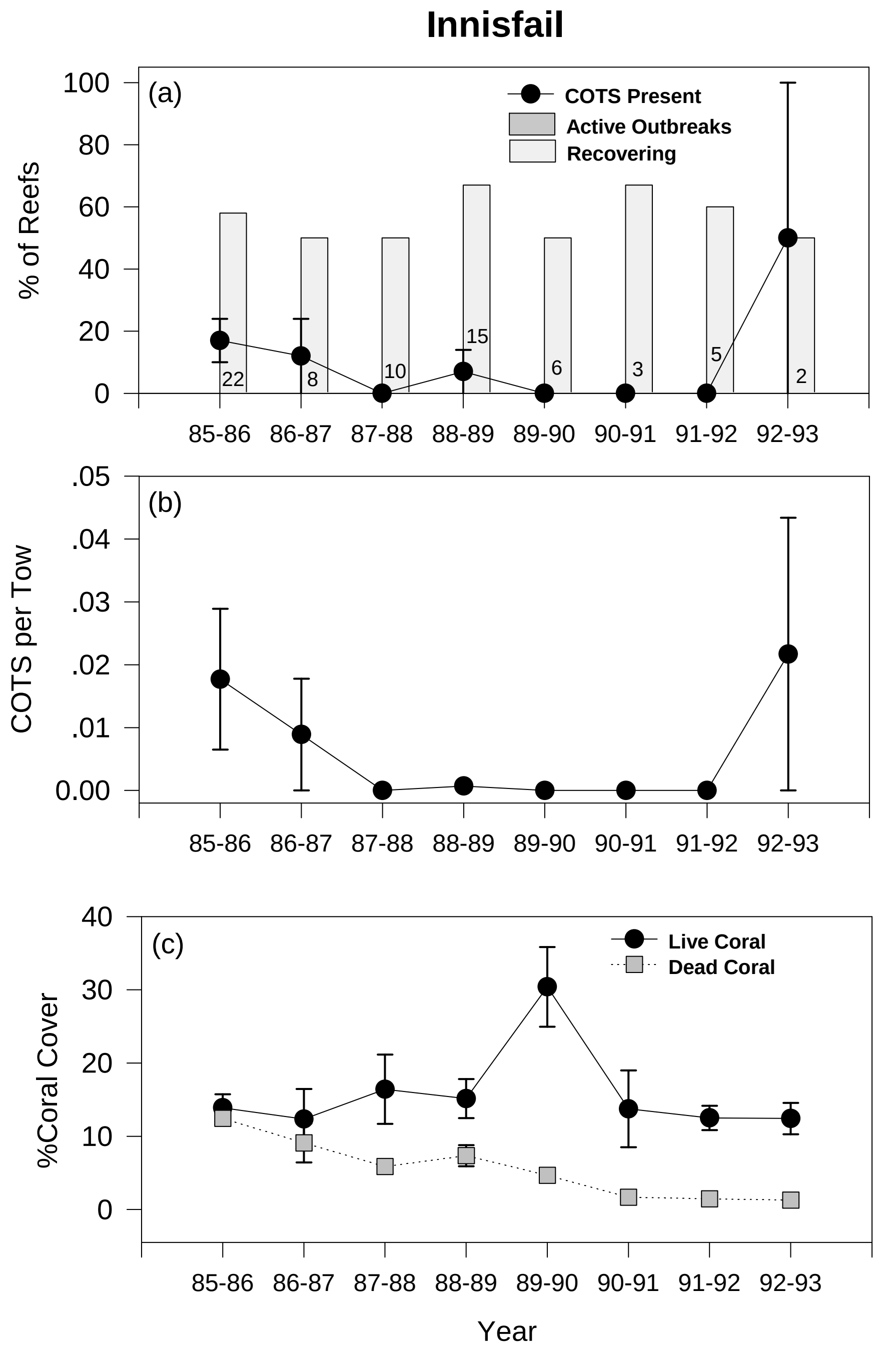


Figure 2.6. Broadscale survey results for the Innisfail sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Innisfail sector

Very few COTS have been recorded in this sector since the beginning of broadscale surveys and no active outbreaks have been recorded. Somewhat over half of the reefs have been classified as Recovering, indicating substantial prior COTS activity. Densities of COTS showed a small decrease in the first 3 years but are still very low compared to outbreak levels. Although an increase is evident in 1992-93 the small sample size for this year (2 reefs) makes it impossible to determine if this is a real trend. Live coral cover has stayed at moderately low levels (15%) during most years while dead coral cover has exhibited a steady decline from 12% to 1% over the monitoring period.

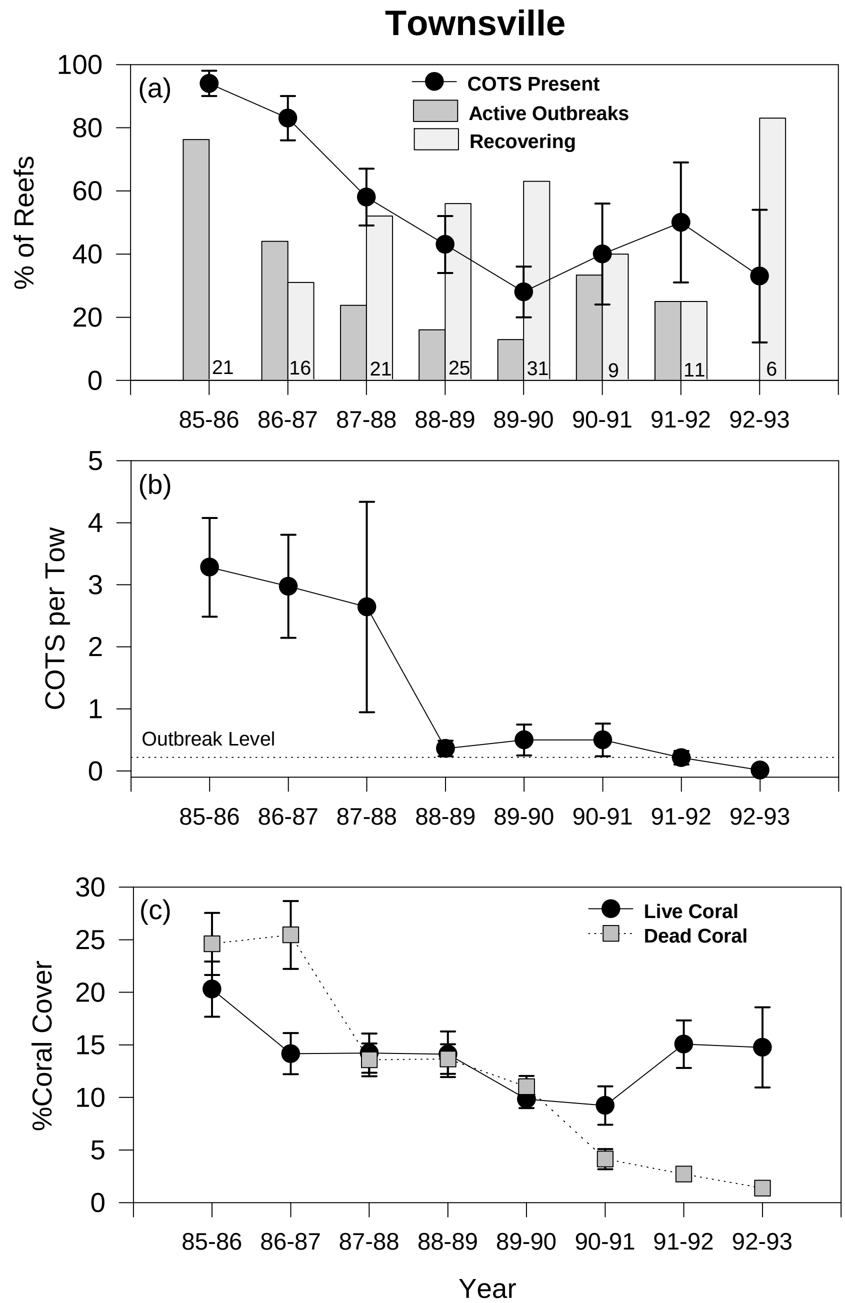


Figure 2.7. Broadscale survey results for the Townsville sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Townsville sector

Relatively high numbers of COTS were observed on most reefs in this sector at the beginning of the survey and nearly 80% of the surveyed reefs had COTS outbreaks in the first year. COTS densities, frequency of occurrence on reefs and percentage of reefs with active outbreaks all show a general decline in subsequent surveys, while recovering reefs have increased proportionally. 1992-93 was the first year where no active outbreaks were recorded on any reefs, although COTS were still present on 30% of the reefs. Live coral cover declined during most of the survey period, although there is some evidence for a recovery in live coral cover in the last 2 surveys. Dead coral cover was high for the first 2 years and then declined quite dramatically from a high of ~25% in 1986-87 to the current level of 1%.

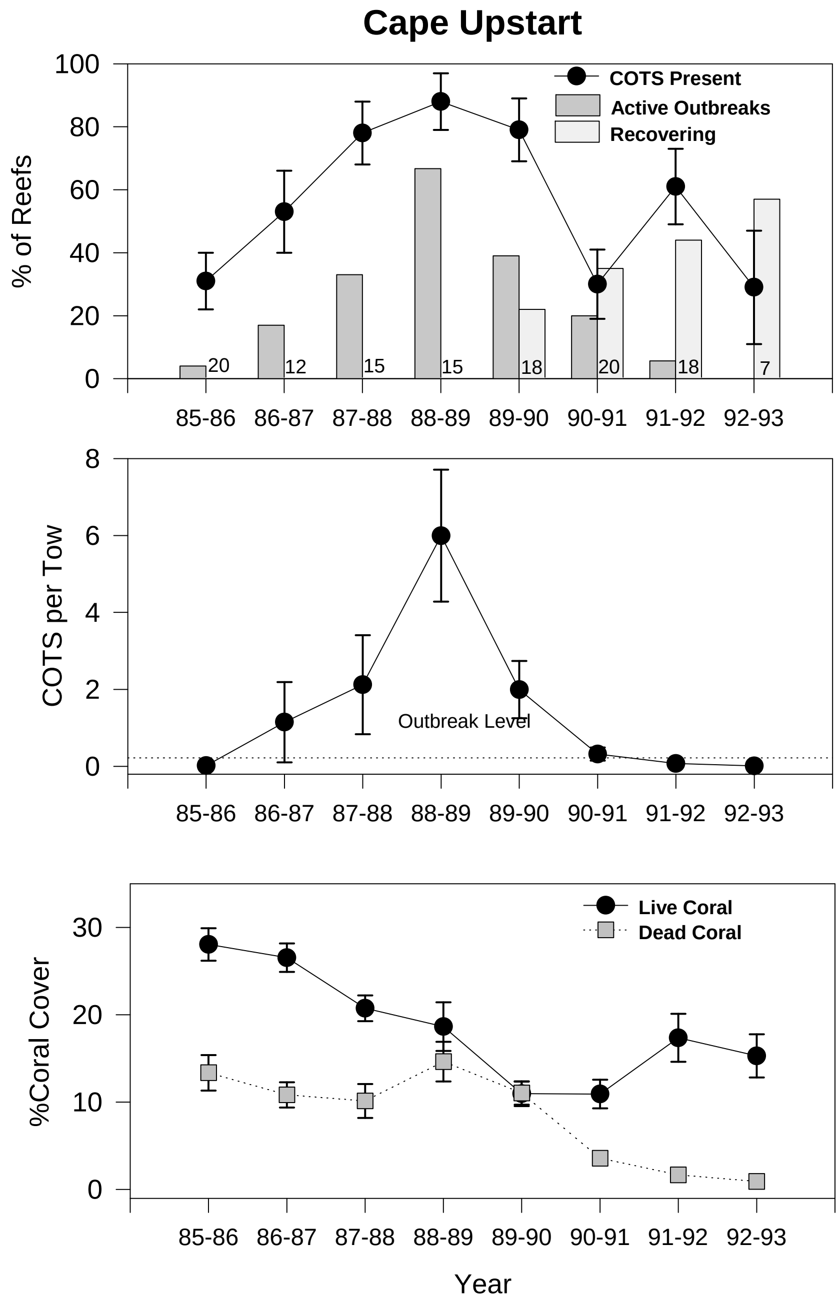


Figure 2.8. Broadscale survey results for the Cape Upstart sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Cape Upstart sector

The data for this sector indicate that there was a significant build up of COTS densities and outbreaks starting in 1985-86 and reaching a peak in 1988-89. The percentage of reefs with COTS and active outbreaks, and the density of COTS have all declined since this peak, while the percentage of recovering reefs has increased. Live coral cover showed a coincident decline during the period of increasing COTS densities, and there is some evidence for recovery in the last 2 surveys. Dead coral cover has also declined in the last 3 surveys, indicating a drop in COTS induced coral mortality.

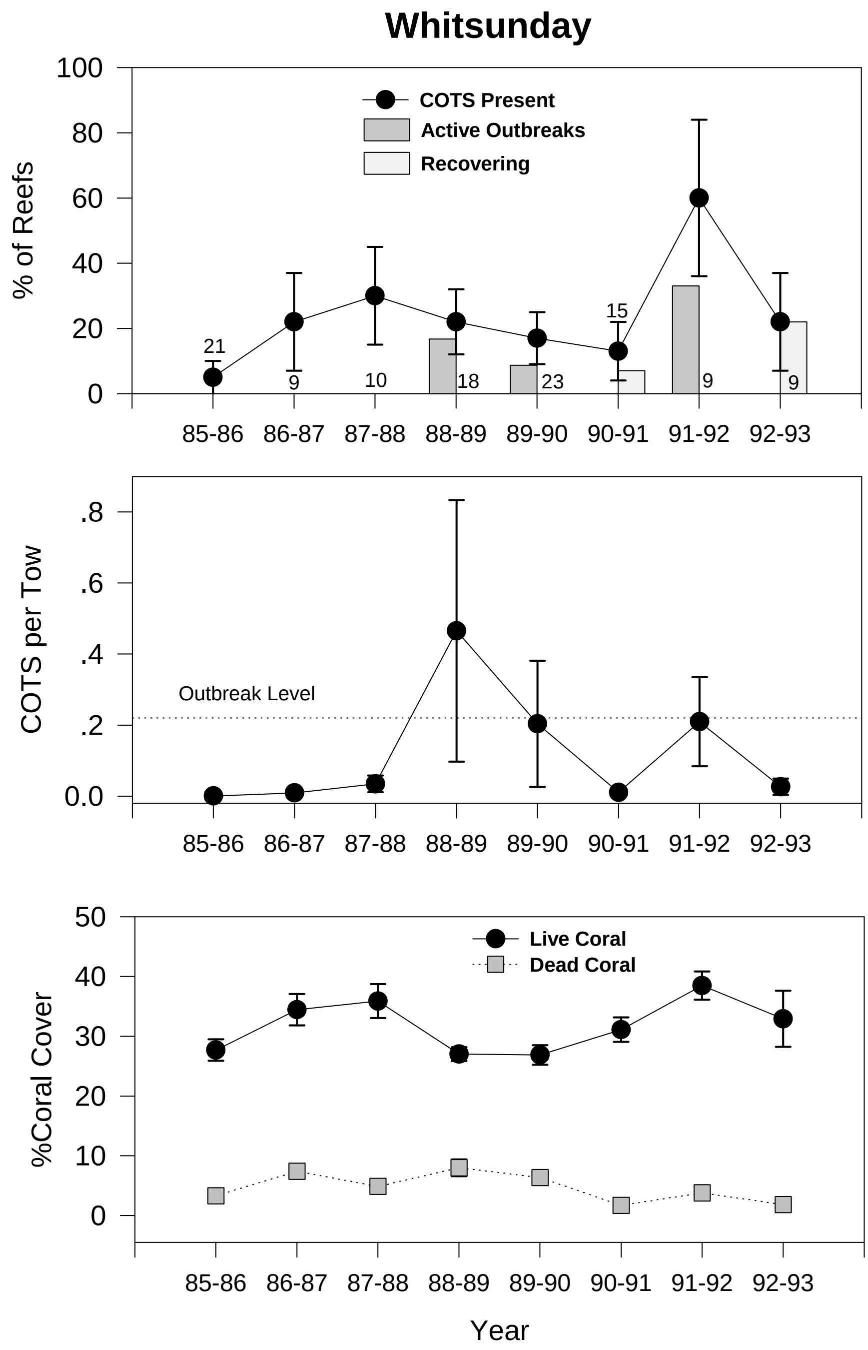


Figure 2.9. Broadscale survey results for the Whitsunday sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Whitsunday sector

COTS activities in this sector were initially low, and showed a slight increase beginning in 1988-89 which continued until 1991-92. In the most recent survey no outbreaks were detected, although COTS were recorded on ~20% of the reefs and a similar percentage of reefs were categorised as Recovering. Live coral has remained consistently high (25-40%) and dead coral cover has stayed low (1-10%) during the entire period, indicating only minor COTS-related impacts.

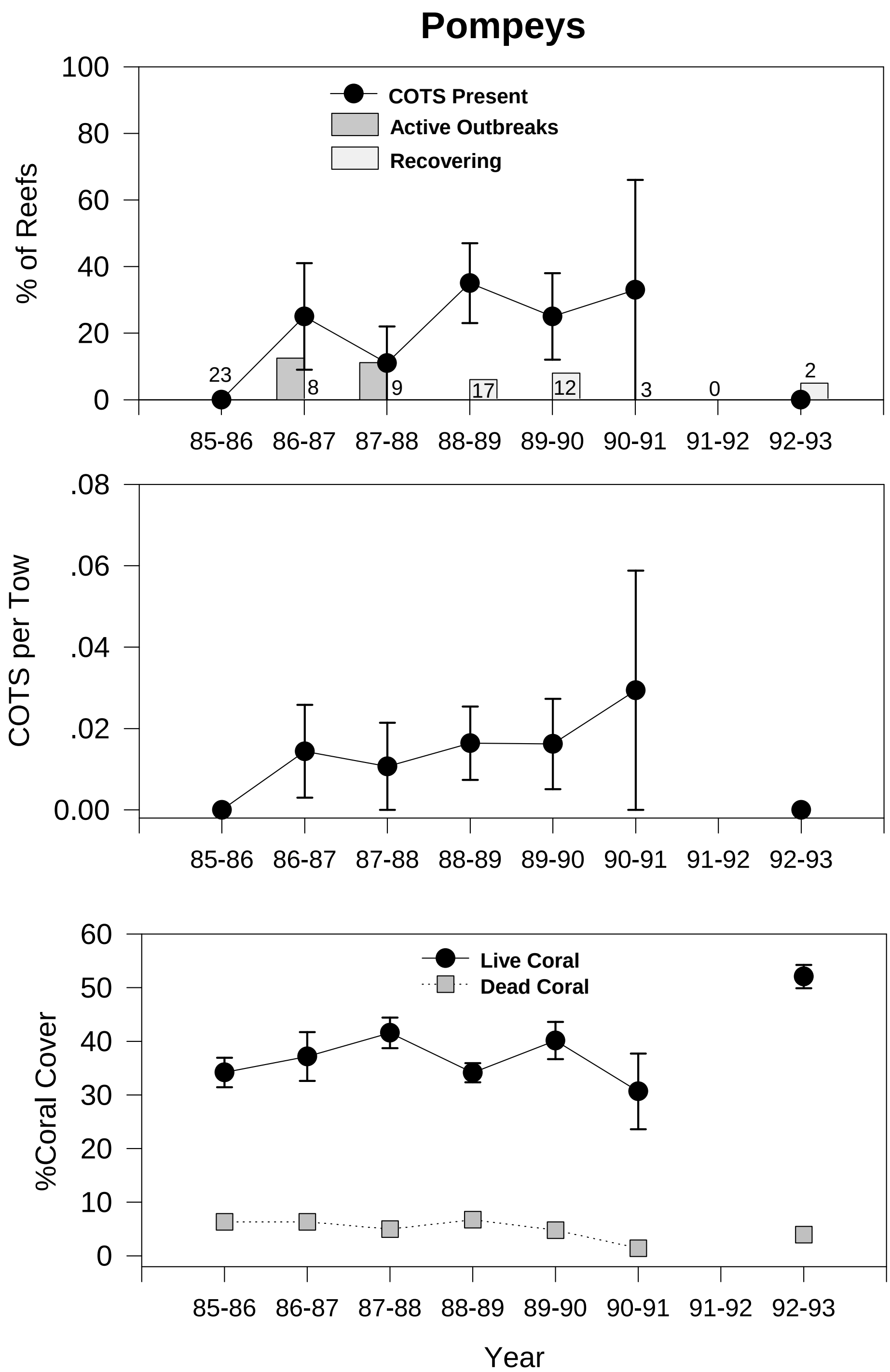


Figure 2.10. Broadscale survey results for the Pompey sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Pompey sector

Although COTS have been observed on a small proportion of reefs during most survey years, Active Outbreaks were observed only on a single reef during two surveys in 1986-87 and 1987-88. Recent trends are difficult to assess due to a low sampling effort, but there are no indications of any COTS activity at present. Coral cover has remained high (~30-50%) and dead coral cover low (<10%) during the entire survey period.

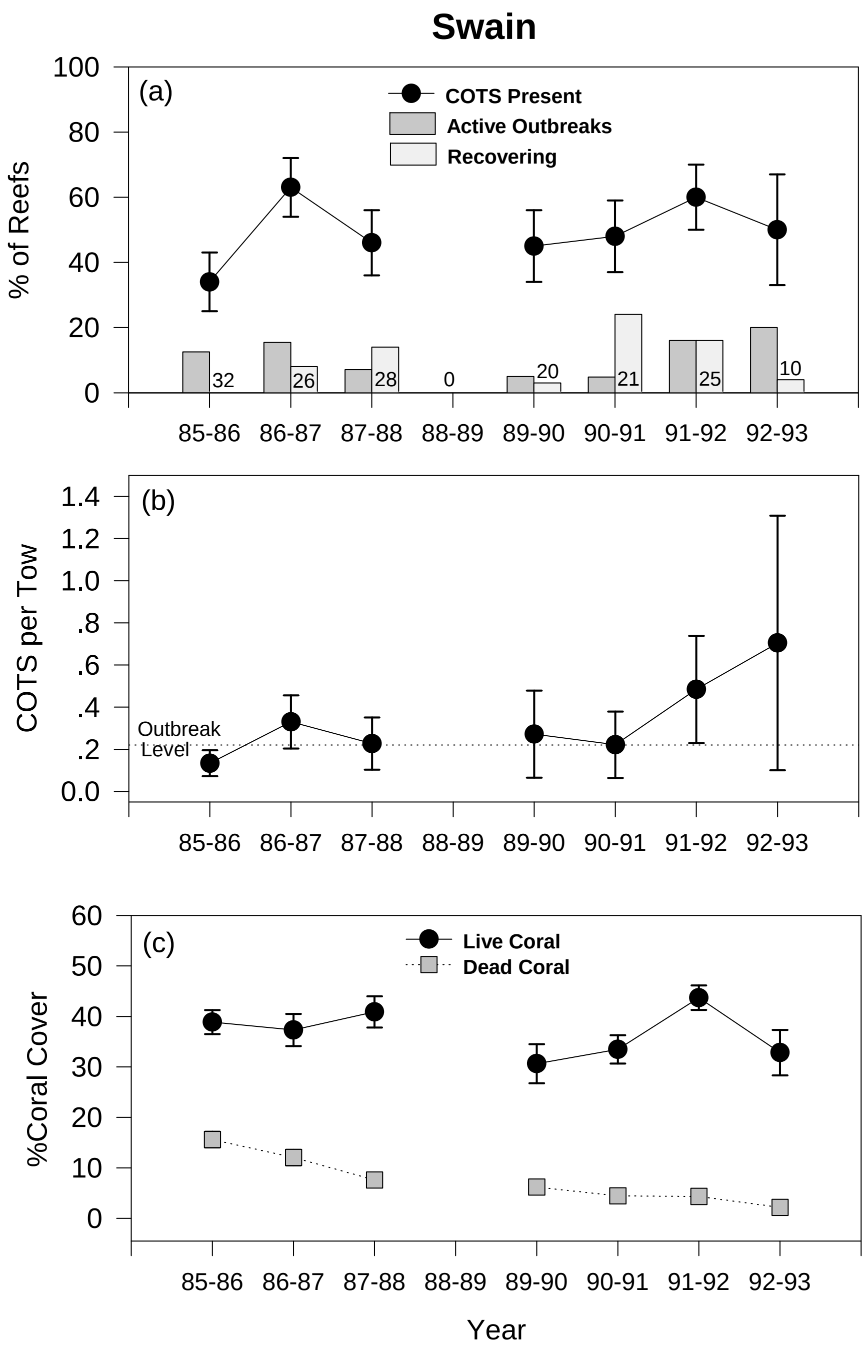


Figure 2.11. Broadscale survey results for the Swain sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Swain sector

There has been consistently minor COTS activity in this sector throughout the survey period. The Swain sector is the only one in which Active Outbreaks have been recorded during every survey. Although a relatively high proportion of reefs had COTS (~20-60%), only a small proportion were classified as Active Outbreaks (≤20%). Overall COTS densities have been close to typical outbreak levels (0.2) and have never reached the densities observed in the Townsville or Cape Upstart sectors. Live coral cover has been consistently high (30-45%) while dead coral cover has exhibited a slight decline from about 16% to 3% in the most recent survey.

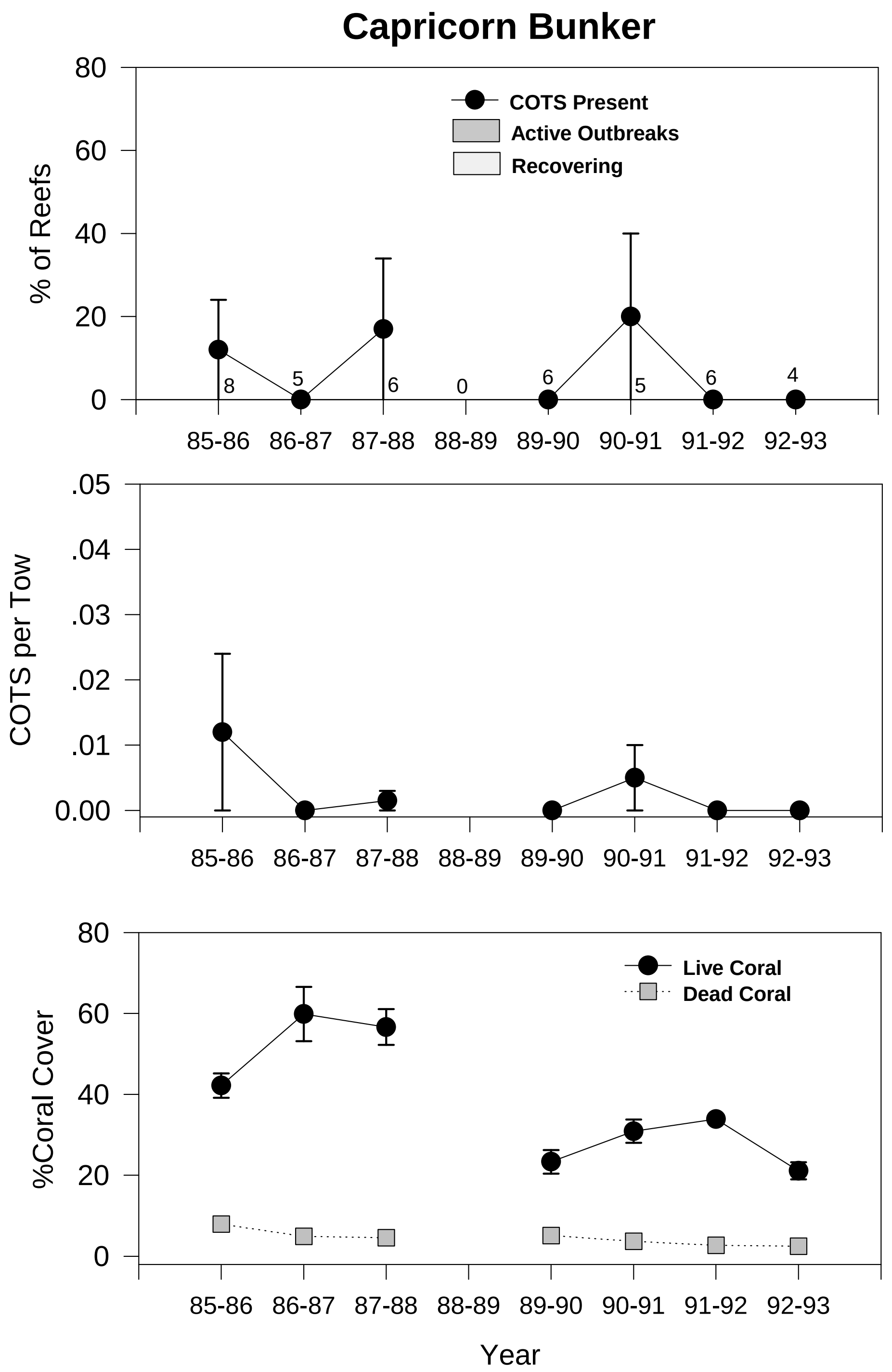


Figure 2.12. Broadscale survey results for the Capricorn Bunker sector showing: **a)** % of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates typical minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors in all cases.

Capricorn Bunker sector

No COTS outbreaks have been recorded in the Capricorn Bunker sector during the survey period, and COTS have only occasionally been recorded on a single reef during any one survey year. COTS densities have remained well below typical outbreak levels. Live coral cover was very high during the first three years (~40-60%), but showed a substantial drop between 1987-88 and 1989-90. No change was seen in dead standing cover, which remained below 10% at all times. The reasons for the decrease in live coral cover are not known, but do not appear to be related to COTS activity.

Discussion

The results for 1992-93 indicate that COTS activities on the GBR have continued to decline, and that the wave of southward propagating outbreaks described in Moran *et al.* (1992) petered out in the Whitsunday region. For the first time since surveys began in 1985, no outbreaks are currently active between Townsville and the Whitsunday sectors. Only small outbreaks now exist in the far north and far south of the GBR, where occasional isolated outbreaks appear to be a persistent feature.

Gannet Cay Reef in the Swain sector, is the only reef on which large numbers of COTS appear to have had a major impact. This reef has had large numbers of COTS since 1989-90, but it is only in the last 2 surveys that there has been an overall decline in live coral cover for the reef (Figure 2.13). Dead coral cover has not increased appreciably for the entire reef, but is now quite high (31-50%) in areas where COTS are concentrated (Bainbridge *et al.* 1994). As suggested by Moran *et al.* (1992), it would appear that the outbreak at Gannet Cay and other Swain reefs is unrelated to the main wave of southward progressing outbreaks observed over the last decade (see also Figure 2.1). A small proportion of reefs in this sector have been experiencing outbreaks since the beginning of the monitoring program.

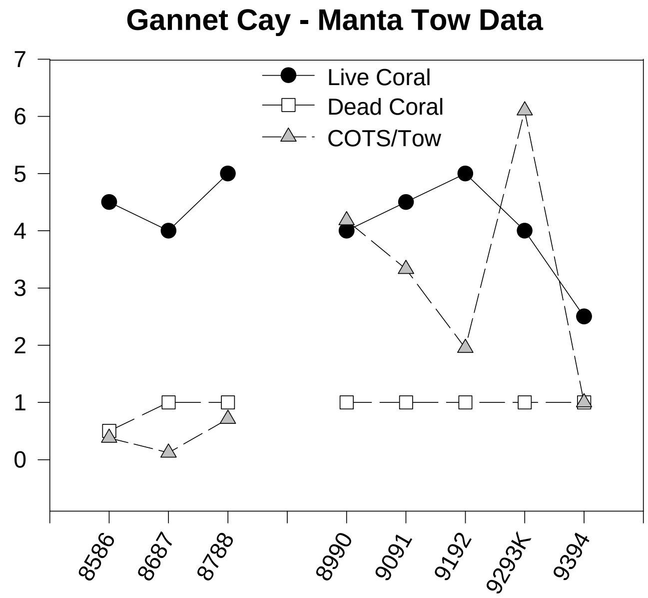


Figure 2.13. Trends in COTS density and coral cover at Gannet Cay.

A conspicuous feature of the results for the Capricorn Bunker sector is the drop in coral cover between 1987-88 and 1989-90. Unfortunately, there were no surveys during 1988-89, so it is not certain exactly when the change occurred. However, the lack of any COTS sightings by the survey team, or by other reef users, and the lack of large amounts of dead standing coral indicate the COTS were probably not the responsible agent. The lack of increase in dead standing coral suggests that the corals may have been physically destroyed rather than experiencing tissue mortality caused by other corallivores (*Drupella*), disease or physiological stress due to environmental perturbations (e.g. extremes of light, temperature, exposure).

The other common agent of large-scale destruction (which also causes physical destruction of coral colonies) is cyclones. But an inspection of the Bureau of Meteorology records indicated that no cyclones were recorded in the vicinity of any of the Capricorn Bunker reefs between 1986 and 1991. At this stage the cause of the drop in coral cover in the Capricorn Bunkers remains uncertain. Further monitoring will, however, indicate if recovery occurs, or whether there is evidence for chronic disturbance which prevents a re-establishment of previous levels of coral cover.

The results for the Cairns and Cooktown/Lizard Island sectors indicate a small increase in COTS densities and percentage of reefs with COTS present over the last 3 years. While absolute numbers of COTS are still very low, and no active outbreaks have been recorded, it is noteworthy that GBRMPA received a report of 17 COTS in a area of high tourist use (Michaelmas Reef) and that moderate numbers of crown-of-thorns (13 individuals) were subsequently sighted at during a swim search by AIMS researchers of the same area. More intensive searches in this area resulted in the collection of 102 starfish. These results suggest that Michaelmas Reef, in particular, and reefs in the 2 northern sectors, may be experiencing an increase in COTS numbers. As the reefs in these sectors (~16°S) have been identified as a possible source for primary outbreaks of COTS (Moran *et al.* 1992), it is possible that the present results are the first indicators of a new wave of COTS outbreaks. Surveys in subsequent years will clearly be important in substantiating these initial results.

3. Water Quality

M. Devlin, M. Lourey, J. Oliver & G. De'ath

Introduction

Reef biota are sensitive to the biophysical, chemical and biological composition of the waters in which they occur. Thus any attempt to identify possible causal factors behind long-term changes in reef communities must include an investigation of possible corresponding changes in water quality. As a results, water quality monitoring is a critical component of the AIMS Long-term Monitoring Program

The aims and objectives of the overall monitoring program and each of its components are described in Chapter 1. One of the major methodological issues associated with water quality sampling is resolving temporal and spatial variability. Because currents and tides are constantly moving water around in complex patterns, and because the sources of nutrients (e.g. river runoff and upwelling) are non-uniformly distributed in space and time, most of the water quality variables measured in this program are known (or are likely) to be highly variable in space and time. Data from the first two years of the sampling program are therefore being used to determine the appropriate scale and frequency of sampling which should be used in future years to provide reliable and relevant information to the program. Preliminary analysis of the sampling design based on the first year's data has been carried out and is presented in a separate document. In this chapter we present the results of water quality sampling during the first year of the program, involving 94 stations within 11 sectors along the Great Barrier Reef. Although this project represents one of the first attempts to investigate water quality parameters over the entire GBR (see also Furnas, 1991), the limited nature of the data from this first year prevents any comprehensive regional or temporal comparisons from being made. In particular, it is not valid, at this time, to compare the results from one sector with those of most other sectors because, in almost all cases, the data were collected at different times of the year, and previous work has shown that there can be strong seasonal fluctuations in most water quality variables (e.g. Revelante & Gilmartin 1982). Instead we present the data in a largely unaggregated format in order to illustrate the range of variability observed in different sectors at different times. For two subsets of the data, however, the sampling configuration allowed a preliminary examination cross-shelf, latitudinal and seasonal variation to be conducted.

Methods

Field sampling procedures

Sampling was conducted from the AIMS research vessels, 'R.V. Sirius' and 'R.V. The Harry Messel' during the 1992/1993 financial year. Each voyage was centred on a particular latitudinal based sector of the Great Barrier Reef and lasted between twelve and eighteen days (Table 3.1).

Table 3.1. Sampling dates of cruises conducted between July 1992 and June 1993.

Cruise #	Initial date	Final date	Sectors included.
1	10/08/92	17/08/92	Townsville
2	30/9/92	10/10/92	Swain
3	18/10/92	31/10/92	Capricorn Bunker / Pompey
4	23/11/92	28/11/92	Townsville to far north
5	8/12/92	19/12/92	Cape Grenville / Princess Charlotte Bay / Cooktown Lizard Is
6	2/2/93	13/2/93	Whitsunday
7	20/3/93	29/3/93	Townsville to far north
8	28/4/93	17/5/93	Cairns / far northern
9	11/6/93	25/6/93	Cairns

During the first year, samples and data were collected from 94 stations in the Great Barrier Reef between 11 and 23°S. Of these, 44 stations were located near reefs on which sessile benthos, crown-of-thorns starfish and fishes were being monitored. Another 34 of the stations were located within open waters of the Great Barrier Reef lagoon and were sampled in conjunction with the AIMS Bio-Oceanography projects. Finally, 16 stations were sampled at varying distances from river mouths as part of a study on nutrients in sediments. Summary data on all sites is presented in Appendix 3.1. It can be seen from the distribution of sampling stations among sectors and cross-shelf positions and cruises (Table 3.2), that it was usually not possible to sample in more than one sector during a single cruise, or from the same sector on several occasions. However during cruises 4 and 7, both the Cairns and Innisfail sectors were sampled on inner-shelf and mid-shelf reefs, allowing a restricted analysis of temporal (4 month) and latitudinal (100-200 km) variation. Similarly during cruises 1 and 9, the replicate stations were sampled for inner, mid, and outer-shelf positions in the Townsville and Cairns regions respectively. This allowed an analysis of cross-shelf variation.

Table 3.2. Distribution of sampling effort among cruises and sectors

		Trip number								
Sector	Shelf Position	1 Aug 92	2 Oct 93	3 June 93	4 Nov 92	5 Dec 92	6 Feb 92	7 Mar 93	8 May 93	9 June 93
Cape Grenville	Inner					7		2		
	Mid					1		2		
	Outer					2				
Princess Charlotte Bay	Inner					1				
	Mid					1				
	Outer					1				
Cooktown/ Lizard	Inner					3				
	Mid					2			4	
	Outer					1			3	
Cairns	Inner				4	1		4	1	8
	Mid				2			2		5
	Outer									3
Innisfail	Inner				4			4		
	Mid				2			2		1
	Outer									
Townsville	Inner	4								
	Mid	3								
	Outer	3								
Whitsunday	Inner			3			3			
	Mid						5			
	Outer									
Pompey	Inner			2						
	Mid			1			1			
	Outer									
Swain	Inner									
	Mid		7							
	Outer									
Capricorn Bunker	Inner									
	Mid									
	Outer			4						

Sampling design

Water sampling near reefs was conducted on two occasions at two stations near each survey reef. Both stations were sampled approximately two hours apart and re-sampled between one to three days later. At every station two replicate casts were made and duplicate samples taken from both the top and bottom of the water column (Figure 3.1). A total of 32 samples were collected at each reef during each cruise. Sediment and bio-oceanography stations generally involved just one site and one time (8 samples per visit). Appendix 3 lists the name and location of all stations.

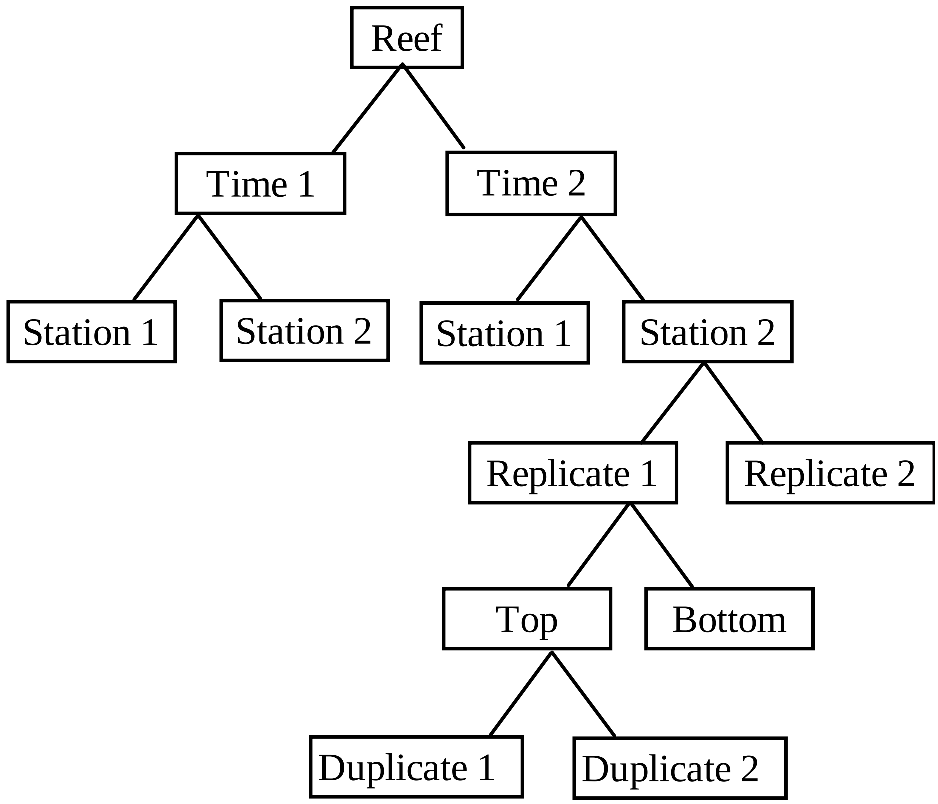


Figure 3.1 Graphical representation of sampling design. for reef-based sampling. Sampling at bio-oceanography and sediment stations had only one site and one time.

