LONG-TERM MONITORING OF THE GREAT BARRIER REEF

Status Report
Number 2 1997

Edited by H. Sweatman

AUSTRALIAN INSTITUTE OF MARINE SCIENCE

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Executive Summary

This report presents the results of the AIMS Long-term Monitoring Program on the Great Barrier Reef for 1993-4 and 1994-5. The program monitors the status of reefs using both broadscale and intensive surveys.

- Broadscale surveys cover the length of the GBR in 11 latitudinal sectors and have been carried out since 1985-6. The perimeters of 83 reefs were surveyed using manta tows in 1993-4; 103 reefs were surveyed in 1994-5.
- Intensive surveys of fixed sites on NE aspects of reefs in six of these sectors have been carried out annually since 1992-3 (see Oliver *et al*. 1995). Thirty two reefs were surveyed in 1993-4 and 48 in 1994-5. Detailed changes in fish and benthic communities over all three years are presented for 14 of these reefs.

Major results were:

Crown-of-Thorns starfish (COTS)

Broadscale surveys in 1993-4 recorded the lowest number of COTS since the program began, though numbers increased in the north in 1994-5.

- From 1993-4 to 1994-5 the numbers of COTS recorded in the Cairns and Cooktown-Lizard Island sectors tripled. This is thought to be the site of initiation of major outbreaks that spread throughout the GBR.
- From 1993-5 only two survey reefs (both in the Swain Reefs) had COTS in “outbreak” numbers.

Coral Cover

- The broadscale surveys showed that the highest live coral cover was found in the Pompey sector in 1993-4 (45%) and in the Pompey (44%) and Cape Grenville (43%) sectors in 1994-5.
- Lowest live coral cover was in the Cape Upstart sector in 1993-4 (11%) and the Innisfail sector in 1994-5 (18%).
- Coral cover generally increased in the Innisfail, Townsville and Cape Upstart sectors. These had low coral cover after being affected by COTS in the 1980s.
- Coral cover declined in the Whitsunday and Pompey sectors. Coral cover was initially higher than average in these sectors. The decline was not due to COTS.

Water Quality

Water quality varied greatly in space and time with concentrations being more variable inshore, particularly adjacent to the Wet Tropics in the central GBR.

- Salinity, chlorophyll and dissolved nutrients were sampled at 460 stations in 1993-4 and 646 stations in 1994-5.
- Concentrations varied least in the southern GBR: the Swains and Capricorn-Bunker sectors which are exposed to oceanic conditions.
- Consistently high concentrations of chlorophyll were found in the Whitsunday sector and Pompey reefs.

Fishes

Visual surveys of reef fishes confirmed regional differences in fish assemblages.

- There was more variation in numbers of species and in abundance among reefs spread across the shelf at one latitude than among reefs in similar shelf locations at different latitudes.
- The patterns became more distinct when reefs were classified by exposure to oceanic conditions rather than strictly by position on the shelf.
- Of 14 reefs surveyed repeatedly, only one (20-104) showed simultaneous declines in several groups of fishes over time. Another reef (Davies Reef) showed simultaneous increases in as many groups. Coral cover increased on both these reefs over the three years.

Benthic Communities

Intensive surveys using underwater video transects found that benthic assemblages varied regionally within the GBR. Coral cover increased on most reeefs that were surveyed repeatedly, made possible by low disturbance by COTS or cyclones.

- While average total live coral cover on the NE faces of reefs was similar among latitudes, there were regional differences in the dominant growth forms of corals.
- Using broad categories, the patterns became more distinct when reefs were classified by exposure to oceanic conditions rather than strictly by position on the shelf.
- Cover of live coral increased at an average of 3-5% annually over three years (based on repeated surveys of 12 reefs without significant COTS populations).
- Two out of 14 reefs showed a decline in coral cover; both had significant crown-of-thorns starfish populations.

The Ability of the Program to Detect Change

- ❐ Statistical analyses indicate that the current program design for the surveys would detect changes of 10% of total cover per year in hard coral (on an average reef using generally accepted criteria).
- ❐ The Program could detect changes of 30-40% per year for most fish families.

1. Introduction

BACKGROUND

The Australian Institute of Marine Science (AIMS) initiated a Long-term Monitoring Program for the Great Barrier Reef (GBR) in 1992 in conjunction with the Great Barrier Reef Marine Park Authority (GBRMPA). Though the program grew out of some previous monitoring initiatives, the program represents the first concerted attempt to make assessments of a range of ecological variables at a relatively large number of reefs spanning most of the GBR. In 1993 the Long-term Monitoring Program was included as a task of the newly formed Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef.

OBJECTIVES

Coral reefs are always changing through natural processes such as recruitment, growth and mortality, and disturbance by storms. A major function of the Long-term Monitoring Program (LTMP) is to provide measures of those changes and of geographic patterns in rates of change, so as to be able to distinguish changes that fall within a natural range from atypical changes that might require management intervention. The objectives of the program are:

- To monitor the status and changes in distribution and abundance of reef biota on a large scale.
- To provide environmental managers with a context for assessing impacts of human activities within the Great Barrier Reef Marine Park and with a basis for managing the GBR for ecologically sustainable use.

PROGRAM DESIGN

Measurement Variables

The data collected by the Long-term Monitoring Program can be divided into four “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, NO_3, NO_2), phosphorous (PO_4, dissolved and particulate), silicate, suspended solids, chlorophyll
Benthic Organisms	Video transects at selected sites on NE reef flanks	Percentage cover of all identifiable sessile benthic organisms (with emphasis on hard corals)
Fishes	Visual surveys of fish at selected sites on NE reef flanks	Counts of most mobile non-cryptic fish species (see Appendix 3)

Sampling Design

Selection of reefs

The original sampling design identified 52 reefs where all variables listed in Table 1.1 would be assessed annually. These are listed in Appendix 2 and their locations are shown in Appendix 1. The reefs were chosen to provide wide geographic spread throughout the GBR, and to encompass variations in the composition of coral and fish communities (Done 1982, Williams 1982) and water quality (Furnas *et al.*1988, 1995). 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).

The sample reefs were selected within six of the 11 cross-shelf sectors (Figure 1.1) previously defined for manta-tow surveys for crown-of-thorns starfish (Bainbridge *et al.* 1994). As far as is possible, three or more reefs have been selected in each of the inshore, mid-shelf and outer shelf regions of each of these sectors (see maps and full listing in Appendices 1 and 2). In the Capricorn Bunker sector, there are no adjacent inshore or mid-shelf reefs, so only outer shelf reefs were selected.

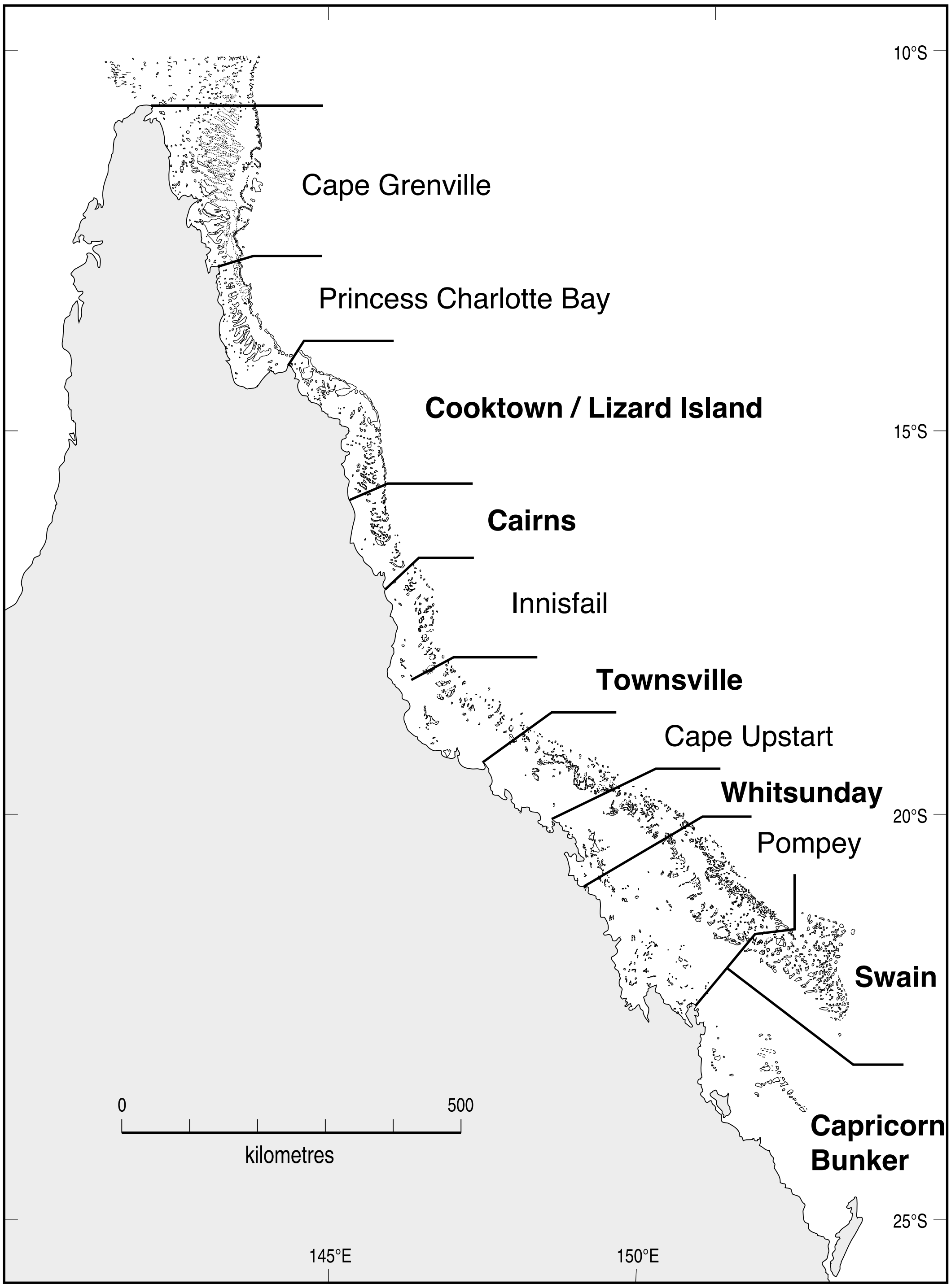


Figure 1.1. Map of the GBR showing the locations of latitudinal sectors.