At each site, descriptive details were recorded as follows: cloud cover, wind speed, wind direction, tide and water depth. Water transparency was measured by secchi disk and presence of surface *Trichodesmium* noted.

Water samples were collected with 8 litre Niskin bottles from two depths, one at three metres below the surface and the other three metres above the sea bed. *In situ* temperatures were recorded by digital reversing thermometers attached to the Niskin bottles.

On the ship, processing of samples was carried out using a workstation which included a vacuum pump, vacuum reservoir, and filtration manifold. Subsamples were dispensed from the Niskin bottles into appropriate containers. Filtration of water samples for chlorophyll analyses and suspended solids was carried out on the filtration manifold, and nutrient and silicate samples were filtered with a 50 ml plastic syringe and Sartorius Minisart-N™ filter holder. Discrete subsamples were retained for salinity measurements. Table 3.3 summarises the water quality parameters measured in this monitoring program.

Table 3.3. Acronyms and symbols for measured variables used in this report.

Code	Variable	Units
TEM	Temperature	°C
SAL	Salinity	‰, ppt
SDEP	Secchi depth	m, meters
SS	Suspended solids	mg/litre
NH_4	Ammonium	µM, µmol/litre
NO_2	Nitrite	µM, µmol/litre
NO_3	Nitrate	µM, µmol/litre
DIN	Dissolved Inorganic Nitrogen = NH_4+NO_2+NO_3	µM, µmol/litre
DON	Dissolved Organic Nitrogen = TDN-DIN	µM, µmol/litre
TDN	Total Dissolved Nitrogen	µM, µmol/litre
DIP	Dissolved Inorganic Phosphorus = PO_4	µM, µmol/litre
DOP	Dissolved Organic Phosphorus = TDP-DIP	µM, µmol/litre
TDP	Total Dissolved Phosphorus	µM, µmol/litre
Si	Silicate, silicic acid $Si(OH)_4$	µM, µmol/litre
Chl	Chlorophyll	µg/litre
Pha	Phaeophytin	µg/litre

Nutrient Subsamples

Collection

Seawater sub-samples were taken in duplicate (2 x 10 ml) for total measurements of dissolved nutrients, dissolved inorganic nutrients and dissolved silicate. Samples for dissolved nutrient analysis were dispensed from the Niskin bottles into a rinsed 50 ml plastic syringe. Approximately 10 ml of seawater was flushed through a connected 0.45 µm filter device (Sartorius Minisart-N™), before the filtered subsample was dispensed into acid washed, pre rinsed 10 ml plastic test tubes. Samples for analysis of dissolved phosphorous and nitrogen species were immediately placed in a clean freezer and stored frozen until analysis. It has been previously demonstrated (Ryle and Mueller 1981) that short term storage in this manner has a relatively minor effect on nutrient levels other than ammonium. Samples for silica analysis were stored at room temperature.

Analysis

Dissolved inorganic nutrient and silicate samples were analysed at AIMS. Samples for total dissolved nutrient analyses were thawed and photo-oxidized with UV light for seven hours (Strickland & Parsons 1972) The oxidised samples were then re-frozen until analysis. Analyses of total (oxidised) and un-oxidised inorganic nutrient species were determined by standard wet chemical procedures (Treguer & Le Corre 1975) implemented on a SKALAR™ 20/40 multi-channel segmented flow analyser adapted for low level nutrient determination in tropical waters (Ryle *et al*. 1981).

Quality Control

During the sample process, field blanks of nutrient-free artificial sea water were dispensed and stored in parallel with nutrient samples. To assess the potential levels of storage contamination, standard and blank nutrient samples were frozen in plastic sample vials and carried during the cruise. Cruise blanks and standards were compared to control blanks and standards stored frozen at AIMS.

Suspended solids

Collection

Duplicate sub-samples of water were dispensed from the Niskin bottles into rinsed 1 litre plastic bottles. The sub-samples were then filtered under vacuum (<$^{1}/_{3}$ atm) through preweighed 0.4 µm pore diameter, 47 mm poly-carbonate membrane filters. Filters were stored at room temperature in clean glass scintillation vialsuntil analysed.

Analysis

Filters were dried overnight in an oven at 60°C. Vial lids were loosened to allow for complete drying. The dried filter papers were weighed on a five figure Mettler™ AE 163 balance. The difference in weights between filter papers before and after filtration is used to calculate the amount of suspended solid in the sample.

Quality Control

Every fourteen filter papers, a field blank was processed. In the laboratory, the blank filters were processed identically to the samples to determine any error introduced by the balance weighing the filter papers. Filter paper blanks were periodically tested for loss/gain of weight, due to wetting agents and glues, by passing one litre of filtered seawater through them and observing weight differences.

Chlorophyll and phaeophytin

Collection

Chlorophyll sub-samples (100 ml) were collected in pre-rinsed plastic measuring cylinders. Samples were filtered under low vacuum pressure (<$^{1}/_{3}$ atm) onto 25 mm Whatman™ GF/F glass fibre filter (Parsons *et al*. 1984) Prior to filtration, two drops of 5% magnesium carbonate suspension was added to the sample to stabilise the chlorophyll during storage. The filter papers were stored frozen (-10°C) in aluminium foil pouches until analysis.

Analysis

Samples collected on the GF/F filter papers were ground with a high speed tissue grinder in 90% acetone (V/V). Ground samples were transferred to plastic centrifuge tubes and extract volume made up to 10 ml. The sample was then left for 30 minutes to allow complete extraction of the chlorophyll pigment. They are then centrifuged in a Hettich Rotanta/p clinical centrifuge for 10 minutes. After centrifugation the contents of the plastic tube were poured carefully into a rinsed 10 ml quartz fluorometer cuvette. The red flourescence emitted from the chlorophyll was measured with a Turner Designs™ fluorometer linked to a digital multimeter. Phaeophytin levels were measured by taking fluorescence readings before and after acidification of the sample in the cuvette. The digital fluorescence readings are converted to concentrations of chlorophyll *a* and phaeophytin using a BASIC computer program.

Quality Control

During analysis, unused filter papers were analysed every nine samples to correct for potential interference caused by the filter papers. The fluorometer (Turner Designs 005R) was standardised spectrophotometrically (Jeffrey & Humphrey 1975) against extracts of pigments from exponentially growing cultures of the diatom *Chaetoceros simplex.*

Salinity samples

Collection

Duplicate seawater samples were dispensed from the Niskin bottles into 500 ml plastic bottles. The plastic bottles were rinsed with the sample water prior to sub-sample collection. The mouth of the bottles were covered with paraffin film before replacing the lid to minimise loss due to evaporation. Samples were stored in a cool dark place for the duration of the survey.

Analysis

Prior to analysis, salinity samples were removed from storage under cool conditions (10^{o}C), and allowed to come to room temperature. Salinities were determined through the precise measurement of conductivity using a Hytech™ model No. 6220 salinometer. The conductivity of individual samples is expressed as a ratio to the conductivity of a sample of standard seawater (IAPSO standard) The electrical conductivity measured by the salinometer is proportional to the salinity of the sample and values are transferred to a salinity value using a BASIC program

Quality Control

Salinity samples were analysed against a sea water sub-sample calibrated with IAPSO international standards.

Data storage and analyses

The data was imported into an ASCII data file via a scanner using a computer program, Paper Keyboard™. Data contained in the ASCII file are loaded into an ORACLE™ database. Data are entered into the relevant tables using SQL*Loader™. The series of tables are linked by 'Sample ID'. Access to the data is via SQL (Structured Query Language) command statements.

Missing values and outliers are replaced by a Null value. Limits of detection were no less than 0.1µmole/litre for all nutrient values and subsequently values less than 0.01 were registered as a negative value. Negative nutrient values were replaced with a zero. Suspended solid values are calculated using a SQL program after loading into ORACLE™. Chlorophyll and Salinities are calculated using a BASIC program before loading into the ORACLE™ database.

Statistical analysis

Two data sets were analysed using analysis of variance. Firstly data from 12 stations all of which were sampled on each of 2 cruises approximately 110 days apart were analysed by univariate repeated measures analysis of variance. The reefs were from 2 sectors (Cairns and Innisfail) and from 2 cross-shelf locations (inner and mid-shelf). Factors representing these effects and those of surveys (time) were included in the model. The data were proportionally balanced since there were 4 inner and 2 mid-shelf stations in each sector.

For the two trips where complete cross-shelf transects in single sectors were done (Cairns and Townsville), data were analysed using 2-way analysis of variance with sector, cross-shelf position and their interaction included in the model. The data were unbalanced and sequential sums of square were used for all significance tests. The effects labelled sector are confounded with sampling time and are thus uninterpretable. The interaction between sector and shelf position was similarly uninterpretable. Before analysis, data for all variables excepting salinity was log transformed ($\log_{10}(x+0.01)$, and then averaged for all samples taken from each station and each cruise. Thus all samples from different sites, times, replicates, duplicates and depths were considered to be sub-samples. Preliminary analysis of these effects justified this approach.

Results

Station means for all variables and all cruises are shown in Figure 3.2. Although the data are plotted as a function of time, it is important to note that since different sectors were sampled at different times, it is unclear whether the variation along the x-axis is caused by seasonal changes or differences between sectors. For most variables, there is very little pattern in the data, which shows as much variation between stations during a cruise as between sectors or cruises. However, values for DIP, NH_4 and DIN show quite tight clustering within separate cruises and quite clear differences between means for some cruises. This clearly indicates that these variable can vary significantly between sectors and/or times. Some extreme values were also recorded. For instance very high values for chlorophyll were recorded at one inshore station in the Cape Grenville sector (Lloyd Bay). Similarly the extreme values for all inorganic nitrogen variables occurred at Apostle Bay in the inshore Whitsunday sector, while very high suspended solids occurred at the Cairns airport station.

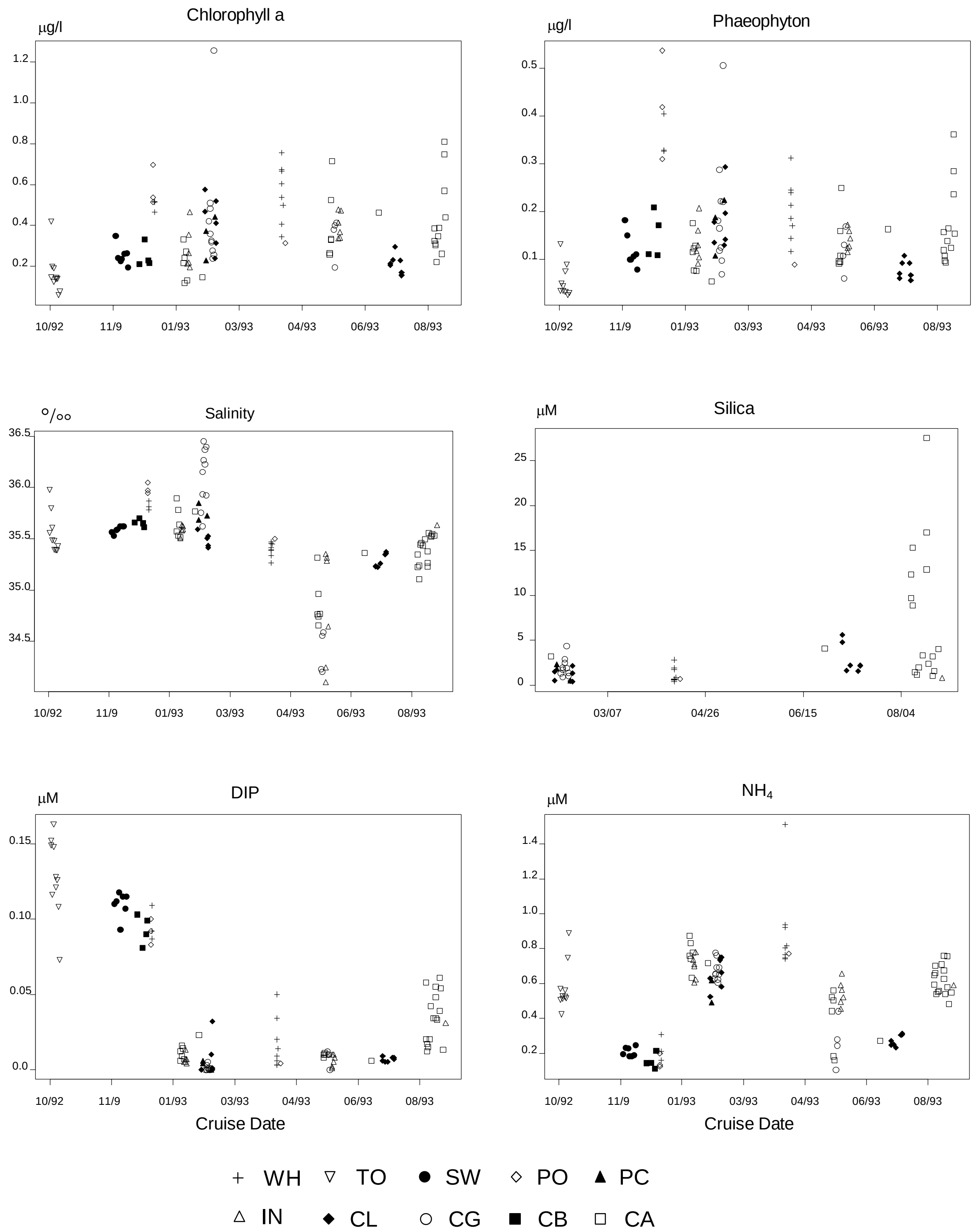


Figure 3.2. Station means for all cruises and sectors

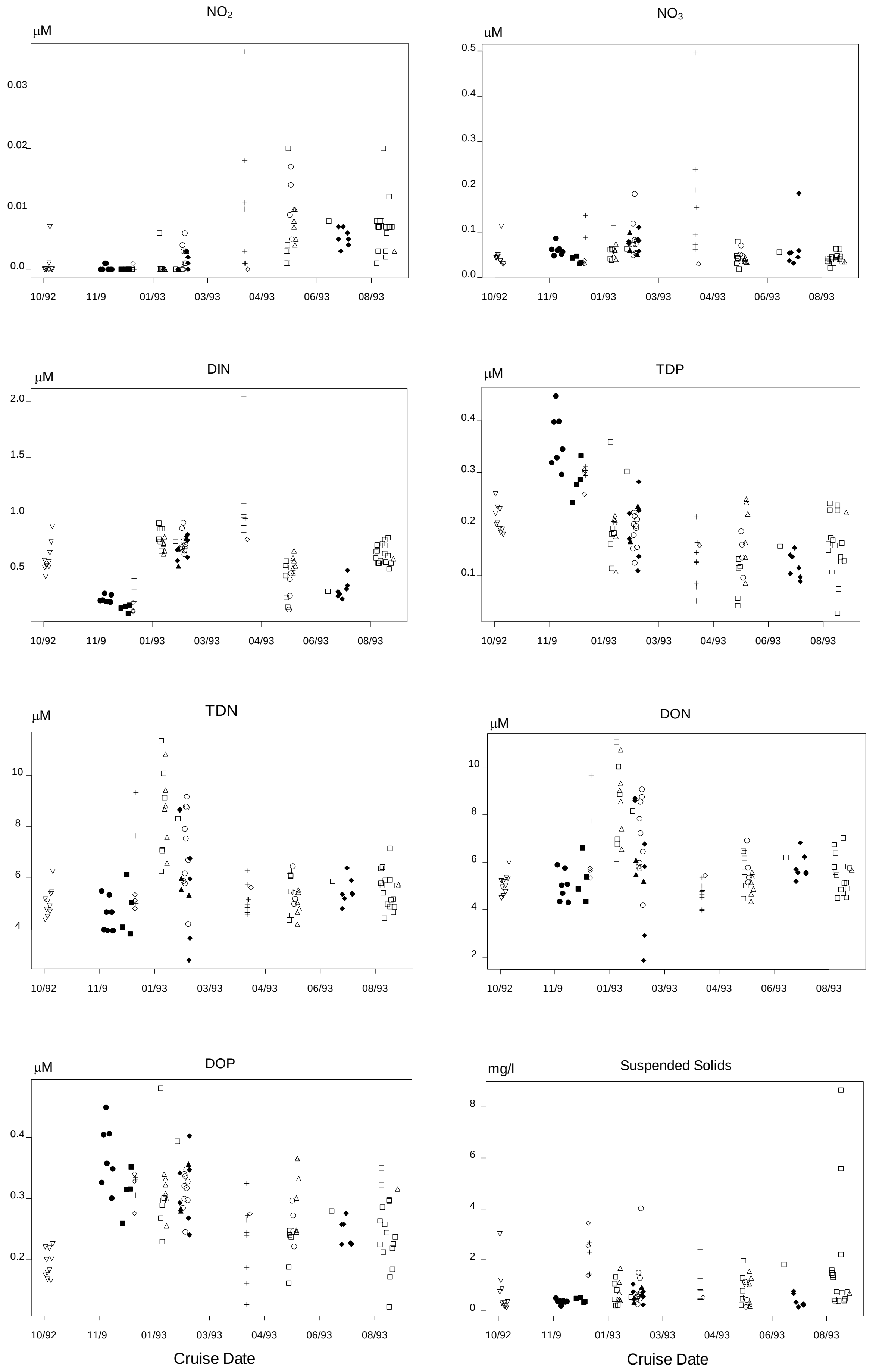


Figure 3.2 (cont'd)

Small-scale spatial and temporal variability

In the previous figure, each data point represented the mean of several samples, which were taken at two different sites, times and depths. A detailed analysis of this variation, and its implications for future sampling will be published separately. However Figures 3.3 and 3.4 illustrate the finding that for repeated sampling over a period of two days and at sites separated by less than a few kilometres, there are very few consistent differences. For instance, Figure 3.3 shows that there is little variation between different sites and times compared to the variation among samples taken at a particular site and time. More detailed examination of the samples for each site/time combination at Martin Reef (Figure 3.4), indicate that the differences between top and bottom water samples for Chlorophyll a are not consistent between replicates taken a few minutes apart, and are often less than the differences between replicates or between duplicate analyses of the same sample.

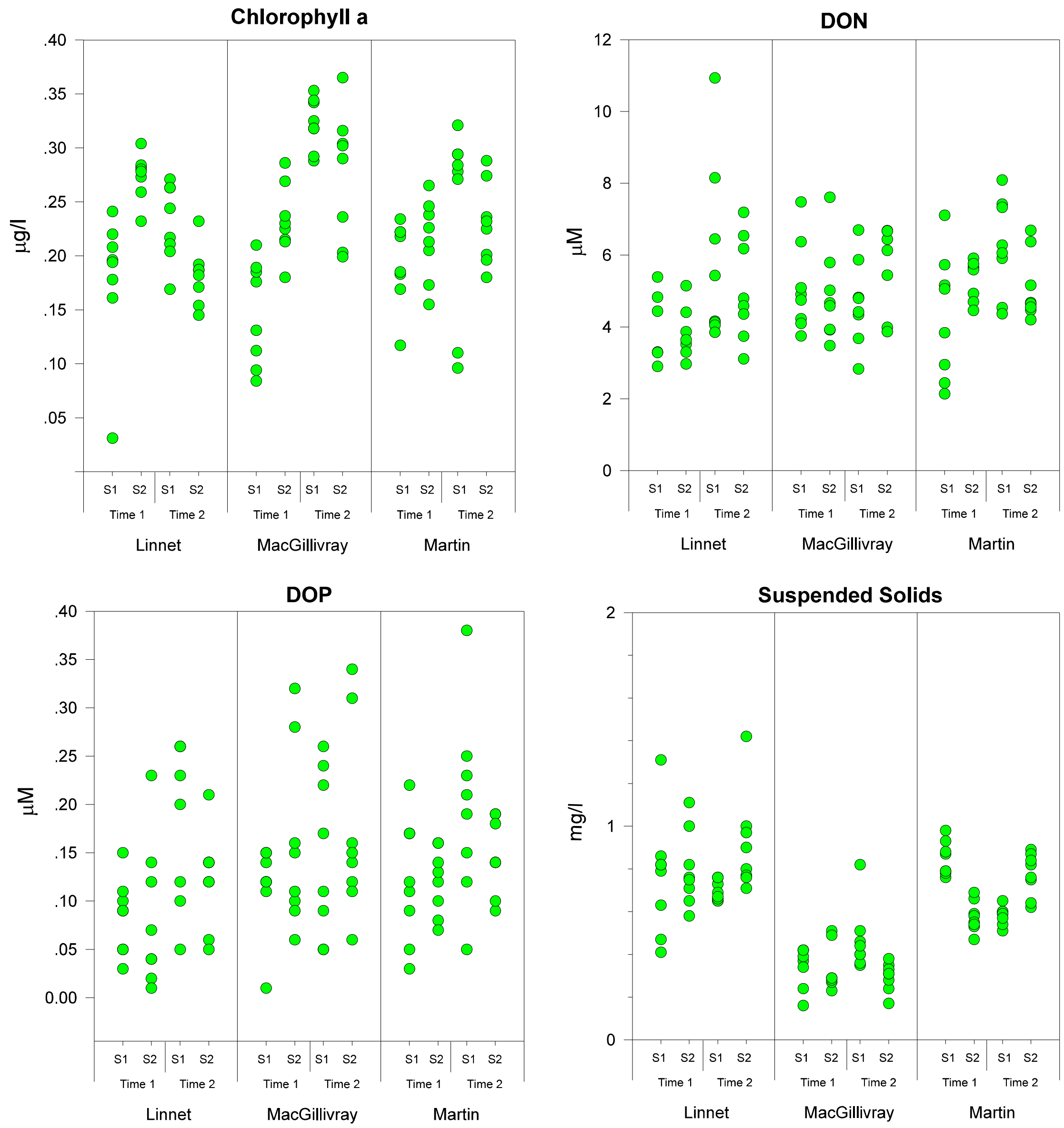


Figure 3.3. Variation in water quality variables among different sites and times for three different reefs

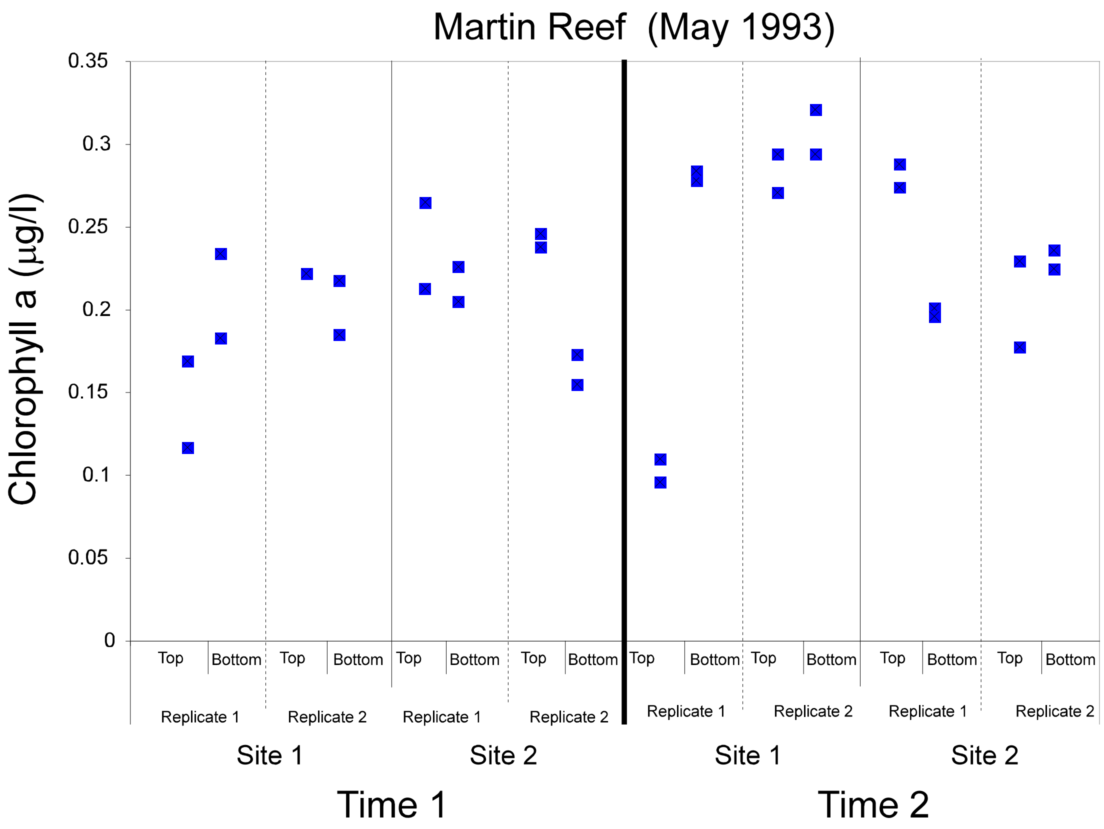


Figure 3.4 Variation in Chlorophyll a among samples at Martin Reef taken at different depths, sites and times. Each sample combination is analysed in duplicate.

Variation between sectors and time

Table 3.5 shows the results of the analysis of variance for sector and time effects. The analysis was restricted to the inner and mid-shelf reefs in the Cairns and Innisfail sectors. Cell means and standard errors (untransformed) are shown in Figure 3.5. Eight of the thirteen variables analysed showed significants effects for time (different cruises). Chlorophyll a (and thus phytoplankton) and NO_2 were higher in March 1993 compared to November 1992, although the presence of a significant sector by time interaction indicates that for NO_2, this effect was most pronounced in the Innisfail sector. NH4, NO3, DIN, TDN and DON were all significantly lower in March 1993, possilby due to uptake by the increased levels of phytoplankton. Salinity was also higher in March 1993 but a time by shelf interaction suggests that this was most evident on mid-shelf stations. Differences between sectors were only significant for DIP, which was highest for Cairns, and DOP which was highest in the Innisfail sector. Finally, significant shelf effects were found for Chlorophyll a, Phaeophytin and suspended solids, which were all highest on inner-shelf stations.

Table 3.5. Analysis of variance results for test of sector, shelf-position and time for inner and mid-shelf stations in the Cairns and Innisfail sectors. Significant effects (P<.05) are highlighted in bold.

	Effect													
	Sector		Shelf		Shelf x Sector		Time		Sector x Time		Shelf x Time		Sector x Shelf x Time	
Variable	$F_{(1,8)}$	*P*	$F_{(1,8)}$	*P*	$F_{(1,8)}$	*P*	$F_{(1,8)}$	*P*	$F_{(1,8)}$	*P*	$F_{(1,8)}$	*P*	$F_{(1,8)}$	*P*
Chl a	1.536	*0.250*	8.035	***0.022***	.0994	*0.347*	30.991	**<*0.001***	1.560	*0.247*	1.754	*0.222*	0.245	*0.634*
Phaeo	1.181	*0.309*	7.017	***0.029***	0.310	*0.593*	0.802	*0.397*	0.039	*0.849*	0.908	*0.368*	0.860	*0.777*
Salinity	0.322	*0.586*	4.504	*0.067*	1.340	*0.280*	58.285	**<*0.001***	0.015	*0.904*	11.093	***0.010***	0.267	*0.619*
DIP	13.580	***0.006***	3.189	*0.112*	2.764	*0.135*	0.267	*0.619*	0.046	*0.836*	0.453	*0.520*	0.004	*0.953*
NH4	2.887	*0.128*	1.332	*0.282*	3.653	*0.092*	16.214	***0.004***	4.505	*0.066*	1.240	*0.298*	1.741	*0.224*
NO2	0.171	*0.690*	0.706	*0.425*	0.158	*0.701*	59.657	**<*0.001***	6.028	***0.039***	0.907	*0.369*	0.010	*0.924*
NO3	0.204	*0.664*	0.591	*0.464*	0.213	*0.657*	5.827	***0.042***	0.002	*0.963*	0.024	*0.880*	0.149	*0.709*
DIN	2.646	*0.142*	1.479	*0.259*	4.085	*0.078*	18.770	***0.003***	4.452	*0.066*	1.115	*0.322*	1.537	*0.250*
TDP	4.317	*0.071*	0.124	*0.734*	1.170	*0.311*	3.745	*0.089*	2.702	*0.139*	0.007	*0.935*	0.055	*0.820*
TDN	0.289	*0.605*	0.218	*0.653*	0.222	*0.650*	27.274	***0.001***	0.431	*0.530*	0.056	*0.819*	0.012	*0.914*
DON	0.368	*0.561*	0.202	*0.665*	0.502	*0.499*	24.698	***0.001***	0.879	*0.376*	0.115	*0.743*	0.006	*0.981*
DOP	6.249	***0.037***	0.295	*0.602*	0.887	*0.374*	3.519	*0.098*	3.169	*0.113*	0.006	*0.940*	<0.001	*0.994*
SS	0.004	*0.949*	14.943	***0.005***	0.067	*0.802*	0.002	*0.963*	3.563	*0.096*	1.245	*0.297*	3.575	*0.095*

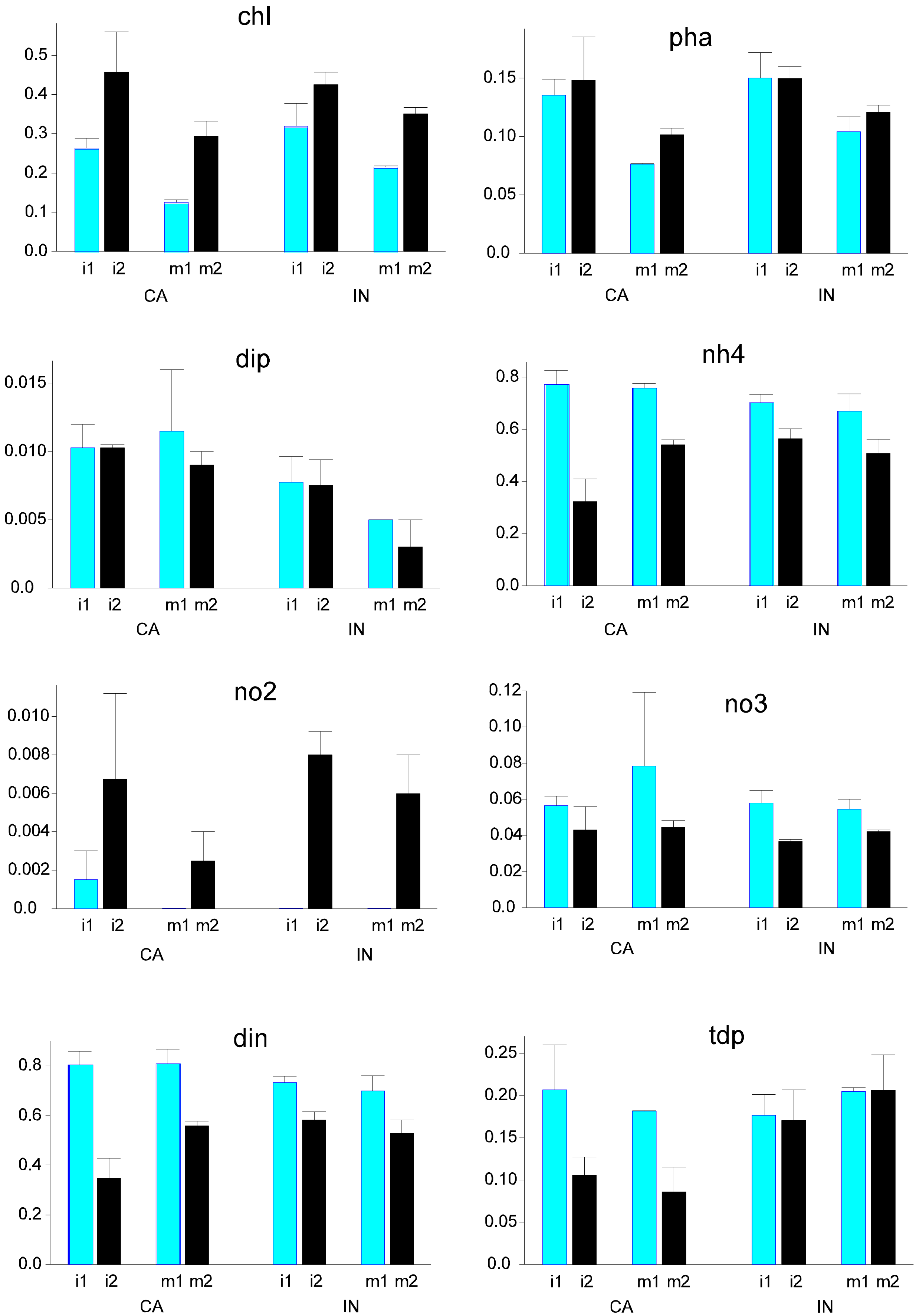


Figure 3.5. Means and standard errors for water quality variables taken from inner and mid-shelf reefs (i,m) in the Cairns and Innisfail sectors (CA,IN) on 2 different occasions (1,2; =March & November).

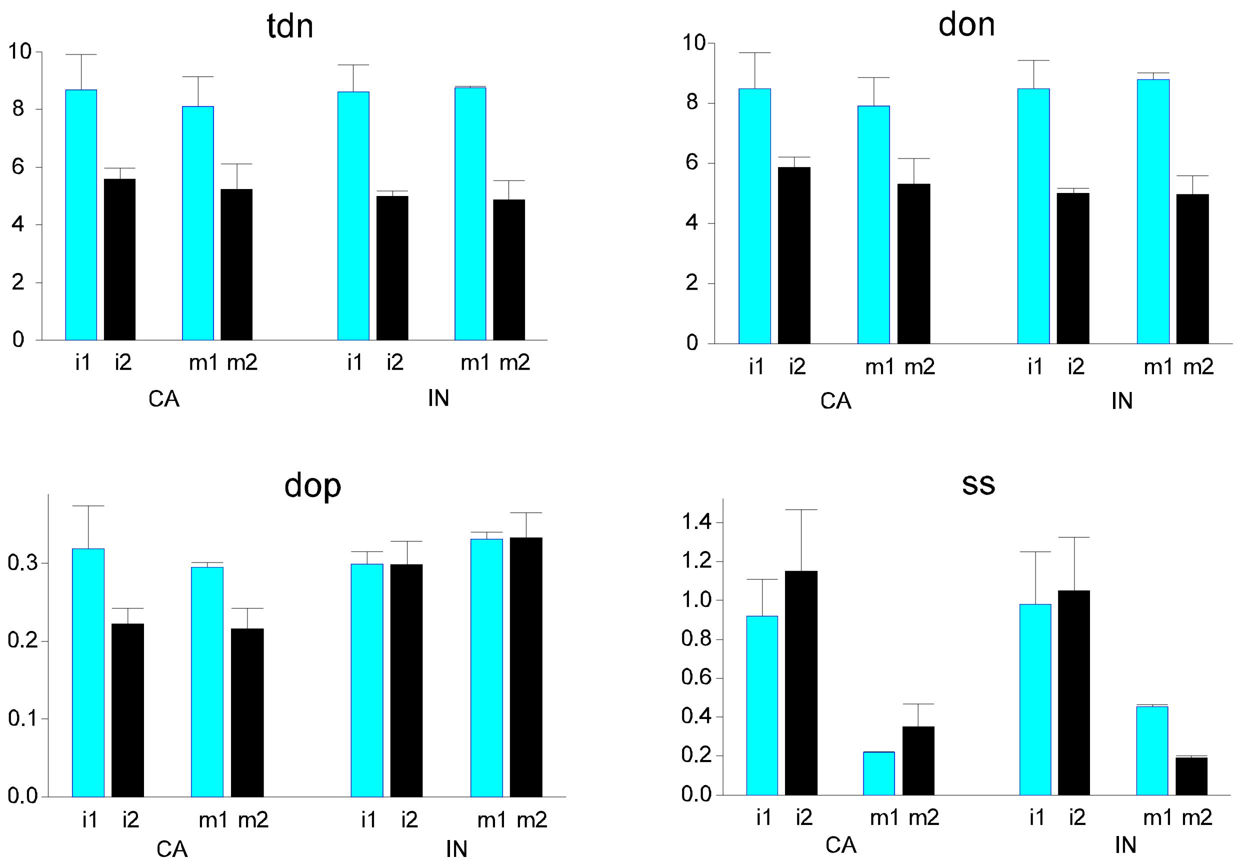


Figure 3.5. (cont'd)

Cross-shelf variation

The results for the test of shelf-position effects for those sectors (Cairns and Townsville) where a complete set of samples for inner, mid and outer-shelf stations was obtained are shown in Table 3.6 and presented graphically in Figure 3.6. Suspended solids exhibited the most pronounced and significant changes across the shelf, with much higher values at inshore stations decreasing towards the shelf-edge. Chlorophyll a also decreased from inshore to outer-shelf stations, while NO_2 exhibited the opposite trend. All variables except NO_3 exhibited significant sector, or sector by shelf effects. These effects showed no consistent patterns among variables, and since the sector effect is also combined with differences between cruise dates, further interpretation is not warranted.

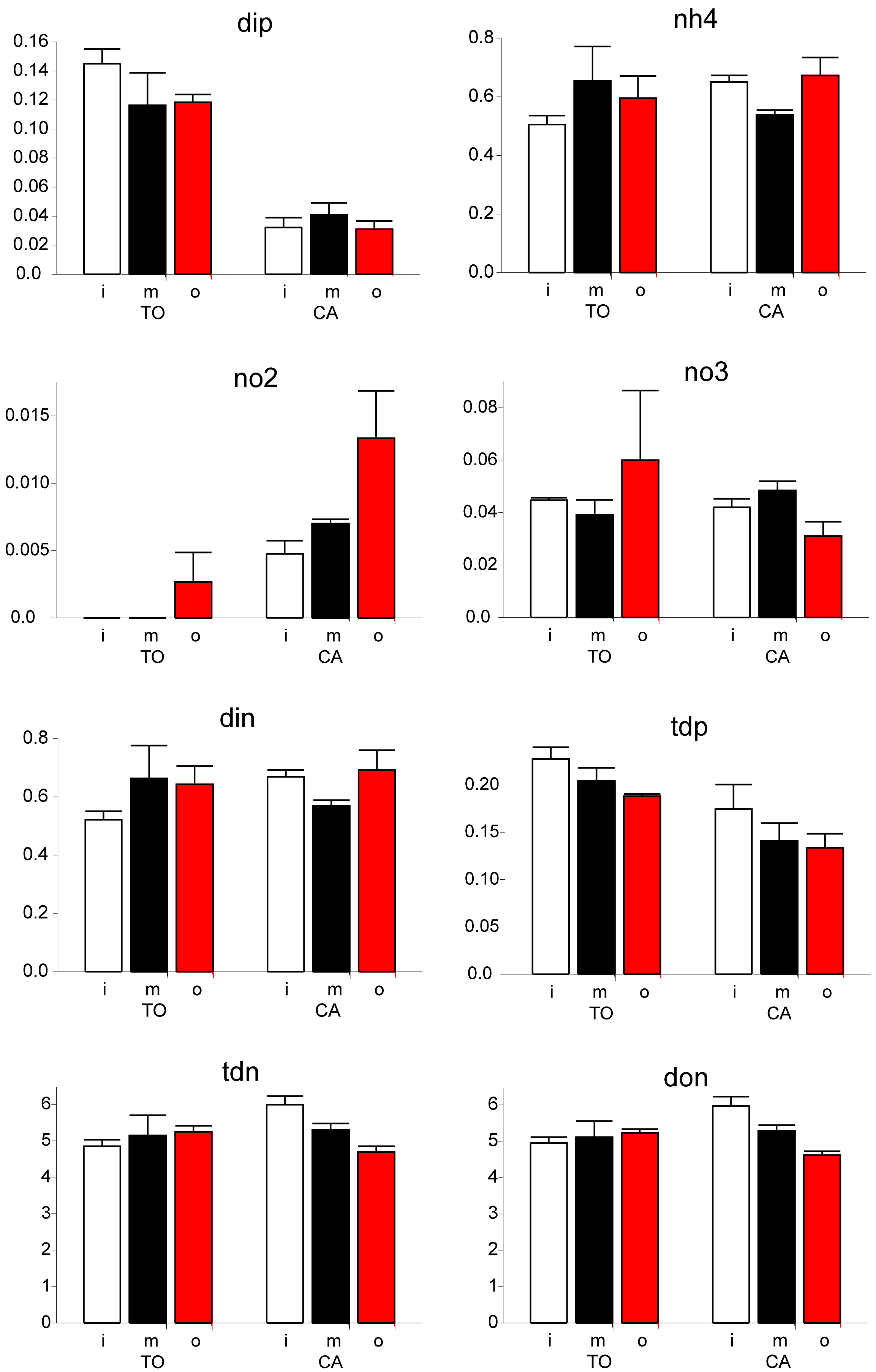


Figure 3.6. Means and standard errors for water quality variables at different cross-shelf positions(i=inner, m=middle, o=outer) in the Cairns (CA) and Townsville (TO) sectors.

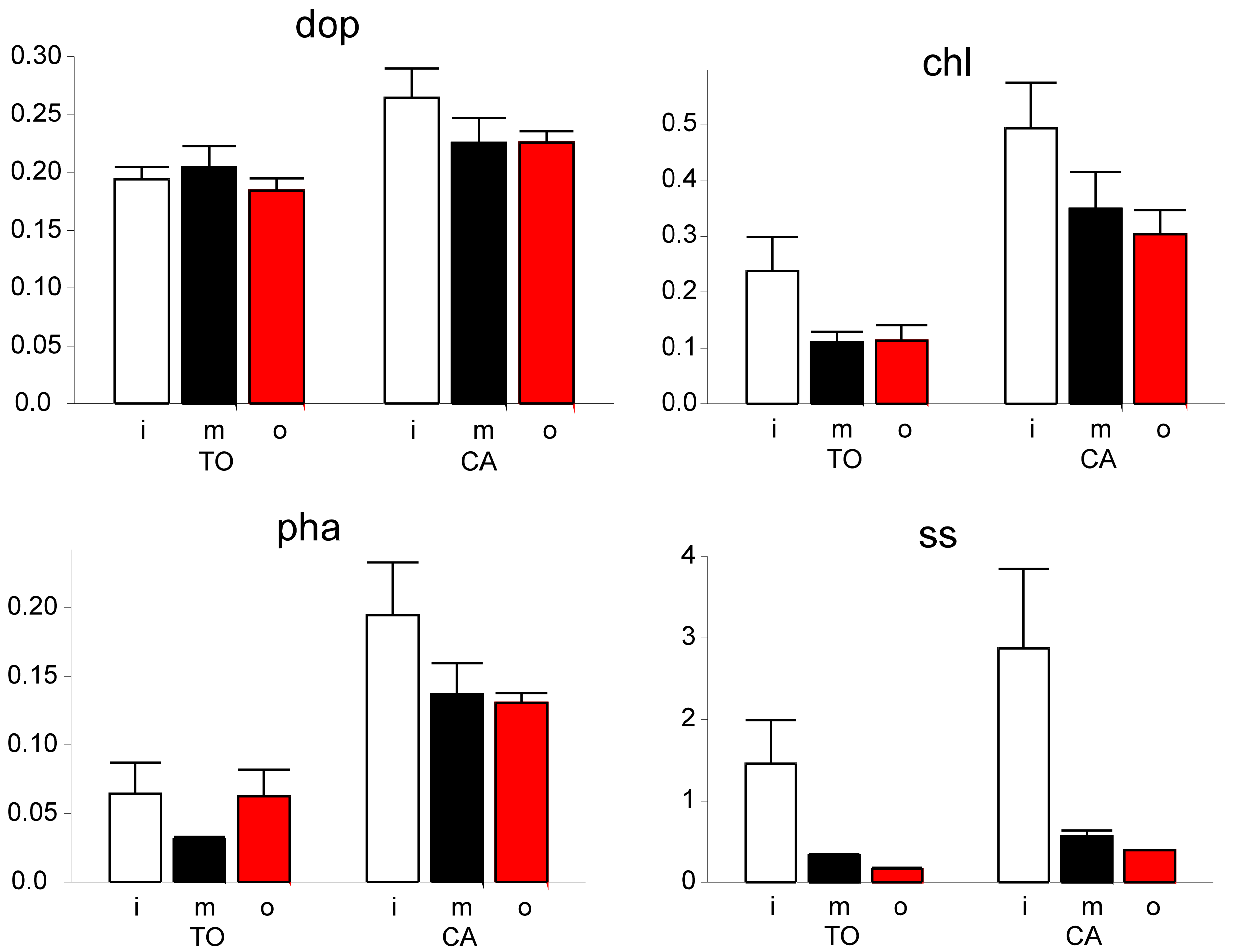


Figure 3.6 (cont'd)

Table 3.6. ANOVA results for 2 sectors (Cairns and Townsville) where all cross-shelf areas were sampled during the same cruise. Note that sector is confounded with time for this analysis.
* denominator degrees of freedom = 16 due to missing data

	Effect					
	Sector		Shelf		Shelf by Sector	
Variable	$F_{(1,20)}$	*P*	$F_{(2,20)}$	*P*	$F_{(2,20)}$	*P*
Chl a*	33.058	***<0.001***	4.162	***0.035***	0.463	*0.637*
Phaeo*	31.924	***<0.001***	1.332	*0.292*	0.423	*0.662*
DIP	65.129	***<0.001***	0.129	*0.879*	0.878	*0.431*
NH4	1.951	*0.118*	0.754	*0.484*	4.288	***0.028***
NO2	43.488	***<0.001***	8.571	***0.002***	1.132	*0.342*
NO3	0.490	*0.492*	0.269	*0.767*	2.611	*0.098*
DIN	1.800	*0.195*	1.144	*0.339*	3.788	***0.040***
TDP	4.444	***0.048***	0.327	*0.725*	0.007	*0.993*
TDN	4.549	***0.045***	2.231	*0.133*	5.011	***0.017***
DON	3.475	*0.077*	3.123	*0.066*	4.797	***0.020***
DOP	5.162	***0.034***	0.450	*0.644*	0.368	*0.697*
SS	12.242	***0.002***	25.692	***<0.001***	0.203	*0.818*

Discussion

The small number of samples taken so far within each region consitutes the major limitation of this study. This results in strong confounding between temporal (seasonality) and spatial variability. In order to distinguish any changes in the status of water quality in the Great Barrier Reef it is essential to separate each type of variability. Differences in water quality between reefs will be affected by the location of the reef and the time of year the sample was taken. Revelante and Gilmartin (1982) stated that there was a clear summer-winter difference in nutrient concentration in the Great Barrier Reef waters off Townsville, while numerous studies (Furnas *et al*. 1993; Brodie *et.al* 1992) have commented on the strong impact that a flood event or heavy wet season can have in the GBR lagoon waters. Reefs separated by any distance will be affected in different ways by weather patterns, oceanographic processes and external inputs, or cyclonic resuspension of bottom sediments.

In order to separate temporal and spatial sources of variation a program of repeat sampling over time and space is required. The magnitude of sampling required for separation of spatial and temporal variability is unavailable at this stage of the study. As more data becomes available (through collection by this project and by assimilation with other projects) a more detailed analysis of water quality processes on the Great Barrier Reef may be undertaken. The limited scope of the conclusions that can be drawn from this year's data clearly indicate that in order to isolate any trends in water quality, associated with either natural or anthropogenic inputs, an extended commitment to this type of long-term monitoring program is required.

Despite the above limitations, the provisional results for this year indicate that differences between sectors, and between different sampling dates do occur.Further long-term data for more sectors will be needed before these results can be more broadly interpreted.

Significant results for cross-shelf position were also obtained for some variables in two sectors, and these results are more readily interpretable. Both Chlorophyll a and suspended solids were high at inshore stations and decreased offshore. Previous studies have shown that a major source of suspended solid into the lagoon is likely to be from river runoff. The amount of rainfall and wind, as well as the nature of mixing with outer shelf waters and resuspension from sediments after periods of rough weather will also affect suspended solids levels (Orr, 1933; Wolanski *et al*. 1981). It is not surprising that higher suspended solid concentration occurred at the inner shallower stations given the inputs of sediments and wind driven resuspension near the coast. The difference between mid and outer shelf reefs was moderate, suggesting minimal mixing of inner and midshelf water bodies. The low suspended solid concentration within the outer shelf reef matrix reflects the greater importance of lateral exchange with adjacent low-level oceanic waters (Furnas *et al*. 1993).

The concentration of chlorophyll is dependant on the amount of algae present which is in turn dependant on the concentration of available dissolved nutrients in the water column and the amount of grazing that is occurring. Waters with high levels of phytoplankton present could be expected to strip nutrients very quickly, resulting in suppression of nutrient levels in the area. This effect may have been manifest in the results for the Cairns and Innisfail sectors, where higher chlorophyll concentrations were associated with lower values for most inorganic nutrients during the second sampling period (Figure 3.5). As a result chlorophyll *a* levels are often preferred over straight nutrient determinations as a measure of eutrophication (Bell 1991).

In this study chlorophyll and phaeophytin levels displayed significant trends across the reef shelf. This result agrees with the cross-shelf chlorophyll trends identified in other studies. Furnas *et al*. (1988), Furnas *et al.* (1990), Revelante and Gilmartin (1982), Andrews (1983), Charpy and Charpy-Roubard and Wolanski *et al*. (1981) all found that chlorophyll *a* concentrations in reef lagoon and inner shelf waters were higher than in outer shelf and Coral Sea waters.

Nutrient levels in waters of the Great Barrier Reef are governed by many factors including river run off, ground waters, sewage, precipitation, resuspension from sediments, upwelling, remineralisation and nitrogen fixation. Nutrients may be lost from the water column by denitrification, uptake by algae or lost to the sediments (Furnas 1992). Nutrient inputs, nutrient sinks, physical processes, biological processes and environmental conditions combine in a complex relationship to determine the nutrient concentration at a particular place in the water column at any point in time. The result being highly variable and uncertain nutrient conditions. The ability to monitor nutrient variations and understand the processes they reflect in coral reef ecosystems may prove to be of practical value to environmental management agencies.

Under certain conditions it would be reasonable to expect a pattern across the reef shelf to occur. Furnas *et al*. (1993) determined that a very large percentage of annual nutrient inputs from rivers are delivered by flood events within short periods (days - 2 weeks). Under flood conditions a large amount of nutrients would be delivered to the inner lagoon in a short period of time. The result would be high nutrient readings for inner shelf reefs compared to outer shelf reefs.

Numerous other studies also identified cross-shelf nutrient trends. Crossland *et al*. (1984) found that nutrient concentrations were greater inside the reef complex than in adjacent oceanic regions. It was postulated that remineralisation of algal material forms a significant nutrient source inside the reefs. Charpy and Charpy-Roubaud (1988) found that phosphorus levels in a coral atoll lagoon were 1.4 times greater than in surrounding ocean waters. The main difference between the two areas is in the organic fraction, dissolved fractions did not differ. Furnas *et al*. (1988) found that dissolved inorganic nutrient concentrations of the Whitsunday lagoon area were generally greater than the reef shelf area. It was concluded that the higher levels of nutrients in lagoon waters was likely to be due to resuspension of nutrients from sediments as the area is well mixed by wind and tidal currents.

Conversely, Andrews (1983) found that surface waters of the outer central Great Barrier Reef exhibited no significant gradients in phosphate, nitrate, nitrite or silicate across the reef zone. However, near bottom waters did display correlated increases in nitrate and phosphate levels seaward across the reefs to the shelf break. The increase is most likely due to inundation by cool nutrient rich deep ocean waters.

Furnas *et al.* (1993) reported that the presence or absence of cross-shelf gradients in nutrient concentration varied between nutrient species, season and location. The data suggests that there is no definite cross-shelf pattern for the majority of the nutrient species. This relates to the high variability of factors affecting nutrients at both local and regional scales.

Given the above considerations, it is not surprising that only one nutrient species showed a significant cross-shelf effect. In this case nitrite showed an increase across the shelf, possibly due to an upwelling event at the shelf edge. Clearly if consistent cross-shelf patterns, or trends are to be detected on the GBR, further intensive and well structured sampling, over several years, will be needed.

4. Fish

A. Halford, A.Thompson, J. Oliver & G. De'ath

Introduction

The overall objectives of the AIMS Long-term Monitoring Program, and its general design have been set out in Section 1. This section presents the results of fish surveys on 33 reefs during 1992-93. The results are preliminary in the sense that only 1 year of data is available for analysis and because only 33 of the 52 reefs selected for annual monitoring have been surveyed. The aims of this preliminary analysis are to:

1. Summarise the baseline conditions at each of the surveyed reefs
2. Look for obvious patterns and/or trends among reefs grouped according to their cross-shelf and north-south position.
3. Use both univariate and multivariate methods to detect such differences in geographic patterns
4. Compare these results with the fish count data collected by Williams (unpub) in the early 1980's

As with the coral data, two different approaches have been taken in the analysis of the fish data. We have used classical univariate techniques (ANOVA) to look for statistically significant cross-shelf and north-south differences in fish abundance for each family (or each genus within the Pomacentridae). Multivariate ordination analyses have also been conducted to determine if cross-shelf and/or latitudinal effects can be more readily detected when all families or species are considered in a single analysis.

Previous studies of the spatial structure of fish communities on the GBR have shown that there is systematic spatial variability at within and between reef scales, with major cross-shelf and weaker latitudinal patterns being particularly evident (Williams, 1991). Causal explanations of these patterns include habitat heterogeneity and patterns of recruitment (Doherty & Fowler, 1994; Doherty & Williams, 1988). Comparable data on the temporal variability of reef fish communities is much more limited. Research over the last two decades has demonstrated that the temporal structure of fish assemblages at the local scale can be highly variable (e.g. Sale *et al*., 1994). Although considerable variability in fish abundances does occur at larger scales, it is relatively small compared to large-scale spatial patterns. Williams (1986) examined short-term effects of *Acanthaster* outbreaks on fish communities in the central GBR. Changes in abundance of species before and after (18 mo - 2 yrs) the outbreaks were comparable to cross-shelf differences among reefs. Year to year variation in abundances of fishes on reefs unaffected by the outbreaks appear to be even less than differences among reefs at a given location at any time.

Methods

Study sites

The basic design of the monitoring program, including which reefs have been selected for annual monitoring, and which of these were surveyed during 1992-93 are presented in Chapter1 and Table 1.2. In summary, 33 reefs were surveyed for fish in 1992-93. At each surveyed reef, 3 permanent sites were set up on the north-eastern end. At each site 5 permanently marked, 50 metre transects were established haphazardly along the 6-9 m depth contour. The transects were marked with a star picket at each end and reinforcing rod every 10 metres along the transect.

Sampling techniques

Two widths of transect were used to census the reef fish community at each site. During the first swim along the transects the relatively large and more mobile fish species (listed in Appendix 4.1(a)) were counted to a distance of 5 metres either side of the transect line. The 5 metre distance was visually estimated as the observer carried out the survey then verified using a fibreglass tape measure at the end of each transect. Once all five transects had been surveyed the observer returned along the transects counting fish from the family Pomacentridae (Appendix 4.1(b)) in a 2 metre wide strip up slope from the transect line, which is used as the lower boundary of the belt. For a more detailed description of the sampling procedure refer to Halford and Thompson (1994).

To minimise sampling variability due to diurnal changes in observability and fish behaviour, surveys were undertaken between 0830 and 1630 hrs. During other periods close to the low light periods of dawn and dusk, counting and identification of fish species are difficult due to the low angle and intensity of available light. These crepuscular periods are also unsuitable for monitoring since they are associated with high variability in fish numbers and behaviour caused by the change-over between the nocturnal and diurnal communities (Hobson, 1972, 1973).

The sampling design used in this program has a number of limitations which have been discussed in the general introduction. For fish surveys the most important limitation, is that there is only one sample of fish taken per year, at different times of the year on different reefs. As yet unquantified short term fluctuations in fish numbers make it difficult to assess how representative a single sample is in estimating average abundances for a reef in any given year. Until the studies outlined in Table 1.3 have been completed, the reader should exercise caution in interpreting and generalising the results presented below.

Data handling and processing

Univariate analyses

In order to obtain reasonable sample sizes, and to reduce the number of separate analyses, the data were grouped at the family level, and for Pomacentrids, to the genus level. Table 4.1 list the families and genera used in the analyses, as well as the abbreviated codes used to display the results. Analysis of variance was used to investigate whether any of the variations in estimates of fish abundance at the scale of

Table 4.1 List of families and genera used in analysis of fish data.

Family	Code	Genus (Pomacentridae)	Code
Acanthuridae	ACAN	Acanthochromis	ACN
Chaetodontidae	CHAE	Amblyglyphidodon	AMB
Labridae	LABR	Amphiprion	AMP
Lethrinidae	LETH	Chromis	CHR
Lutjanidae	LUTJ	Chrysiptera	CHY
Pomacentridae	POMA	Dascyllus	DAS
Scaridae	SCAR	Dischistodus	DIS
Serranidae	SERR	Neoglyphidodon	NEG
Siganidae	SIGA	Neopomacentrus	NEO
Zanclidae	ZANC	Plectroglyphidodon	PGY
		Pomacentrus	POM
		Stegastes	STE

the reef were systematically related to the geographic location of the reef. i.e. shelf position (inner middle and outer), or latitudinal sector (Cooktown/Lizard Is, Cairns, Townsville, Whitsunday, Swain or Capricorn Bunker). An initial ANOVA with both shelf position and sector as main effects, and reefs and sites nested within shelf position and sectors was conducted (Figure 4.1). Reefs from the Capricorn Bunker and Swain sectors were excluded from this analysis as these sectors contained reefs in only one shelf position. The resulting data set was still unbalanced with respect to

Table 4.2 Numbers of reefs sampled in each sector and cross-shelf position. Sector codes are: CL - Cooktown/Lizard; CA - Cairns; TO - Townsville; WH - Whitsunday; SW - Swain; CB - Capricorn Bunker

	CL	CA	TO	WH	SW	CB
Inner	2	2	1	2		
Mid	1	3	2	3	6	
Outer	2	1	2	2		4

reef numbers for shelf position and sector (Table 4.2). Families or genera which were not significantly ($p>0.2$) related to shelf position or shelf position x sector were then analysed using a single factor nested ANOVA with sector as the main factor. This second design allowed us to incorporate reefs from the Swain and Capricorn Bunker sectors and investigate sector effects over the entire sector range. Separate analyses were conducted for each fish family, and for each genus within the family Pomacentridae. Data were transformed ($\log_{10}(x+1)$) prior to analysis in order to reduce heterogeneity of variances, and to prevent the analyses from being swamped by a few large values.

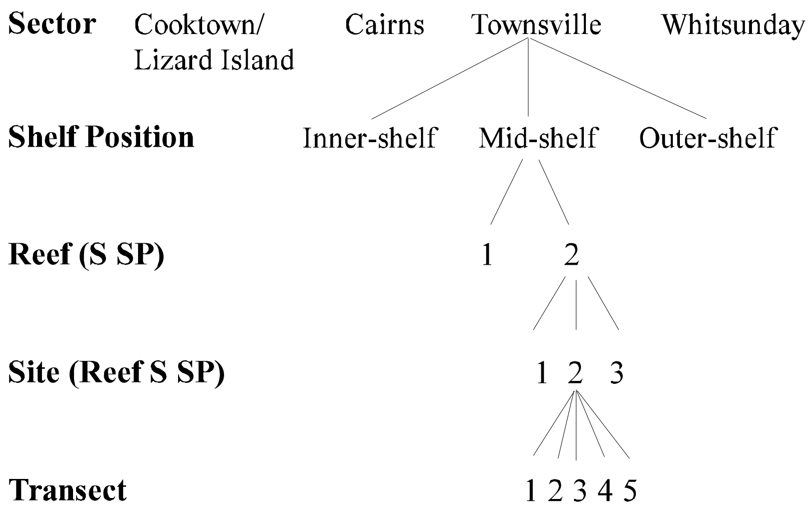


Figure 4.1. Outline of sampling design for ANOVA model one. Parentheses indicate a nested term. Sector and Shelf Position are treated as fixed orthogonal terms and reef and site are regarded as random. The second ANOVA model (not shown) is similar except that shelf position has been removed from the model and the Swain and Capricorn Bunker sectors have been added.

Multivariate analyses

Multivariate analysis allows several variables to be considered simultaneously, thus providing insights that are not immediately obvious from separate univariate analyses. In conjunction with more traditional ways of displaying variable distributions, such as histograms, multivariate analyses form a powerful approach to investigating patterns in the data. In the first year's data the spatial distribution of reefs was looked at using families or species as variables.

Two data matrices were subjected to multivariate analyses to seek spatial patterns in fish community structure. The rows of each matrix corresponded to mean values for individual reefs (3 sites on the NE flanks of reefs), while each column represented either a different family or species. Reefs were chosen as the basic unit for the multivariate analysis (as opposed to sites or transects) because in this first year of the program we were most interested in groupings and affinities between reefs and because a preliminary cluster analysis showed strong similarities between sites within reefs relative to the variation between reefs (see also Table 4.5).

Prior to analyses the data were $\log_{10}(x+1)$ transformed to reduce the skewness of the data. The resulting matrices were then column centred or double centred prior to analysis. The results were then displayed as symmetric biplots. Eighty percent confidence ellipses were used to highlight predetermined groups of reefs (i.e. cross shelf position or latitudinal position). For a detailed description of data centring, symmetric biplots and confidence ellipses see Box 4.2.

Temporal comparison of spatial patterns

Changes over a decadal period were examined by comparing the Long-term Monitoring Program data to those collected by Williams during the early 1980's. Although the methods of data collection varied, the same sectors and habitat were surveyed in both cases. Williams used 45 minute zigzag swims to accumulate abundance estimates on a $\log_5$ scale (Williams 1982). Abundance and species richness for the families, Acanthuridae, Chaetodontidae, Scaridae and Pomacentridae were compared using only those species targeted by both studies.

As a result of the different methods used to count fish in the two surveys, it is not possible to directly compare fish abundances on a "per unit area" or "per unit effort" basis between surveys. Differences in total numbers between surveys are therefore likely to be due to different sampling effort rather than to any changes in actual abundances. However, it is possible to compare the pattern of relative abundances of fish among sectors. For example, if averaged abundances at all reefs during the present survey were much lower than during the first survey, it would not be possible to conclude that any change had taken place since the difference might be due to sampling effects. However, if abundances at some reefs were much lower than all the others during the present survey, but no such differences existed during the initial survey, then it can be concluded that a change in fish numbers at some reefs in the period between surveys has caused this alteration in the pattern of relative abundances. It should be stressed that the nature of the data do not allow us to conclude if the observed change in relative abundances might be caused by decrease in those reefs with relatively low numbers, or an increase in reefs with comparatively high numbers (or both).

For the comparison, the $\log_5$ counts were first converted to absolute counts by taking the geometric mean of each $\log_5$ abundance category (English *et al.* 1994). Data from both surveys were then transformed using $\log_{10}(x+1)$ prior to calculation of the mean and standard error for each reef. Note that the standard errors are a measure of the variability at the time of the surveys and not a measure of annual variability. Species richness was calculated using the total number of species present per site averaged to reef level.

Two 2-way ANOVAs, with sectors and families as factors, and abundance and species richness as response variables, were conducted. These analyses therefore tested whether the proportional change in fish numbers and in number of fish species between surveys was consistent between families and/or between sectors. The data used for species richness was the difference in estimates between the early 1980's and 1992-93. For both comparisons, proportions were calculated from values for the early 1980's divided by the values from 1992/93 were used. In both cases the error term was the interaction between families and regions. The analyses were done separately for mid-shelf and outer-shelf reefs since some sectors were only surveyed at one shelf position.

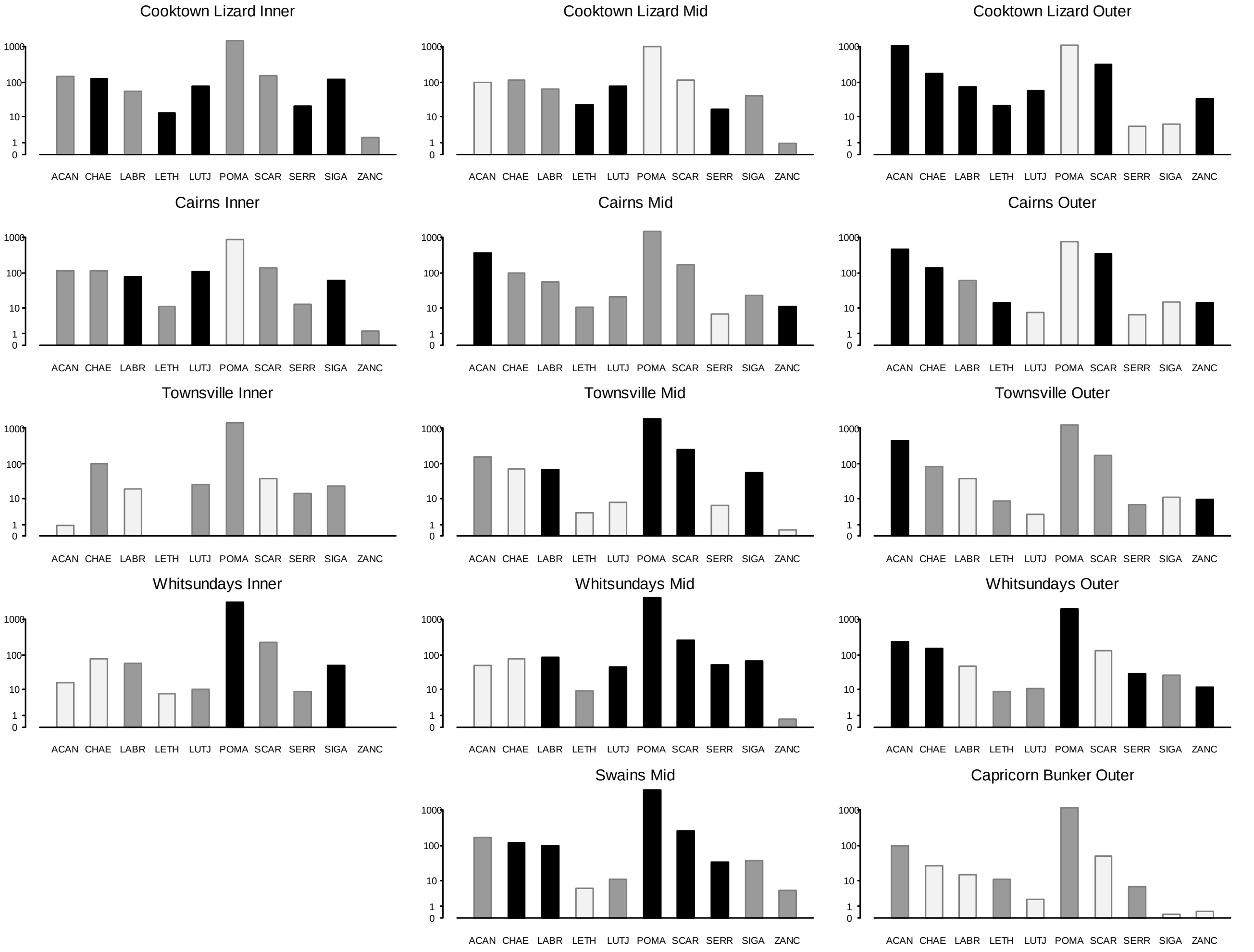


Figure 4.2. Average abundance of different fish families for different sectors and cross-shelf positions. The shading for each bar indicates how abundant the family was for a particular sector/shelf "location" compared with other locations. Black bars for a family indicate it was among the top 4 most abundant locations, dark grey bars indicate the middle 5, while light grey bars indicate the 5 locations with the smallest abundance for that family. From this shading pattern it can be seen, for instance, that the outer reefs in the Capricorn Bunker sector had low to medium abundances of all fish families, while the inner reef in the Cooktown/Lizard Island sector had high to medium abundances compared with other locations.

Results

Summary results

A summary of the raw survey data is presented in Figures 4.2 & 4.3. The raw data were pooled to family (10 metre transects) and genus (2 metre transects) then summed across transects for each site. Each histogram in Figure 4.2 represents the average number of fish per site, for all reefs within a combination of sector and shelf position. In general the graphs indicate that the larger fish on outer-shelf and, to a lesser extent, mid-shelf reefs are dominated by Acanthurids and Scarids. Inshore reefs did not exhibit any clear pattern of dominance, although Chaetodontids and Scarids were conspicuously abundant in the Townsville and Whitsunday sectors respectively.

Damselfish numbers recorded from the 2 m transects (Figure 4.3) indicated that species of *Pomacentrus* were dominant at most reefs, or were co-dominant with *Neopomacentrus* or *Chromis*. Finally, it is clear that the Capricorn Bunker reefs had low numbers of all fish except *Pomacentrus*. Mean abundance values for each reef are tabulated in Appendices 4.2 and 4.3.

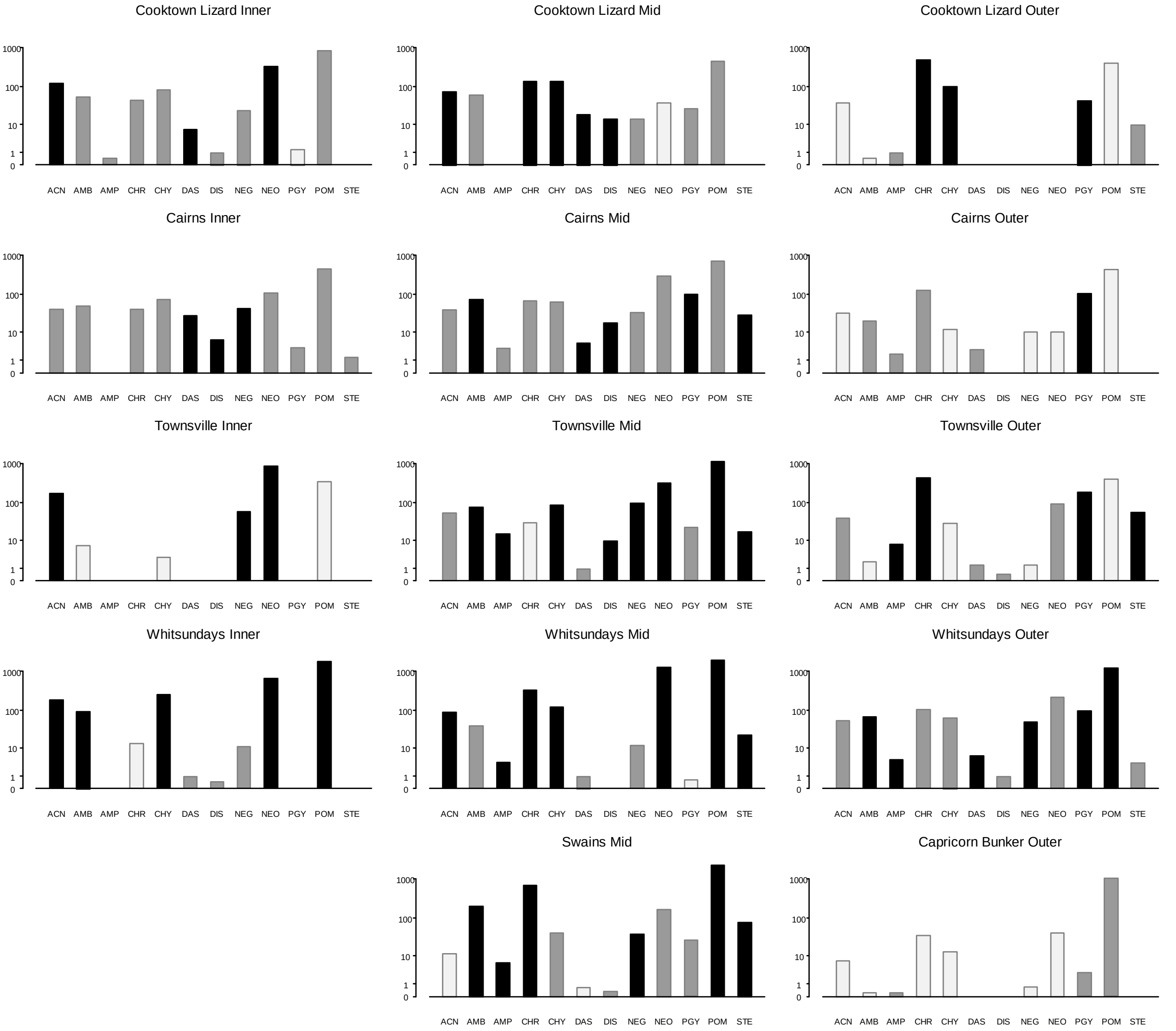


Figure 4.3. Mean abundance of genera within the family Pomacentridae for reefs in different sectors and cross-shelf positions. See previous figure for an explanation of bar shading.

Table 4.3. Two-way analysis of variance of reef means for 10 families from 24 reefs assessing cross-shelf position (I,M,O) and 4 sectors (CL,CA,TO,WH). P values are marked in bold if P<0.05, if (for main effects) there is no significant interaction.

	Effect					
	IMO		Sector		IMO by Sector	
Family	$F_{(2,12)}$	*P*	$F_{(3,12)}$	*P*	$F_{(6,12)}$	*P*
Acanthuridae	19.82	**<0.001**	5.15	**0.018**	2.23	*0.118*
Chaetodontida	5.12	**0.027**	4.06	**0.036**	1.22	*0.364*
Labridae	5.14	*0.026*	7.62	*0.005*	5.76	**0.006**
Lethrinidae	1.98	*0.184*	1.85	*0.196*	0.26	*0.943*
Lutjanidae	5.80	**0.019**	5.22	**0.017**	1.84	*0.180*
Pomacentridae	3.76	*0.057*	16.11	**<0.001**	1.00	*0.471*
Scaridae	20.72	*<0.001*	7.81	*0.005*	16.28	**<0.001**
Serranidae	1.79	*0.212*	4.44	**0.028**	2.86	*0.062*
Siganidae	14.29	**<0.001**	1.55	*0.257*	2.24	*0.116*
Zanclidae	56.22	*<0.001*	8.38	*0.004*	3.40	**0.038**

Analysis for all 6 sectors with pooled IMO	$F_{(5,27)}$	*P*
Lethrinidae	1.40	*0.255*
Pomacentridae	12.16	**<0.001**
Serranidae	2.94	**0.030**

Table 4.4. Two-way analysis of variance of reef means for 10 genera from 24 reefs assessing cross-shelf position (I,M,O) and sector (CL,CA,TO,WH).

	Effect					
	IMO		Sector		IMO by Sector	
Variable	$F_{(2,12)}$	*P*	$F_{(3,12)}$	*P*	$F_{(6,12)}$	*P*
Acanthochromis	*3.37*	*0.072*	*2.20*	*0.146*	*0.27*	*0.941*
Amblyglyphidodon	*4.53*	**0.037**	*2.37*	*0.127*	*2.37*	*0.102*
Amphiprion	*6.65*	**0.013**	*2.50*	*0.114*	*1.08*	*0.428*
Chromis	*4.66*	**0.034**	*0.77*	*0.533*	*0.34*	*0.904*
Chrysiptera	*4.11*	*0.046*	*9.19*	*0.002*	*3.49*	**0.035**
Dascyllus	*0.129*	*0.881*	*1.05*	*0.408*	*1.25*	*0.354*
Dischistodus	*2.50*	*0.128*	*0.66*	*0.595*	*1.20*	*0.374*
Neoglyphidodon	*3.14*	*0.083*	*1.04*	*0.413*	*3.19*	**0.046**
Neopomacentrus	*12.9*	**0.001**	*6.56*	**0.008**	*1.19*	*0.379*
Plectroglyphidodon	*22.4*	**<0.001**	*2.27*	*0.137*	*1.56*	*0.248*
Pomacentrus	*4.14*	**0.046**	*16.42*	**<0.001**	*1.84*	*0.179*
Stegastes	*3.72*	*0.058*	*0.88*	*0.481*	*1.65*	*0.222*

Analysis for all 6 sectors with pooled IMO	$F_{(5,27)}$	*P*
Acanthochromis	9.54	**<0.001**
Dascyllus	1.84	*0.139*
Dischistodus	1.44	*0.243*
Stegastes	5.01	**0.002**

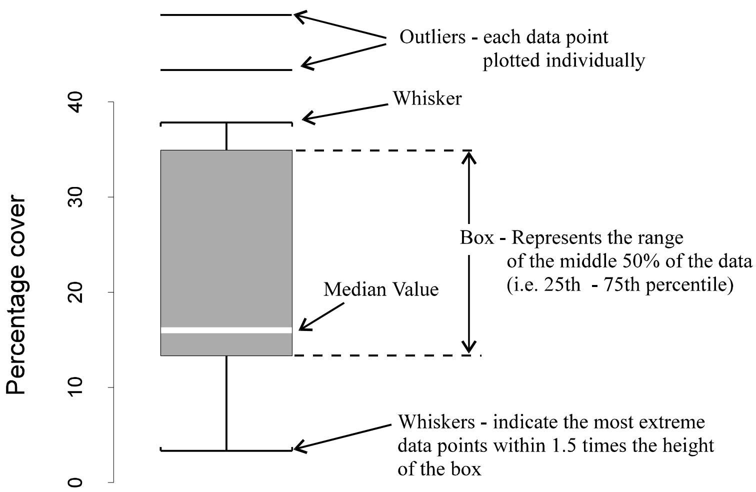
Univariate Analyses

The 2 factor ANOVAs (Tables 4.3 & 4.4) indicated that there were significant cross-shelf and/or shelf position effects for several groups. Summary statistics (boxplots) for differences which were statistically significant are shown in Figures 4.4-4.9 (see Box 4.1 for a guide to the interpretation of Boxplots). Lethrinids, Pomacentrids and Serranids did not exhibit any shelf effects, nor any interaction between sector and shelf position.

These groups were therefore re-analysed using pooled values for shelf position, and with the Swain and Capricorn Bunker sectors added. The results of this analysis are shown in Table 4.3 and Figure 4.6. Similarly pooled results for Pomacentrid genera which showed no shelf position effects are presented in Table 4.4 and Figure 4.7. The statistically significant results from all the analyses are summarised below, together with comments on the patterns indicated in the graphs of summary statistics.

Box 4.1
Anatomy of a Boxplot

Background
Boxplots have proven to be quite a good exploratory tool, especially when several boxplots are placed side by side for comparison. The most striking visual feature is the box which shows the limits of the middle half of the data. The line inside the box represents the median and the upper and lower lines of the box denote the 75th and 25th percentiles; thus the box contains 50% of the data. The whiskers which extend from the box are drawn to the nearest value not beyond a standard span from the quartiles; points beyond (outliers) are drawn individually. The standard span is 1.5 times the Inter-Quartile Range (75%ile - 25%ile). Extreme points are also highlighted by lines beyond the whiskers. Boxplots not only show the location and spread of data but indicate skewness, as well.



Shelf Position Effects:

Family Patterns: (Figure 4.4)

- **Acanthurids and Chaetodontids** were more numerically abundant on outer-shelf reefs compared with inner or mid-shelf reefs;
- **Lutjanids and Siganids** showed the opposite trend with highest numbers inshore and lowest values offshore.

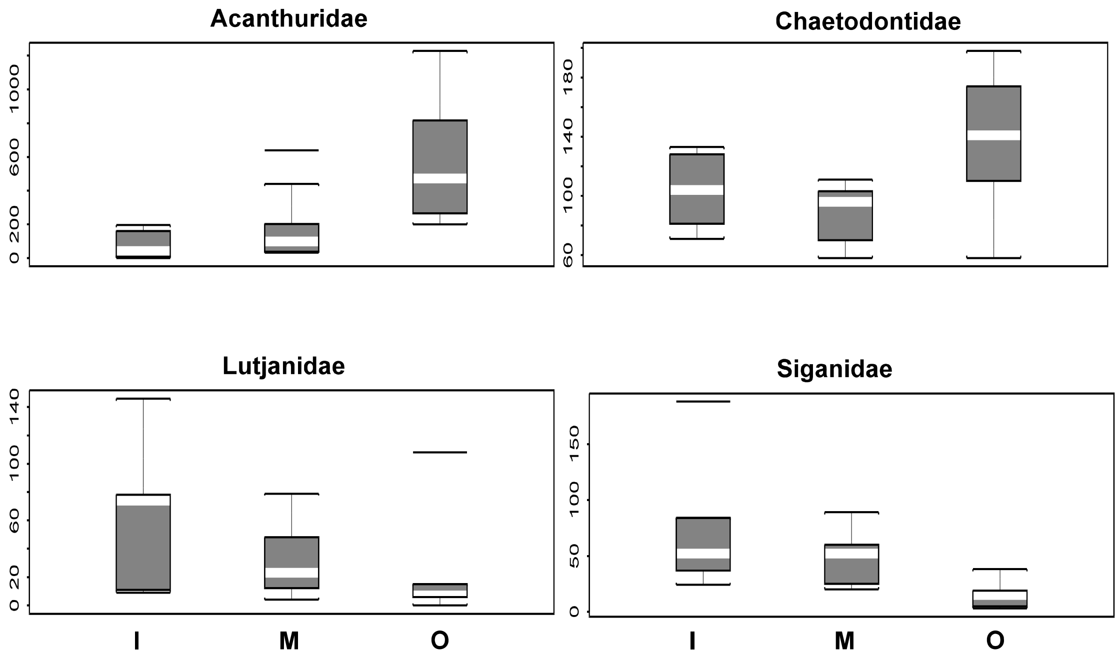


Figure 4.4 Boxplots for Families with significant shelf position effects.