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). Water quality is sampled at two sites approximately 500 m north and south of the reef. These are sampled twice about 48 hours apart. Fish and benthos are sampled at three sites in a standardised habitat on each reef. The habitat selected is defined as the first stretch of continuous 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. This habitat is usually situated on the north-east flank of the reef. Sites are separated by 250 m if the area of suitable habitat allows for this degree of spread. If the reef is very small, the sites may extend around the reef to the east and south-east flanks. There are five 50 m transects within each site which are permanently marked with a star picket at each end and sections of reinforcing rod at 10 m intervals. The transects run approximately parallel to the reef crest along the middle of the slope (generally at 6-9 m depth). In the first instance, transects were laid in a haphazard manner over hard substratum with distances between each transect varying 10-40 m.

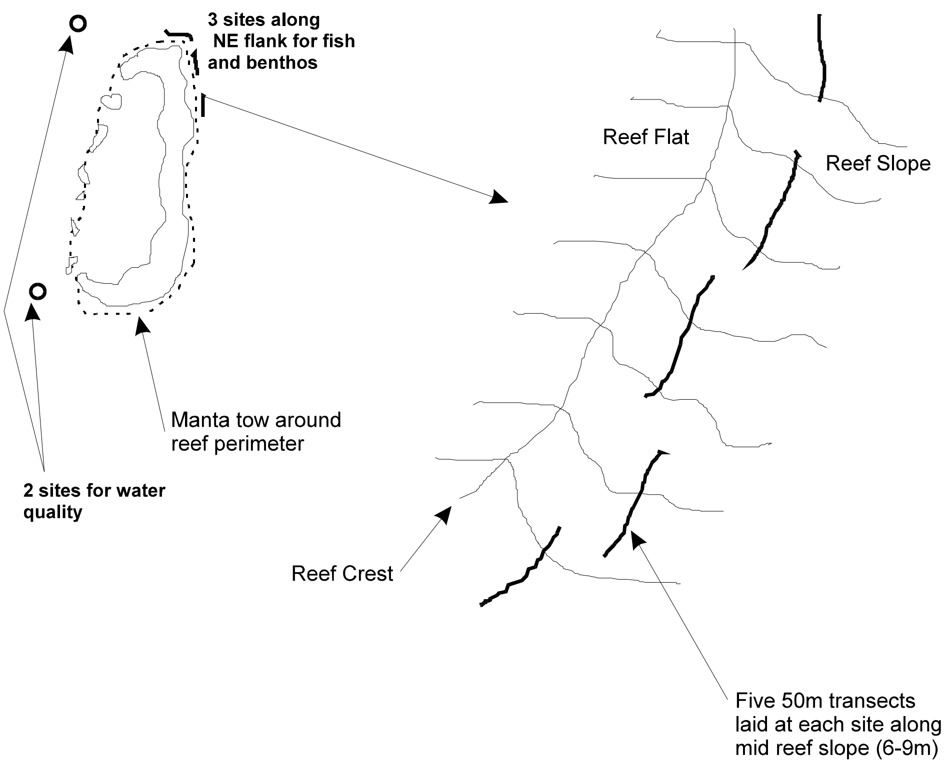


Figure 1.2. Schematic arrangement of sampling effort on a reef.

Because standard habitats are sampled, readers should keep in mind that the term "reef" is used to refer to data from a reef, which in fact comes only from the study areas on that reef. While a change in status that affects the whole reef will be manifest in the study areas, it does not necessarily follow that a change in the study area is representative of change on the whole reef. The broadscale surveys of coral cover around the perimeter of each study reef provide a basis for assessing the broader extent of change on reef slopes.

Sampling in the three years of the study

While 52 reefs have been identified for annual sampling, the first and second years of the project involved marking out the transects as well as surveying them. The extra work meant that 34 reefs were set up and surveyed in 1992-93. Transects were marked out and surveyed on 16 more reefs in 1993-94 and 16 previously established reefs were resurveyed. Two additional reefs were surveyed for the first time in 1994-95 but weather conditions and poor visibility meant that 49 reefs in total were successfully surveyed for fishes and 48 were surveyed for benthic animals in the 1994-95 field season.

As well as the core survey reefs, additional broadscale surveys were made on 51 other reefs in 1993-94 and on 55 additional reefs in 1994-95. Sampling effort is summarised in Appendix 2.

DATA STORAGE AND ACCESS

All data are held in an Oracle™ database on the AIMS computer system through a number of purpose-designed data entry and checking programs. The structure of the monitoring database is described in Baker and Coleman (in prep.). Summaries of the data will be included on the AIMS home page (http:/www.aims.gov.au). Anyone wishing for information from the database should contact the LTMP project leader at AIMS (postmaster@aims.gov.au).

QUALITY CONTROL

In a long term study such as this it is important to maintain consistency in the way data are collected and processed, so that differences that appear over time reflect real differences rather than differences in method. Each part of the program has quality control measures in place, but one general approach has been to produce a series of Standard Operating Procedures (SOPs, Table 1.2). These document the methods of data collection and processing in considerable detail. They are reviewed at least every two years and updated as necessary. Great care is also taken to train new staff members and the SOPs are useful for this purpose. Current Standard Operating Procedures are available in electronic form on the Long-term Monitoring Program home page.

Table 1.2. Titles of standard operating procedures and related documents

Broadscale surveys	Bass DK and Miller IR (1995) Crown-of-thorns starfish and coral surveys using the manta tow and SCUBA search techniques. Standard Operating Procedure No. 1, AIMS, Townsville. 33 pp.
Water quality and sediments	Devlin MJ and Lourey MJ (1996) Water quality - field and analytical procedures. Standard Operating Procedure No. 4, AIMS, Townsville. 34 pp.
	Devlin MJ (1996) Refinement of the water sampling design for the water quality component of the AIMS Long-term Monitoring Program. AIMS report No. 26. 20 pp.
	Lourey MJ (in press) Field and analytical techniques for the collection of marine sediments. Standard Operating Procedure No. 5, AIMS, Townsville.
Fishes	Halford AR and Thompson AA (1996) Visual census surveys of reef fish. Standard Operating Procedure No. 3, AIMS, Townsville. 24 pp.
Benthos	Christie CA, Bass DK, Neale SJ, Osborne K and Oxley WG (1996) Surveys of sessile benthic communities using the video technique. Standard Operating Procedure No. 2, AIMS, Townsville. 42 pp.
Data handling	Baker V.J. and Coleman G (in prep) A guide to the Reef Monitoring database. Standard Operating Procedure No. 6, AIMS, Townsville.

NOTES ON STATISTICAL ANALYSES

Two broad types of statistical analyses are used.

Univariate analyses

Univariate analyses, primarily analyses of variance, were used to investigate any systematic relationships between variables and geographic location. Data were checked for homoscedasticity by examining residual plots and transformed as necessary.

Geographic patterns in particular were examined with series of contrasts addressing particular questions. Such contrasts follow a logical sequence and, in some instances, significant interaction terms or tests for heterogeneity among groups of regional means dictate that subsequent contrasts must be interpreted with careful reference to graphs of treatment means (e.g. Fig. 4.1, 5.1, etc.). This is because subsequent (main effect) contrasts are comparisons of pairs of *means* and the statistical significance of previous tests implies that the values contributing to one of the means vary considerably. When such a subsequent contrast is significant, this implies that the *mean* abundances (or percent cover values) differ significantly over and above variation among the contributing values. When such a contrast is not significant it indicates that *mean* abundances do not differ, but that may be because the contributing values vary in such a way that their differences cancel out. Thus lack of significance in such a contrast does not imply that all the contributing values are similar. Tests that require careful interpretation are indicated in the summary tables.

Multivariate analyses

Multivariate analyses, specifically ordinations, were used to examine how the relationships among groups of variables change over space or time. Biplots display multidimensional clouds of datapoints, each representing the values of several variables (usually abundance of taxa) for one observational unit (OU, usually a reef), by projecting them on a two-dimensional space whose axes represent uncorrelated derived combinations of variables that account for the greatest portion of the variation among the OUs in the data cloud. **For interpretation**, OUs that map together in the biplot are likely to have similar values of many variables and OUs that map far from the origin of the vectors are likely to have divergent values for some variables.

The angles between overlying vectors represent correlations between variables while length of vectors represent the displacement in multidimensional space due to individual variables, which is related to the standard deviation for that variable. **For interpretation**, the length of the vectors indicate the amount of variation among OUs accounted for by that variable, so a long vector indicates that values of that variable vary widely among OUs. At the same time, OUs that map at a distance from the origin of the vectors and lie along the line of a vector associated with a particular variable are likely to have high values of that variable. Conversely, OUs that map at a distance from the origin but in the opposite direction are likely to have low values of that variable.