Genera (Pomacentrids): (Figure 4.5)

- **Chromis and Plectroglyphidodon** showed a pattern of increasing abundance from inshore to offshore;
- **Amblyglyphidodon** showed the reverse pattern, with decreasing abundance from inshore to offshore;
- **Amphiprion** was lowest on inshore reefs;
- **Neopomacentrus** was lowest on offshore reefs;
- **Pomacentrus** was variable but slightly lower on offshore reefs.

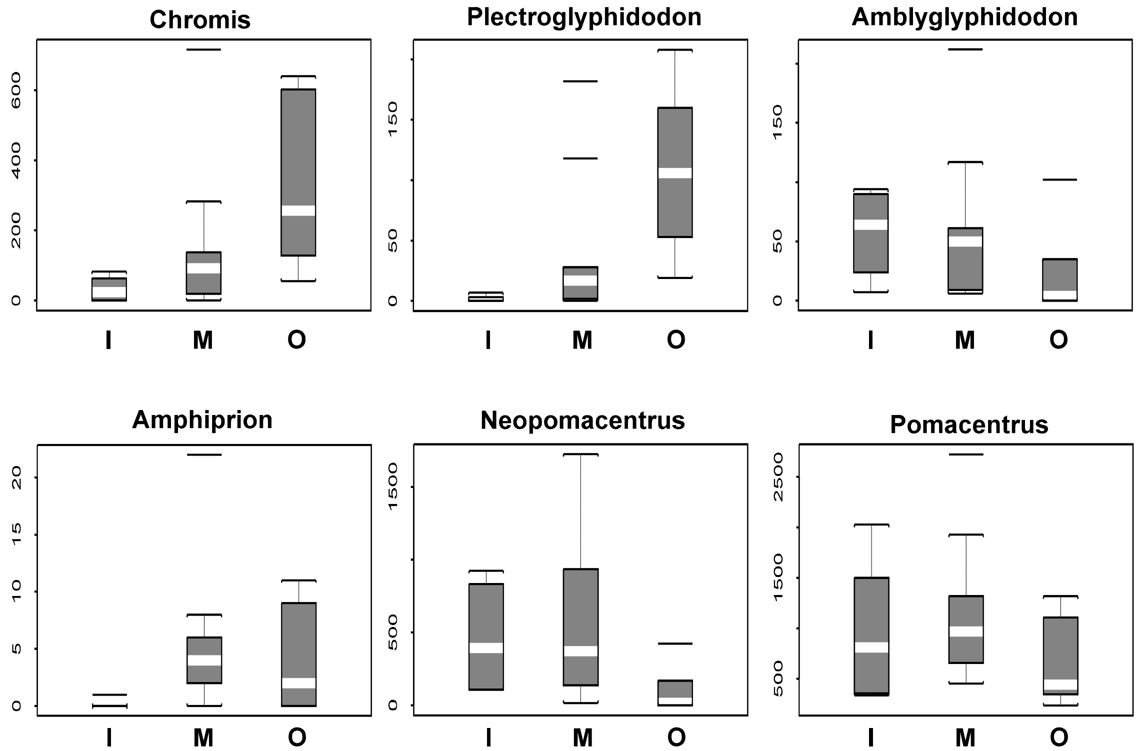


Figure 4.5. Boxplots for genera with significant shelf position effects.

Sector Effects (Figure 4.6)

Family Patterns:

- **Acanthurids and Chaetodontids** showed a general trend from higher numbers in the north (Cooktown/Lizard Is) to lower numbers in the Whitsunday sector;
- **Lutjanids** showed somewhat higher abundances in the northern sectors (Cooktown/ Lizard Is & Cairns) compared to the other sectors;
- **Lethrinids** showed non-systematic differences between sectors when all 6 sectors were analysed. The Townsville and Swain sectors were generally lower than the others;
- **Pomacentrids and Serranids** were higher in the Whitsunday and Swain sectors compared with the other sectors.

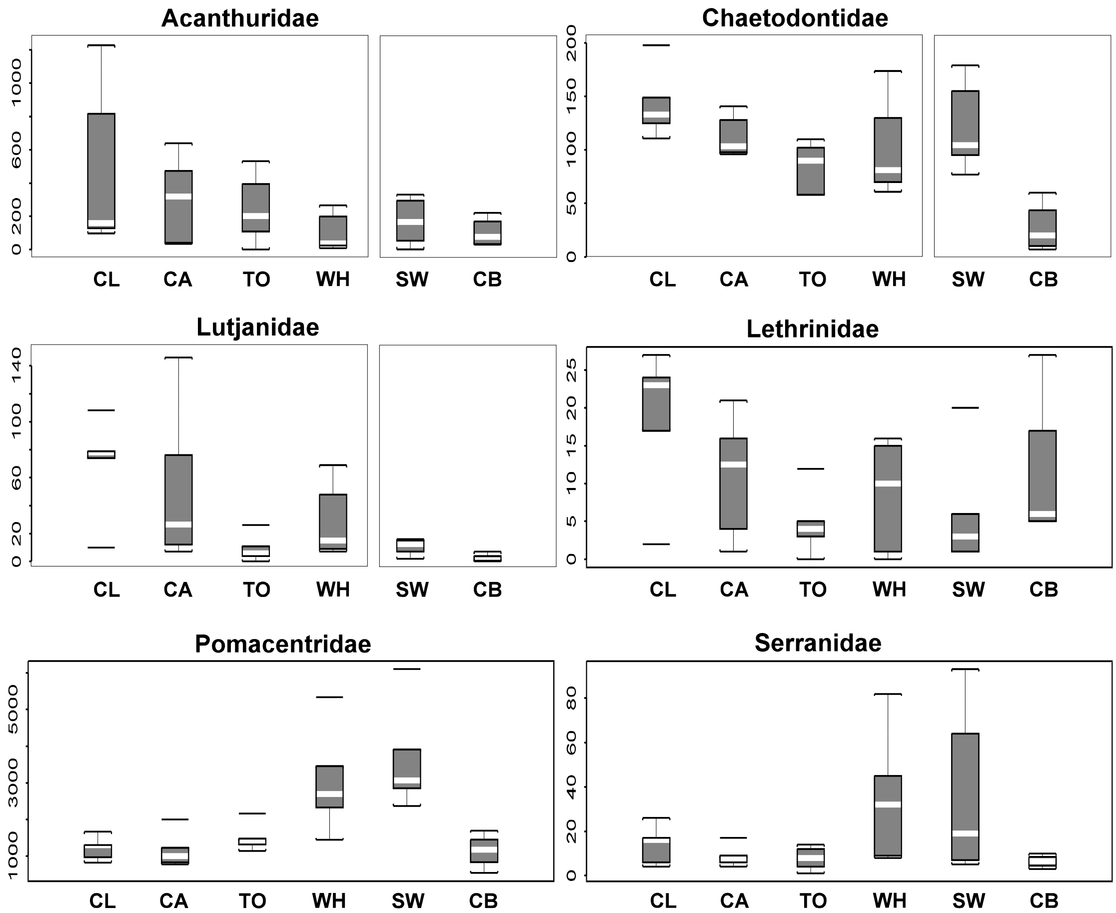


Figure 4.6 Boxplots for Families with significant sector effects. Note that results are shown here for all sectors, but for Acanthurids, Chaetodontids and Lutjanids only the first 4 sectors (displayed in a separate box) were analysed in the ANOVA since the other sectors were not represented by all cross-shelf positions. For the other families, the lack of any significant effects of shelf position permitted pooled results to be analysed for all 6 sectors. See Table 4.2 for explanation of sector codes.

Genera (Pomacentrids):

- **Pomacentrus, Neopomacentrus and Acanthochromis** all showed a tendency for higher abundances in the Whitsunday sector;
- **Stegastes** was more abundant in the Swain sector compares to other sectors (however it is likely that this is an artefact caused by confusion between *Stegastes* and *Pomacentrus* during sampling in the Swain sector);
- **Dascyllus and Dischistodus** were slightly more abundant, but highly variable in the Cooktown/Lizard Is sector, although absolute abundances were very low on all reefs compared with other genera.

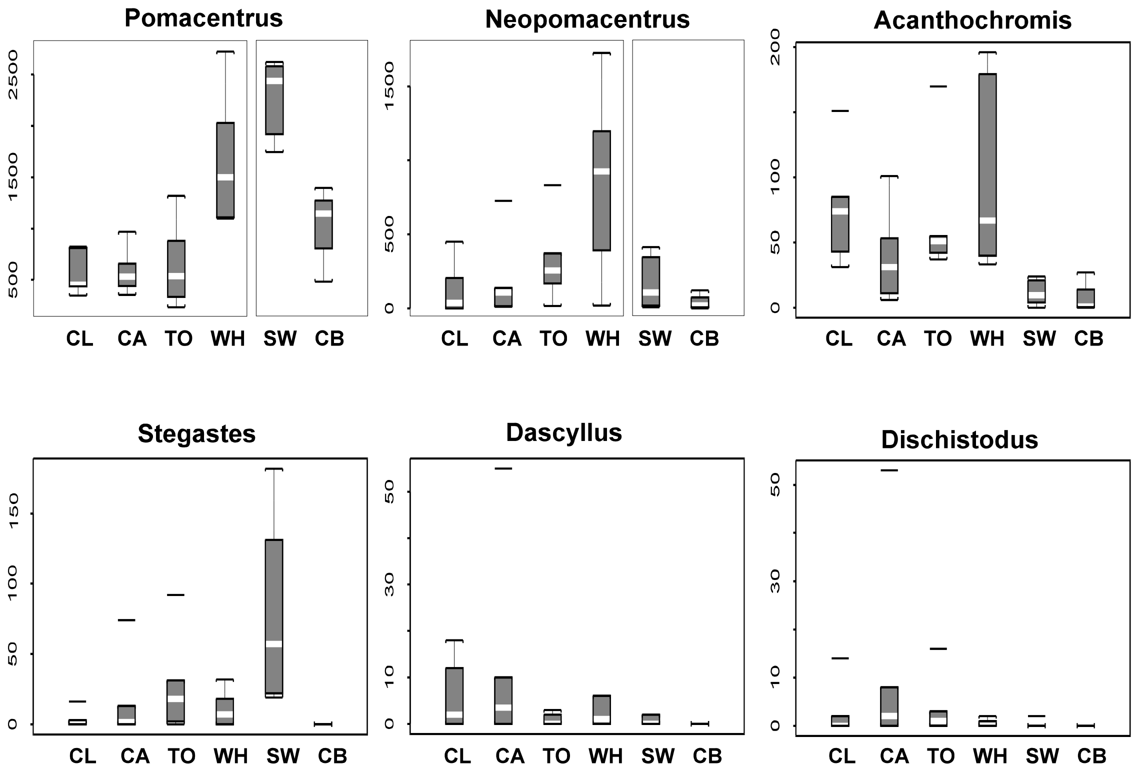


Figure 4.7. Boxplots for genera with significant sector effects. Where the Swain and Capricorn Bunker sectors are placed in a separate box, this indicates that they were not included in the analysis.

Interactions (Figure 4.8 & 4.9) (*where there is a significant shelf (or sector) effect, but only for some of the sectors (or shelf positions)*)

Family Patterns:

- **Labrids** were very low on inshore reefs in the Townsville sector;
- **Scarids** were low on inshore Townsville reefs, but high on outer reefs in the Cooktown /Lizard and Cairns sectors;
- **Zanclids** were very high at the outer reefs in the Cooktown/Lizard Is sector, and on mid-shelf reefs in the Townsville and Cooktown/Lizard Is sectors.

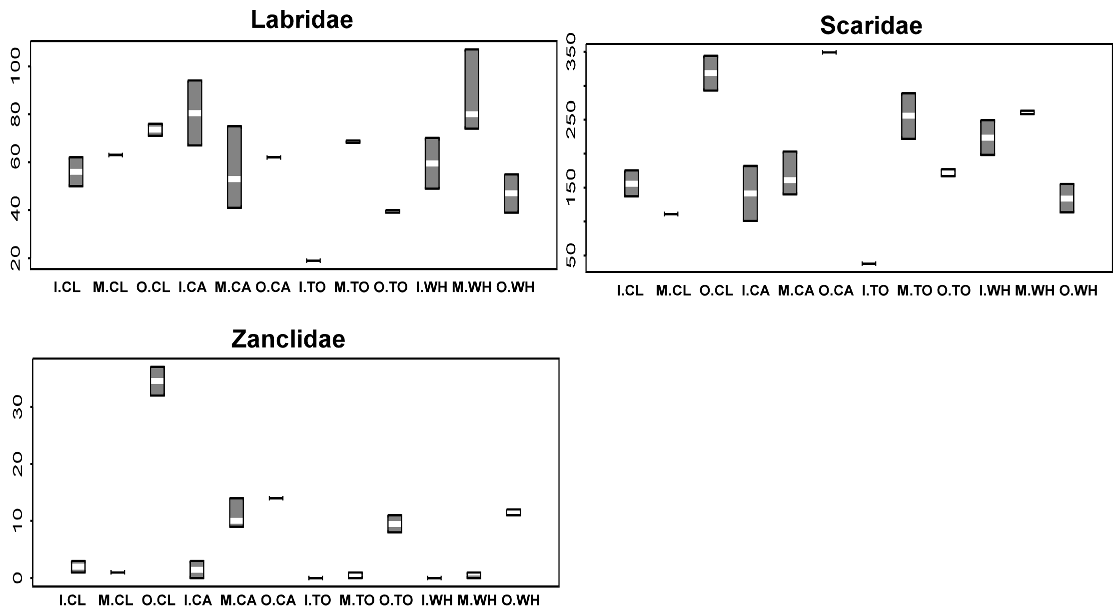


Figure 4.8 Boxplots for Families with significant interaction effects.

Genera (Pomacentrids):

- **Chrysiptera** was higher on outer reefs in the Cairns and Townsville sectors and on mid-shelf reefs in the Whitsunday sector;
- **Neoglyphidodon** was variable between reef and sector combinations, but particularly high on mid-shelf Townsville reefs.

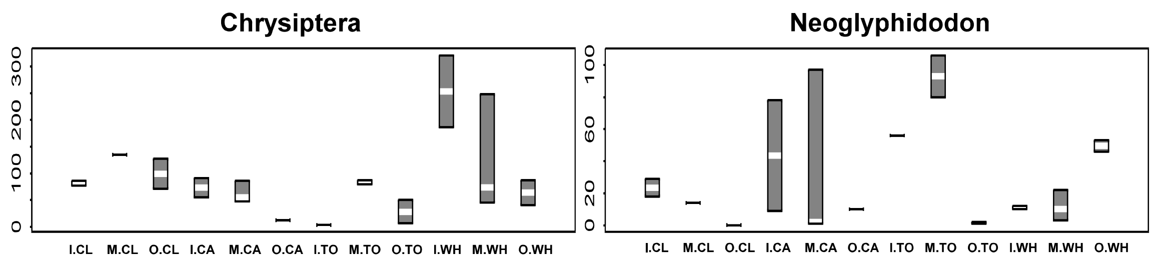


Figure 4.9. Boxplots for genera with significant interaction effects.

Variance and precision estimates at different sampling scales

Although reef averages are the primary unit for analysis and comparison in this program, it is useful to compare the amount of variation in the data which is accounted for, and the level of precision attributable to, means at the transect, site and reef level (see Figure 4.1 for a synopsis of the sampling design). Such a comparison can be used in conjunction with more detailed power analyses in order to determine where sampling effort should be focussed. In addition, it can provide ecological insights into the scale of patchiness and possible patch dynamics within the reef community.

The results of these calculations are presented in Table 4.5, and indicate that for most of the variables, the majority of the variation resides either at the reef level, or is split between the reef level and the transect level. By contrast there is comparatively little variation at the site level (.8-32%). This indicates that there is a high degree of uniformity between sites on a reef, but that abundance can vary considerably from transect to transect within a site, and also from reef to reef within a region. Values for coefficients of variation suggest that with the current sampling regime, estimates of means are least precise at the reef level.

Table 4.5. Estimated components of variance (PV, expressed as a % of total variance) and precision (expressed as CV) at the reef, site and transect level. PVs are the estimated components of variance at each level (reef, site and transect) expressed as a proportion of the total variance. SEMs are the standard errors of the mean at each level. CVs are SEMs divided by the overall mean.

		Sampling Level					
		Reef		Site		Transect	
Family	**Geometric Mean**	**PV**	**CV**	**PV**	**CV**	**PV**	**CV**
ACAN	106.2	81.0	19.7	8.2	11.4	10.6	8.9
CHAE	86.2	46.3	14.5	6.3	8.4	47.2	11.2
LABR	50.3	46.2	19.6	16.6	11.3	37.0	10.8
LETH	6.3	16.1	31.4	16.4	18.1	67.3	21.1
LUTJ	13.5	45.4	28.2	8.2	16.3	46.3	20.5
POMA	1720.6	59.3	10.4	15.6	6.0	24.9	5.3
SCAR	150.0	61.8	16.3	11.6	9.4	26.5	9.1
SERR	11.9	31.8	22.3	32.4	12.9	35.7	18.5
SIGA	20.8	34.7	22.1	32.0	12.7	33.2	18.1
ZANC	2.8	86.6	27.5	0.9	15.8	12.4	23.5
Genus							
ACN	27.1	53.3	30.9	17.1	17.8	29.5	15.6
AMB	22.0	64.7	32.1	11.9	18.5	23.2	16.9
AMP	1.9	10.9	35.9	6.5	20.7	82.5	30.4
CHR	47.9	63.2	36.1	9.8	20.8	26.9	21.5
CHY	39.2	54.9	26.5	11.3	15.3	33.8	16.2
DAS	1.3	12.6	66.3	31.0	38.3	56.2	34.3
DIS	0.8	51.8	42.3	0.8	24.4	47.2	40.4
NEG	10.3	47.8	39.9	21.6	23.0	30.5	18.7
NEO	86.4	48.7	42.5	15.9	24.5	35.3	23.5
PGY	8.7	73.3	27.5	3.3	15.8	23.3	21.0
POM	952.4	64.8	11.6	12.3	6.7	22.8	6.0
STE	5.2	53.3	23.6	20.3	13.7	26.3	23.6

Multivariate analyses

Symmetric biplot ordinations based on all 179 target species show a distinct separation of reefs in concordance with previously described cross shelf and latitudinal patterns in fish communities on the GBR (see Williams 1991). Cross shelf distinction of fish communities are highlighted in the first two dimensions of the column centred ordination (Figure 4.10(a)), while the latitudinal distinction is evident in the first and third dimensions (Figure 4.10(b)). There is some overlap between the outer and mid- shelf reefs, however further inspection of the outlying points reveals that they represent two Cairns sector mid-shelf reefs, Michaelmas and Hastings and

Box 4.2
Terms and Procedures Used in Multivariate Analyses

Column Centring
Column centring is achieved by subtracting the overall mean of a column, in a two-dimensional data matrix, from each variable in that column. This has the effect of reducing abundance differences due to columns. By column centring we are reducing overall abundance differences between the species groups and thus focusing on relative species abundance rather than absolute values. Column centring therefore prevents an abundant species group from dominating the results.

Symmetric biplots
Biplots graphically display the relationship of the rows (reefs) and columns (species) of a data matrix on a single two-dimensional plot. Each reef is represented by a point on the plot. If there were just two species in the data set, then the data could simply be plotted with two axes (species 1 against species 2). However, where there are 3 or more species, a plot of the raw data would involve three dimensional or multidimensional graphs. These are difficult, if not impossible, to represent on paper. Consequently the multivariate data are reduced to just two or more uncorrelated derived variables which are linear combinations of the original variables, and which have been calculated to account for the maximum amount of variability in the data. A symmetric biplot displays the data as a plot against the any two derived variables (usually the first two dimensions are plotted, thus displaying the most informative 2 dimensional view of a multidimensional distribution). In addition, a symmetric biplot, can show the relationships of the original variables to each other and indicates their role in explaining the observed spatial pattern. This is achieved by super-imposing vectors for the original variables (i.e. species) over the spatial pattern. In the case of column centred data the vectors will generally form an arc defining the gradient (direction) of greatest abundance. The length of a vector approximates the variability (standard deviation) of the associated species. Thus short vectors mean that the species is consistent in abundance between reefs and a long vector means that the species is highly variable between reefs. If a reef has a high abundance of a particular species, the reef point and species vector are far away from the origin and in the same direction. If a reef has a low abundance of a particular species, the reef point and species vector are in opposite directions and far apart. Reef points close to the origin represent reefs which have typical abundances of all species or taxonomic groupss. Reefs which are close together on the symmetric biplot have a similar "profile" i.e similar proportions of most species.

The angle between two vectors represents the correlation between the two species that the vectors represent. Thus if the angle between them is small (0°) the species are highly correlated, if large (180°) the species are negatively correlated and if at right angles (90°) the species are uncorrelated.

Confidence ellipses
Confidence ellipses (a two-dimensional analogue of univariate confidence intervals) highlight spatial patterns on a symmetric biplot of an a priori known grouping of reefs. The confidence ellipses are constructed so that, if the data are multivariate normal, the ellipse will contain ~80% of the points. In the monitoring data such groupings are spatially related reefs; inner, mid and outer shelf reefs and northern, central and southern sectors of the Great Barrier Reef.

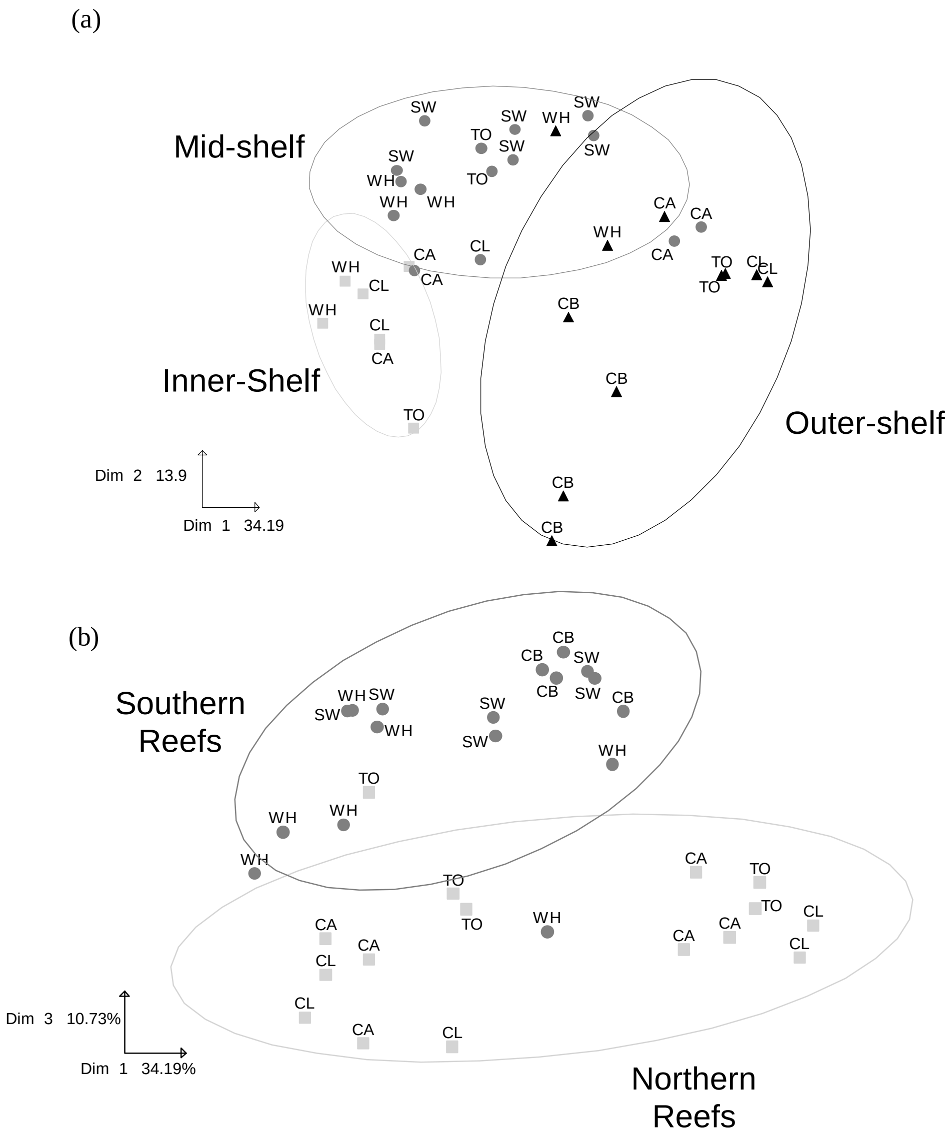
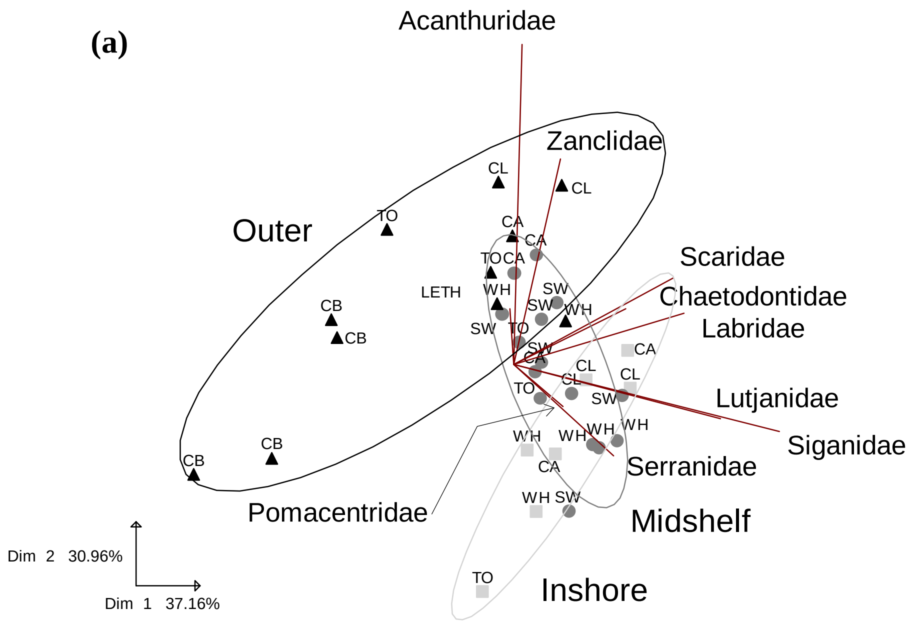


Figure 4.10. Spatial distribution of reefs from biplots of log transformed, column centred data of all 179 species surveyed. The ellipses cover 80% confidence limits of each reef and highlight reefs grouped together according to (a)shelf position ■ = Inner-shelf, ● = Mid-shelf, ♦ = Outer-shelf and (b) longitudinal position ■ = Northern sector, ●= Southern sector.

one Whitsunday outer-shelf reef, 19-159. Of these it can be argued that Michaelmas and Hastings Reefs are the most exposed to open ocean influences of any of the reefs classified as mid-shelf, hence their position in the ordinations. Another feature highlighted by Figure 4.10(a) is the distinct nature of the fish communities on reefs in the Capricorn Bunker sector.

Determining key factors responsible for the observed patterns required a reduction of the number of variables in the ordination. As such the data was pooled to the family level which reduced the number of variables from 179 to 10. The symmetric biplots at the family level (Figure 4.11) revealed similar spatial patterns to those described by the species level data set (compare Figure 4.10 and 4.11). As with the ordination for all species the first and second dimensions of the column centred family data highlights the separation of communities by shelf position. The latitudinal separation however is more strongly displayed using double centred data suggesting the



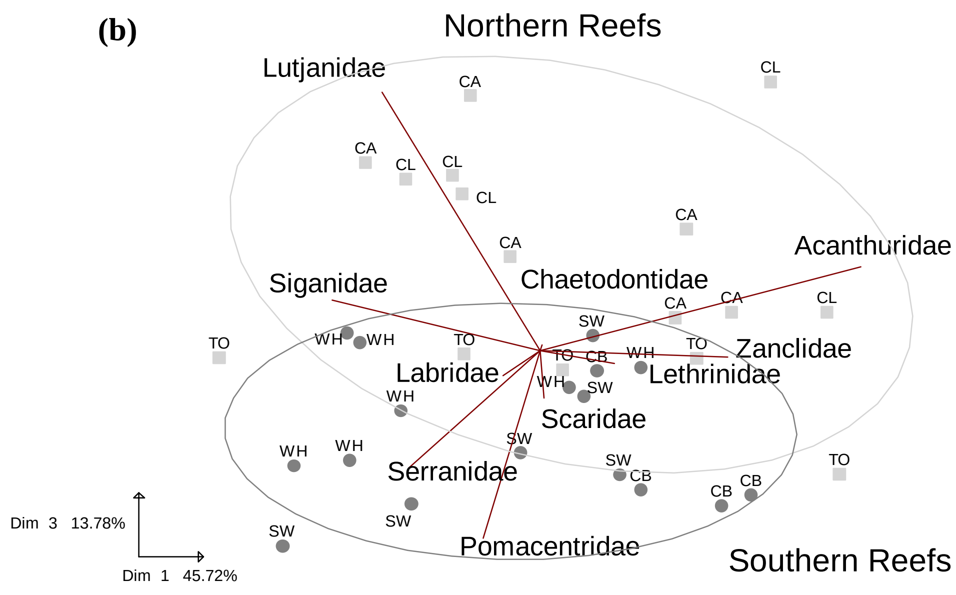


Figure 4.11. Biplots of log transformed (a) column centred (1st v 2nd dimensions) and (b) double centred (1st v 3rd dimensions) data of all families surveyed. The ellipses cover 80% confidence limits of each reef and highlight reefs grouped together according to (a) shelf position ■ = Inner-shelf, ● = Mid-shelf, ♦ = Outer-shelf and (b) longitudinal position ■ = Northern reefs, ● = Southern reefs.

separation is due to differences in the relative proportions of families rather than overall abundances.

The direction and magnitude of the vectors in Figure 4.11a highlight differences between shelf positions which can also be directly observed in histograms of the raw data (Figure 4.2) and in the univariate analyses. Figure 4.11a shows large vectors for Acanthuridae and Zanclidae in the direction of the outer-shelf reefs and vectors for Siganidae, Lutjanidae and Serranidae in the direction of inner-shelf and Whitsunday mid-shelf reefs suggesting relatively high abundances of these families in these areas. From Figure 4.2 it can be seen that the abundance of Acanthuridae follows a gradient across shelf positions from a low on inner-shelf reefs to a high on the outer-shelf reefs. In contrast, the abundances of Siganidae and Lutjanidae follow a reverse trend with highest numbers on inner-shelf reefs.

As with shelf position, latitudinal differences between fish communities highlighted by the symmetric biplot can be seen in univariate data. Figure 4.11(b) shows that the family profiles of reefs in the northern section differ from those in the southern section with southern reefs having a higher proportion of the community comprised of Serranids and Pomacentrids. Figure 4.3 shows the relatively low overall abundance of Pomacentrids in the Cooktown/Lizard Is, Cairns and Townsville sectors as opposed to the Whitsunday and Swain sectors. Figure 4.2 shows the opposite relationship with relatively high overall abundances of families counted along 10 m wide transects on the northern reefs. The exceptions being Serranids and Scarids which are proportionally higher on southern reefs.

The striking feature of the biplots is the separation of the Capricorn Bunker reefs from the other surveyed reefs. Inspection of Figure 4.2 indicates that this is due to the relatively depauperate nature of fish communities in the Capricorn Bunker sector. Abundance in this sector is considerably lower for all families included in surveys of 10 metre x 50 metre transects (Figure 4.2). This is also the case with the Pomacentridae (Figure 4.3) except for the *Pomacentrus* genus which has comparable abundance to other sectors. Of the reefs surveyed in the CB, Wreck Island and One Tree Island have the lowest overall abundances.

Temporal comparison of spatial patterns

The 2-way ANOVA results for proportional changes in abundance and species richness (Table 4.6) indicate that on mid-shelf reefs there were significant differences among families for both species richness and abundance, but no differences among sectors. Figure 4.12 shows that during the most recent surveys, there were disproportionately more species of Scarids and Pomacentrids and more individuals of Pomacentrids (compared with other families).

For outer-shelf reefs, there were no differences among families, but highly significant differences among sectors (Table 4.6). Both species richness and abundances were disproportionately smaller in the Capricorn Bunker secotr compared with the surveys from the early 1980's (Figure 4.13).

Table 4.6. Results of 2-way analysis of variance testing for sector and family effects. ***** indicates significant effect at $\alpha = 0.05$.

		Abundance		Species Richness	
	D F	**F value**	**P**	**F value**	**P**
Outer-Shelf					
Sector	3	13.092	0.001*	17.494	<.001*
Family	3	0.917	0.471	3.121	0.081
Error	9				
Mid-Shelf					
Sector	4	0.649	0.639	0.311	0.865
Family	3	4.982	0.018*	9.046	0.002*
Error	12				

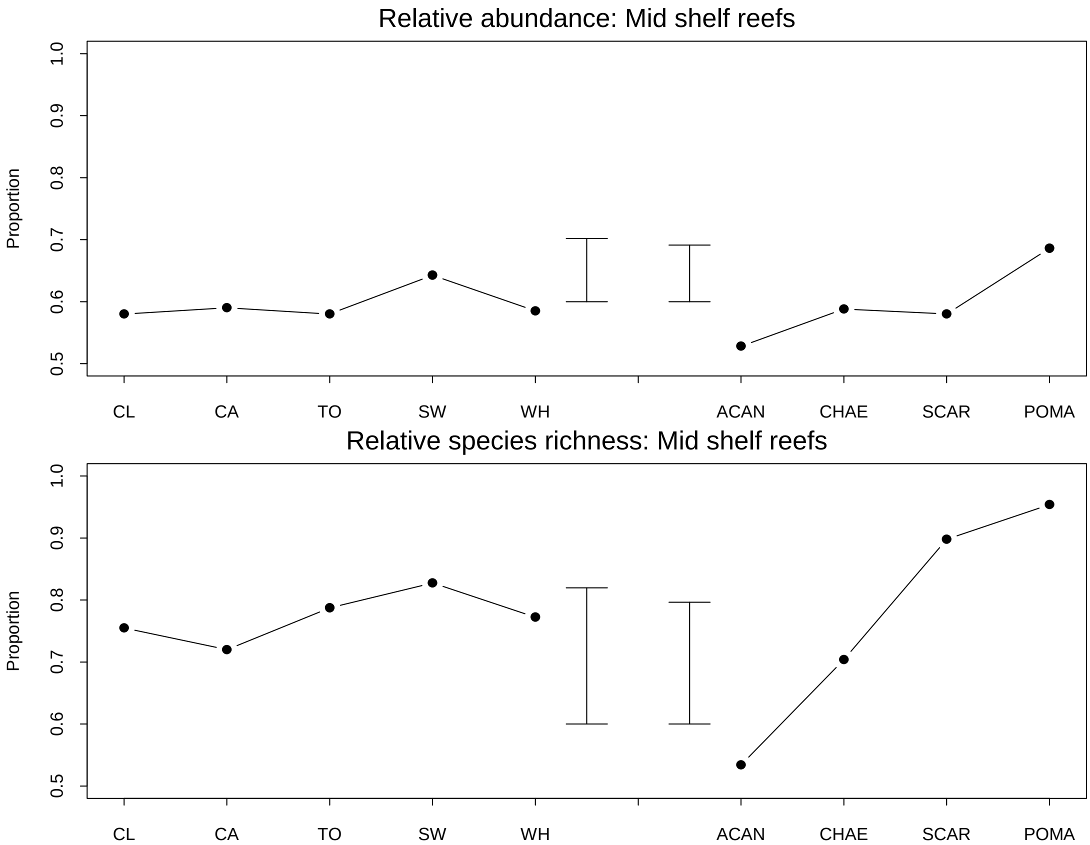


Figure 4.12. Proportional change in abundance and species richness between early 1980's (Williams, unpub.) and early 1990's (current surveys) on mid-shelf reefs. Differences in proportional change among different sectors are shown on the left. Differences among families are shown on the right. Abbreviations for sectors and families are described in Tables 4.1 &4.2. Error bars indicate Least Significant Differences at p=.05 for sectors (left) and families (right).

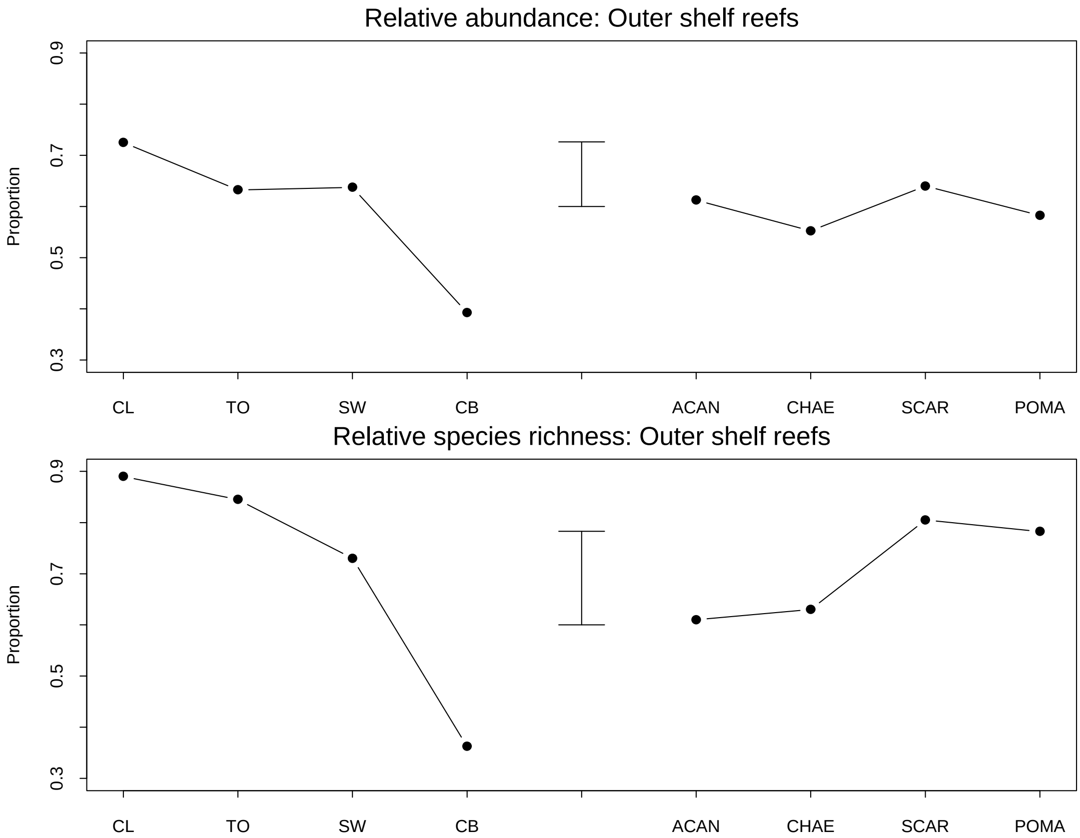


Figure 4.13. Proportional change in abundance and species richness between early 1980's (Williams, unpub.) and early 1990's (current surveys) on outer-shelf reefs. Differences in proportional change among different sectors are shown on the left. Differences among families are shown on the right. Abbreviations for sectors and families are described in Tables 4.1 & 4.2. Error bars indicate Least Significant Differences at p=.05 which were identical for both sector and family.

Discussion

In this section we have documented the baseline conditions for fish abundances at 33 reefs distributed over most of the length and breadth of the Great Barrier Reef. While the primary purpose of subsequent reports will be to report on changes from these baseline conditions, some aspects of the spatial distribution patterns in the present data warrant brief discussion.

The results indicate that there are significant cross-shelf and latitudinal differences in fish numbers for some species, which showed a broad correspondence with trends previously described by other researchers Williams (1982, 1986), Williams & Hatcher (1983) and Russ (1984).