Data are often transformed prior to analysis; commonly a logarithmic transform is used. This reduces the emphasis given to extreme values, making the scale of measurement proportional: a difference between 0.1 and 1.0 is equivalent to the interval between 10 and 100.

GOALS OF THIS REPORT

This report follows the first Status Report (Oliver *et al*. 1995) and is based on data collected in the second and third years of the Program. Because of the labour involved in marking reef transects to be able to locate them again each year, it was not possible both to set up and to monitor all the projected sites in a single field season. The first status report concerned observations from 34 reefs where sampling sites were established and surveys were completed in 1992-93. The first status report was primarily concerned with geographic patterns in biota. As well as considering geographic patterns in biota based on a more complete set of sample reefs, this report also deals with change in assemblages of reef animals. This will be the main focus of the LTMP in future.

2. Broadscale Surveys

Ian Miller, Debbie Bass and Hugh Sweatman

INTRODUCTION

AIMS began broadscale surveys of the Great Barrier Reef in the mid 1980's. The primary objective of the broadscale survey component of the Long-term Monitoring Program is to detect and monitor populations of crown-of-thorns starfish (COTS) on the Great Barrier Reef. The manta tow method also estimates percent cover of living and dead coral and so allows assessment of the impact of COTS outbreaks and other large scale disturbances and of subsequent recovery.

This report updates the long-term trends in COTS activity summarised by Moran *et al.* (1993) and more recently by Oliver, Miller *et al.* (1995). The overall objectives and design of the AIMS Long-term Monitoring Program are described in Section 1. This section presents the results of surveys from the 1993-94 and 1994-95 years. In total, 186 surveys were conducted during this time at 11 latitudes (sectors) from Cape Grenville in the north to the Capricorn Bunker group in the south (Appendix 2).

METHODS

The general design of the monitoring program is described in Section 1. Broadscale surveys use the manta tow technique as described by Bass and Miller (1995) and English *et al.* (1997).

Study sites

In total, 83 reefs were surveyed in the 1993-94 year (Table 2.1) and 103 in the 1994-95 (Table 2.2). Under the current sampling scheme a core of 63 'key' reefs have been identified for survey by manta tow each year. Variable numbers of additional 'cycle' reefs (approximately 50) have been scheduled to be sampled one year in three. Factors such as bad weather and poor visibility have meant that some of these reefs were omitted. The full list of reefs which are surveyed as part of the Long-term Monitoring Program is in Appendix 2.

Table 2.1. Summary of COTS for each sector in 1993-94. "AO" = active outbreak, "RE" = recovering, "NO" = no recent outbreak.

Sector	No. of reefs	No. COTS per tow	No. COTS	Number (%) of reefs with COTS		Median (range) coral cover		Mean coral cover ± SE	% AO reefs	% RE reefs	% NO reefs
Cape Grenville	6	0.004	1	1	(16.7)	3-	(2- to 4+)	37.70±7.44	0	0	100
Princess Charlotte Bay	6	0.025	7	1	(16.7)	2+	(1+ to 3-)	22.94±2.91	0	33.3	66.7
Cooktown/Lizard Island	16	0.064	44	9	(56.3)	2+/3-	(2- to 4-)	29.91±2.67	0	37.5	62.5
Cairns	12	0.009	5	3	(25)	1+/2-	(1- to 3+)	15.18±2.95	0	25	75
Innisfail	5	0.008	2	2	(40)	2-	(1- to 2+)	20.22±2.76	0	100	0
Townsville	6	0.003	1	1	(16.7)	2+	(1+ to 3+)	23.59±3.39	0	33.3	66.7
Cape Upstart	5	0.005	1	1	(20)	1+	(1- to 2-)	11.49±2.50	0	80	20
Whitsunday	7	0.007	2	1	(14.3)	2+	(1- to 3-)	24.55±3.76	0	14.3	85.7
Pompey	6	0.031	8	3	(50)	3-/3+	(3- to 4+)	44.88±6.88	0	0	100
Swains	10	0.109	46	5	(50)	2-/2+	(2- to 4-)	27.49±3.55	20	10	70
Capricorn Bunkers	3	0.000	0	0	(0)	2-	(1+ to 2+)	19.36±3.87	0	0	100

Table 2.2. Summary of COTS for each sector in 1994-95. "AO" = active outbreak, "RE" = recovering, "NO" = no recent outbreak.

Sector	No. of reefs	No. COTS per tow	No. COTS	Number (%) of reefs with COTS		Median (range) coral cover		Mean coral cover ± SE	%AO reefs	%RE reefs	%NO reefs
Cape Grenville	9	0.004	1	1	(11)	3-/3+	(2+ to 4+)	43.25±4.23	0	0	100
Princess Charlotte Bay	6	0.013	3	1	(16.7)	2-	(1- to 3+)	19.77±4.25	0	16.7	83.3
Cooktown/Lizard Island	19	0.120	118	9	(47.4)	2+	(1- to 3+)	22.37±2.02	0	36.8	63.2
Cairns	18	0.043	30	8	(44.4)	2-	(1- to 3+)	21.78±2.38	0	27.8	72.2
Innisfail	7	0.009	3	3	(42.9)	2-	(1- to 3+)	18.42±3.22	0	42.9	57.1
Townsville	8	0.000	0	0	(0)	2-	(1+ to 3+)	23.85±3.62	0	62.5	37.5
Cape Upstart	6	0.000	0	0	(0)	2-/2+	(1- to 3+)	21.08±4.97	0	50	50
Whitsunday	11	0.000	0	0	(0)	2+	(1- to 3-)	23.07±3.37	0	18	82
Pompey	4	0.017	2	2	(50)	3+	(3- to 3+)	43.79±1.62	0	0	100
Swains	12	0.253	142	6	(50)	2+	(1+ to 3+)	27.17±2.58	16.7	8.3	75
Capricorn Bunkers	3	0.006	1	1	(33.3)	2-	(2- to 2+)	24.51±1.37	0	0	100

Sampling techniques

Each reef is surveyed using two teams working in opposite directions around the reef perimeter. A team consists of a boat driver and an observer who is towed behind the boat on a manta board. At 2 minute intervals the boat stops and the observer records several kinds of information (Table 2.3).

At the completion of manta tow surveys of a reef, incidental observations made during surveys is used to complete a "reef aesthetics" data sheet. This information is designed to provide a broad description of the reef slope, dominant coral type, general aesthetics, giant clam sightings and other phenomena of interest.

Table 2.3. Primary variables recorded during manta tows, see Bass and Miller (1995) for more details.

Variable	Data recorded	Categories
Number of COTS	number observed	actual counts
Size class of COTS	size class	A = juvenile (<25cm) B = adult (>25cm)
Presence of feeding scars	abundance categories	A = absent (0) P = present (1-10) C = common (>10)
Live coral	estimated cover categories (scale of 0-5)	0 = 0% 1- = >0-5%
Dead coral	estimated cover categories (scale of 0-5)	1+ = >5-10% 2- = >10-20% 2+ = >20-30% 3- = >30-40%
Sand/rubble	estimated cover categories (scale of 0-5)	3+ = >40-50% 4- = >50-62.5% 4+ = >62.5-75% 5- = >75-87.5% 5+ = >87.5-100%
Visibility	distance categories (scale of 1-4)	1 = <6m 2 = 6-12m 3 = 12-18m 4 = >18m

Quality control

In order to track change in COTS populations and coral cover through time, the information recorded by observers must be precise. Quality control is in two stages. First, all observers are trained before participating in the broadscale surveys (see Bass and Miller 1995). Estimates are influenced by a variety of factors and observers' precision will vary continually (Moran and De'ath 1992) so on each sampling cruise, selected reefs are towed by two teams following the same path to give a measure of the variability between observers. When observers show signs of bias (see Miller and Müller 1997) they are retrained.

Data handling

The median benthic cover category scores (for live coral, dead coral and sand and rubble), the number of COTS counted per reef and the average number of COTS per tow for each reef are calculated. These derived variables are used in conjunction with other anecdotal reports to classify each reef in terms of its outbreak status (Fernandes 1991; Moran and De'ath 1992). Reefs are assigned to one of three categories: Active Outbreak (AO); Recovering (RE); or No recent Outbreak (NO). In concept, an Active Outbreak occurs when population densities reach levels where loss of coral tissue through starfish feeding is estimated to be faster than the growth of the coral. Practical criteria have evolved over the time that surveys have been made. Initially categorisation was qualitative: reefs with active outbreaks were those where >40 COTS were recorded over the whole reef and >30% of coral was dead. Extensive examination of manta tow data from reefs of all categories found that 90% of reefs with active outbreaks by these criteria supported >1500 COTS km^{-2} (Moran and De'ath 1992). This is approximately 0.22 COTS per two-minute tow. In 1995, consideration of the relative costs of Type I and Type II errors, the criterion for an Active Outbreak was revised upwards (to 1.0 COTS per tow) and additional classes of outbreaks were recognised (Lassig and Engelhardt 1995, Engelhardt *et al*. 1997). The criterion of 0.22 COTS per tow is used in this section for continuity with previous AIMS reports.

Recovering reefs are those that have had outbreaks at least within the preceding decade and continue to show evidence of that in having substantial quantities of dead coral. For this report, percentage cover of live and dead coral has been calculated by representing each cover category by the mid-point of its range.

RESULTS

The 1993-94 surveys recorded the lowest total number of COTS since the broadscale survey program began: 117 COTS were observed on 27 out of 83 reefs surveyed. COTS were recorded in all sectors except the Capricorn Bunker sector. Examination of the data by sector (Table 2.1) shows only two reefs in the Swain sector had active outbreaks, (Reef 22-088 and Gannet Cay). In the following year (Table 2.2) there was an obvious increase in COTS activity with the total number of COTS almost tripling between the 1993-94 and 1994-95 surveys. Three hundred COTS were recorded on 26 of the 103 reefs surveyed in 1994-95. Although an increase in COTS numbers and two active outbreaks were recorded in the Swains sector (Horseshoe and 22-088), the threefold increase in COTS populations in the Cairns and Cooktown/Lizard Island sectors is of particular interest. This area has previously been identified as the likely centre for the primary outbreaks that lead to increased COTS activity throughout the GBR (Reichelt *et al*. 1990, Moran *et al.* 1993). However, these populations were not sufficiently large to be classified as Active Outbreaks. Few COTS were observed in the central section of the GBR, ie, the Townsville, Cape Upstart and Whitsunday sectors in either the 1993-94 or 1994-95 survey years

The highest mean coral cover was recorded in the Pompey sector in 1993-94 (45%) and in 1994-95 (44%) together with the Cape Grenville sector. The lowest coral cover was recorded in the Cape Upstart sector in 1993-94 and the Innisfail sector in 1994-95. Mean coral cover has increased over the two year period in the Cape Grenville, Cairns, Cape Upstart, and Capricorn/ Bunker sectors. This was particularly evident in the Cape Upstart sector where the coral cover had almost doubled (though this was from very low levels following severe COTS outbreaks in the late 1980s). In the same period, the coral cover decreased in the Cooktown/Lizard Island sector. This coincided with the general increase in COTS activity in this sector.

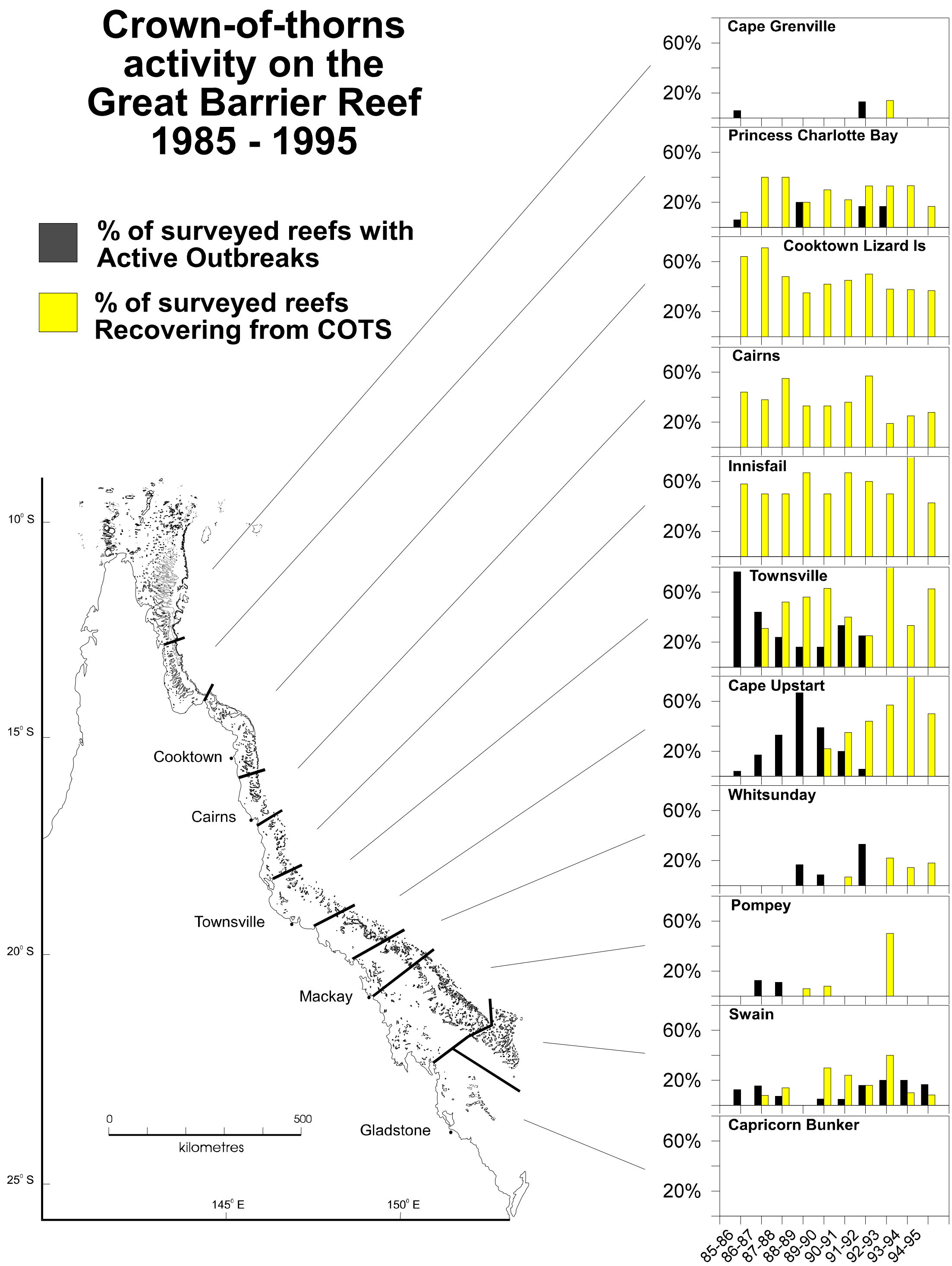


Figure 2.1. Summary results for COTS in the GBR between 1985-86 and 1994-95.

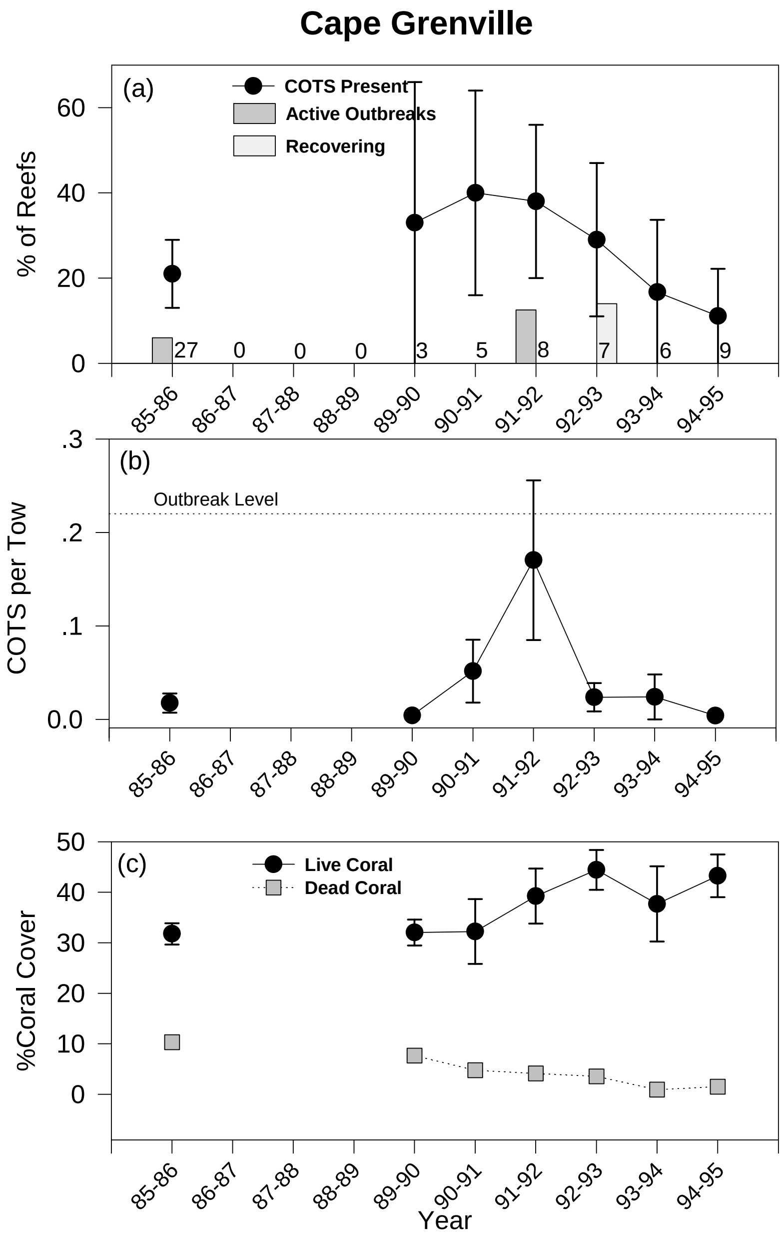


Figure 2.2. Results of broadscale surveys of the Cape Grenville sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates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

Cape Grenville sector

The long-term patterns of COTS activity in this sector are difficult to interpret due to the low numbers of reefs surveyed and lack of data for 1986 - 89. Coral cover on reefs in this sector was moderately high (30-50%) and has been increasing in recent years. The number of COTS showed a corresponding decline.