Both cross-shelf and latitudinal effects were also evident in multivariate analyses, which demonstrated that reefs in similar regions exhibit similarities in faunal composition. These similarities were most striking at the species level, but were also discernible at the family level, where a comparison with the univariate results showed that the species showing statistically significant cross-shelf or sector effects were generally the ones responsible for creating the patterns seen in the biplots. Although higher taxonomic groupings are useful to describe broad scale patterns they may mask some important distributional information contained at the species level. This is particularly true for taxa such as *Neopomacentrus* in which the two commonly abundant species have quite distinct distributions with relation to shelf position. As such the grouping at genera level can mask the effects of such taxa in determining pattern. This problem is compounded with the application of higher taxonomic groupings. Thus, in future analyses, the use of species data will probably provide the most sensitive measure of change through time.

We also grouped species into trophic categories (Williams & Hatcher 1983) but no obvious spatial patterns were found, however the importance of trophic structure in community studies cannot be overlooked (Bellwood & Choat 1990) and this aspect will be further investigated in future years.

Because this is the first year of the Long Term Monitoring Program, it is not possible to examine temporal trends. However, a comparison of the results from surveys conducted by Williams in the early 1980's does indicate that some changes may have occurred over the last decade. In particular, the Capricorn Bunker sector exhibited disproportionately fewer individuals and species compared with other sectors. Although the analysis is not capable of determining if this effect was caused by an actual decrease in abundance in the Capricorn Bunker sector, anecdotal reports on fish numbers from the area clearly indicate that this has indeed been the case. In the early 1980's, the fish diversity and abundance on the Capricorn Bunker reefs were among the highest in the GBR (Williams, D. & Doherty, P. 1994, pers. comm.), whereas the present results indicate that they are among the lowest.

The results for both the other univariate and multivariate analyses also highlight the depauperate nature of the fish communities in the Capricorn Bunker sector. In line with the reduced fish community abundances and species richness, there has also been a marked decline in coral cover. Within the areas surveyed hard coral cover estimates are as low as 5% (Christie *et. al.,* chapter 5), down from a high of 70% or more during the early to mid 1980's (Williams, D. & Doherty, P. 1994, pers. comm.). The exact nature and timing of the gross destruction of habitat can only be surmised as there was an eighteen month hiatus in surveys of the Capricorn Bunker sector between November 1987 and October 1989 (Miller *et al*. 1991). A preliminary investigation of weather records does not indicate any storm events of abnormal intensity. Crown-of-thorns starfish have never been present in numbers sufficient to cause such large scale change and there have been no records of coral disease or bleaching events which could explain the reduction in coral cover. It has been at least 5 years since the habitat change occurred and, for the most part, the habitat remains devoid of any structural complexity. However recent manta tow data shows that coral cover is slowly increasing (Bass *et al.* 1993, Bainbridge *et al.* 1994).

The unexplained changes in the reef community in the Capricorn Bunker sector highlight the need for long-term monitoring of the reef environment to provide a greater understanding of natural levels of variability. The speed and extent to which benthic and fish communities react to such large scale disturbances is poorly known. However ongoing studies by AIMS of communities following *Acanthaster* outbreaks, and the continued monitoring of the Capricorn Bunker sector will help to increase our understanding of such perturbations.

5. Corals & Sessile Benthos

C. Christie, S. Neale, W. Oxley, K. Osborne, T. Done, G. De'ath & J. Oliver

Introduction

The objectives and general design of the AIMS Long-term Monitoring Program are described in Chapter 1. This chapter presents the results of surveys for corals and other macro-benthic organisms conducted on reefs during 1992-93. The results are preliminary in the sense that only one year of data is available for analysis and because only 34 of the 52 reefs selected for monitoring have been surveyed. The aims of this preliminary analysis, therefore, are to:

1. Summarise the baseline condition at each of the surveyed reefs
2. Describe patterns and/or trends among reefs grouped according to their cross-shelf and north-south position.

Although referred to as "coral" data because of the pre-eminent importance of hard corals for reef growth and their frequent dominance of the reef surface, the data also include estimates of abiotic substrata, and other major space occupants on the reefs, notably algae, sponges and soft corals.

This report presents two synoptic analyses of the data: univariate analyses (ANOVA) and multivariate analyses (ordination). Both analyses are used to look for patterns of differences and similarities among reefs in different sectors and cross-shelf positions. Subsequent reports will describe changes from these initial baseline conditions.

It should be re-emphasised that the term "reef", as used in this report, actually refers to the study area on each reef. Any generalisations and conclusions resulting from analysis of the benthic data set are therefore only directly pertinent to the middle reef slope on the north-east flanks of reefs.

Methods

Study Sites

The basic design of the monitoring program, including which reefs have been selected for annual monitoring, and which of these were surveyed during 1992-93 are presented in Chapter 1 and Table 1.2. In summary, 34 reefs were surveyed in 1992-93. At each surveyed reef 3 permanent sites were set up on the north-eastern end of reefs. At each site 5 permanently marked, 50 metre transects were set up haphazardly along the 6-9 metre depth contour. The transects were marked with a star picket at each end with reinforcing rod every 10 metres along the transect.

Sampling technique

For corals, the aim is to resolve inter-annual and longer term change at various spatial scales down to the individual 50 m transect. Each transect is filmed annually along a ~0.25 m wide swathe using a down-pointing video camera (~25-30 cm above the substrate). Abundance (percent cover) of corals and other benthic categories (Table 5.1) are estimated using a point sampling technique (after Carleton & Done, 1994). The data are then entered into an ORACLE™ database using software developed at AIMS. Details of the video survey and sampling techniques used in the AIMS LTMP can be found in Christie & Neale (in press). The video tape is paused every 9 seconds, and the identity of the organism or substratum type lying beneath each of 5 points marked on the video monitor was recorded. Corals are identified to the greatest taxonomic detail achievable by the observers. All benthic records are subsequently assigned to two different benthic grouping schemes: "benthic group" and "benthic life form" as shown in Table 5.1.

This sampling strategy has been tested extensively and found to be cost-effective and equivalent in performance at the benthic group level to more randomised or more regular distributions of points on the screen (Christie & Mapstone, in prep). Approximately 200 points are sampled from each video transect and the percentage cover of benthic organisms is determined. The resultant data can be extracted from the database at various classification levels; benthic group, benthic life form, and hard coral family, genus and species. As a pilot

Table 5.1. Benthic group and life form codes used in multivariate and univariate analysis.

BENTHIC GROUP	Code	BENTHIC LIFE FORM	Code
Abiotic	AB		
Soft coral	SC	Soft coral	SC
Hard coral	HC	Branching Encrusting Foliose Massive Sub-massive Solitary mushroom Branching *Acropora* spp. Tabulate *Acropora* spp. Encrusting *Acropora* spp. Corymbose *Acropora* spp.	CB CE CF CM CS CMR ACB ACT ACE ACO
Macro algae	MA	Macro algae *Halimeda* spp.	MA HA
Turf algae	TA	Turf algae	TA
Coralline algae	CA	Coralline algae	CA
Sponge	SP	Sponge	SP
Other	OT	*Millepora* spp.	CME
Indeterminate	IN		

study for this project, the video sampling technique was compared with more conventional line intercept transect techniques. The results showed that the video technique returned similar estimates of percentage cover at the benthic group level (Oxley, in prep). Despite the potential for the introduction of “noise” by minor differences in the path followed by the video-camera, the sampling strategy gives very precise estimates of benthic cover (Davidson, in prep). There were no significant differences in mean, standard deviation, or precision of estimates of percent hard coral cover between multiple estimates from a single video pass, and 1 estimate each from multiple passes. It was concluded that, at the scale of the 50 m video belt transect, the differences in estimates of percent coral cover caused by minor differences in the path of successive video surveys are negligible, and may be ignored.

Data handling and processing:

Univariate analyses

Analysis of variance was used to investigate whether any of the variation in estimates of benthic biota and substrata at the scale of the reef were systematically related to the geographic location of the reef i.e. shelf position (inner, middle and outer), or latitudinal sector (Cooktown/Lizard Island, Cairns, Townsville, Whitsunday, Swain or Capricorn Bunker). An initial ANOVA with both shelf position and sector as main effects, and reefs and sites nested within shelf position and sectors was conducted (Figure 5.1). Reefs from the Capricorn Bunker and Swain sectors were excluded from this analysis as these sectors contained reefs in only one shelf position. The resulting data set was still unbalanced with respect to reef numbers for shelf position and sector (Table 5.2). Benthic organisms and substrates which were clearly not significantly related to shelf position or the interaction between shelf position and sector were then analysed using a single factor nested ANOVA with sector as the main factor. To be conservative we used $p>0.2$ as the critical value for non-significance rather than the usual value of $p>0.05$. This second design allowed incorporation of reefs from the Swain and Capricorn Bunker sectors and

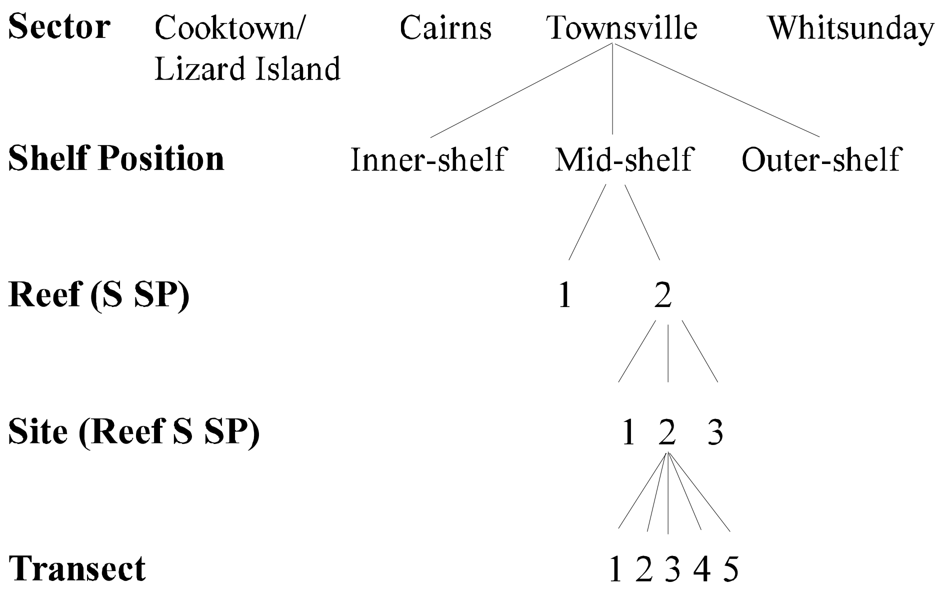


Figure 5.1. Outline of sampling design for ANOVA model one. Parentheses indicate a nested term. Sector and Shelf Position are treated as fixed orthogonal terms and reef and site are regarded as random. The second ANOVA model (not shown) is similar except that shelf position has been removed from the model and the Swain and Capricorn Bunker sectors have been added.

Table 5.2 Numbers of reefs sampled in each sector and cross-shelf position. Sector codes are: CL - Cooktown/Lizard Island; CA - Cairns; TO - Townsville; WH - Whitsunday; SW - Swain; CB - Capricorn Bunker

	CL	CA	TO	WH	SW	CB
Inner	2	2	2	2		
Mid	1	3	2	3	6	
Outer	2	1	2	2		4

the investigation of sector effects over all sectors. Separate analyses were conducted for each "benthic group": turf algae, coralline algae, macro algae, abiotic, hard coral, soft coral and sponge. Data were not transformed, but for coralline algae, macro algae and sponges, the analyses were weighted to account for the variances of cells being proportional to the mean (i.e. unequal variances). Thus observations were weighted by 1/(cell means) to give equal effective weight to observations.

Multivariate analyses

Several data matrices were subjected to multivariate analyses to seek spatial patterns in benthic community structure. The rows of each matrix corresponded to mean values for individual reefs (3 sites on the NE flanks of reefs), while each column represented a different classification level. Five separate analyses were carried out using the different benthic groupings listed in Table 5.1 (benthic group, benthic life form).

Reefs were chosen as the basic unit for the multivariate analysis (as opposed to sites or transects) because a preliminary cluster analysis showed strong similarities between sites within reefs relative to the variation between reefs (see also Table 5.4) and because in this first year of the program we were most interested in groupings and affinities between reefs.

The data for the multivariate analyses were the percentage cover estimates at each reef surveyed. The data matrices used are shown in Appendix 5. A $\log_{10}(x + 0.01)$ transformation was applied to the data matrix prior to analysis. The resulting data matrices were then column centred. Data are displayed graphically as symmetric biplots and confidence ellipses (see Box 5.2).

Results

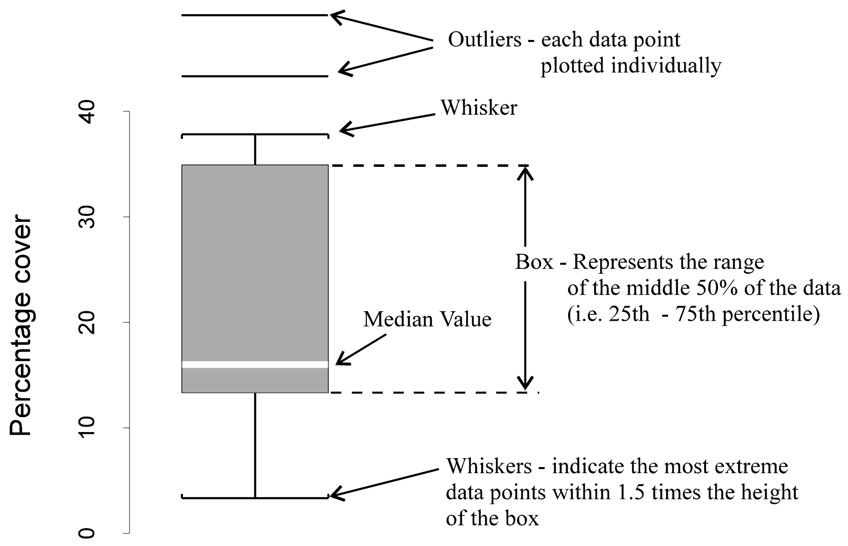
Summary results

All transects contained a mixture of benthic organisms and non-living substrates (i.e. muds, sands, gravels, rubble). Overall, the mean percentage cover of living benthos ranged from ~80% (inshore) and ~90% (mid-shelf) to nearly 100% (outer reefs).

Box 5.1 Anatomy of a Boxplot

Background

Boxplots have proven to be quite a good exploratory tool, especially when several boxplots are placed side by side for comparison. The most striking visual feature is the box which shows the limits of the middle half of the data. The line inside the box represents the median and the upper and lower lines of the box denote the 75th and 25th percentiles; thus the box contains 50% of the data. The whiskers which extend from the box are drawn to the nearest value not beyond a standard span from the quartiles; points beyond (outliers) are drawn individually. The standard span is 1.5 times the Inter-Quartile Range (75%ile - 25%ile). Extreme points are also highlighted by lines beyond the whiskers. Boxplots not only show the location and spread of data but indicate skewness, as well.



The abundances of all benthic organisms were highly variable (Figure 5.2, Appendices 5.1& 5.2). Hard coral cover usually averaged between 20 - 30% across all reefs within a sector (with the exception of the Capricorn Bunker sector). Reef averages ranged from 59% at one of the Swain Reefs to 4% at one of the Capricorn Bunker reefs. There was up to 80% cover of turf algae among the sparse corals of the Capricorn Bunker reefs, whereas more usual values in all other sectors were around 30%. Macro algae averages were never >8%, and only six reefs exceeded 10%. Reef averages for soft corals were never >15% but were extraordinarily variable among reefs, regardless of sector (e.g. range in the Whitsunday sector was 3% to 42%).

Average percentage cover estimates for each benthic group plotted according to sector and shelf position are shown in Figure 5.2. A full set of graphs showing summary statistics at the reef level for all surveyed reefs is shown in Appendix 5 (see Box 5.1 for a guide to the interpretation of boxplots). Inspection of these graphs suggests the following general trends:

- turf algae and hard coral are major constituents of most of the reefs, although these and other components show considerable variability between reefs and sector/shelf combinations;
- turf algae are clearly the single most dominant component at the Capricorn Bunker reefs and are particularly abundant on the Cairns inner and mid-shelf reefs;

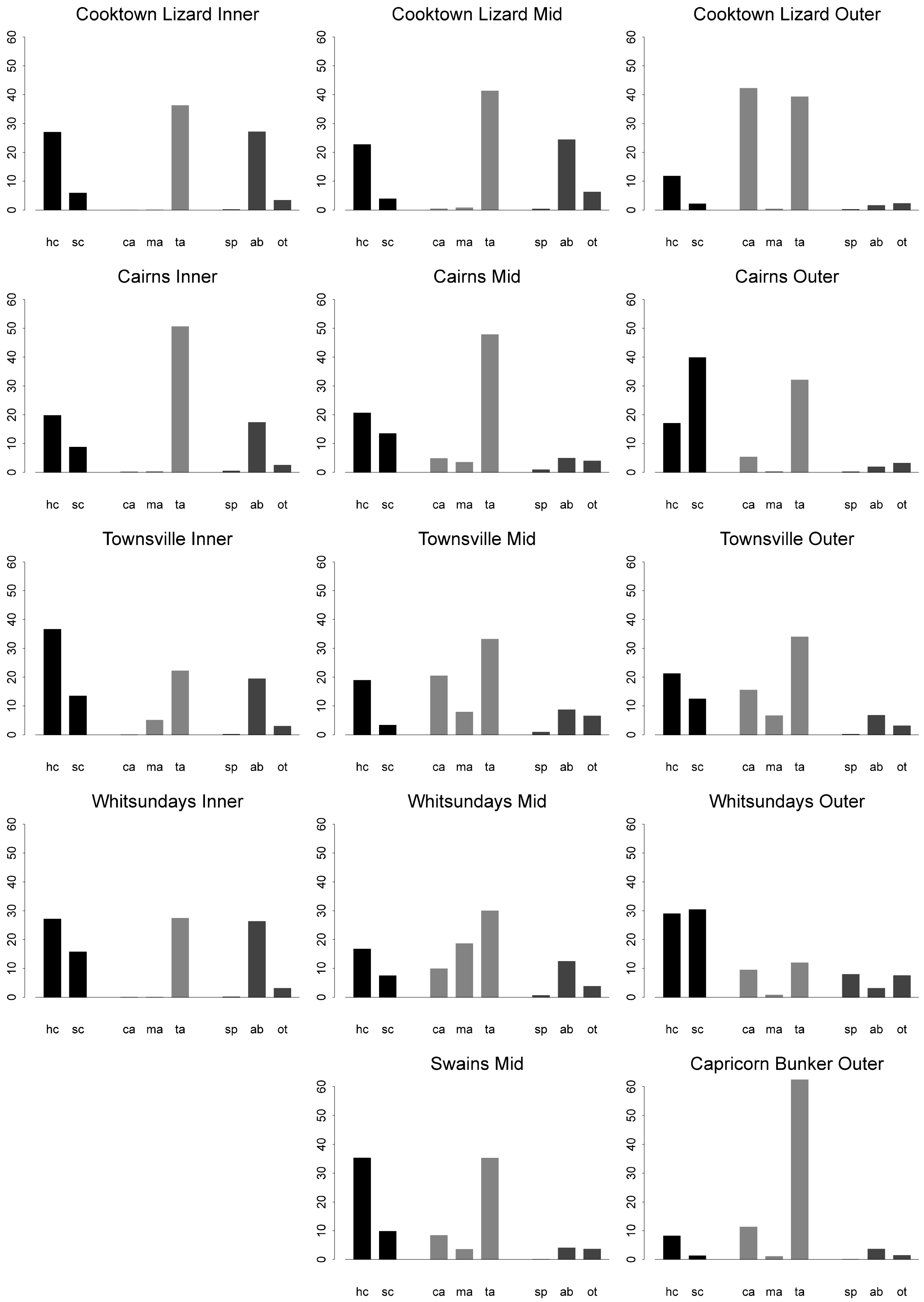


Figure 5.2. Average percentage cover for different benthic groups at each combination of sector and cross-shelf position. hc - hard coral; sc - soft coral; ca - coralline algae; ma - macro algae; ta - turf algae; sp - sponge; ab - abiotic; ot - other.

- coralline algae are dominant only at the two outer reefs in the Cooktown/Lizard Island sector and are virtually absent from the inshore reefs.

Univariate analyses

Table 5.3 summarises the results of the first ANOVA in which both sector and cross-shelf position are tested. Summary statistics for differences which were statistically significant are shown in Figures 5.3-5.5. Hard corals and turf algae did not exhibit any shelf position effects, nor any interaction between sector and shelf position. These groups were therefore re-analysed using pooled values for shelf position, and with the Swain and Capricorn Bunker sectors added to the analysis. The results of this analysis are shown in Table 5.3 and Figure 5.4. The statistically significant results from these analyses are summarised below, together with comments on the patterns indicated in the graphs of summary statistics.

Table 5.3. Two-way analysis of variance of reef means for 8 benthic groups from 24 reefs assessing cross-shelf position (I,M,O) and sector (CL,CA,TO,WH). P values are highlighted in bold if P<0.05 and if (for main effects) the corresponding interaction term is non-significant.

	Effect					
	IMO		Sector		IMO by Sector	
Variable	$F_{(2,12)}$	*P*	$F_{(3,12)}$	*P*	$F_{(6,12)}$	*P*
AB	6.59	**0.011**	0.79	*0.524*	0.39	*0.870*
CA	54.52	*<0.001*	8.65	*0.002*	9.91	**<0.001**
HC	1.47	*0.269*	0.46	*0.713*	0.74	*0.631*
MA	4.23	**0.041**	4.47	**0.025**	1.51	*0.255*
OT	6.67	*0.011*	1.78	*0.204*	5.09	**0.008**
SC	5.01	**0.026**	4.02	**0.034**	1.76	*0.191*
SP	18.31	*<0.001*	12.80	*<0.001*	7.53	**0.002**
TA	1.10	*0.362*	4.00	**0.035**	0.86	*0.548*
Analysis for all 6 sectors (pooled shelf position)						
			$F_{(5,28)}$	*P*		
HC			3.49	**0.014**		
TA			12.29	**<0.001**		

Shelf Position Effects: (Figure 5.3)

- **Abiotic** substrate exhibited a trend with high levels inshore and low levels offshore;
- **Macroalgae** were slightly more abundant on mid-shelf reefs. Inspection of the raw data indicated that this was caused by high cover of the green calcareous alga *Halimeda;*
- **Soft coral** was slightly lower on mid-shelf reefs and highest and most variable on outer- shelf reefs.

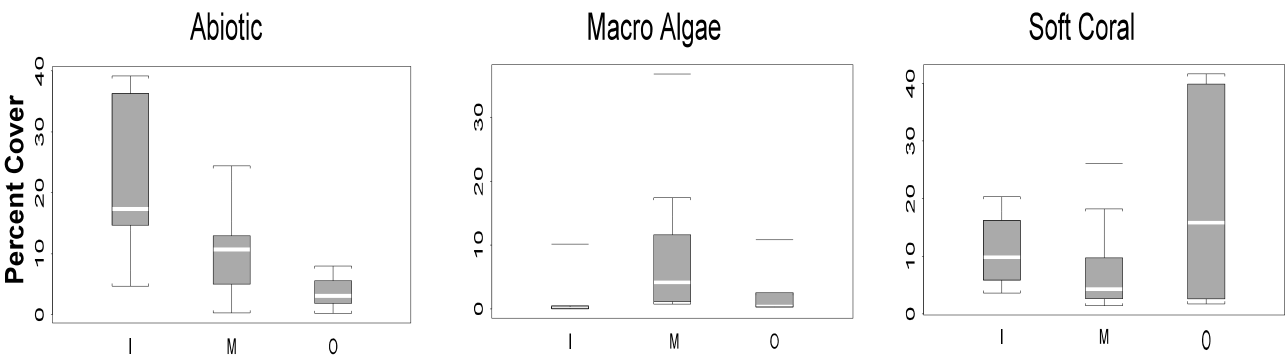


Figure 5.3. Mean values for benthic groups with significant shelf position effects.

Sector Effects: (Figure 5.4)

- **Macroalgae** had higher and more variable cover in the Townsville and Whitsunday sectors;
- **Soft coral** was consistently low at all reefs in the Cooktown/Lizard Island sector and (although not included in the ANOVA) also at the Capricorn Bunker sector;
- **Turf algae** was consistently highest in the Capricorn Bunker sector;
- **Hard coral** was lowest in the Capricorn Bunker sector compared to the other sectors.

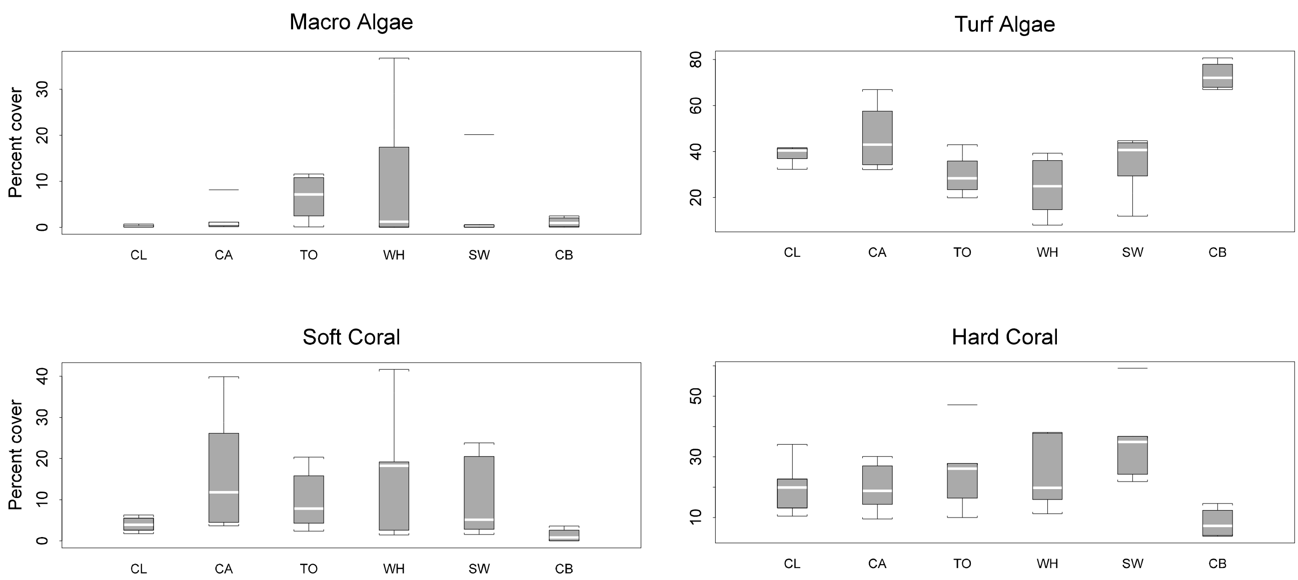


Figure 5.4. Mean values for benthic categories with significant sector effects. Results for macro algae and soft coral include means for the Swain and Capricorn Bunker sectors for visual comparison. However they were not included in the ANOVA because cross shelf effects could not be pooled for these variables (see Table 5.3).

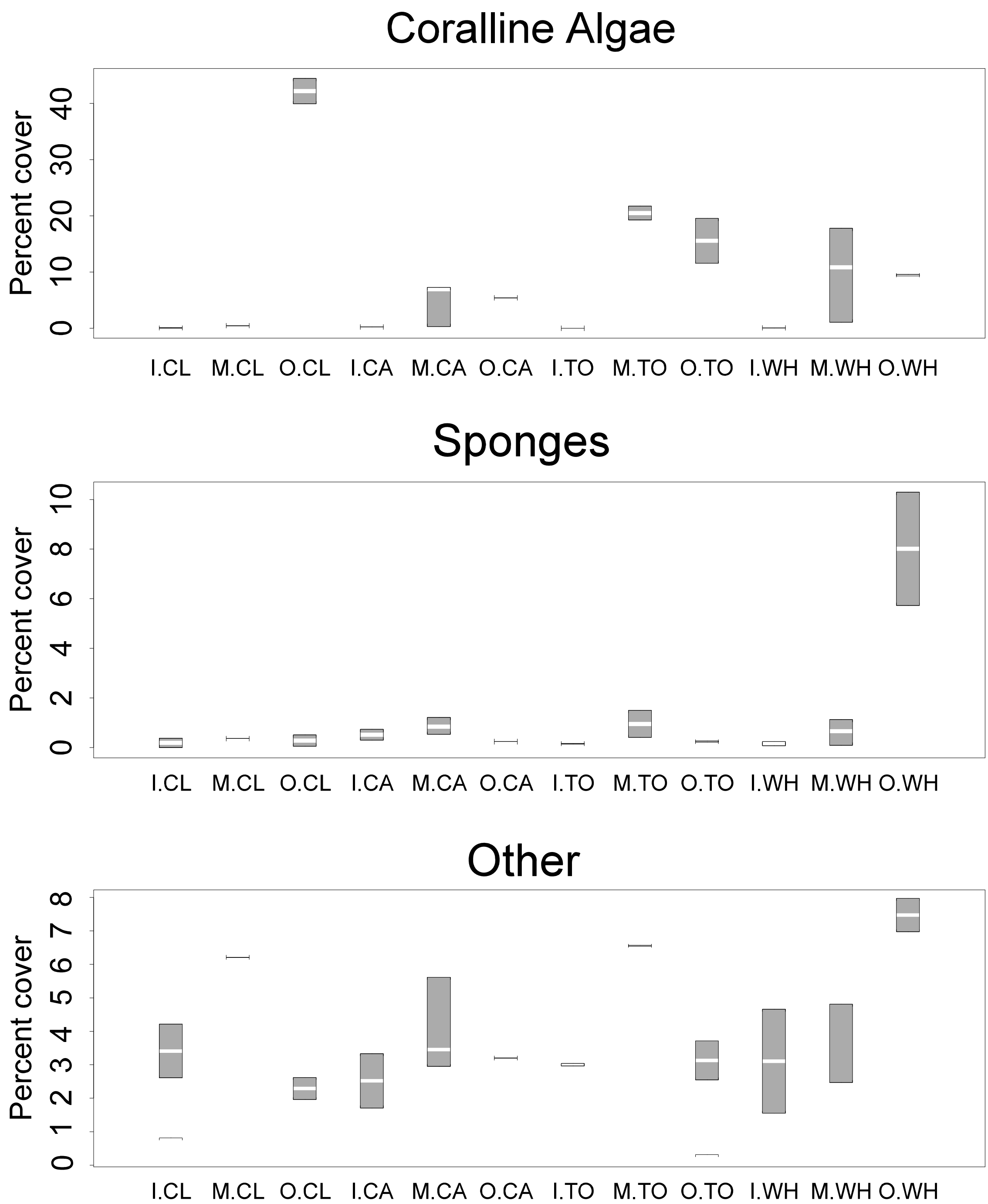


Figure 5.5. Mean values for benthic categories with significant interaction between sector and shelf position. Label for x axis indicate cross-shelf position to the left of the period (I=inner, M-mid, O=outer) and sector to the left of the period (see Table 5.1 for sector abbreviations).

Interactions: (Figure 5.5) (*where there is a significant shelf (or sector) effect, but only for some of the sectors (or shelf positions)*)

- **Coralline algae** were very high on the outer-shelf - but only in the Cooktown/Lizard Is Sector. Although not statistically significant for all sectors, Figure 5.2 suggests that there was also a shelf-position effect, with coralline algae being virtually absent from the inshore reefs, and present in variable quantities on mid-shelf and offshore reefs.

- **Sponges** were comparatively much higher on outer-shelf reefs in the Whitsunday's, although absolute cover was only between 6% and 10%;
- **Other Organisms** were high at the outer Whitsunday reefs, and on mid-shelf reefs in the Townsville and Cooktown/Lizard Island sectors.

Variance and precision estimates at different sampling scales

Although reef averages are the primary unit for analysis and comparison in this program, it is useful to compare the amount of variation in the data which is accounted for, and the level of precision attributable to, means at the transect, site and reef level (see Figure 5.1 for a synopsis of the sampling design). Such a comparison can be used in conjunction with more detailed power analyses in order to determine where sampling effort should be focused. In addition, it can provide ecological insights into the scale of patchiness and possible patch dynamics within the reef community.

The results of these calculations (Table 5.4) indicate that for all variables except sponges and "other", the majority of the variation (56-80%) occurs at the level of the reef. This indicates that differences between reefs tend, on average to be greater than the differences between sites within a reef, or transects within a site. In other words, most organisms exhibit a fair degree of uniformity within a reef, but can vary considerably from reef to reef. Of the two exceptions, sponges were normally uncommon but were very high on just a few transects on 2 reefs (note enormous CV at transect level). The "other" category probably contains a heterogenous mix of organisms showing high variability between transects. Values for standard errors and coefficients of variation suggest that with the current sampling regime, estimates of means are most precise at the reef level. In proportion to their mean values, hard coral and turf algae were measured the most precisely for estimates at the reef scale (CVs of 16.0% and 11.1% respectively).

Table 5.4. Estimated components of variance (PV, expressed as a % of total variance) and precision (expressed as SEM and CV) at the reef, site and transect level. PVs are the estimated components of variance at each level (reef, site and transect) expressed as a proportion of the total variance. SEMs are the standard errors of the mean at each level. CVs are SEMs divided by the overall mean.

		Sampling Level								
		Reef			Site			Transect		
Variable	Mean	PV	SEM	CV	PV	SEM	CV	PV	SEM	CV
AB	9.95	56.2	3.73	37.5	17.3	6.47	64.9	26.5	7.00	70.3
CA	9.46	80.9	2.14	22.6	8.1	3.71	39.1	11.0	3.83	40.5
HC	22.91	65.1	3.67	16.0	15.1	6.36	27.7	19.8	6.48	28.2
MA	3.99	68.8	2.21	55.3	15.0	3.82	95.7	16.2	3.61	90.3
OT	3.64	26.0	0.97	26.6	17.2	1.68	46.1	56.8	2.37	65.0
SC	10.44	69.3	2.87	27.4	12.3	4.97	47.6	18.4	5.33	51.0
SP	0.78	47.7	0.60	76.8	5.3	1.03	133.1	47.0	1.84	237.7
TA	38.80	74.2	4.32	11.1	11.4	7.49	19.3	14.4	7.53	19.4

Multivariate analyses

Although analyses were carried out for several different levels of benthic groupings ("benthic group", "benthic life form", coral family, genus and species) only those results for benthic group and life form are presented here since these were the only ones which returned obvious differentiation of shelf position. None of the analyses exhibited any tendency to cluster according to sector (i.e. latitude).

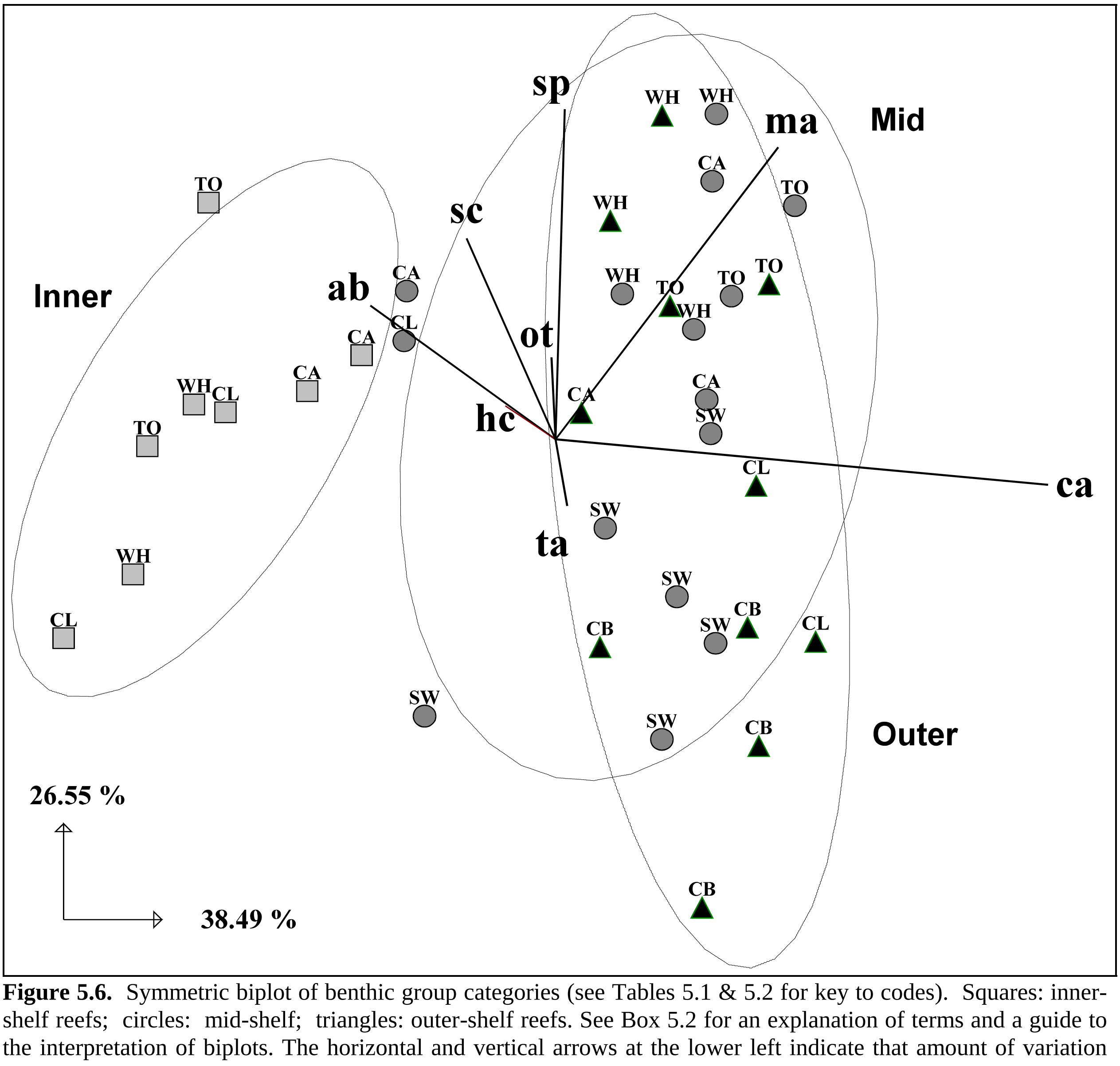


Figure 5.6. Symmetric biplot of benthic group categories (see Tables 5.1 & 5.2 for key to codes). Squares: inner-shelf reefs; circles: mid-shelf; triangles: outer-shelf reefs. See Box 5.2 for an explanation of terms and a guide to the interpretation of biplots. The horizontal and vertical arrows at the lower left indicate that amount of variation explained by the first and second dimensions respectively of the biplot.

Figure 5.6 shows the result of the ordination for benthic group data. It is clear that the inner-shelf reefs form a distinct group from the mid and outer-shelf reefs. Inspection of the vectors for each variable indicates that this differentiation is a result of higher values

Box 5.2
Terms and Procedures Used in Multivariate Analyses

Column Centring
Column centring is achieved by subtracting the overall mean of a column, in a two-dimensional data matrix, from each variable in that column. This has the effect of reducing abundance differences due to columns. By column centring we are reducing overall abundance differences between the species groups and thus focusing on relative species abundance rather than absolute values. Column centring therefore prevents an abundant species group (e.g. branching Acropora) from dominating the results.

Symmetric biplots
Biplots graphically display the relationship of the rows (reefs) and columns (species) of a data matrix on a single two-dimensional plot. Each reef is represented by a point on the plot. If there were just two species in the data set, then the data could simply be plotted with two axes (species 1 against species 2). However, where there are 3 or more species, a plot of the raw data would involve three dimensional or multidimensional graphs. These are difficult, if not impossible, to represent on paper. Consequently the multivariate data are reduced to just two or more uncorrelated derived variables which are linear combinations of the original variables, and which have been calculated to account for the maximum amount of variability in the data. A symmetric biplot displays the data as a plot against any two derived variables (usually the first two dimensions are plotted, thus displaying the most informative 2 dimensional view of a multidimensional distribution). In addition, a symmetric biplot, can show the relationships of the original variables to each other and indicates their role in explaining the observed spatial pattern. This is achieved by super-imposing vectors for the original variables (i.e. species) over the spatial pattern. In the case of column centred data the vectors will generally form an arc defining the gradient (direction) of greatest abundance. The length of a vector approximates the variability (standard deviation) of the associated species. Thus short vectors mean that the species is consistent in abundance between reefs and a long vector means that the species is highly variable between reefs. If a reef has a high abundance of a particular species, the reef point and species vector are far away from the origin and in the same direction. If a reef has a low abundance of a particular species, the reef point and species vector are in opposite directions and far apart. Reef points close to the origin represent reefs which have typical abundances of all benthos. Reefs which are close together on the symmetric biplot have a similar "profile" i.e similar proportions of most species.