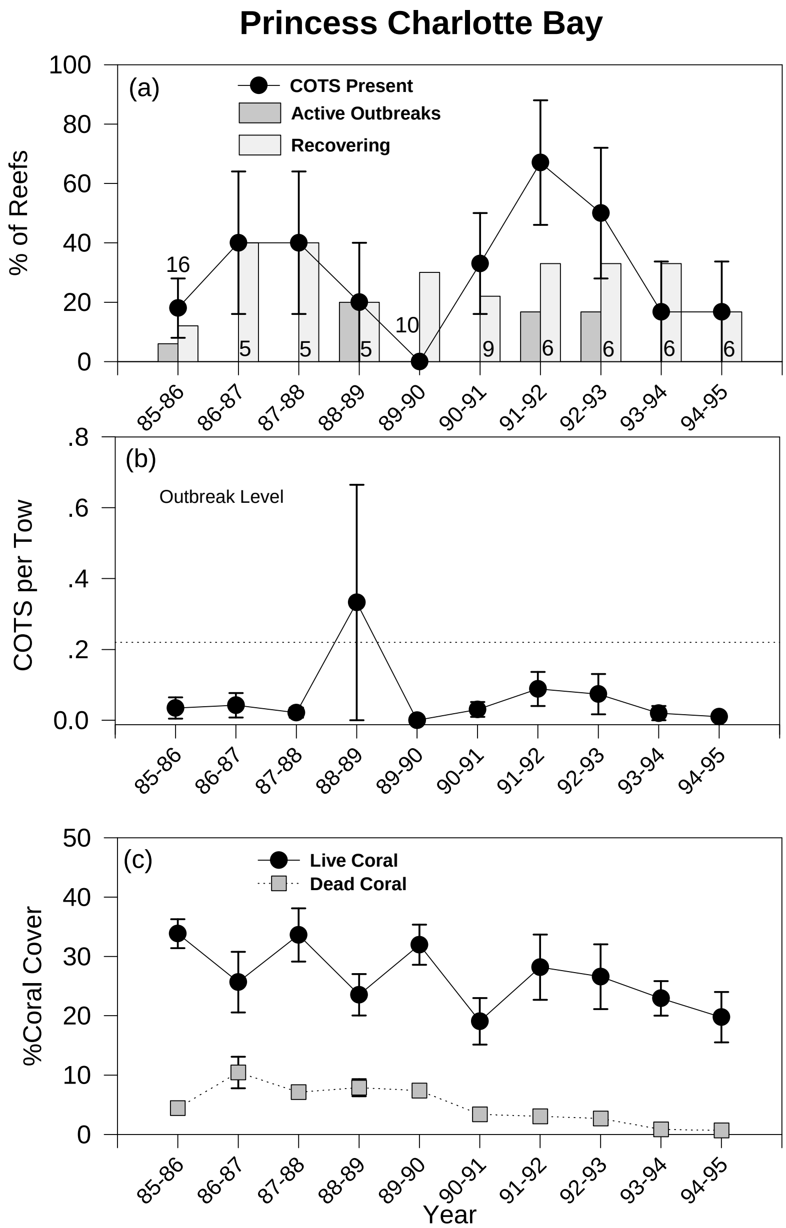


Figure 2.3. Broadscale survey results for the Princess Charlotte Bay sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line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

Princess Charlotte Bay sector

COTS have been present in this sector in most survey years and outbreaks have been recorded on three occasions. COTS densities have been low in all years except 1988-89 when there was an active outbreak on Clack Reef. Live coral cover has averaged 20-35% and has shown a small general decline.

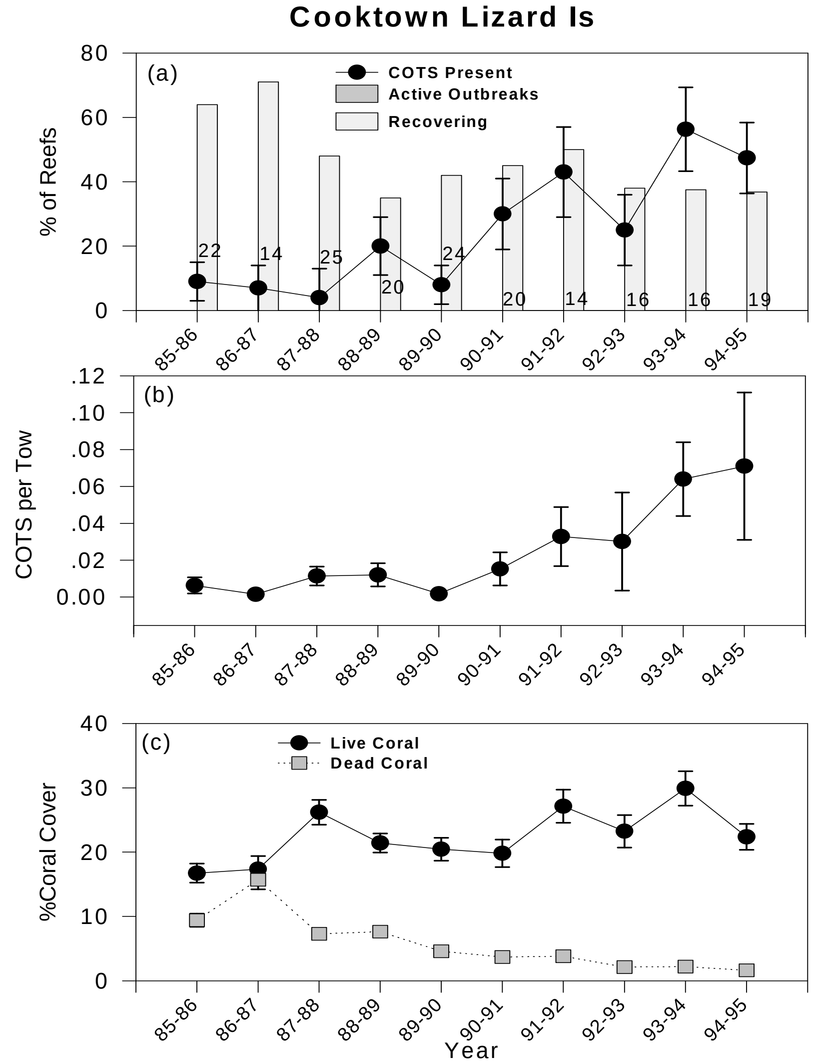


Figure 2.4. Results of broadscale surveys of the Cooktown/Lizard Island sector showing: **a**) percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b**) COTS densities for the entire sector expressed as number of COTS per tow; **c**) averaged percent cover of live and dead coral. Error bars represent standard errors.

Cooktown/Lizard Island sector

During the initial years of surveys, the reefs in this sector had very low numbers of COTS on a few reefs. No active outbreaks were observed during this period. There has been a general increase in the number of COTS in this sector since 1990. The percentage of affected reefs increased although most of the starfish in 1994-95 were recorded on only five of the 19 survey reefs (Forrester Reef, Lizard Island, Mackay Reefs, North Direction and Swinger Reef). Starfish densities remained well below outbreak levels in 1994-95 with mean live coral cover of 20- 30%. Dead coral continued to decline to below 5%.

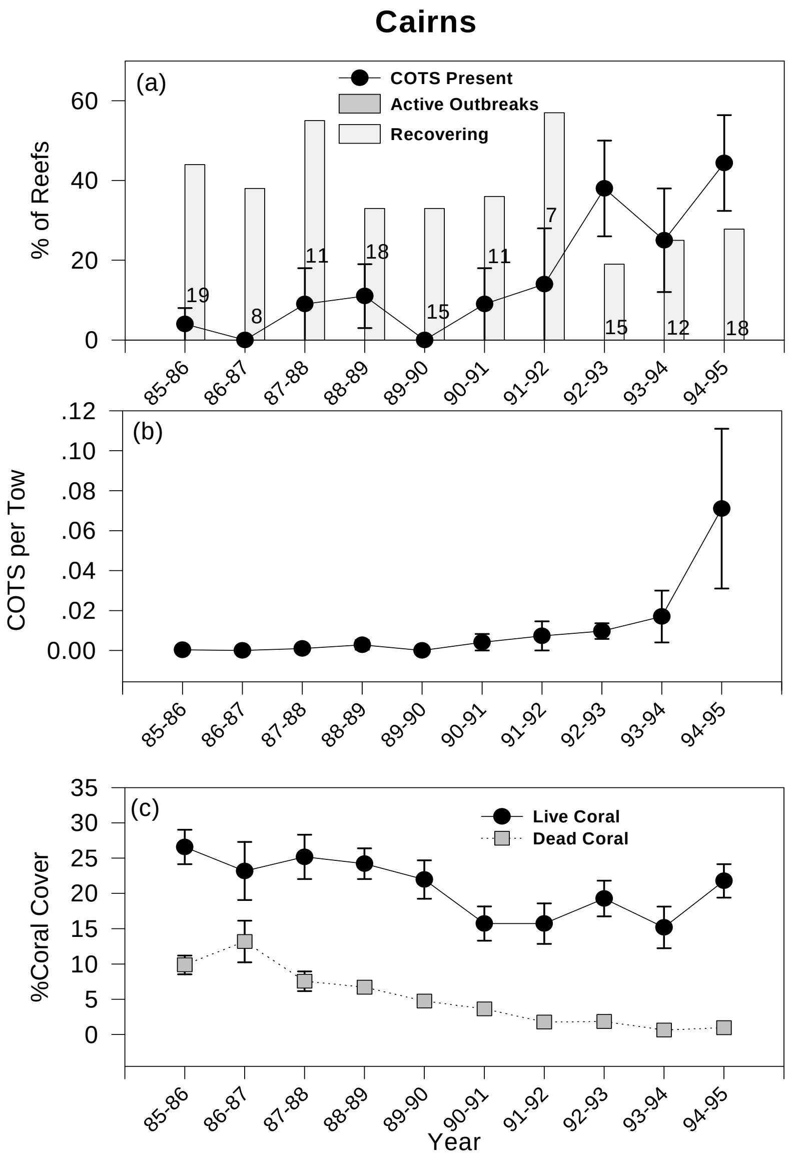


Figure 2.5. Results of broadscale surveys of the Cairns sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow; **c)** averaged percent cover of live and dead coral. Error bars represent standard errors.

Cairns sector

Although there were several outbreaks in the years preceding the initiation of the COTS monitoring program, few COTS have been recorded in this sector and no active outbreaks have been detected. However, the number of COTS has increased consistently since 1990-91. SCUBA searches by AIMS also indicated recent COTS recruitment on some reefs. COTS densities were still well below outbreak levels.

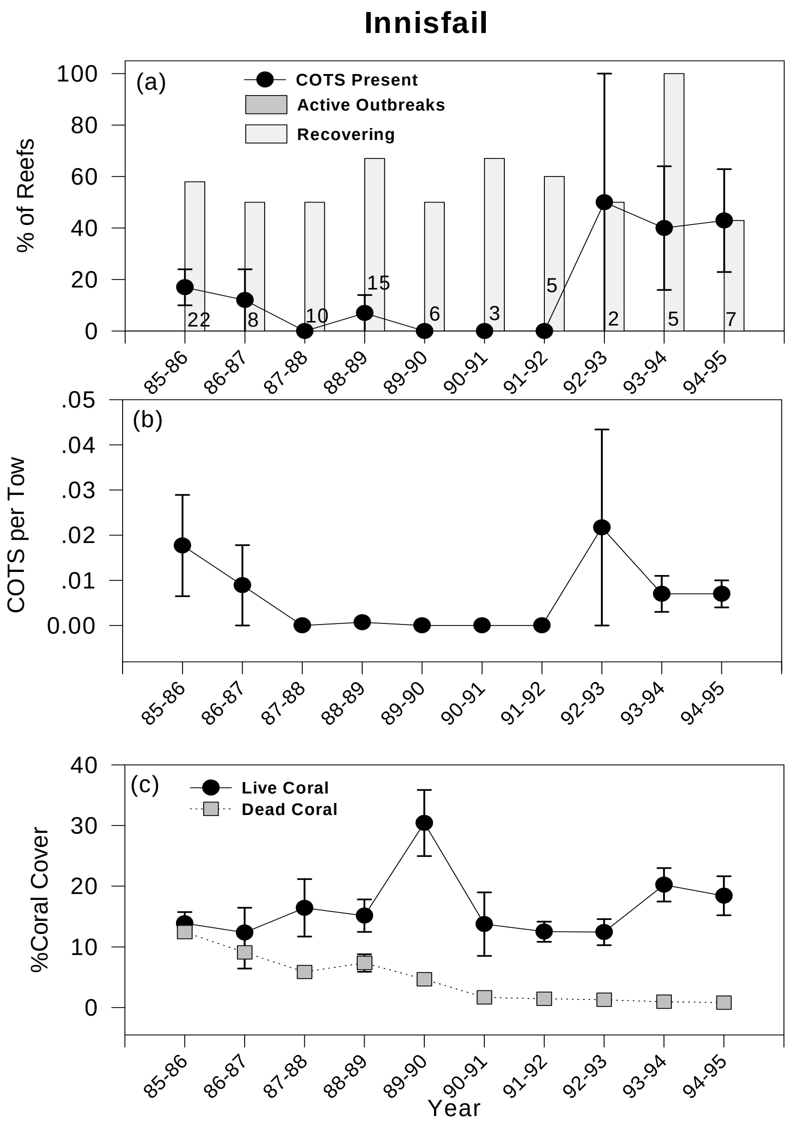


Figure 2.6. Results of broadscale surveys of the Innisfail sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow; **c)** averaged percent cover of live and dead coral. Error bars represent standard errors.

Innisfail sector

AIMS surveys have generally recorded low numbers of COTS in this sector and no active outbreaks have been identified. Over half of the reefs were classified as Recovering from prior COTS activity. Densities of COTS showed a small decrease in the first three years and then remained below outbreak densities. The small increase in COTS activity in the 1992-93 survey year was probably an artefact of the small number of reefs sampled in that year. COTS numbers remained low with less than five seen on all seven reefs surveyed in 1994-95. Coral cover on reefs in this sector increased gradually in the two years to moderate levels (10-30%).

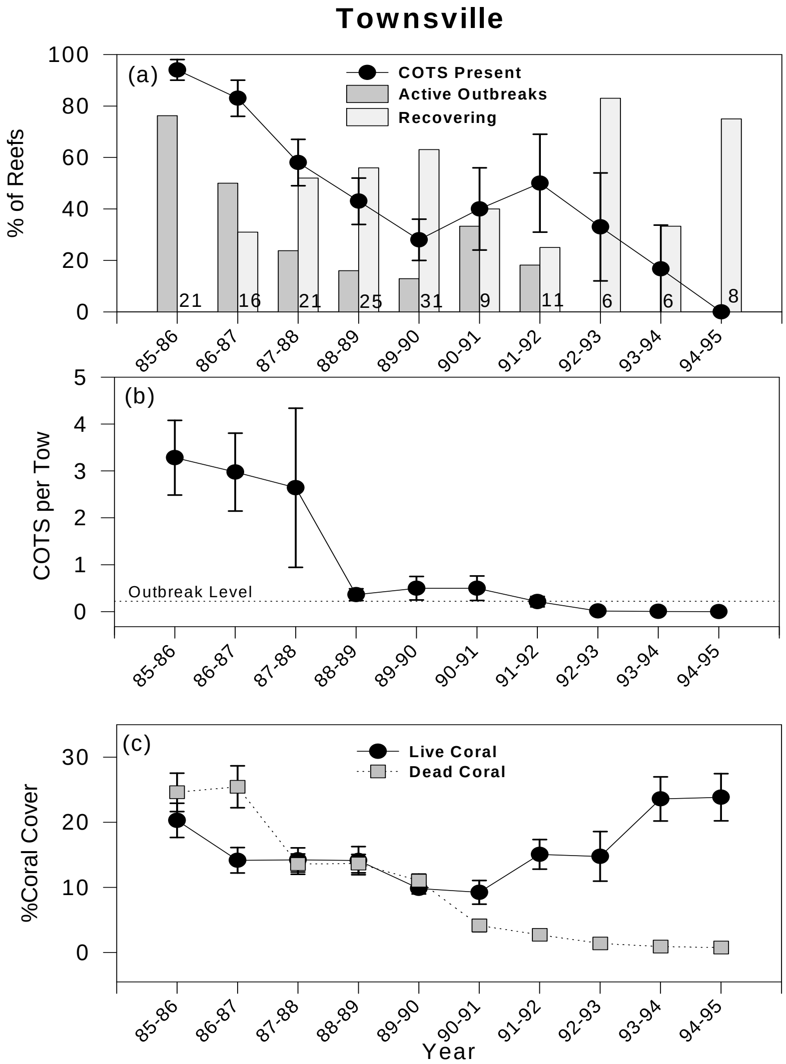


Figure 2.7. Results of broadscale surveys of the Townsville sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates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

Townsville sector

COTS activity has declined since the beginning of AIMS' surveys when nearly 80% of reefs surveyed were classified as having Active Outbreaks. COTS densities, frequency of occurrence on reefs and percentage of reefs with active outbreaks all showed a general decline in subsequent surveys and coral cover increased accordingly. The 1992-93 survey was the first time COTS were not recorded in this sector since the broadscale surveys started. Townsville reefs showed signs of recovering from past COTS outbreaks: live coral cover showed a gradual increase to levels (20-30%) recorded during the peak of the COTS outbreaks in 1985-86. There was a corresponding drop in dead coral from 10-30% cover in 1985-86 to less than 5% in 1994-95.

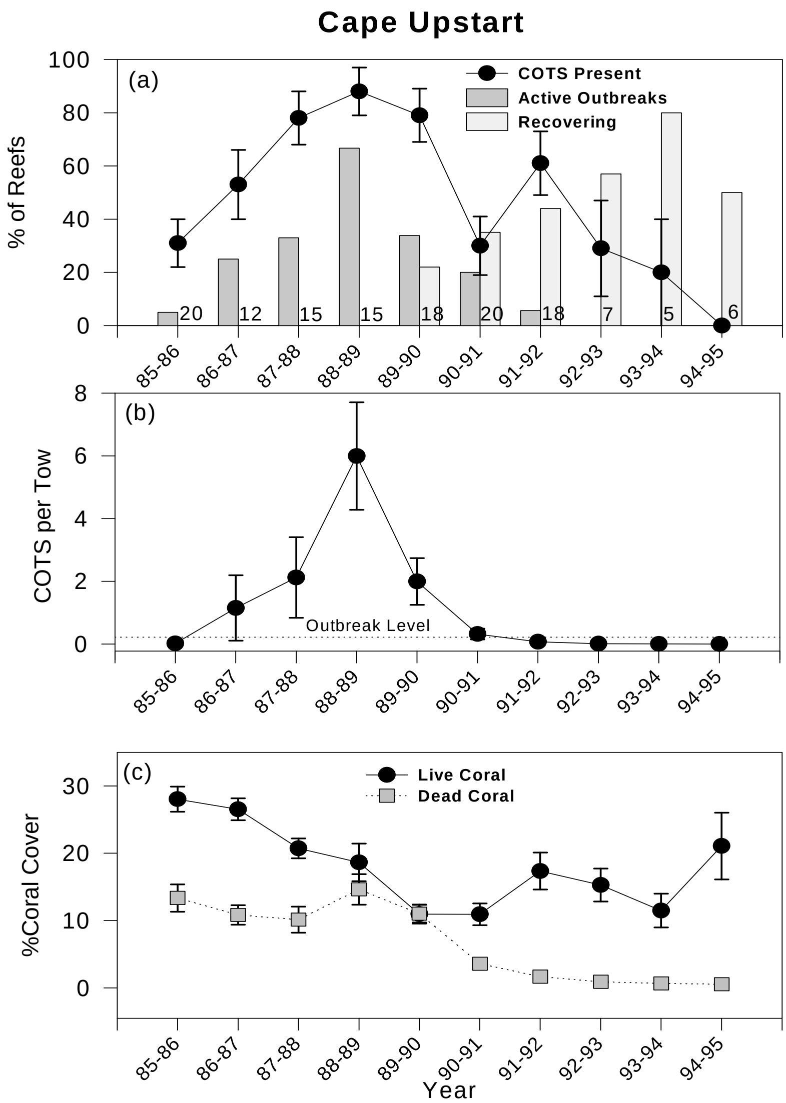


Figure 2.8. Results of broadscale surveys of the Cape Upstart sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates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

Cape Upstart sector

Survey results from this sector showed a significant build up of COTS densities starting in 1985-86, reaching a peak in 1988-89 and then declining. No reefs have had active outbreaks since 1991-92. There was a corresponding drop in live coral cover from nearly 30% to approximately 10% towards the end of outbreaks in 1990-91. Cover fluctuated over the next three years, but increased sharply in 1994-95 from 11% to 21%. Dead coral cover continued to decline to below 5%. No COTS were observed in this sector in the 1994-95 survey.