The angle between two vectors represents the correlation between the two species that the vectors represent. Thus if the angle between them is small (0°) the species are highly correlated, if large (180°) the species are negatively correlated and if at right angles (90°) the species are uncorrelated.

Confidence ellipses
Confidence ellipses (a two-dimensional analogue of univariate confidence intervals) highlight spatial patterns on a symmetric biplot of an a priori known grouping of reef. The confidence ellipses are constructed so that, if the data are multivariate normal, the ellipse will contain ~80% of the points. In the sessile benthic data such groupings are spatially related reefs; inner, mid and oute- shelf reefs and northern, central and southern sectors of the Great Barrier Reef. Confidence ellipses indicating reefs from the northern, central and southern sectors of the Great Barrier Reef are not included in this report as no patterns were highlighted.

for abiotic substrate and lower values for coralline algae on inner-shelf reefs. This supports the results of the univariate analysis (Figures 5.2 & 5.5)

The analysis of the benthic life form data (Figure 5.7) also indicated a differentiation between reefs based on cross-shelf position. Inner-shelf reefs again form a distinct group (together with one mid-shelf reef in the Swain sector - Gannet Cay). In this plot the stronger differentiation between mid and outer-shelf reefs is caused by higher values for coralline algae (CA), encrusting *Acropora (ACE)*, and macro algae (MA).

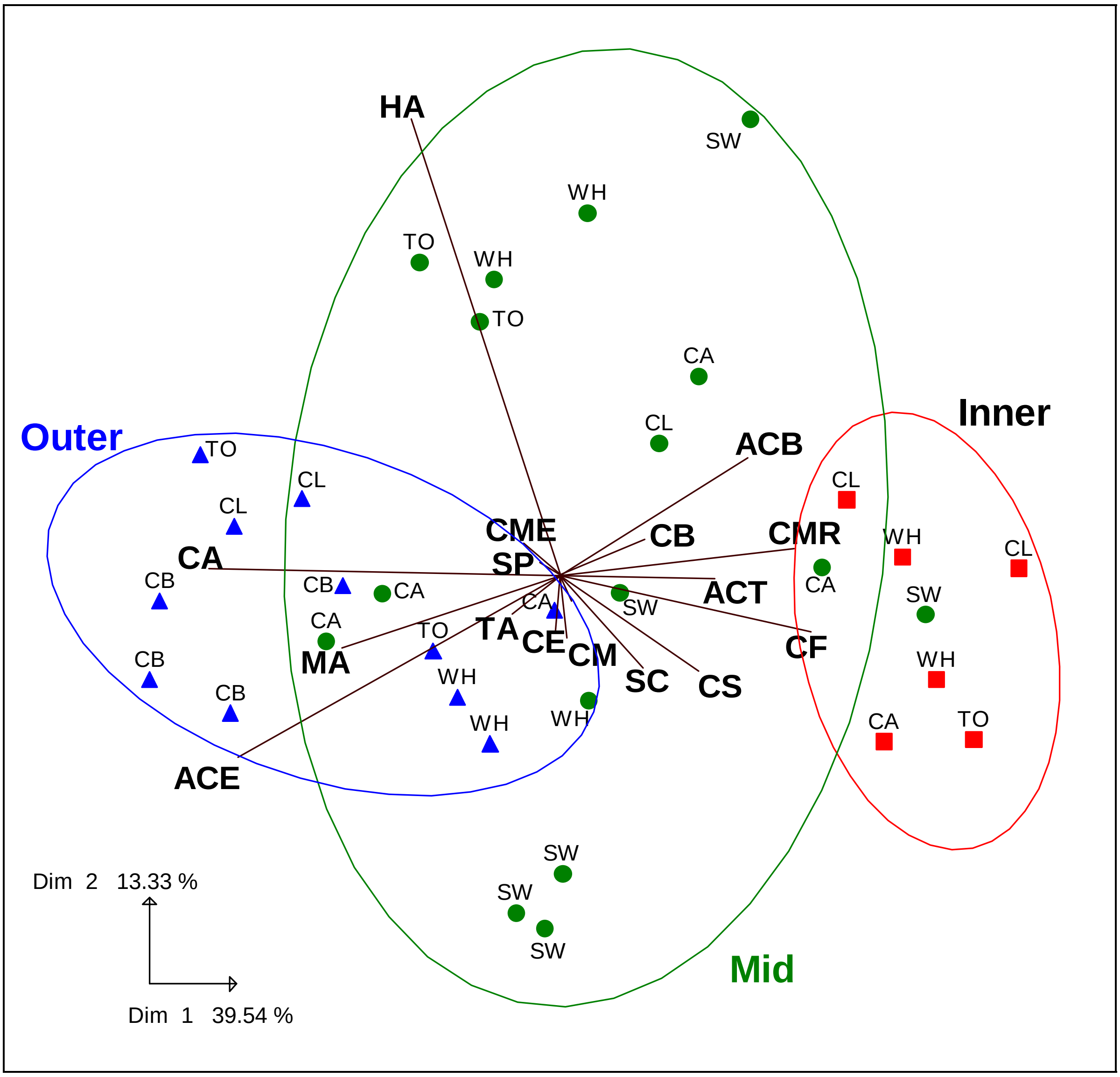


Figure 5.7. Symmetric biplot of benthic life form categories (see previous figure for key to codes). The two arrows at the lower left indicate that amount of variation explained by the first two dimensions of the ordination.

Discussion

The most important result of this first year of benthos monitoring is that there now exists a set of well defined baseline conditions for the NE flanks of 34 reefs. It is the changes through time in these reefs (and the remaining survey reefs established in 1993-94) which will form the primary focus for discussion in future reports. There are, however some statistically significant spatial patterns among the surveyed reefs which warrant a brief discussion.

The univariate analyses demonstrated a number of significant effects for different factors (i.e. sector and shelf position) and different benthic groups. While the ecological importance of some of these results, though statistically significant, is either minor or obscure, the patterns revealed for hard coral, turf algae, coralline algae and abiotic substrates are noteworthy because they reflect substantial differences in cover values.

Abiotic substrata were most abundant on inshore reefs (~23%) and decreased away from the coast to a low of 3.6% on offshore reefs. This was the only major unequivocal change detected between inshore and offshore reefs, and may be a result of the tendency of many inshore reefs to lack a consolidated, well colonised reef slope. Instead such reefs are often a mix of hard reef substrate and large patches of sand and/or soft sediment. Although this pattern might at first seem to be a structural difference between inshore and offshore reefs, which is unlikely to change over ecological time scales, certain corals such as arborescent *Acropora* are able to colonise sediment zones if other physical factors such as light, water quality and water motion are favourable and thus substantially increase the proportion of hard substrate over a decadal time scale. In contrast, if conditions are unfavourable for coral growth, the effects of bioerosion, and severe episodic storms and cyclones, can increase the amount of abiotic sedimentary deposits on a reef. Thus the proportion of abiotic substrate on a reef may prove to be a relevant variable for long-term monitoring of reef status and possible anthropogenic effects.

Coralline algae also exhibited a cross-shelf effect, with virtually zero cover on inshore reefs compared to variable cover on mid-shelf and outer-shelf reefs. However this effect was not significant for all sectors. Outer-shelf reefs in the Cooktown/Lizard Is sector (Yonge and Carter Reefs) had the highest overall cover of coralline algae (40-44%). This pattern is consistent with numerous other studies of coral communities which suggest that reefs subject to high level of wave exposure have high cover of crustose coralline algae (Wells, 1957; Littler, 1972; Littler & Doty, 1975).

The most striking pattern among the sectors was the low level of hard coral and high level of turf algae in all of the reefs in the Capricorn Bunker sector compared to all the other sectors. Hard coral averaged about 10% in the Capricorn Bunker sector compared with 18-35% in other sectors. On the other hand, turf algae accounted for approximately 73% of the benthic cover in the Capricorn Bunker sector compared with only 24-46% for the rest of the GBR. Long-term observations on COTS and coral cover using the manta-tow technique have shown that there was a major reduction in coral cover in the Capricorn Bunkers sector during the late 1980's (Miller *et al.* 1991) which was not associated with COTS activity or any major cyclones. Coral cover recorded during these surveys has remained low since 1989. However, the high values for encrusting *Acropora* in this sector (Figure 5.7) are due to large numbers of juvenile branching or tabulate *Acropora* spp (C.C. pers. obs.), which suggests that recovery is occurring. The results for the fish monitoring (Chapter 4) also showed that fish populations have also been affected. While the causes of these changes are not known, the Monitoring Program will play an important role in documenting the rate and nature of any recovery on these reefs.

The main outcome of the multivariate data analysis was the clear differentiation of all inshore reefs from mid and outer-shelf reefs. This separation was evident in analyses based on both benthic group and life form. The only anomaly to this pattern was Gannet Cay in the Swain reefs, which clustered with the inner-shelf reefs on the life form analysis due to its cover of branching corals. In a more comprehensive study of coral communites in the Townsville sector, Done (1982) also found that inner-shelf reefs were clearly distinct from mid and outer-shelf reefs in term of species composition and abundance.

In this report, all analyses have been carried out on groupings of organisms which are not based on detailed taxonomic criteria. Both “benthic group” and “benthic life form” classifications are based on a mixture of taxonomic levels and morphological differences. Time constraints have precluded more detailed analyses, but in future reports, analyses will also be conducted on pure taxonomic groups and a comparison of the advantages and disadvantages of various grouping schemes will be undertaken.

In conclusion, the first year of the Monitoring Program has provided detailed baseline information on specific habitats on 34 different reefs, and has shown that major differences in benthic communities can be detected and quantified. Future reports will document baseline conditions on the remaining reefs and analyse subsequent changes (if any) through time. In addition, ongoing methodological and quality control studies will investigate the effectiveness of the current design to estimate benthic cover with both accuracy and precision, and to detect ecologically or managerially relevant changes with maximum power and efficiency.

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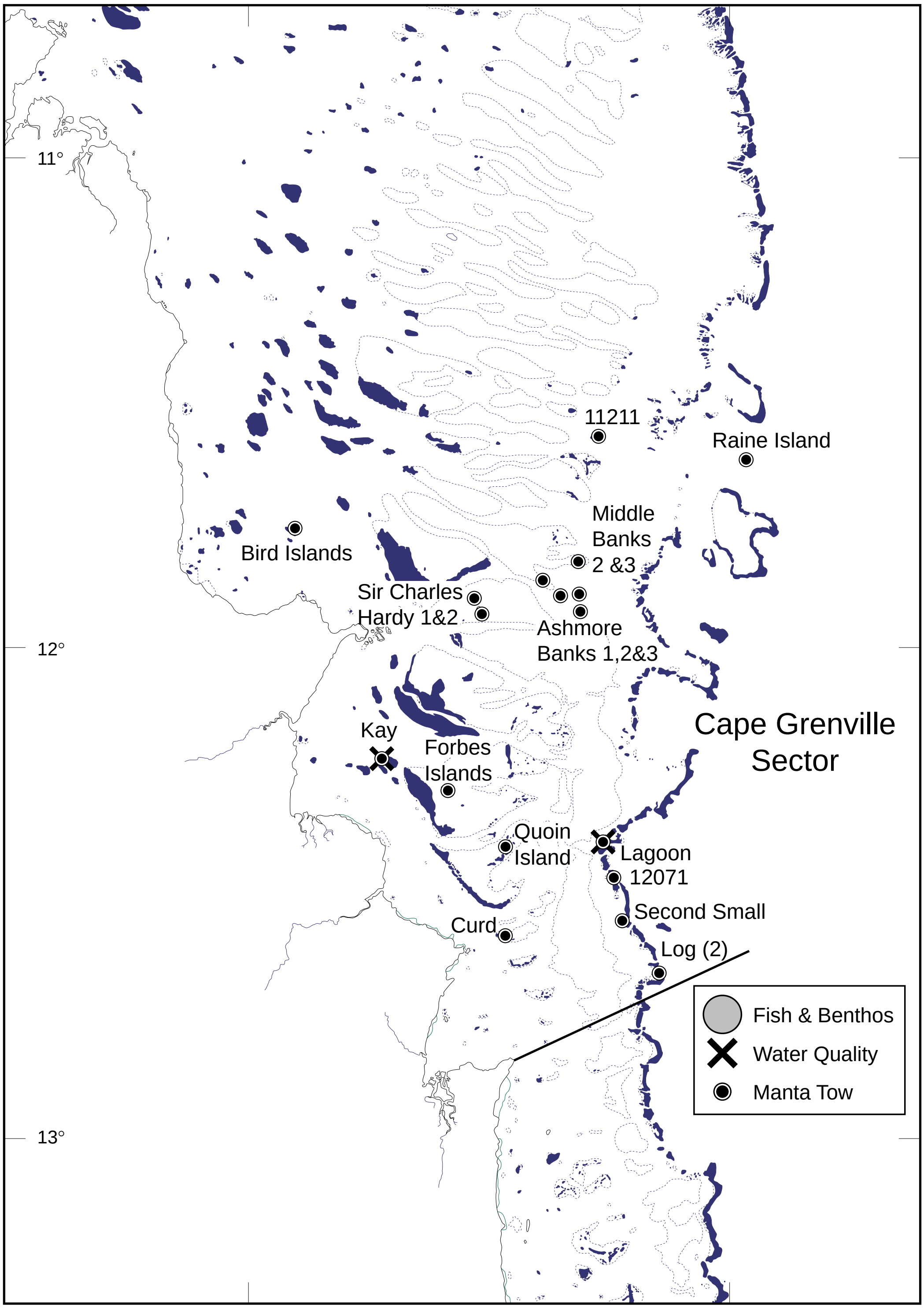
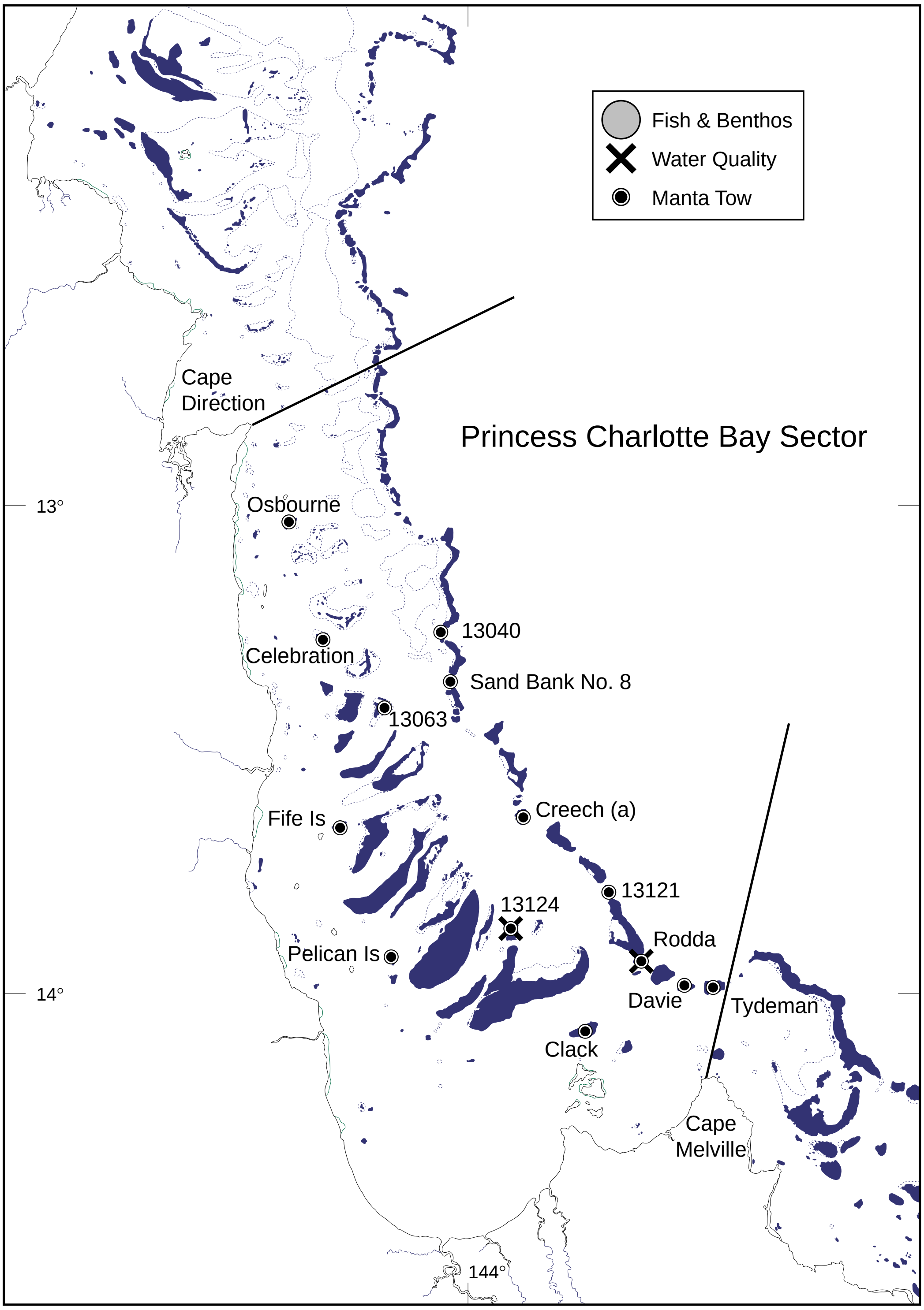
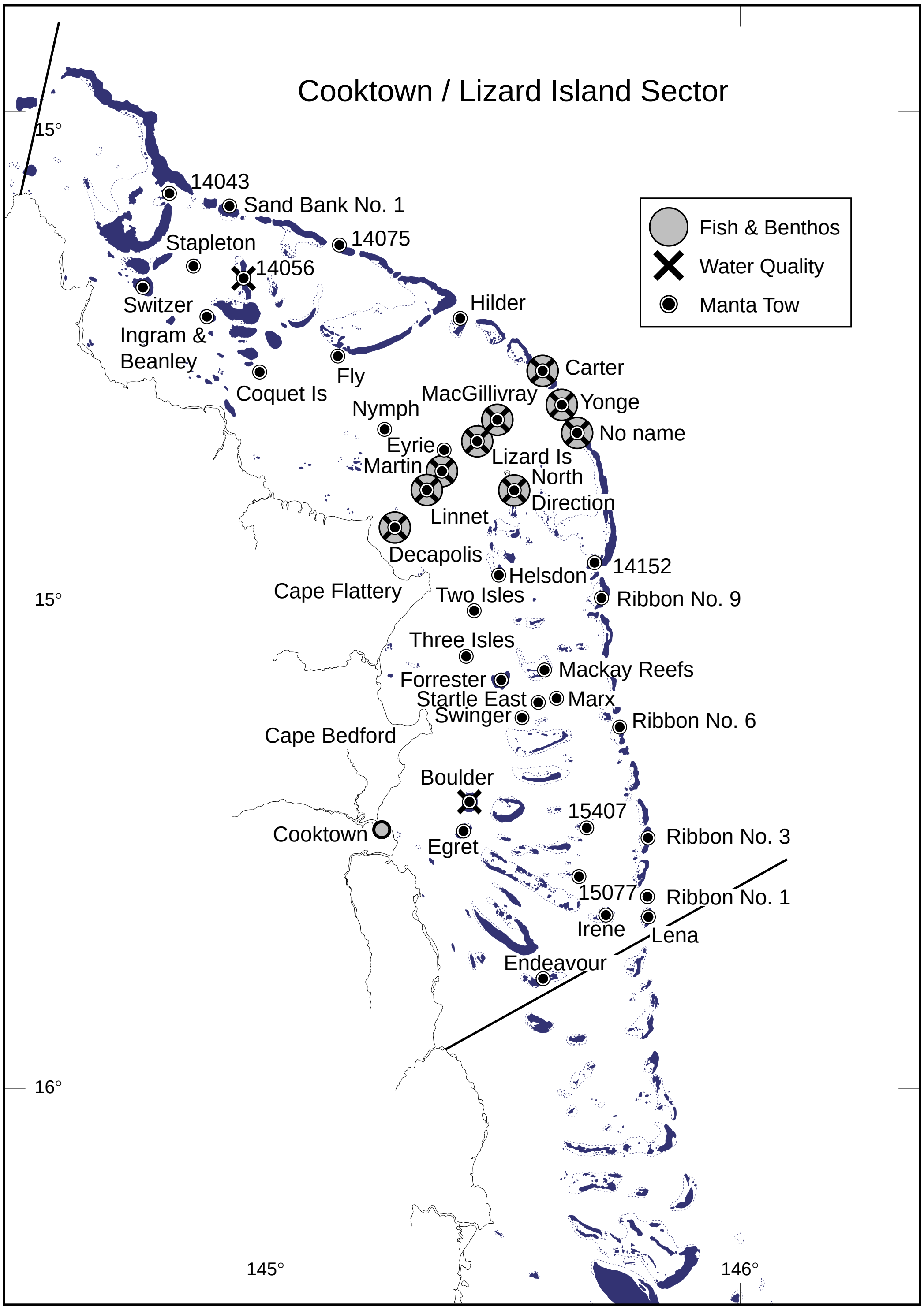
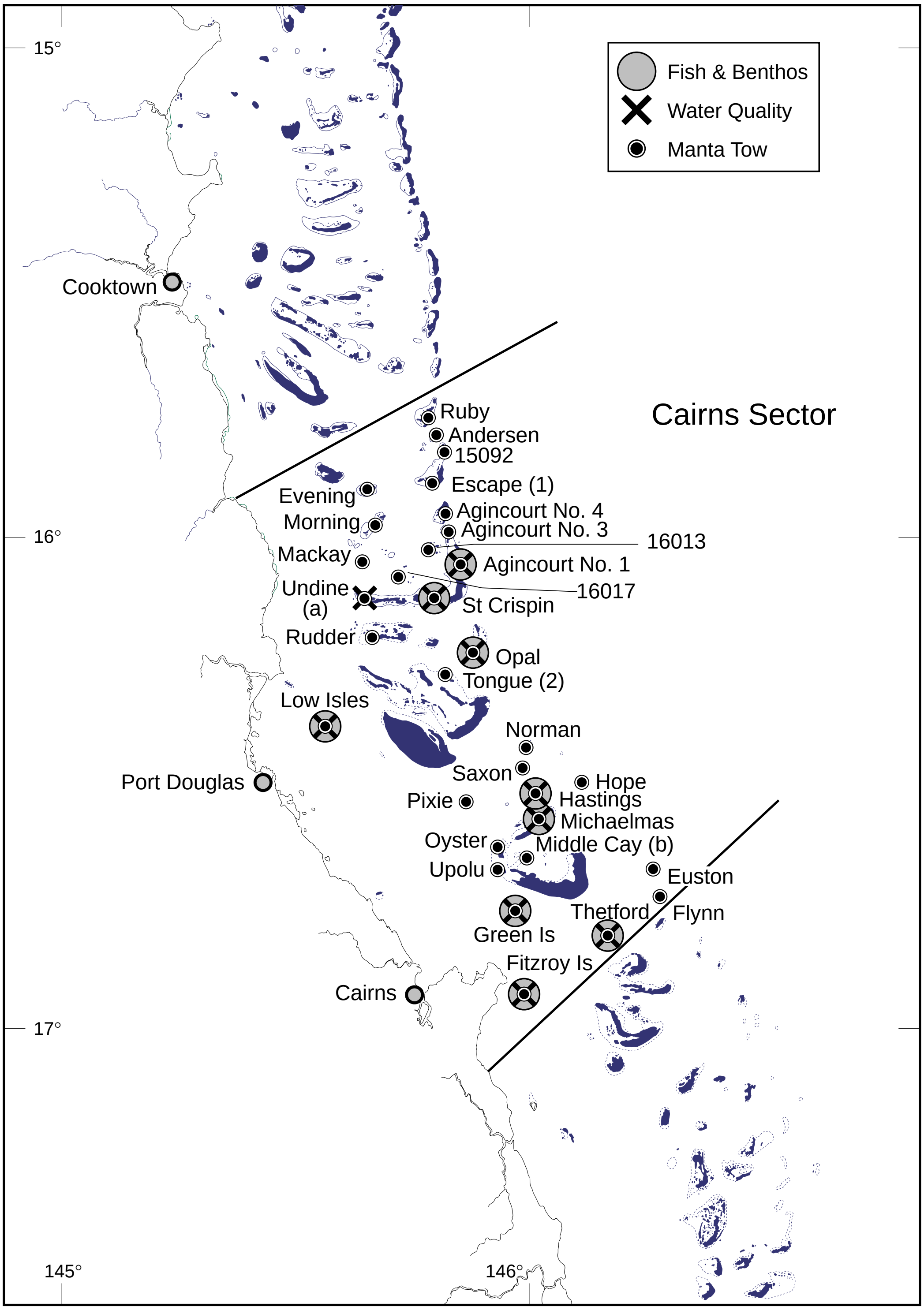
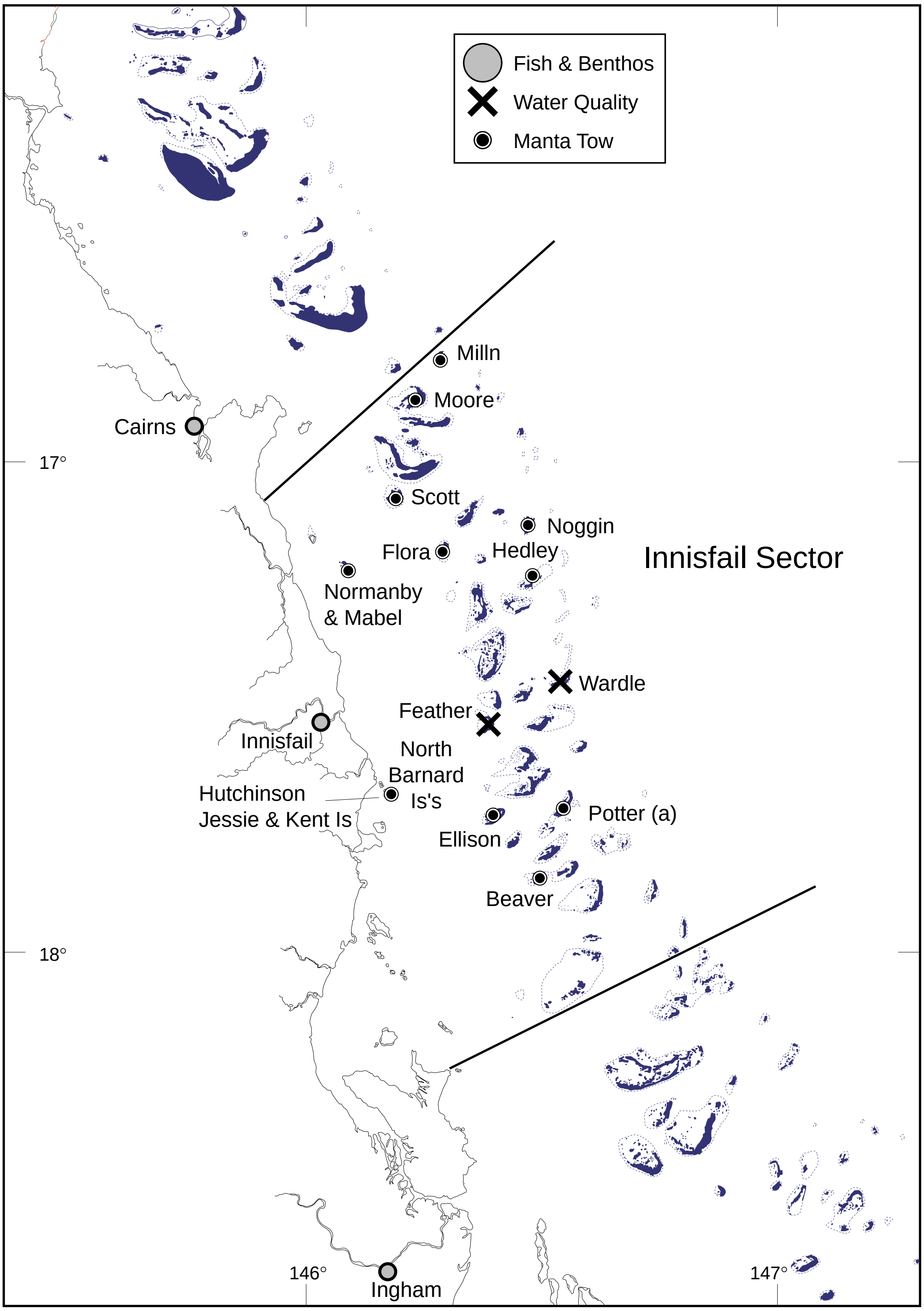
Locations of survey reefs and the types of samples taken.

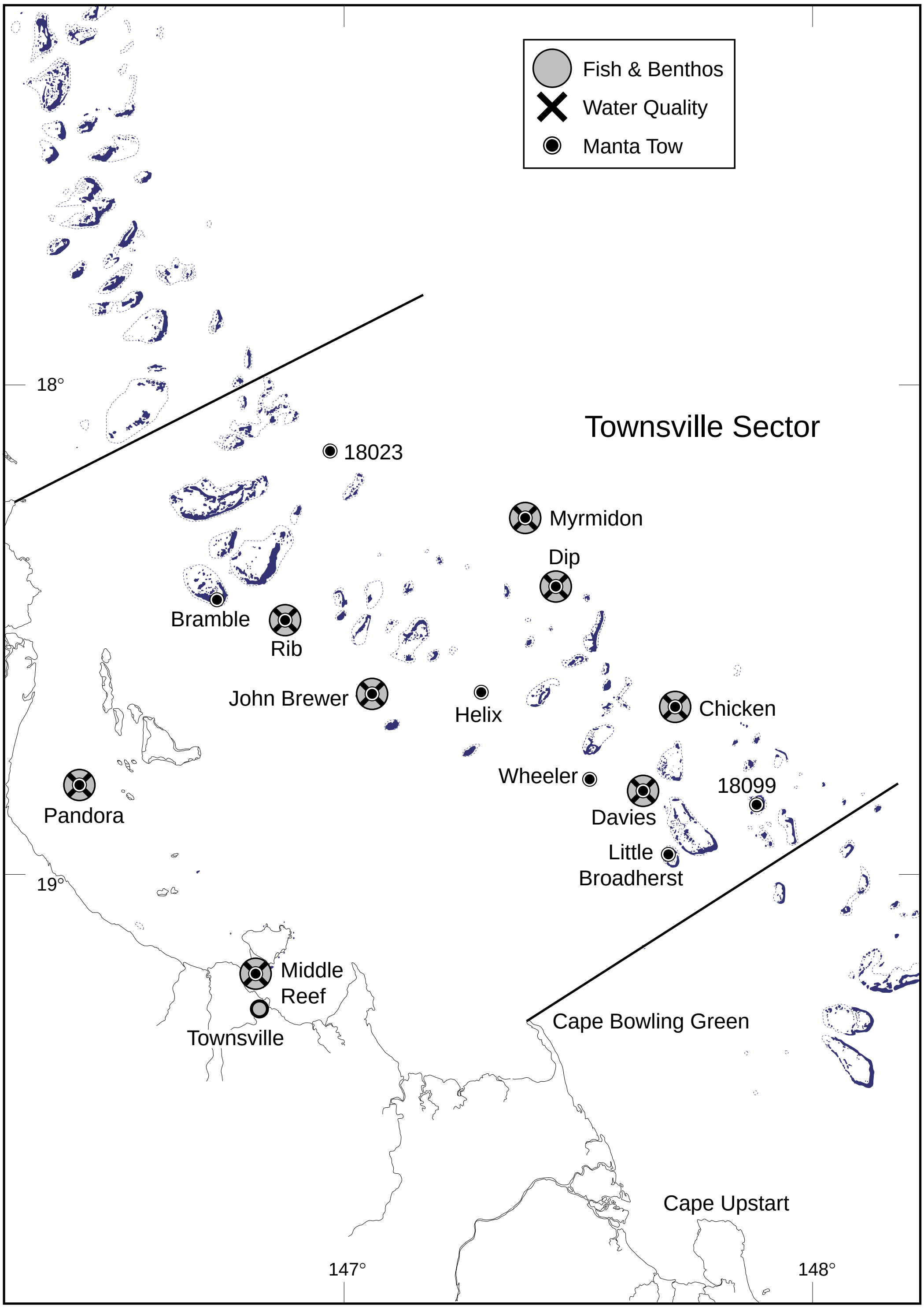


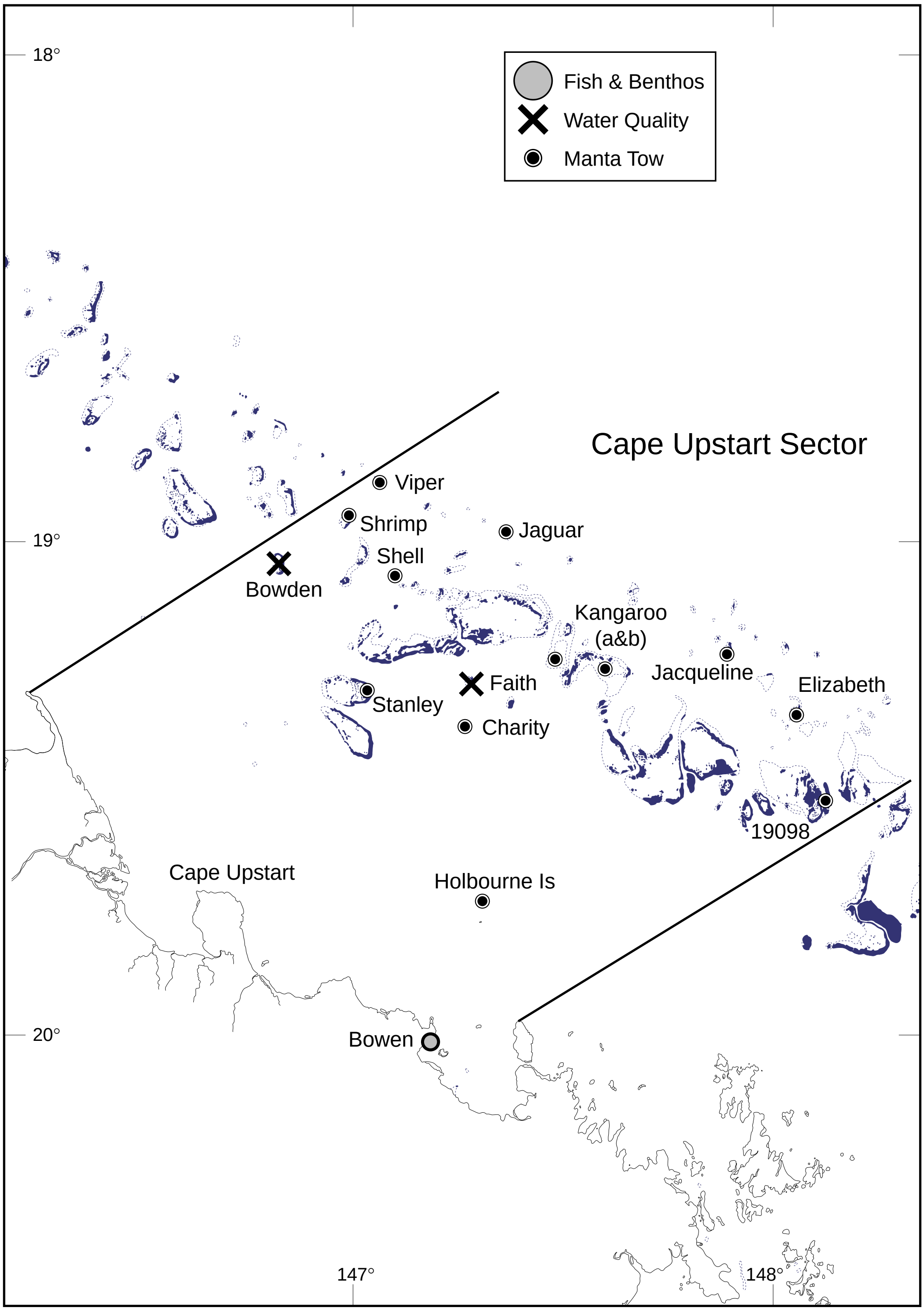

Fish & Benthos
Water Quality
Manta Tow
Princess Charlotte Bay Sector
Cape
Direction
13°
14°
144°
Osbourne
13040
Celebration
Sand Bank No. 8
13063
Fife Is
Creech (a)
13121
13124
Rodda
Pelican Is
Davie
Tydeman
Clack
Cape
Melville


Cooktown / Lizard Island Sector
Fish & Benthos
Water Quality
Manta Tow
15°
15°
16°
145°
146°
14043
Sand Bank No. 1
Stapleton
14075
14056
Switzer
Ingram &
Beanley
Hilder
Fly
Coquet Is
Carter
MacGillivray
Yonge
Nymph
No name
Eyrie
Lizard Is
Martin
North
Direction
Linnet
Decapolis
14152
Helsdon
Cape Flattery
Two Isles
Ribbon No. 9
Three Isles
Mackay Reefs
Forrester
Startle East
Marx
Swinger
Ribbon No. 6
Cape Bedford
Boulder
15407
Cooktown
Egret
Ribbon No. 3
15077
Ribbon No. 1
Irene
Lena
Endeavour

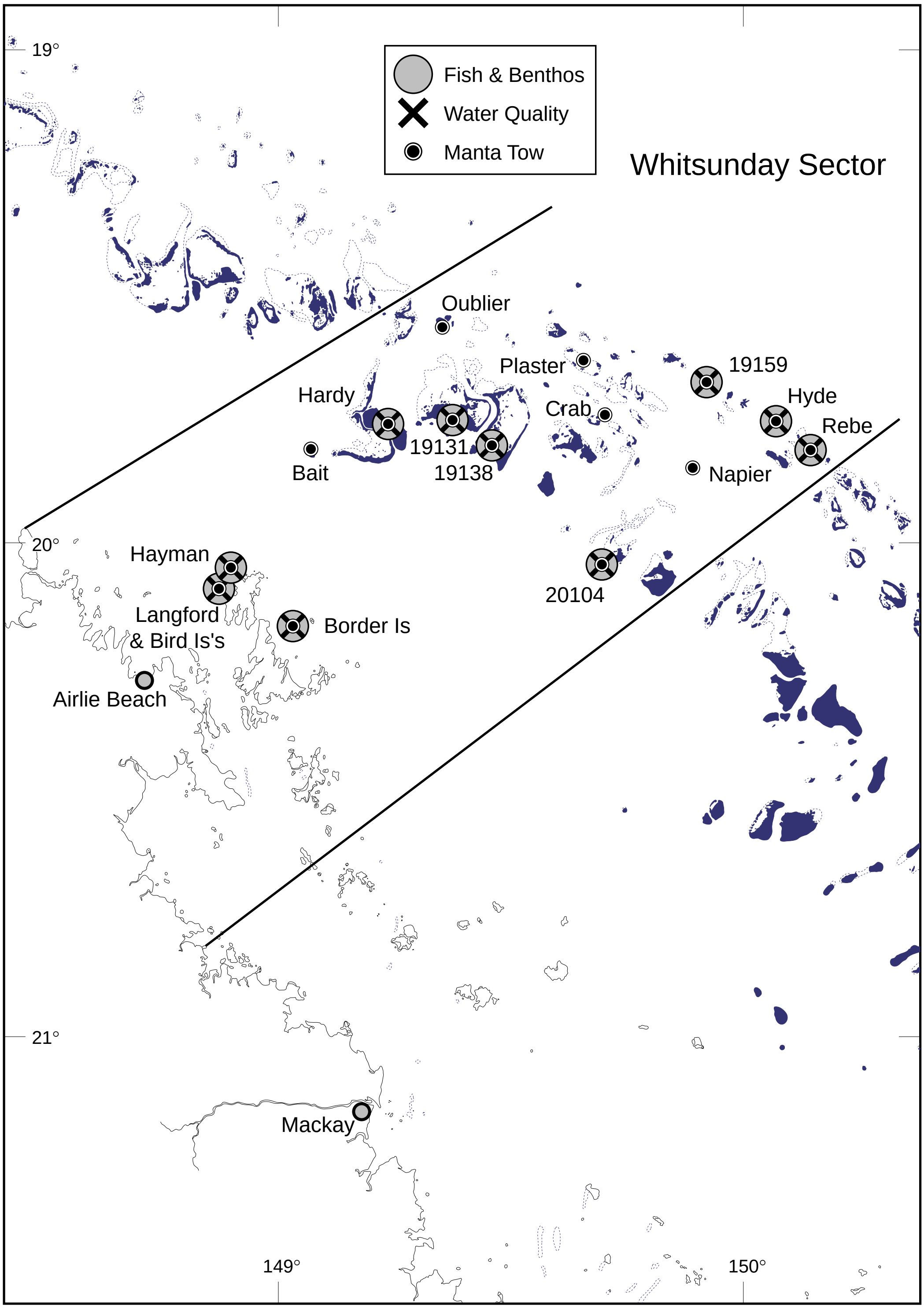

Fish & Benthos
Water Quality
Manta Tow
Cairns Sector
15°
16°
17°
145°
146°
Cooktown
Ruby
Andersen
15092
Escape (1)
Evening
Morning
Agincourt No. 4
Agincourt No. 3
16013
Mackay
Agincourt No. 1
Undine
(a)
16017
St Crispin
Rudder
Opal
Tongue (2)
Low Isles
Norman
Port Douglas
Saxon
Hope
Pixie
Hastings
Michaelmas
Oyster
Middle Cay (b)
Upolu
Euston
Thetford
Flynn
Green Is
Fitzroy Is
Cairns