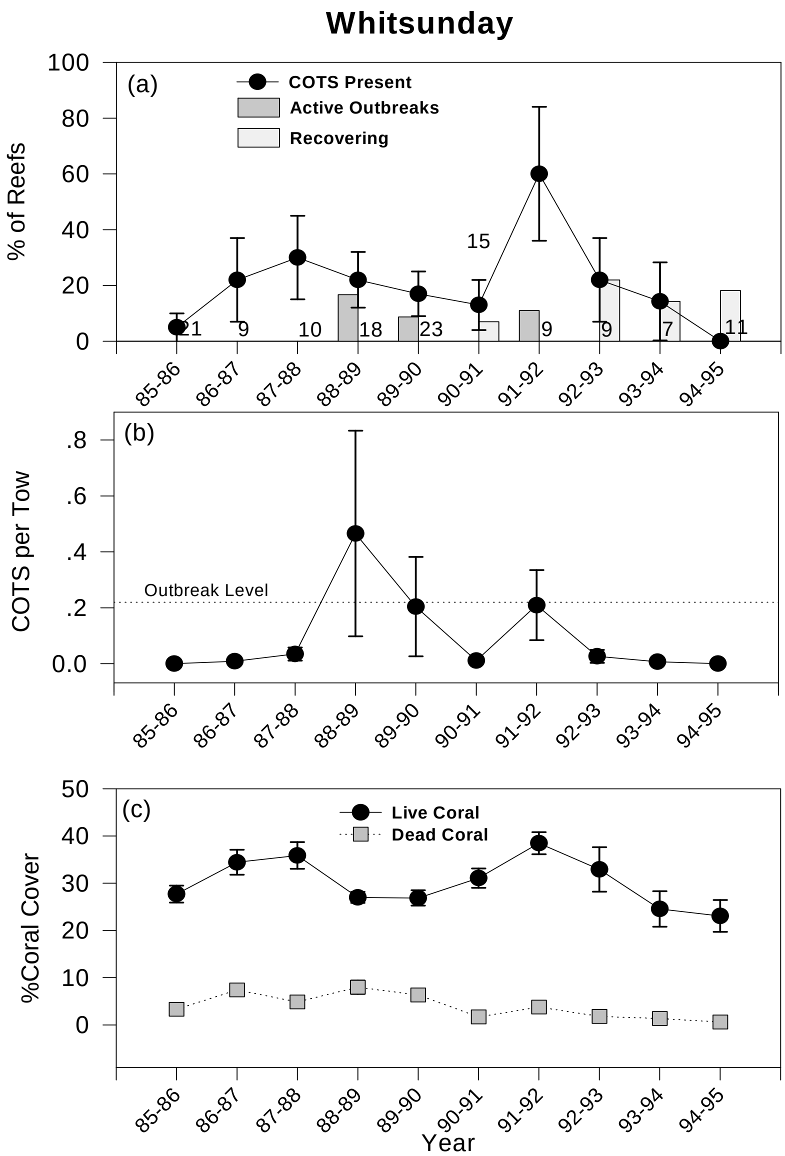


Figure 2.9. Results of broadscale surveys of the Whitsunday sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates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

Whitsunday sector

COTS activity was initially low and showed some increase from 1988-89 until 1991-92. Since then COTS populations have continued to decline and no COTS were recorded in surveys of this sector in 1994-95. Coral cover declined slightly when COTS activity was highest, but recovered to previous levels in 1991-92. Since then coral cover declined slightly to 20-30%. The majority of reefs in this sector were non outbreaking.

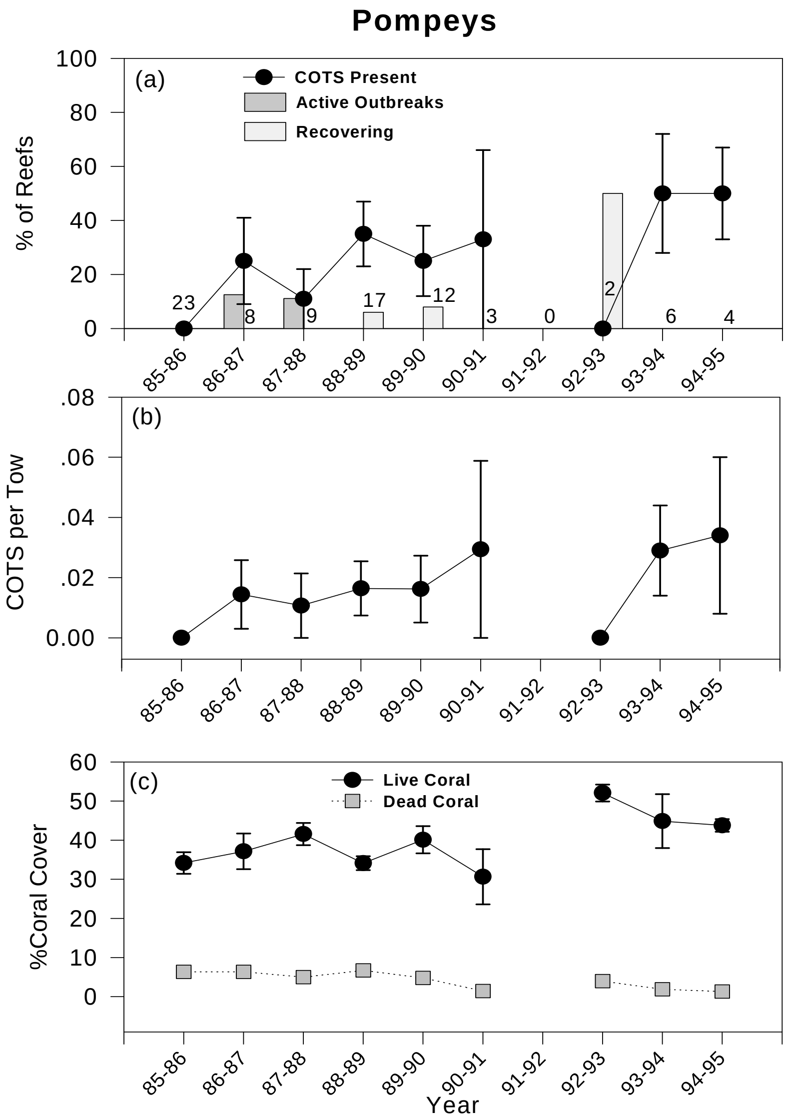


Figure 2.10. Results of broadscale surveys of the Pompey sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow; **c)** averaged percent cover of live and dead coral. Error bars represent standard errors.

Pompey sector

Although COTS have been present in this sector since the beginning of broadscale surveys, Active Outbreaks were only recorded on one reef during 1986-87 and 1987-88 survey years. Trends are difficult to assess due to a limited sampling in this sector, but there was no indication of any COTS activity in the sample period. There was little change in coral cover on survey reefs, with coral cover remaining generally high (30-50%) in 1994-95. This sector has consistently had the highest average coral cover of all the sectors.