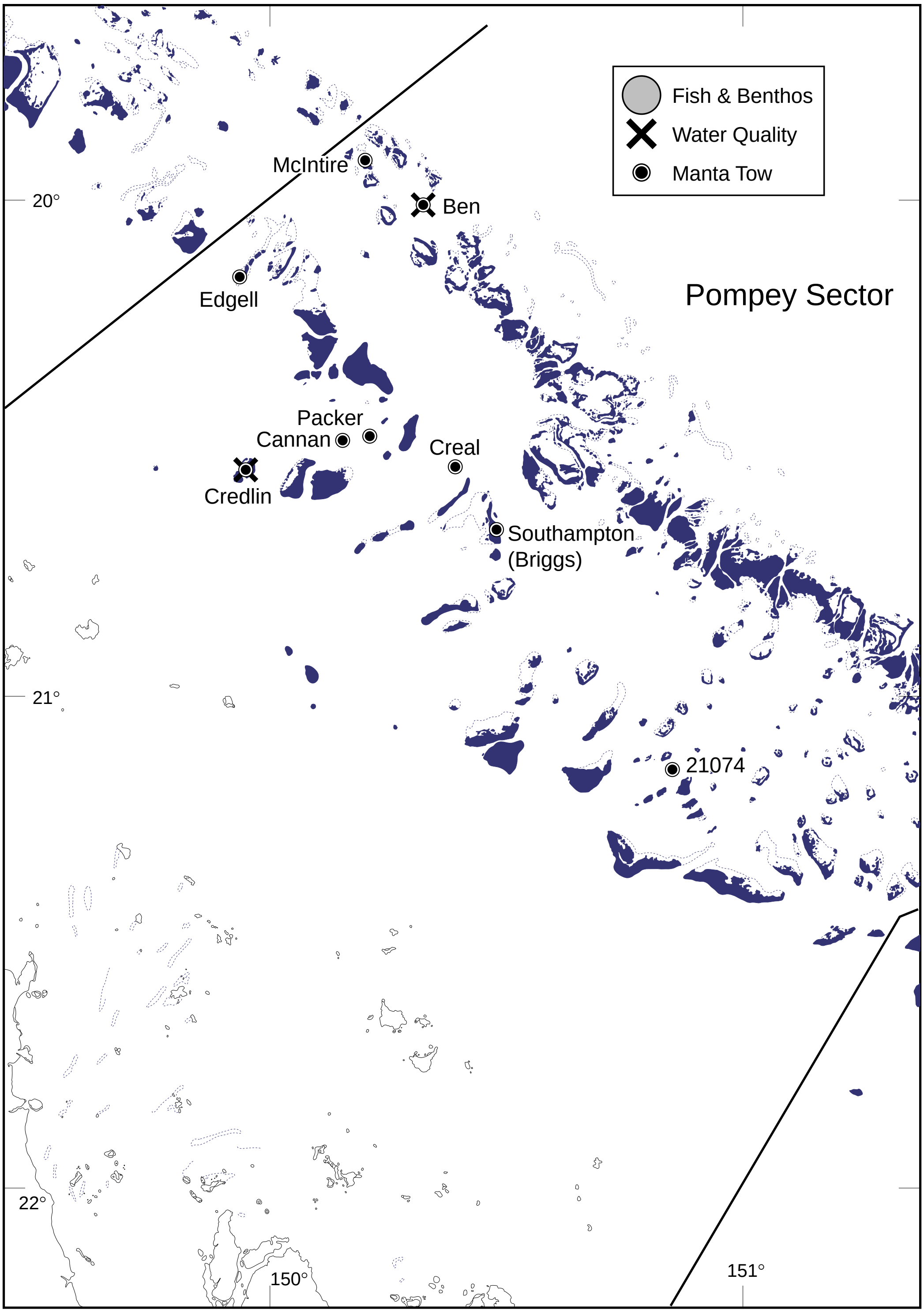

Fish & Benthos
Water Quality
Manta Tow
Innisfail Sector
Cairns
Milln
Moore
Scott
Noggin
Flora
Hedley
Normanby
& Mabel
Wardle
Feather
Innisfail
North
Barnard
Is's
Hutchinson
Jessie & Kent Is
Potter (a)
Ellison
Beaver
Ingham
17°
18°
146°
147°

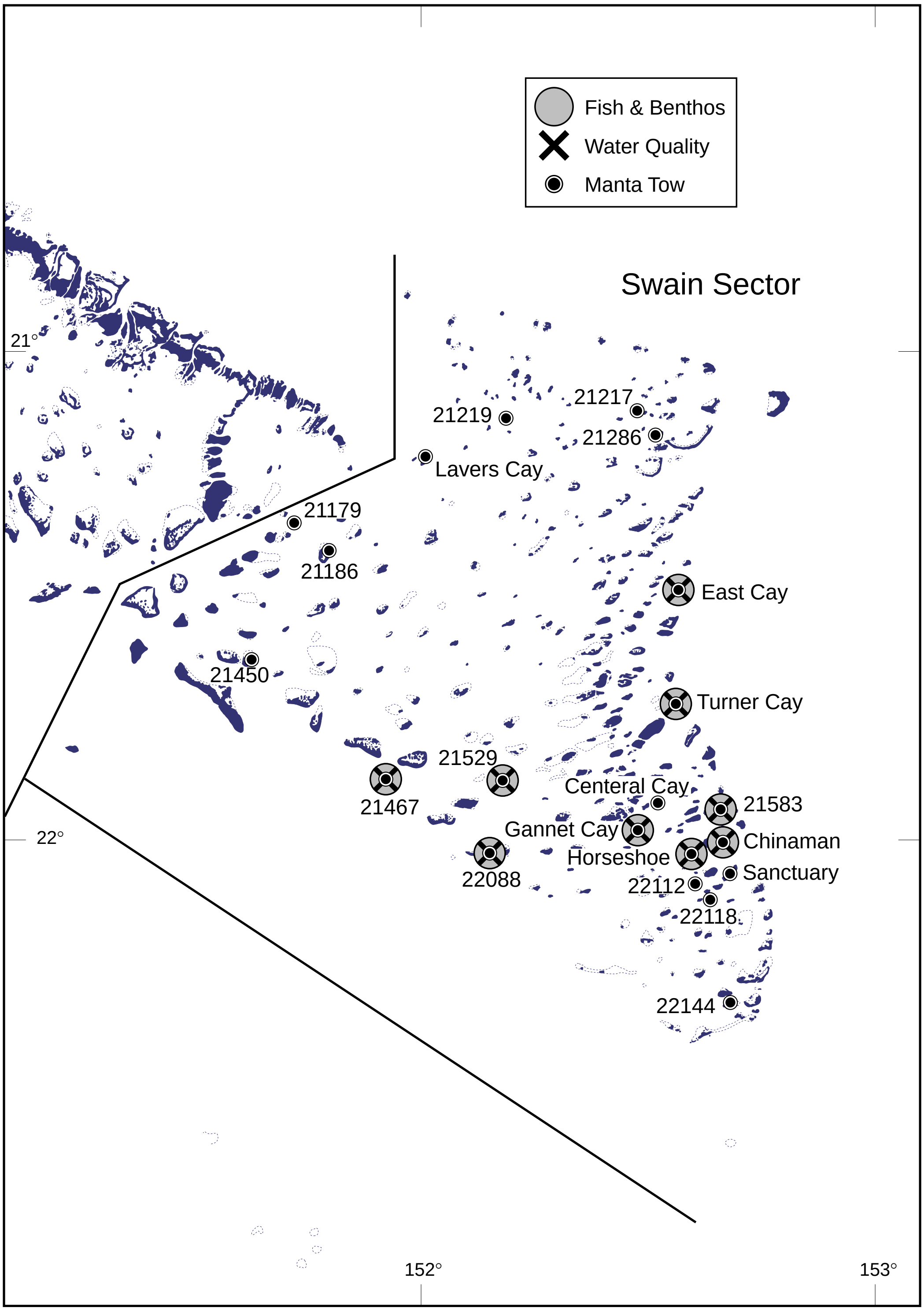

Fish & Benthos
Water Quality
Manta Tow
Townsville Sector
18°
19°
147°
148°
18023
Myrmidon
Dip
Bramble
Rib
John Brewer
Helix
Chicken
Pandora
Wheeler
Davies
18099
Little Broadherst
Middle Reef
Townsville
Cape Bowling Green
Cape Upstart



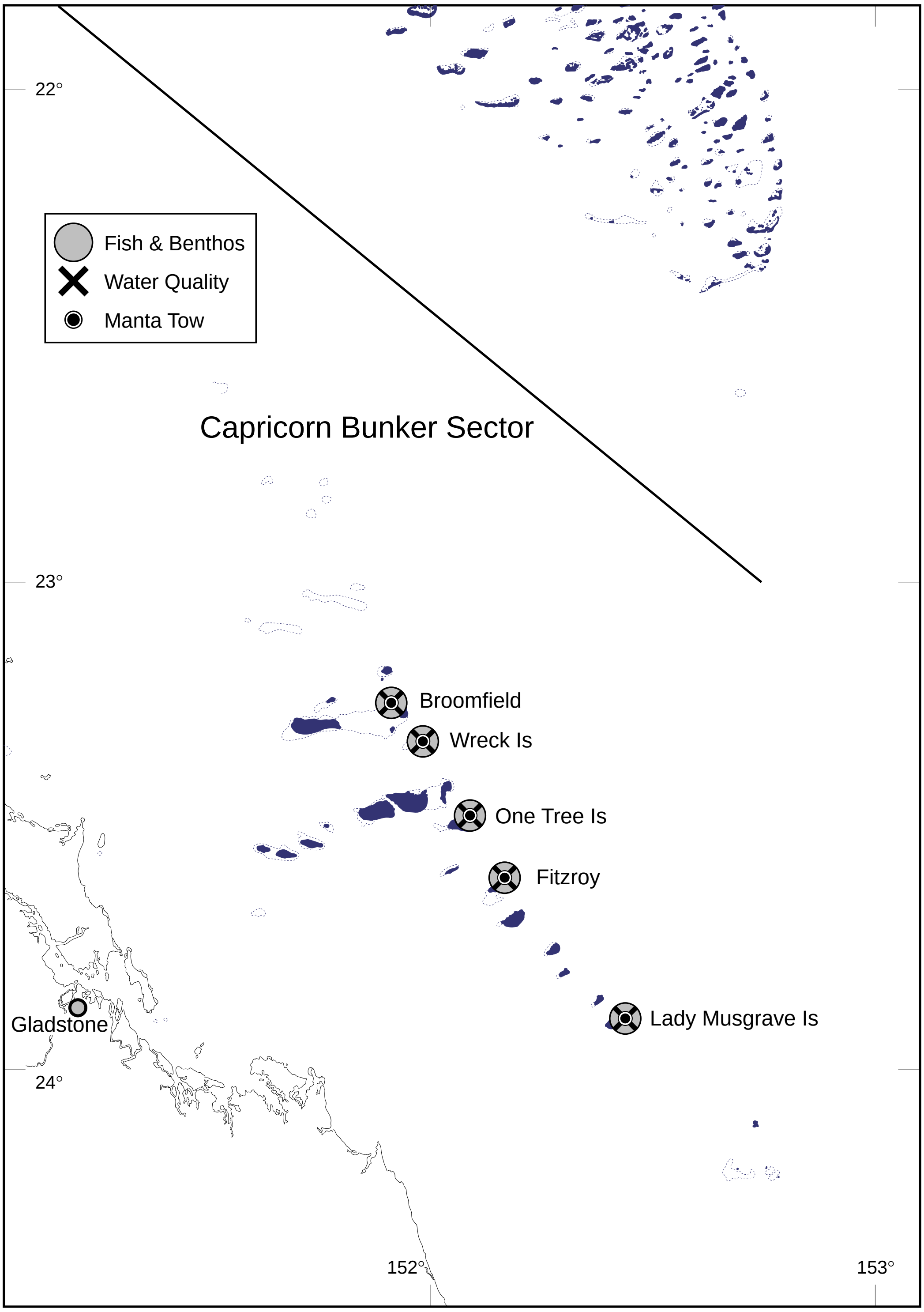
Fish & Benthos
Water Quality
Manta Tow
Cape Upstart Sector
18°
19°
20°
147°
148°
Viper
Shrimp
Shell
Jaguar
Bowden
Kangaroo
(a&b)
Jacqueline
Elizabeth
Faith
Stanley
Charity
19098
Cape Upstart
Holbourne Is
Bowen


Fish & Benthos
Water Quality
Manta Tow
Whitsunday Sector
19°
20°
21°
149°
150°
Oublier
Plaster
19159
Hyde
Rebe
Hardy
Crab
19131
19138
Bait
Napier
Hayman
Langford
& Bird Is's
Border Is
20104
Airlie Beach
Mackay


Fish & Benthos
Water Quality
Manta Tow
Pompey Sector
McIntire
Ben
Edgell
Packer
Cannan
Creal
Credlin
Southampton
(Briggs)
21074
20°
21°
22°
150°
151°



Fish & Benthos
Water Quality
Manta Tow
Swain Sector
21°
22°
152°
153°
21219
21217
21286
Lavers Cay
21179
21186
21450
East Cay
Turner Cay
21529
21467
Centeral Cay
21583
Gannet Cay
Chinaman
Horseshoe
Sanctuary
22088
22112
22118
22144



Fish & Benthos
Water Quality
Manta Tow
Capricorn Bunker Sector
22°
23°
24°
152°
153°
Broomfield
Wreck Is
One Tree Is
Fitzroy
Lady Musgrave Is
Gladstone

Appendix 1.2 Tabulation of all reefs surveyed for the Long-term Monitoring Program. An * indicates that the reef is surveyed every year for that purpose, while a number indicates that the reef is surveyed only every third year on a cyclical basis. the number indicates which year of the cycle it is surveyed. Thus all reefs designated “1” are surveyed on the same year.

Sector	Shelf_pos	REEF NAME	ID No	MANTA	WQ	FISH	BNTH
Cape Grenville	Inner-shelf	KAY	12010	*	*		
		CURD	12102	1			
		BIRD IS'S	11167	2			
	Mid-shelf	SIR CHARLES HARDY (1 & 2)	11184	1			
		FORBES IS'S	12016	1			
		QUOIN IS	12027	2			
		ASHMORE BANKS (1,2 & 3)	11233	3			
		11211	11211	3			
		MIDDLE BANKS (B & C)	11222	3			
	Outer-shelf	LAGOON	12061	*	*		
		12071	12071	1			
		LOG (2)	12107	2			
		SECOND SMALL	12098	2			
		RAINE IS	11243	3			
Princess Charlotte Bay	Inner-shelf	OSBORNE	13006	1			
		CLACK	14017	2			
		PELICAN IS	13107	3			
		FIFE IS	13081	3			
	Mid-shelf	13124	13124	*	*		
		13063	13063	1			
		CELEBRATION	13041	2			
	Outer-shelf	RODDA	13127	*	*		
		SAND BANK NO.8	13056	1			
		TYDEMAN	13133	1			
		13040	13040	2			
		13121	13121	2			
		CREECH (A)	13118	3			
		DAVIE	13130	3			
Cooktown/Lizard Island	Inner-shelf	DECAPOLIS	14131	*	*	*	*
		LINNET	14126	*	*	*	*
		MARTIN	14123	*	*	*	*
		BOULDER	15012	*	*		
		COQUET IS	14097	1			
		EGRET	15013	1			
		TWO ISLES	15002	1			
		THREE ISLES	15005	2			
	Mid-shelf	LIZARD IS	14116	*	*	*	*
		MACGILLIVRAY	14114	*	*	*	*
		NORTH DIRECTION IS	14143	*	*	*	*
		14056	14056	1	*		
		15047	15047	1			
		ENDEAVOUR	15089	1			
		HELSDON	14135	1			
		FLY	14109	2			
		INGRAM AND BEANLEY IS'S	14064	2			
		FORRESTER	15009	2			
		IRENE	15084	2			
		MARX	15027	2			
		14152	14152	2			

		MACKAY	15024	3			
		NYMPH	14115	3			
		STAPLETON IT	14054	3			
		STARTLE (EAST)	15028	3			
		SWINGER	15030	3			
		SWITZER	14061	3			
		EYRIE	14118	3			
		15077	15077	3			
	Outer-shelf	CARTER	14137	*	*	*	*
		YONGE	14138	*	*	*	*
		NO NAME	14139	*	*	*	*
		RIBBON NO.9	14154	1			
		SAND BANK NO.1	14045	1			
		LENA	15085	2			
		RIBBON NO.6	15032	2			
		HILDER	14085	2			
		RIBBON NO.1	15080	3			
		RIBBON NO.3	15050	3			
		14075	14075	3			
Cairns	Inner-shelf	FITZROY IS	16054	*	*	*	*
		GREEN IS	16049	*	*	*	*
		LOW ISLETS	16028	*	*	*	*
	Mid-shelf	HASTINGS	16057	*	*	*	*
		MICHAELMAS	16060	*	*	*	*
		THETFORD	16068	*	*	*	*
		UNDINE (A)	16020	*	*		
		MORNING	15098	1			
		OYSTER (A)	16043	1			
		PIXIE	16040	1			
		RUDDER	16023	1			
		SAXON	16032	1			
		16017	16017	2			
		16024	16024	2			
		MIDDLE CAY (B)	16044	2			
		EVENING	15095	3			
		UPOLU	16046	3			
		16013	16013	3			
	Outer-shelf	AGINCOURT NO.1	15099	*	*	*	*
		ST. CRISPIN	16019	*	*	*	*
		OPAL	16025	*	*	*	*
		AGINCOURT NO.4	15096	1			
		RUBY	15088	1			
		ANDERSEN	15090	2			
		AGINCOURT NO.3	15099	2			
		ESCAPE (1)	15094	2			
		HOPE	16058	2			
		FLYNN	16065	3			
		NORMAN	16030	3			
		EUSTON	16063	3			
		15092	15092	3			
Innisfail	Inner-shelf	NORMANBY AND MABEL IS'S	17012	1			
		NORTH BARNARD IS	17043	3			
	Mid-shelf	FEATHER	17034	*	*		
		FLORA	17010	1			

		BEAVER	17051	2			
		ELLISON	17044	2			
		MOORE	16071	3			
		SCOTT	17004	3			
	Outer-shelf	WARDLE	17032	*	*		
		GILBEY	17057	1			
		MOSS	17068	1			
		HEDLEY	17014	2			
		POTTER (A)	17059	2			
		NOGGIN	17008	3			
Townsville	Inner-shelf	MIDDLE	19011	*	*	*	*
		PANDORA	18051	*	*	*	*
		PHILLIPS	18067	*	*	*	*
	Mid-shelf	DAVIES	18096	*	*	*	*
		JOHN BREWER	18075	*	*	*	*
		RIB	18032	*	*	*	*
		LITTLE BROADHURST	18106	1			
		HELIX	18076	1			
		BRAMBLE	18029	2			
		WHEELER	18095	3			
		18099	18099	3			
	Outer-shelf	CHICKEN	18086	*	*	*	*
		MYRMIDON	18034	*	*	*	*
		DIP	18039	*	*	*	*
		18023	18023	2			
Cape Upstart	Inner-shelf	HOLBOURNE IS	19103	3			
	Mid-shelf	BOWDEN	19019	*	*		
		FAITH	19044	*	*		
		KANGAROO (A)	19063	1			
		KANGAROO (B)	19063	1			
		STANLEY	19045	1			
		SHRIMP	18118	2			
		ELIZABETH	19082	2			
		JACQUELINE	19061	2			
		CHARITY	19047	3			
		SHELL	19028	3			
		SHOWERS	19076	3			
	Outer-shelf	JAGUAR	18120	1			
		VIPER	18112	1			
		19098	19098	2			
Whitsunday	Inner-shelf	BORDER IS (A)	20067	*	*	*	*
		HAYMAN IS	20014	*	*	*	*
		LANGFORD AND BIRD IS'S	20019	*	*	*	*
	Mid-shelf	19131	19131	*	*	*	*
		19138	19138	*	*	*	*
		20104	20104	*	*	*	*
		HARDY	19135	*	*	*	*
		BAIT	19137	1			
		NAPIER	19195	1			
		PLASTER	19147	2			
		OUBLIER	19120	2			
		CRAB	19177	3			
	Outer-shelf	19159	19159	*	*	*	*
		HYDE	19207	*	*	*	*
		REBE	19209	*	*	*	*

		19151	19151	3			
Pompey	Mid-shelf	CREDLIN	20287	*	*		
		CANNAN	20144	1			
		20354	20354	1			
		21104	21104	1			
		EDGELL	20112	2			
		MCINTYRE	19219	2			
		PACKER	20145	2			
		CREAL	20297	2			
		21137	21137	3			
		SOUTHAMPTON (BRIGGS)	20299	3			
		21074	21074	3			
		21140	21140	3			
	Outer-shelf	BEN	20113	*	*		
		RIP CAY	20370	1			
Swain	Inner-shelf	21467	21467	*	*	*	*
		SNAKE	22088	*	*	*	*
		21529	21529	*	*	*	*
	Mid-shelf	CHINAMAN	22102	*	*	*	*
		GANNET CAY	21556	*	*	*	*
		HORSESHOE	22104	*	*	*	*
		22112	22112	1			
		22118	22118	1			
		22144	22144	1			
		CENTRAL	21577	1			
		LAVER'S CAY	21235	2			
		21219	21219	2			
		21286	21286	2			
		21217	21217	2			
		SANCTUARY	22109	3			
		21179	21179	3			
		21186	21186	3			
		21450	21450	3			
	Outer-shelf	EAST CAY	21305	*	*	*	*
		21583	21583	*	*	*	*
		TURNER CAY	21562	*	*	*	*
Capricorn Bunker	Outer-shelf	BROOMFIELD	23048	*	*	*	*
		FITZROY	23077	*	*	*	*
		LADY MUSGRAVE IS	23082	*	*	*	*
		ONE TREE IS	23055	*	*	*	*
		LEWELLYN	23078	*	*	*	*
		WRECK IS	23051	*	*	*	*

Appendix 2

Appendix 2.1. Summary of manta tow data for each reef surveyed in 1992/93. The percentage cover of live and dead coral cover, and sand/rubble are expressed as median categories. A split value (e.g. 1/2) is given where the median falls between two categories. Reefs are classified as Key or Cycle and given a reef status with respect to COTS activity (see Materials and Methods).

Reef Name	Key/ Cycle	Survey date	Live coral	Dead coral	Sand/ rubble	No. of tows	No. of COTS	Status
Cape Grenville sector								
Curd Reef	C	17/12/92	2	1	2/3	24	2	NO
Forbes Islands	C	16/12/92	4	1	2	37	3	NO
Kay Reef	K	16/12/92	3	1	2	50	0	NO
Lagoon Reef	K	13/12/92	3	1	1	58	0	NO
Reef No. 12-071	C	13/12/92	3	1	1	26	0	NO
Sir Charles Hardy (1)	C	14/12/92	3	0	2	18	0	RE
Sir Charles Hardy (2)	C	14/12/92	4	1	2	19	0	NO
Princess Charlotte Bay sector								
Osborne Reef	C	17/12/92	3	1	2	37	13	AO
Reef No. 13-063	C	12/12/92	2	1	3	73	1	NO
Reef No. 13-124	K	11/12/92	2	1	3	65	5	NO
Rodda Reef	K	11/12/92	3	0	1	46	0	RE
Sand Bank No. 8	C	12/12/92	2	0	1	28	0	NO
Tydeman Reef	C	11/12/92	1	0	3	61	0	RE
Cooktown/Lizard Island sector								
Boulder Reef	K	12/05/93	2	0	2	70	0	NO
Carter Reef	C	22/05/93	1	0	2	84	0	RE
Coquet Is Reef	C	01/05/93	1	0	2	18	0	NO
Egret Reef	C	13/05/93	2	0	3	50	0	NO
Endeavour Reef	C	09/12/92	3	1	2	100	1	RE
Helsdon Reef	C	30/04/93	2	1	3	44	1	RE
Linnet Reef	C	07/05/93	2/3	0	3	32	0	NO
MacGillivray Reef	K	09/05/93	3	1	2	14	6	RE
Martin Reef	C	05/05/93	2	1	3	50	0	NO
Reef No. 14-043	K	01/05/93	1	0	4	33	0	NO
Reef No. 14-056	C	02/05/93	1	0	3	49	1	NO
Reef No. 15-047	C	29/04/93	2	0	2	47	0	NO
Ribbon No. 9 Reef	C	19/12/92	2	0	3	77	0	RE
Sand Bank No. 1	C	10/12/92	2	0	2	38	0	NO
Two Isles	C	30/04/93	3	1	2	21	0	NO
Yonge Reef	K	16/05/93	1	0	2	81	0	RE

Reef Name	Key/ Cycle	Survey date	Live coral	Dead coral	Sand/ rubble	No. of tows	No. of COTS	Status
Cairns sector								
Agincourt Reef No. 4	C	14/06/93	2	0	1	46	0	NO
Green Island	K	04/09/92	1	0	3	48	0	RE
Hastings Reef	K	08/09/92	1	0	2	61	1	RE
Low Islets	C	11/06/93	2	1	1	33	0	NO
Mackay Reef	C	13/06/93	3	1	2	23	1	NO
Michaelmas Reef	K	06/09/92	1	0	3	124	2	NO
Morning Reef	C	29/04/93	3	1	2/3	18	0	NO
Oyster (a) Reef	C	28/04/93	1	0	4	36	0	NO
Pixie Reef	C	28/04/93	1	0	2	11	0	RE
Ruby Reef	C	24/05/93	2	0	2	68	0	NO
Rudder Reef	C	15/06/93	3	0	2	38	1	NO
Saxon Reef	C	25/05/93	2	0/1	1	20	0	NO
St.Crispin Reef	C	20/06/93	2	0	2	99	1	NO
Tongue (1) Reef	C	11/09/92	2	1	2	28	0	NO
Tongue (2) Reef	C	10/09/92	1	0	4	61	0	NO
Undine (a) Reef	K	15/06/93	1	0	3/4	46	2	NO
Innisfail sector								
Flora Reef	C	26/06/93	2	0	3	46	2	RE
Normanby & Mabel	C	26/06/93	1	0	2	18	0	NO
Townsville sector								
Davies Reef	C	18/08/92	2	0	2	44	2	RE
Dip Reef	C	28/05/92	2	0	3	41	0	RE
Helix Reef	C	09/04/92	1	0	3	14	0	RE
John Brewer Reef	K	08/04/92	2	0	2	79	0	RE
Little Broadhurst	C	19/08/92	1	0	2	58	2	RE
Myrmidon Reef	K	15/08/92	2	0	2	52	0	NO
Cape Upstart sector								
Bowden Reef	K	25/03/93	1/2	0	2	80	0	RE
Faith Reef	K	26/03/93	1	0	2	34	0	RE
Jaguar Reef	C	27/03/93	2	0	3	30	2	NO
Kangaroo (a) Reef	C	27/03/93	2	0	2	83	1	NO
Kangaroo (b) Reef	C	27/03/93	1	0	2	28	0	RE
Stanley Reef	C	26/03/93	1	0	2	106	0	RE
Viper Reef	C	28/03/93	2	0	2	31	0	NO

Reef Name	Key/ Cycle	Survey date	Live coral	Dead coral	Sand/ rubble	No. of tows	No. of COTS	Status
Whitsunday sector								
Bait Reef	C	13/06/92	3	0/1	1/2	48	10	NO
Hardy Reef	C	03/02/93	3	0	2	114	3	RE
Hayman & Arkhurst	K	20/06/92	2	0	2	35	0	NO
Hyde Reef	K	26/06/92	2	0	1	57	0	NO
Langford & Bird Is	C	20/06/92	1	0	2	32	0	NO
Napier Reef	C	22/06/92	3	0	1	40	0	NO
Reef No. 19-138	K	16/06/92	2	1	2	31	0	NO
Reef No. 19-159	C	18/06/92	3	0	1	42	0	NO
Reef No. 20-104	K	11/02/93	1	1	1	25	0	RE
Pompey sector								
Cannan Reef	C	13/02/93	3	1	1	21	0	NO
Credlin Reef	K	13/02/93	4	1	1	62	0	RE
Swain sector								
Central Reef	K	06/10/92	4	0	1	33	0	NO
Chinaman Reef	K	06/10/92	2	0	1	35	4	NO
Gannet Cay Reef	K	04/10/92	4	1	1	20	122	AO
Horseshoe Reef	C	10/10/92	2	0	2	80	1	RE
Reef No. 21-529	C	01/10/92	2	0	2	32	0	NO
Reef No. 22-112	C	12/10/92	3	0	3	12	0	NO
Reef No. 22-118	C	12/10/92	2	1	2	22	0	RE
Reef No. 22-144	C	12/10/92	1	0	3	33	0	RE
Sanctuary Reef	K	08/10/92	2	0	1	54	1	RE
Snake Reef	C	02/10/92	3	0	1	102	82	AO
Capricorn Bunker sector								
Broomfield Reef	C	29/10/92	2	1	2	50	0	NO
Lady Musgrave Is	K	18/10/92	1	0	1	62	0	NO
One Tree Island	K	21/10/92	2	1	2	75	0	NO
Wreck Island	C	26/10/92	2	0	1	45	0	NO

Appendix 3

List of Water Quality Sites for 1992-93.

"Stn/Reef Name" refers to the Station Name in the case of sediment and bio-oceanography stations, or Reef Name in the case of standard Long-term Monitoring reefs.

Sector	SHELF	Stn/Reef Name	PRJ_COD	Latitude	Longitude
CA	I	CAIRNS / N/A	SED	16° 46.8	145° 47
CA	I	CAIRNS AIRPORT / N/A	BIO-OC	16° 49.4	145° 47.4
CA	I	CAIRNS FAIRLEAD / N/A	BIO-OC	16° 51	145° 50.1
CA	I	CAPE GRAFTON / N/A	BIO-OC	16° 47.8	145° 55
CA	I	CAPE TRIBULATION / N/A	BIO-OC	16° 7	145° 29
CA	I	DAINTREE RIVER / N/A	BIO-OC	16° 19	145° 28
CA	I	DOUBLE IS / N/A	BIO-OC	16° 39.9	145° 42
CA	I	FITZROY IS / N/A	SED	16° 55.6	145° 58.9
CA	I	LOW ISLETS / N/A	SED	16° 26	145° 35
CA	I	N/A / LOW ISLETS	LTM	16° 24	145° 33
CA	I	PORT DOUGLAS / N/A	BIO-OC	16° 25	145° 30
CA	M	GREEN IS / N/A	SED	16° 43.9	145° 56.3
CA	M	N/A / GREEN IS	LTM	16° 46.4	146° 2.2
CA	M	N/A / HASTINGS	LTM	16° 32	146° 2.1
CA	M	N/A / MACKAY	LTM	16° 3.5	145° 40
CA	M	N/A / MICHAELMAS	LTM	16° 36.2	146° 2.2
CA	M	N/A / UNDINE (A)	LTM	16° 6.3	145° 36.5
CA	M	THETFORD REEF / N/A	SED	16° 48.4	146° 9.9
CA	O	AGINCOURT REEFS / N/A	BIO-OC	16° 2	145° 46
CA	O	N/A / NORMAN	LTM	16° 25	145° 59
CA	O	N/A / ST. CRISPIN	LTM	16° 8.5	145° 50.4
CB	O	N/A / BROOMFIELD	LTM	23° 15	151° 55.6
CB	O	N/A / LADY MUSGRAVE IS	LTM	23° 55.6	152° 22.7
CB	O	N/A / ONE TREE IS	LTM	23° 30.7	152° 1.9
CB	O	N/A / WRECK IS	LTM	23° 18.7	151° 57.9
CG	I	HOME IS'S / N/A	BIO-OC	12° 0	143° 18
CG	I	LLOYD BAY / N/A	BIO-OC	12° 49.8	143° 25
CG	I	N/A / CURD	LTM	12° 35.2	143° 29.9
CG	I	N/A / KAY	LTM	12° 13.2	143° 15.4
CG	I	PASCOE RIVER / N/A	SED	12° 30	143° 17
CG	I	POLLARD CHANNEL / N/A	BIO-OC	11° 55	143° 22
CG	I	PORTLAND ROADS / N/A	SED	12° 36.2	143° 26
CG	I	SHELBURNE BAY / N/A	BIO-OC	11° 45	143° 0
CG	I	TEMPLE BAY / N/A	BIO-OC	12° 18	143° 10
CG	M	BOURKE REEF / N/A	SED	12° 33.2	143° 30.3
CG	M	DOLPHIN REEF / N/A	SED	12° 37.7	143° 31.9
CG	M	SALAMANDER REEF / N/A	BIO-OC	11° 47.2	143° 40
CG	O	FERGUSON (INSIDE) / N/A	BIO-OC	12° 20	143° 45
CG	O	N/A / LAGOON	LTM	12° 23	143° 44.7
CL	I	COOKTOWN / N/A	BIO-OC	15° 26.9	145° 17
CL	I	N/A / BOULDER	LTM	15° 24.1	145° 25.1
CL	I	STARKE RIVER / N/A	BIO-OC	14° 45.5	145° 2.7
CL	M	FLY / FLY	SED	14° 31.7	145° 9.9
CL	M	LIZARD IS / N/A	BIO-OC	14° 45	145° 27
CL	M	N/A / 14043	LTM	14° 11.6	144° 48.9
CL	M	N/A / LINNET	LTM	14° 48.3'	145° 21.3'
CL	M	N/A / MACGILLIVRAY	LTM	14° 39.7'	145° 29.8'
CL	M	N/A / MARTIN	LTM	14° 46.9'	145° 22.5'
CL	O	LARK PASS (INSIDE) / N/A	BIO-OC	15° 8'	145° 42'
CL	O	N/A / CARTER	LTM	14° 34'	145° 37.6'
CL	O	N/A / YONGE	LTM	14° 38.1'	145° 38.1'
CL	O	ONE-MILE OPENING / N/A	BIO-OC	14° 31.2'	145° 28.9'
IN	I	ELLISON REEF / N/A	SED	17° 42.2'	146° 22.3'
IN	I	FLYING FISH POINT / N/A	SED	17° 29.2'	146° 5.9'
IN	I	NORTH BARNARD IS / N/A	SED	17° 40'	146° 9.1'
IN	I	RUSSEL HEADS / N/A	SED	17° 11.3'	145° 59.1'
IN	M	FEATHER REEF / N/A	SED	17° 31.4'	146° 21.2'
IN	M	FLORA REEF / N/A	SED	17° 11.1'	146° 16.4'

IN	M	N/A / FEATHER	LTM	17° 31.4'	146° 21.2'
PC	I	N/A / CLACK	LTM	14° 4'	144° 13.2'
PC	M	N/A / 13124	LTM	13° 51.6'	144° 3.8'
PC	O	N/A / RODDA	LTM	13° 55.5'	144° 19.7'
PO	I	CAPE TOWNSHEND / N/A	BIO-OC	22° 10'	150° 20'
PO	I	PRUDHOE IS / N/A	BIO-OC	21° 17'	149° 40'
PO	M	DUKE IS'S / N/A	BIO-OC	21° 58'	150° 15'
PO	M	N/A / CREDLIN	LTM	20° 30.8'	149° 58'
SW	M	HERALDS PRONG NO.1 / N/A	BIO-OC	21° 30'	151° 30'
SW	M	N/A / 21529	LTM	21° 51.4'	152° 10.3'
SW	M	N/A / CHINAMAN	LTM	22° 1.1'	152° 38.6'
SW	M	N/A / GANNET CAY	LTM	21° 59.5'	152° 29.2'
SW	M	N/A / HORSESHOE	LTM	22° 1.5'	152° 34.8'
SW	M	N/A / SANCTUARY	LTM	22° 5'	152° 39.1'
SW	M	N/A / SNAKE	LTM	22° 0.5'	152° 10.7'
TO	I	GREAT PALM IS / N/A	BIO-OC	18° 40'	146° 35'
TO	I	MAGNETIC IS / N/A	BIO-OC	19° 5'	146° 55.1'
TO	I	N/A / MIDDLE	LTM	19° 11.7'	146° 49'
TO	I	N/A / PANDORA	LTM	18° 49.7'	146° 25.8'
TO	M	LODESTONE / N/A	BIO-OC	18° 42'	147° 10'
TO	M	N/A / DAVIES	LTM	18° 49'	147° 37.4'
TO	M	N/A / JOHN BREWER	LTM	18° 37.6'	147° 6'
TO	O	FARADAY / N/A	BIO-OC	18° 25'	147° 18'
TO	O	N/A / DIP	LTM	18° 25.5'	147° 26.3'
TO	O	N/A / MYRMIDON	LTM	18° 17.2'	147° 22.6'
WH	I	APOSTLE BAY / N/A	BIO-OC	20° 13'	149° 1'
WH	I	HAMILTON IS / N/A	BIO-OC	20° 19.5'	148° 56.5'
WH	I	N/A / HAYMAN IS	LTM	20° 2.7'	148° 52.5'
WH	I	N/A / LANGFORD AND BIRD	LTM	20° 6.4'	148° 52.7'
WH	I	SHAW IS / N/A	BIO-OC	20° 30'	149° 2.5'
WH	I	SOUTH MOLLE IS / N/A	BIO-OC	20° 17.5'	148° 50'
WH	M	BAIT REEF / N/A	BIO-OC	19° 50'	149° 0'
WH	M	HARDY REEF / N/A	BIO-OC	19° 42'	149° 15'
WH	M	N/A / 19138	LTM	19° 48.3'	149° 26.3'
WH	M	N/A / 20104	LTM	20° 1.1'	149° 41.2'
WH	M	N/A / HARDY	LTM	19° 45'	149° 8.7'

Appendix 4

Appendix 4.1 Target Species

Appendix 4.1(a): Target species for 10 metre x 50 metre transects

ACANTHURIDAE
Acanthurus albipectoralis
Acanthurus blochii
Acanthurus dussumieri
Acanthurus grammoptilus
Acanthurus lineatus
Acanthurus mata
Acanthurus nigricans
Acanthurus nigricauda
Acanthurus nigrofuscus
Acanthurus olivaceus
Acanthurus pyropherus
Acanthurus thompsoni
Acanthurus triostegus
Acanthurus xanthopterus
Ctenochaetus spp. (grouped)
Naso lituratus
Naso tuberosus
Naso unicornus
Paracanthurus hepatus
Zebrasoma scopas
Zebrasoma veliferum

SCARIDAE
Bolbometapon muricatum
Cetoscarus bicolor
Hipposcarus longiceps
Scarus altipinnis
Scarus bleekeri
Scarus chameleon
Scarus dimidiatus
Scarus flavipectoralis
Scarus forsteni
Scarus frenatus
Scarus ghobban
Scarus globiceps
Scarus microrhinos
Scarus niger
Scarus oviceps
Scarus psittacus
Scarus rivulatus
Scarus rubroviolaceus
Scarus schlegeli
Scarus sordidus
Scarus spinus

CHAETODONTIDAE
Chaetodon aureofasciatus
Chaetodon auriga
Chaetodon baronessa
Chaetodon bennetti
Chaetodon citrinellus
Chaetodon ephippium
Chaetodon flavirostris
Chaetodon guentheri
Chaetodon kleinii
Chaetodon lineolatus
Chaetodon lunula
Chaetodon melannotus
Chaetodon meyeri
Chaetodon ornatissimus
Chaetodon pelewensis
Chaetodon plebeius
Chaetodon punctatofasciatus
Chaetodon rafflesi
Chaetodon rainfordi
Chaetodon reticulatus
Chaetodon semeion
Chaetodon speculum
Chaetodon trifascialis
Chaetodon trifasciatus
Chaetodon ulietensis
Chaetodon unimaculatus
Chaetodon vagabundus
Chelmon rostratus
Forcipiger flavissimus
Forcipiger longirostrus
Hemitaurichthys polylepis

SERRANIDAE
Plectropomus areolatus
Plectropomus laevis
Plectropomus leopardus
Plectropomus maculatus
Plectropomus oligacanthus
Variola albimarginata
Variola louti

SIGANIDAE
Siganus argenteus
Siganus corallinus
Siganus doliatus
Siganus lineatus
Siganus puellus
Siganus punctatissimus
Siganus punctatus
Siganus spinus
Siganus vulpinus

LABRIDAE
Cheilinus fasciatus
Cheilinus undulatus
Choerodon fasciatus
Coris gaimard
Epibulus insidiator
Gomphosus varius
Halichoeres hortulanus
Hemigymnus fasciatus
Hemigymnus melapterus

LETHRINIDAE
Lethrinus atkinsoni
Lethrinus erythracanthus
Lethrinus harak
Lethrinus miniatus
Lethrinus nebulosus
Lethrinus obsoletus
Lethrinus olivaceus
Lethrinus rubrioperculatus
Lethrinus xanthochilus
Monotaxis grandoculis

LUTJANIDAE
Lutjanus adetti
Lutjanus argentimaculatus
Lutjanus bohar
Lutjanus carponotatus
Lutjanus fulviflamma
Lutjanus gibbus
Lutjanus kasmira
Lutjanus lutjanus
Lutjanus quinquelineatus
Lutjanus rivulatus
Lutjanus russelli
Lutjanus sebae
Lutjanus semicinctus
Lutjanus vitta
Macolor spp. (grouped)

ZANCLIDAE
Zanclus cornutus

Appendix 4.1(b): Target pecies for 2 metre x 50 metre transects

ACANTHOCHROMIS
Acanthochromis polyacanthus

AMBLYGLYPHIDODON
Amblyglyphidodon aureus
Amblyglyphidodon curacao
Amblyglyphidodon leucogaster

AMPHIPRION
Amphiprion akindynos
Amphiprion chrysopterus
Amphiprion clarkii
Amphiprion melanopus
Amphiprion percula
Amphiprion perideraion

CHROMIS
Chromis acares
Chromis agilis
Chromis atripectoralis
Chromis amboinensis
Chromis atripes
Chromis chrysura
Chromis fumea
Chromis iomelas
Chromis lepidolepis
Chromis margaritifer
Chromis nitida
Chromis retrofasciatus
Chromis ternatensis
Chromis vanderbilti
Chromis viridis
Chromis weberi
Chromis xanthura

CHRYSIPTERA
Chrysiptera biocellata
Chrysiptera cyanea
Chrysiptera flavipinnis
Chrysiptera rex
Chrysiptera rollandi
Chrysiptera talboti

DASCYLLUS
Dascyllus aruanus
Dascyllus melanurus
Dascyllus reticulatus
Dascyllus trimaculatus

DISCHISTODUS
Dischistodus melanotus
Dischistodus perspicillatus
Dischistodus prosopotaenia
Dischistodus pseudochrysopocilus

HEMIGLYPHIDODON
Hemiglyphidodon plagiometopon

NEOGLYPHIDODON
Neoglyphidodon melas
Neoglyphidodon nigroris
Neoglyphidodon polyacanthus

NEOPOMACENTRUS
Neopomacentrus azysron
Neopomacentrus bankieri
Neopomacentrus cyanomos

PLECTROGLYPHIDODON
Plectroglyphidodon dickii
Plectroglyphidodon johnstonianus
Plectroglyphidodon lacrymatus

POMACENTRUS
Pomacentrus amboinensis
Pomacentrus australis
Pomacentrus bankanensis
Pomacentrusrus brachialis
Pomacentrus chrysurus
Pomacentrus coelestis
Pomacentrus grammnorhyncus
Pomacent lepidogenys
Pomacentrus moluccensis
Pomacentrus nagasakiensis
Pomacentrus philippinus
Pomacentrus taeniometapon
Pomacentrus tripunctatus
Pomacentrus vaiuli
Pomacentrus wardi

POMACHROMIS
Pomachromis richardsoni

PREMNAS
Premnas biaculeatus

STEGASTES
Stegastes apicalis
Stegastes fasciolatus
Stegastes nigricans

Appendix 4.2. Family Data

Mean values of fish abundance (grouped to family) for all reefs surveyed duirng 1992-93. Numbers represent the number of fish per site, averaged over all 3 sites on a reef

Reef Number & Name	Sector	Pos	ACAN	CHAE	LABR	LETH	LUTJ	POMA	SCAR	SERR	SIGA	ZANC
14114 MacGillivray	CL	M	98	111	63	23	79	971	111	17	41	1
14123 Martin	CL	I	160	133	50	24	78	1291	137	26	52	1
14126 Linnet	CL	I	129	125	62	2	74	1659	175	16	188	3
14137 Carter	CL	O	1227	198	71	17	108	818	293	6	7	37
14138 Yonge	CL	O	816	149	76	27	10	1304	344	4	5	32
16015 Mackay	CA	M	34	98	75	11	30	1104	140	4	25	9
16019 St. Crispin	CA	O	473	141	62	14	7	766	349	6	15	14
16028 Low Islets	CA	I	41	104	67	1	76	881	101	9	37	0
16049 Green Is	CA	I	195	128	94	21	146	825	182	17	84	3
16057 Hastings	CA	M	638	103	53	16	23	1223	203	7	23	10
16060 Michaelmas	CA	M	440	96	41	4	12	1992	161	8	20	14
18034 Myrmidon	TO	O	391	110	40	5	0	1137	177	1	3	11
18039 Dip	TO	O	531	58	39	12	6	1318	167	12	19	8
18051 Pandora	TO	I	1	102	19	0	26	1407	38	14	24	0
18075 John Brewer	TO	M	202	58	68	4	4	1470	289	4	62	1
18096 Davies	TO	M	109	90	69	3	11	2156	222	8	53	0
19135 Hardy	WH	M	79	104	74	10	69	3452	262	82	60	0
19138 19138	WH	M	37	61	107	6	19	5337	258	45	89	1
19159 19159	WH	O	198	174	55	16	15	2326	155	43	38	11
19207 Hyde	WH	O	265	130	39	1	7	1437	113	15	16	12
20014 Hayman Is	WH	I	7	71	70	0	9	3422	249	8	54	0
20019 Langford and Bird Is	WH	I	25	81	49	15	11	2540	198	9	48	0
20104 20104	WH	M	32	70	80	11	48	2691	263	32	52	1
21529 21529	SW	M	2	100	95	20	15	2990	246	64	33	3
21556 Gannet Cay	SW	M	54	109	99	6	16	6108	307	93	92	9
22088 22088	SW	M	125	155	88	3	7	2366	266	27	24	2
22102 Chinaman	SW	M	331	77	114	3	10	3908	217	11	28	3
22104 Horseshoe	SW	M	206	179	101	1	15	2853	313	5	25	9
22109 Sanctuary	SW	M	294	95	104	1	2	3134	187	7	26	3
23048 Broomfield	CB	O	117	60	36	5	1	1695	77	3	0	1
23051 Wreck Is	CB	O	36	13	4	7	7	1199	7	6	0	0
23055 One Tree Is	CB	O	29	7	0	27	1	1139	3	10	0	0
23082 Lady Musgrave	CB	O	221	27	20	5	0	535	121	7	1	1

Appendix 4.3. Genus Data (from 2m transects)

Mean values of fish genera within the family Pomacentridae for all reefs surveyed duirng 1992-93.
Numbers represent the number of fish per site, averaged over all 3 sites on a reef

Reef Number & Name	Sector	Pos	ACN	AMB	AMP	CHR	CHY	DAS	DIS	NEG	NEO	PGY	POM	STE
14114 MacGillivray	CL	M	74	61	0	138	135	18	14	14	38	27	452	0
14123 Martin	CL	I	85	43	0	24	77	12	2	18	204	0	826	0
14126 Linnet	CL	I	151	64	1	63	86	2	0	29	450	3	810	0
14137 Carter	CL	O	43	1	2	317	71	0	0	0	0	19	347	16
14138 Yonge	CL	O	31	0	0	640	127	0	0	0	0	65	438	3
16015 Mackay	CA	M	101	212	3	19	86	4	53	97	15	4	506	0
16019 St. Crispin	CA	O	33	20	2	129	12	3	0	10	10	106	441	0
16028 Low Islets	CA	I	53	24	0	0	55	0	4	78	108	0	559	0
16049 Green Is	CA	I	29	78	0	83	91	55	8	9	107	7	355	3
16057 Hastings	CA	M	6	6	2	92	55	10	0	1	137	182	658	74
16060 Michaelmas	CA	M	11	6	5	96	47	0	0	2	725	118	969	13
18034 Myrmidon	TO	O	42	4	4	602	6	0	0	1	16	208	236	18
18039 Dip	TO	O	37	0	11	257	50	3	1	2	168	160	537	92
18051 Pandora	TO	I	170	7	0	0	3	0	0	56	834	0	337	0
18075 John Brewer	TO	M	55	35	8	5	87	0	16	80	256	17	880	31
18096 Davies	TO	M	51	117	22	54	79	2	3	106	372	28	1320	2
19135 Hardy	WH	M	175	9	6	283	74	0	0	22	935	2	1930	16
19138 19138	WH	M	33	50	4	716	45	3	0	3	1726	0	2725	32
19159 19159	WH	O	40	102	0	152	87	6	2	53	422	137	1318	7
19207 Hyde	WH	O	67	35	9	55	40	6	0	46	18	53	1108	0
20014 Hayman Is	WH	I	179	90	0	2	186	1	0	12	925	0	2027	0
20019 Langford and Bird Is	WH	I	196	94	0	24	321	1	1	10	394	0	1499	0
20104 20104	WH	M	61	61	1	0	248	0	0	10	1196	0	1096	18
21529 21529	SW	M	11	289	7	509	186	0	0	27	18	0	1921	22
21556 Gannet Cay	SW	M	21	463	8	3007	41	0	2	17	8	3	2356	182
22088 22088	SW	M	8	46	3	1	5	0	0	7	415	3	1747	131
22102 Chinaman	SW	M	24	170	7	537	3	0	0	83	346	75	2623	40
22104 Horseshoe	SW	M	0	157	2	19	6	2	0	8	53	11	2521	74
22109 Sanctuary	SW	M	4	90	10	106	7	2	0	88	163	65	2580	19
23048 Broomfield	CB	O	27	0	0	121	19	0	0	3	121	8	1396	0
23051 Wreck Is	CB	O	1	0	0	6	11	0	0	0	24	1	1156	0
23055 One Tree Is	CB	O	0	0	0	1	8	0	0	0	0	0	1130	0
23082 Lady Musgrave	CB	O	1	1	1	14	14	0	0	0	17	3	484	0

Appendix 5

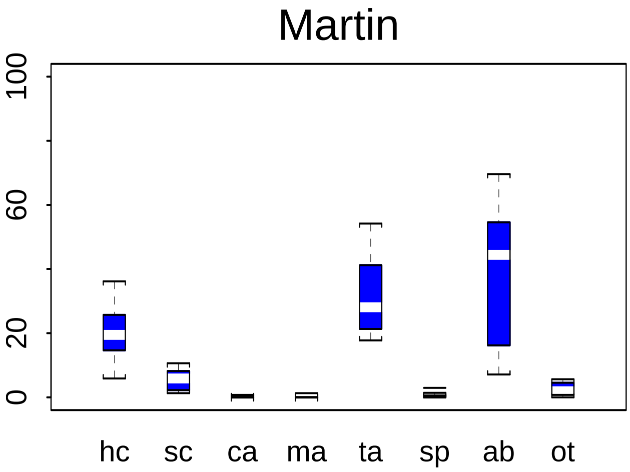
Appendix 5.1 Data Matrices of reef means used for multivariate analyses

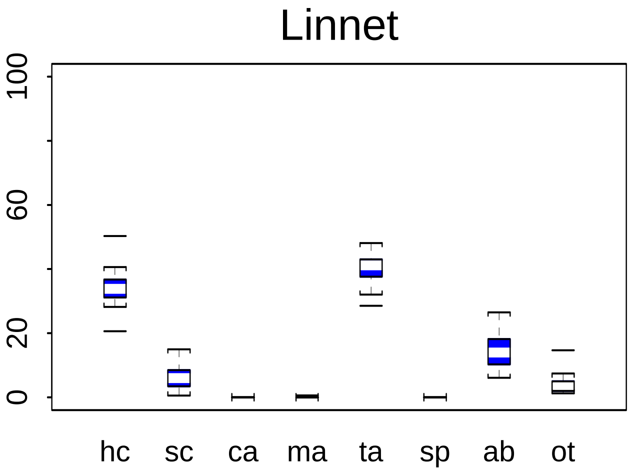
Reef means of percentage Cover for 8 benthic groups.

Reefid	Reef Name	IMO	Sector	ab	ca	hc	ma	ot	sc	sp	ta
14114	MacGillivray	M	CL	24.41	0.44	22.68	0.75	6.21	3.91	0.36	41.28
14123	Martin	I	CL	39.18	0.09	19.90	0.09	2.61	5.51	0.38	32.27
14126	Linnet	I	CL	15.03	0.00	34.16	0.04	4.21	6.24	0.00	40.35
14137	Carter	O	CL	0.20	39.94	13.13	0.39	1.96	2.60	0.05	41.73
14138	Yonge	O	CL	3.08	44.43	10.43	0.31	2.62	1.73	0.51	36.89
16015	Mackay	M	CA	12.94	0.30	26.99	1.15	3.45	4.47	0.84	49.84
16019	St. Crispin	O	CA	1.90	5.39	17.04	0.29	3.20	39.85	0.24	32.11
16028	Low Islets	I	CA	17.82	0.24	30.09	0.15	3.33	13.86	0.30	34.21
16049	Green Is	I	CA	16.89	0.21	9.45	0.49	1.71	3.63	0.74	66.86
16057	Hastings	M	CA	0.31	7.26	20.60	1.17	2.95	9.70	0.53	57.51
16060	Michaelmas	M	CA	1.58	6.96	14.29	8.16	5.61	26.13	1.22	36.07
18034	Myrmidon	O	TO	7.98	11.56	26.08	2.53	3.71	15.82	0.26	32.05
18039	Dip	O	TO	5.56	19.54	16.39	10.80	2.55	9.01	0.22	35.94
18051	Pandora	I	TO	4.68	0.01	47.13	0.09	3.04	20.33	0.14	24.60
18075	John Brewer	M	TO	12.42	19.24	9.96	4.15	6.57	4.30	0.41	42.95
18096	Davies	M	TO	5.01	21.72	27.86	11.60	6.54	2.33	1.50	23.44
19011	Middle	I	TO	34.17	0.00	26.07	10.15	2.96	6.68	0.17	19.81
19135	Hardy	M	WH	10.72	10.85	22.94	17.40	4.08	18.21	1.13	14.70
19138	19138	M	WH	18.10	17.77	15.91	1.74	2.47	2.63	0.66	39.21
19159	19159	O	WH	4.32	9.56	38.13	0.35	6.98	19.19	5.73	15.76
19207	Hyde	O	WH	1.88	9.30	19.72	1.24	7.97	41.61	10.29	7.98
20014	Hayman Is	I	WH	14.31	0.04	37.79	0.11	4.66	12.93	0.24	29.91
20019	Langford	I	WH	38.40	0.08	16.50	0.00	1.55	18.52	0.07	24.91
20104	20104	M	WH	8.55	1.05	11.24	36.77	4.81	1.42	0.09	36.05
21529	21529	M	SW	18.81	8.42	36.57	20.16	2.61	1.53	0.00	11.89
21556	Gannet Cay	M	SW	3.29	2.18	59.16	0.00	3.00	2.85	0.05	29.46
22088	22088	M	SW	1.29	16.76	33.24	0.11	1.47	3.57	0.00	43.56
22102	Chinaman	M	SW	0.11	9.71	21.86	0.59	3.44	20.50	0.00	43.80
22104	Horseshoe	M	SW	0.70	4.26	36.76	0.28	6.50	6.71	0.10	44.68
22109	Sanctuary	M	SW	0.05	9.05	24.25	0.10	5.04	23.79	0.10	37.61
23048	Broomfield	O	CB	7.03	7.00	10.07	0.33	3.00	3.62	0.00	68.96
23051	Wreck Is	O	CB	1.32	11.89	14.56	2.54	1.22	1.59	0.00	66.89
23055	One Tree Is	O	CB	4.64	13.57	4.35	1.57	0.82	0.05	0.00	75.01
23082	Lady Musgrave	O	CB	1.59	12.90	3.78	0.04	0.91	0.00	0.04	80.75

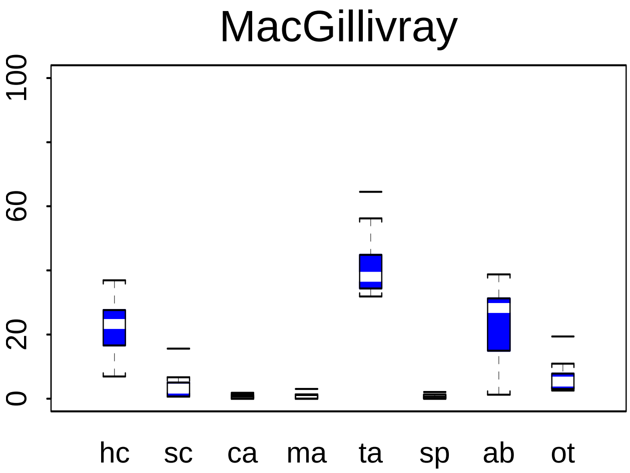
Appendix 5.2. **Summary statistics of benthos for all reefs surveyed for corals and benthos**

Cooktown/Lizard Island - Inner-shelf

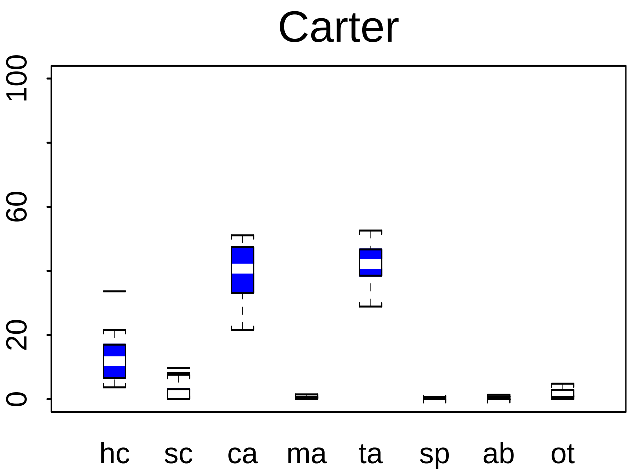


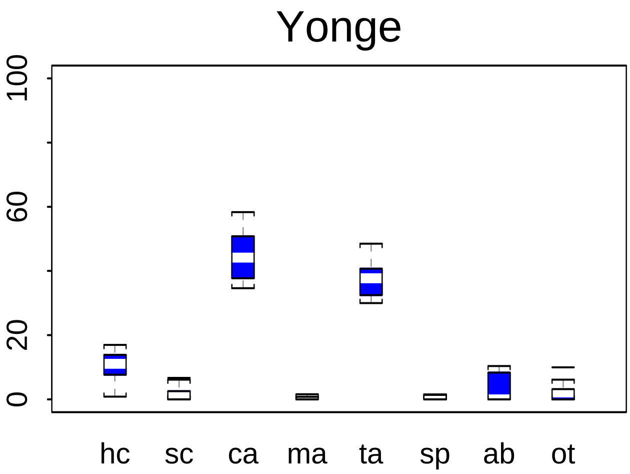


Cooktown/Lizard Island - Mid-shelf

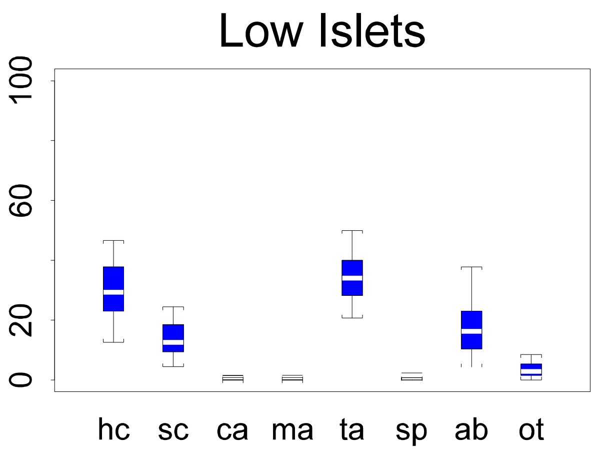


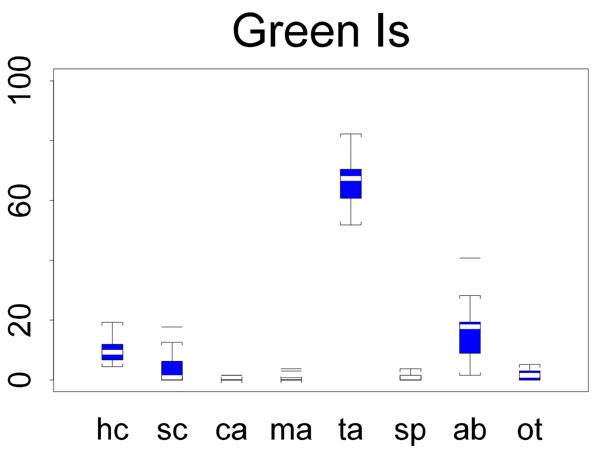
Cooktown/Lizard Island - Outer-shelf





Cairns Inner-shelf





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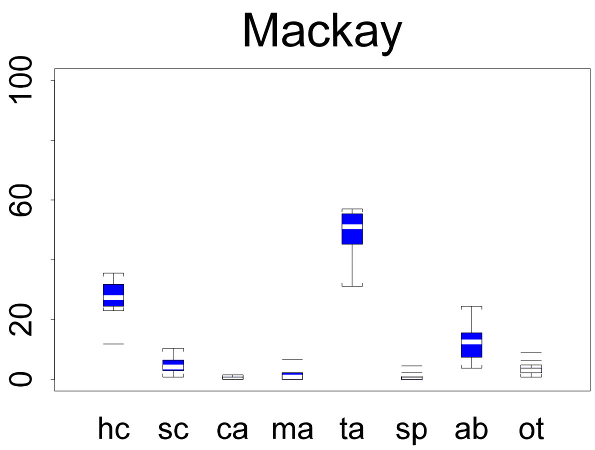
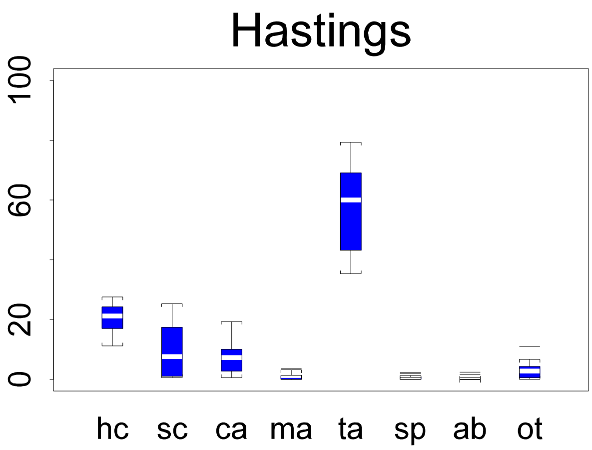
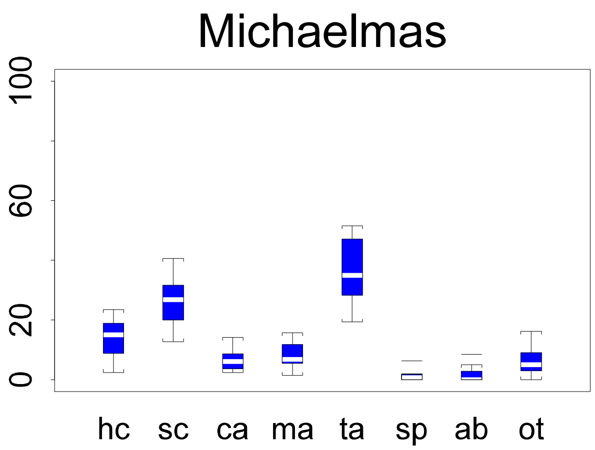
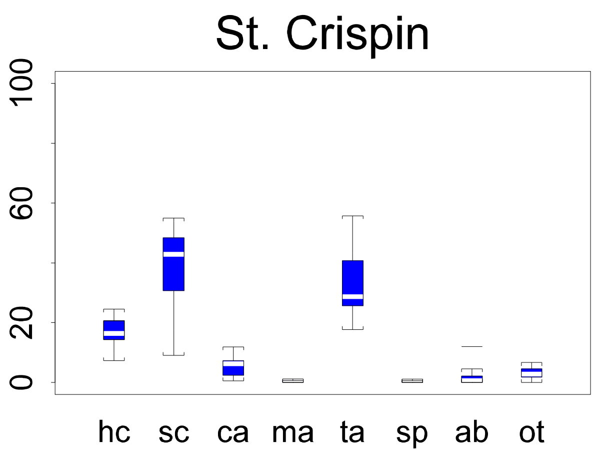


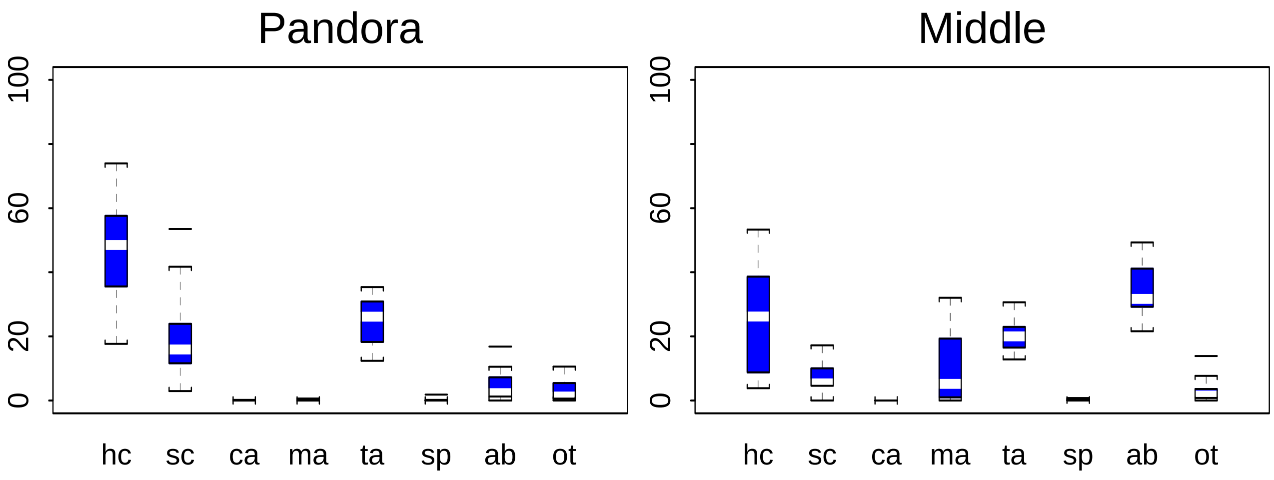




Cairns Outer-shelf



Townsville - Inner-shelf



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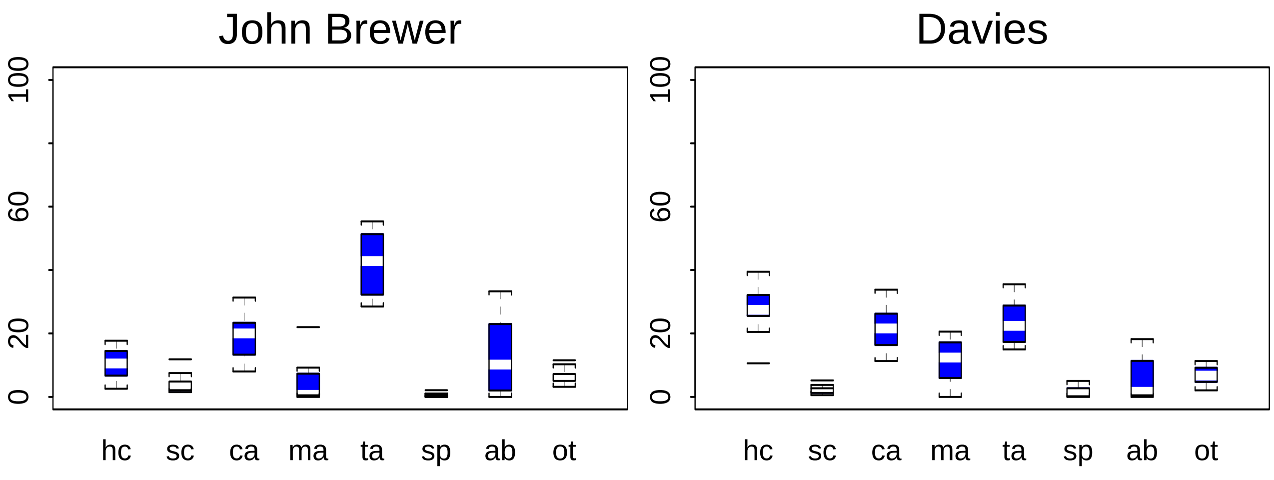

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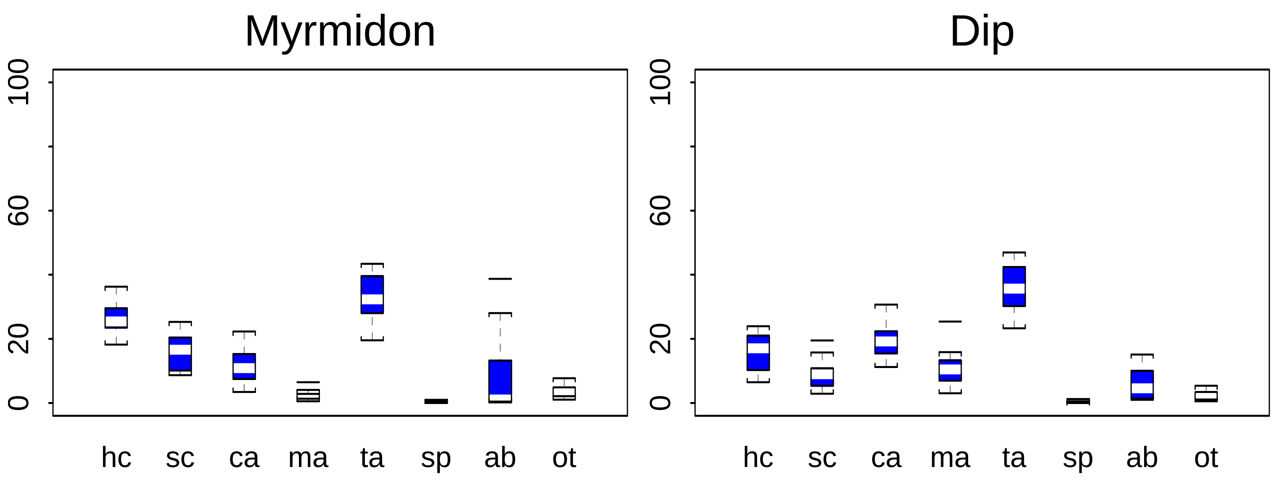
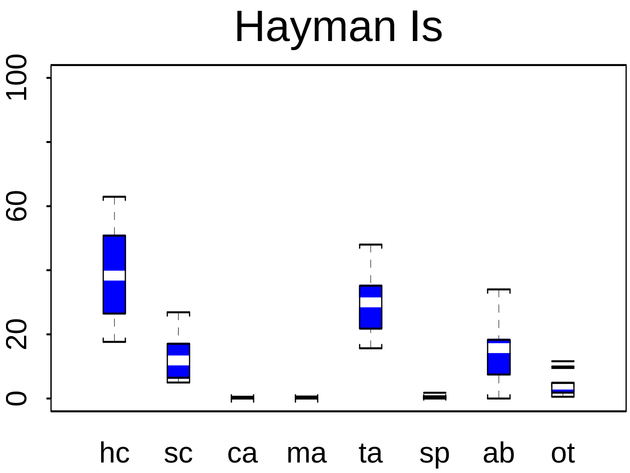
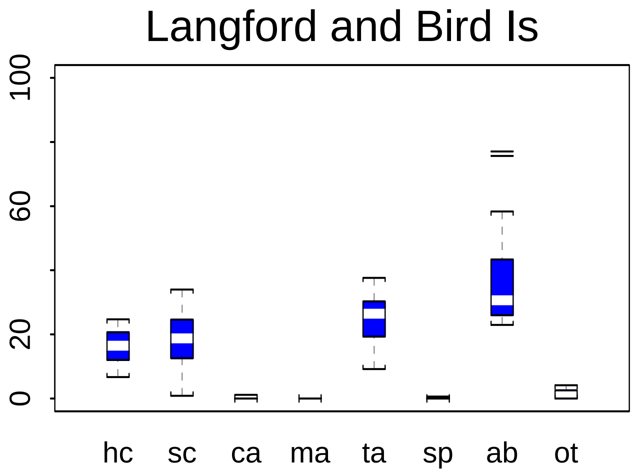
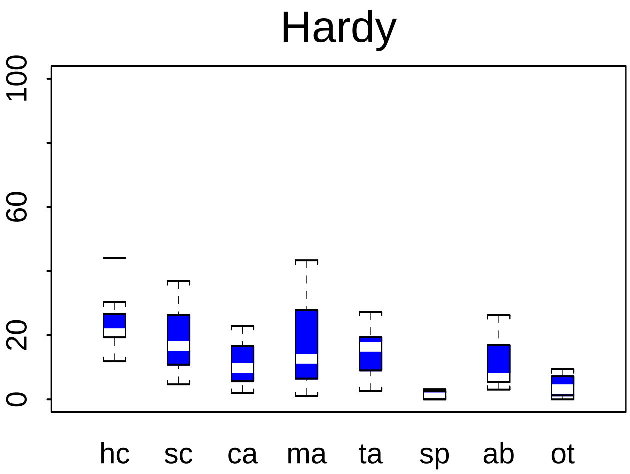


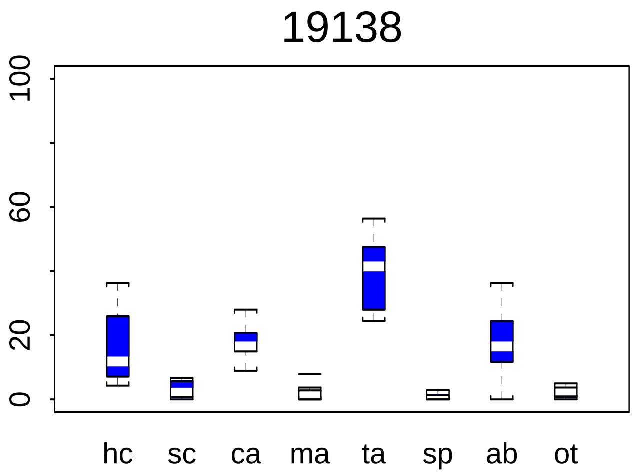
Whitsunday Inner-shelf



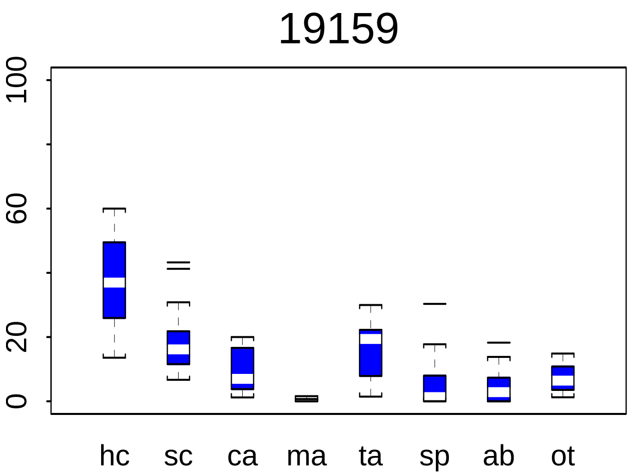


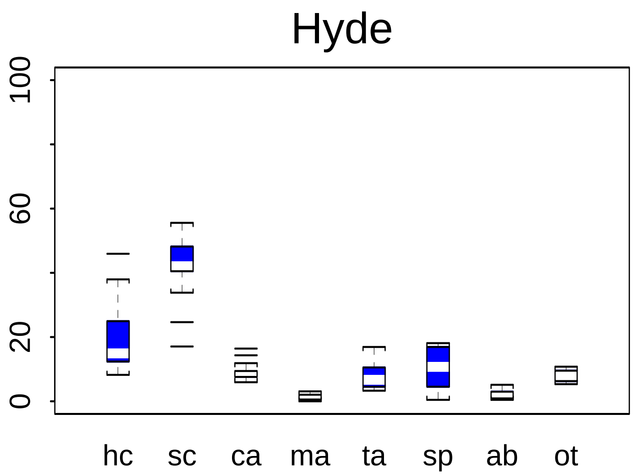
Whitsunday Mid-shelf

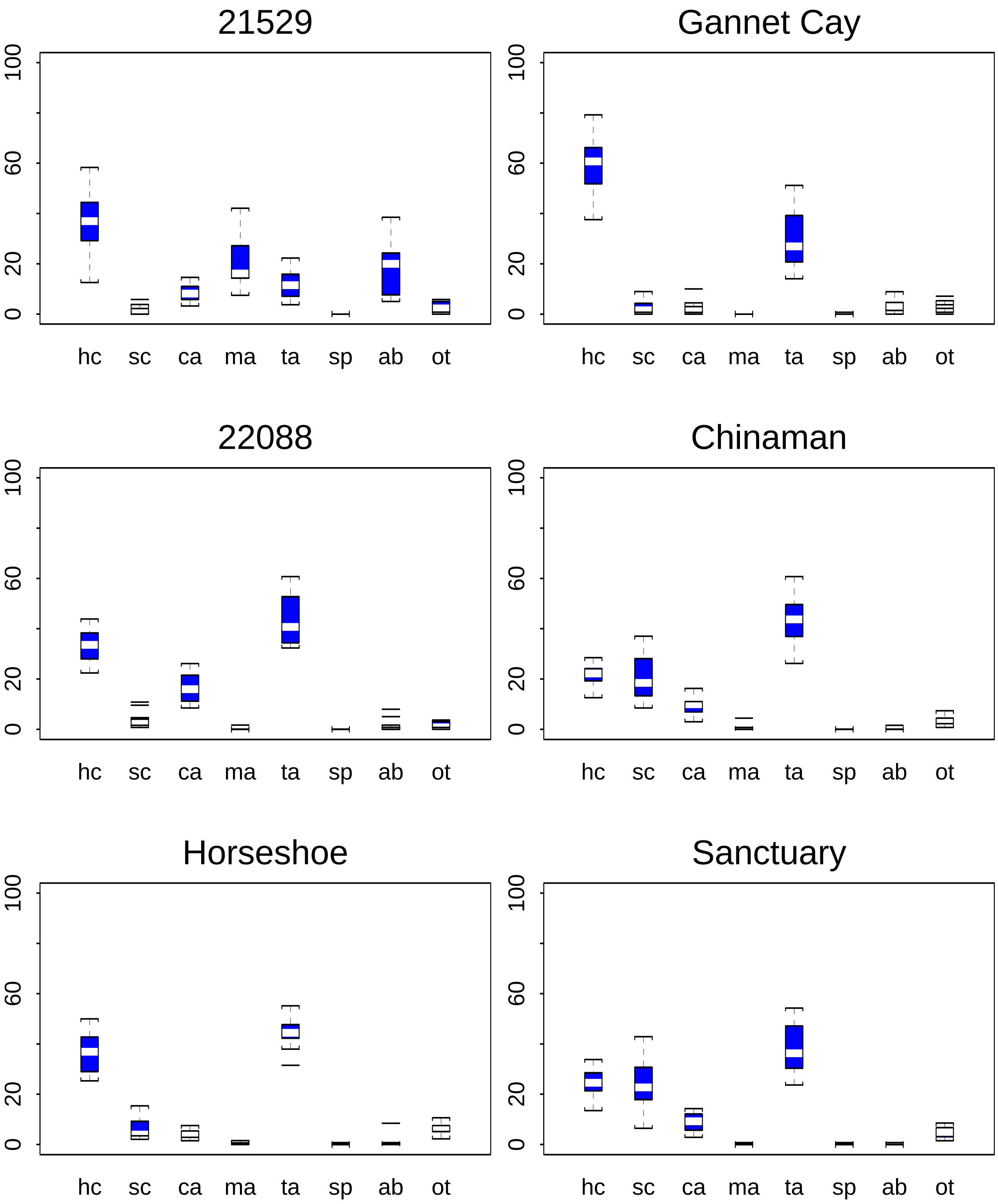




Whitsunday - Outer-shelf






21529
Gannet Cay
22088
Chinaman
Horseshoe
Sanctuary
0
20
60
100
hc
sc
ca
ma
ta
sp
ab
ot

Capricorn Bunker - Outer-shelf