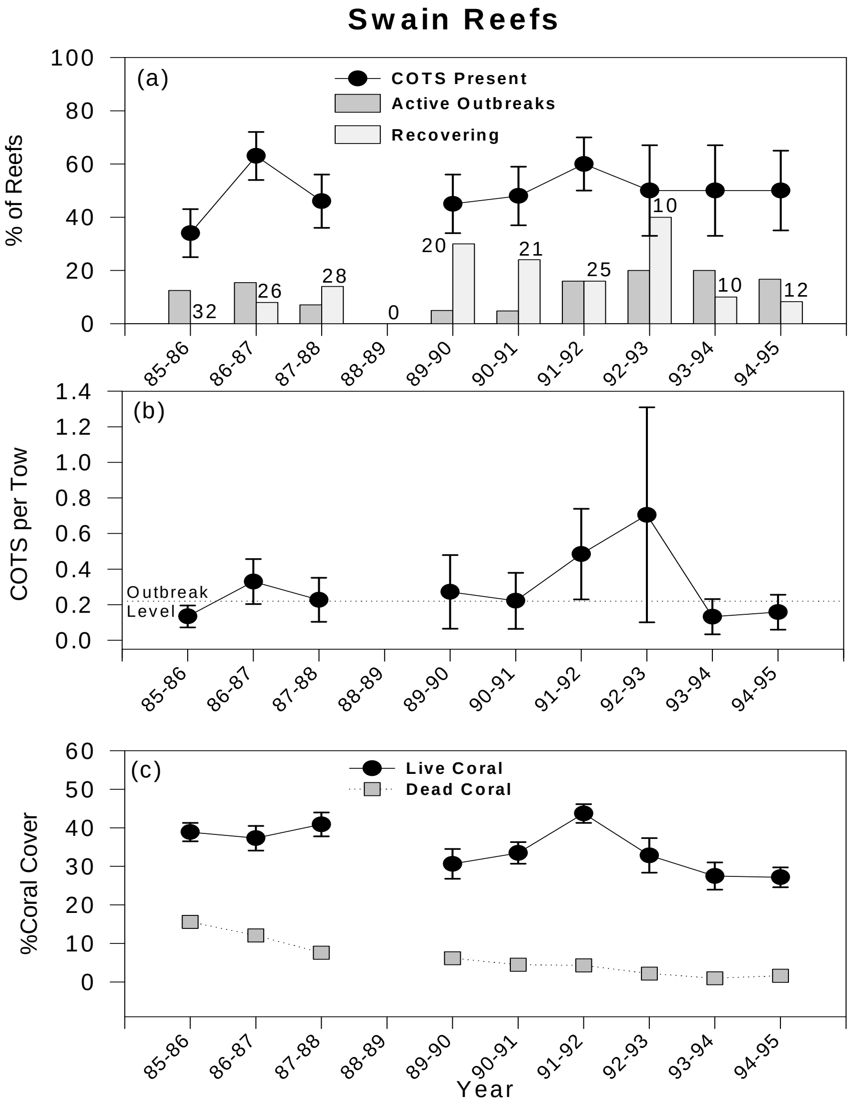


Figure 2.11. Results of broadscale surveys of the Swains sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow (dotted line indicates defined minimum density for an outbreak); **c)** averaged percent cover of live and dead coral. Error bars represent standard errors.

Swains sector

The Swains sector had the highest number of COTS per tow for any sector but coral cover in this sector remained generally high (30-50%). It is the only sector to have had Active Outbreaks recorded in each survey year. Although a high proportion of reefs had COTS, only two reefs (22-088 and Horseshoe) were considered to have Active Outbreaks. Coral cover on Reef 22-088 has declined from 34% to 16%. Gannet Cay had an active outbreak since 1989-90 but was classified as Recovering in 1994-95; the average coral cover on this reef declined from 56% in 1992-93 to 31% in 1994-95. Average coral cover increased on Turner Cay (26% to 39%) and Reef 21-467 (20% to 25%).

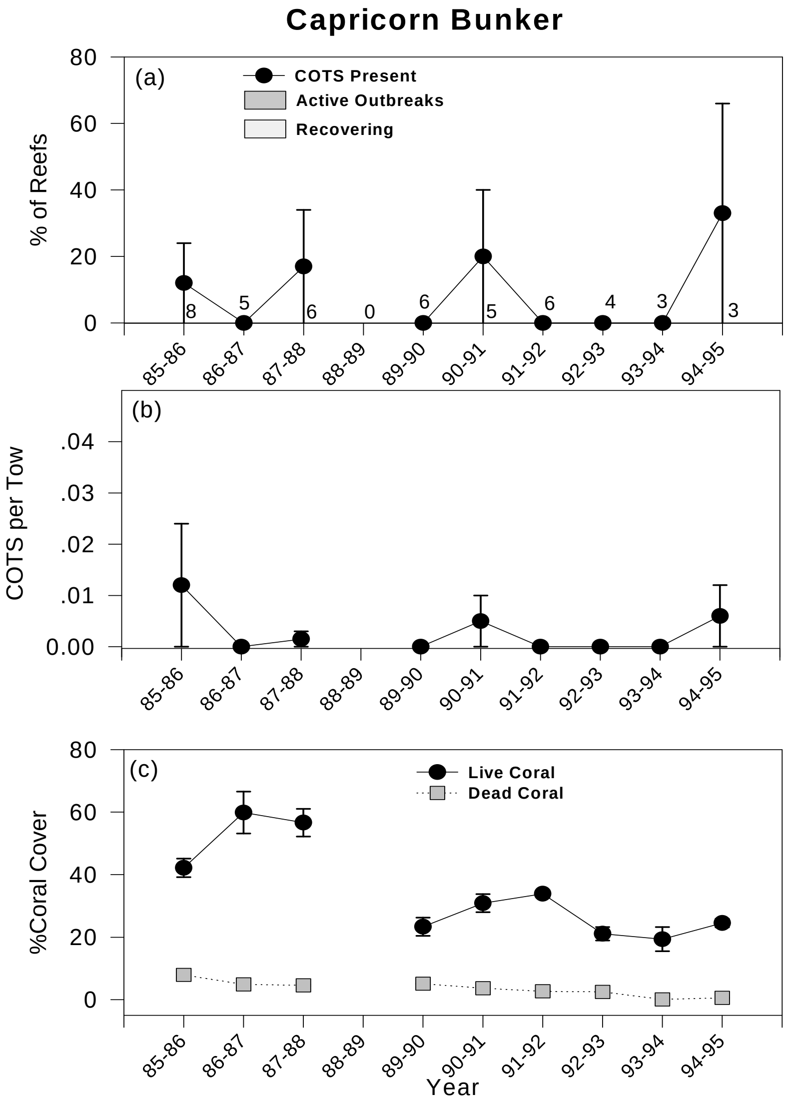


Figure 2.12. Results of broadscale surveys of the Capricorn Bunker sector showing: **a)** percent of surveyed reefs with COTS and with active outbreaks (numbers indicate number of reefs surveyed each year); **b)** COTS densities for the entire sector expressed as number of COTS per tow; **c)** averaged percent cover of live and dead coral. Error bars represent standard errors.

Capricorn Bunker sector

COTS have only occasionally been recorded on a single reef in this sector in any year and in numbers too low to cause significant coral mortality. Reefs in this sector showed a large drop in coral cover (from a very high level of 50-75% to a moderate level of 10-30%) between 1987-88 and 1989-90. Coral cover in this sector remained moderate (10-30%) but there was some indication that it was beginning to recover. Lady Musgrave Island and One Tree Island increased from 18% to 25% and 27% coral cover respectively. The number of reefs sampled in this sector has been reduced from six to three in recent years; this should be considered when drawing conclusions about regional COTS activity.

DISCUSSION

Results from the 1992-93 to 1994-95 surveys show a progressive increase in COTS populations on the GBR. A low level of outbreaks in the Swain sector has persisted for seven years. The number of COTS increased in the far northern sectors but continued to decline in the central sectors (Innisfail to Pompey). Increased COTS activity in the Cairns and Cooktown/Lizard Island reefs was the early manifestation of the current wave of outbreaks on reefs in the Cairns sector (Engelhardt *et al*. 1997). This region has been identified as the likely origin of the previous two series of outbreaks that affected reefs in the central GBR (Moran *et al*.1992). The picture presented by the manta tow data is compatible with the view that outbreaks start in the north, probably in the Cooktown/Lizard Is sector and move south with the East Australian Current as larvae are transported from reef to reef in the manner of stepping stones (Reichelt *et al*. 1990, Moran *et al*. 1992). The resulting cycles of starfish populations are shown in an idealised form by the Cape Upstart Sector (Fig. 2.9b). The subsequent peaks in numbers of COTS per tow in the Whitsunday and Swains sectors may be part of the same population phenomenon, though the occurrence of Active Outbreaks in the Swains in every survey since 1985-86 implies that the true picture is more complex. Conventional wisdom is that outbreak populations die out through starvation and senescence in the absence of regular recruitment. Perhaps the extensive area of reefs in the Swains sector and their configuration allows sufficient replenishment among reefs within the sector to make it likely that population levels will be maintained somewhere in the region.

COTS are a major agent of disturbance on the GBR. They have clear effects on coral cover (see Section 5) and a lesser effect on some fish species (Williams 1986). The AIMS broadscale surveys are the major source of information on status of COTS populations over much of the GBR. As the time series continues, the information will become increasingly useful for assessing hypotheses about mechanisms of outbreaks and their long term effects.

3. Water Quality

Michelle Devlin, Martin Lourey, Hugh Sweatman and Dan Ryan

INTRODUCTION

The levels of nutrients and suspended sediment in waters of the GBR lagoon have the potential to affect benthic assemblages and hence reef communities in general. Enhanced nutrient and sediment loads can have a variety of effects on coral reefs: acute levels of sediment deposition may interfere directly with photosynthesis and feeding by corals and increase energy expenditure through cleaning. Increased nutrient levels can lead to higher phytoplankton densities, lowering light penetration and reducing photosynthesis by corals (Kimmerer *et al*. 1980). Phosphates may inhibit calcification in corals (Simkis 1964). The potential linkage between agricultural chemicals in river inputs and nutrient levels in the GBR lagoon remains an unresolved issue in coastal management of the region.

This section presents information on shelf-scale patterns of water quality from the AIMS Long-term Monitoring Program (LTMP). The section has three aims reflecting the three sub-projects of the water quality program:

- To describe geographic patterns of water quality, principally related to nutrient and chlorophyll levels within the GBR.
- To describe the geographic extent of two regional-scale cyclonic flood events that occurred in the period covered by this report.
- To compare nutrient status of sediments near the mouths of three rivers with contrasting catchments.

WHAT ARE THE BROAD GEOGRAPHIC PATTERNS OF WATER QUALITY OVER THE GBR?

Introduction

The constant motion and mixing of water bodies and the localised nature of inputs lead to much spatial and temporal variability in many components contributing to water quality. This means that large numbers of samples collected over long time periods are required to provide a reliable description of patterns in water quality. The other sampling tasks of the LTMP are based on data from single annual visits to reefs spread over a wide area, so there is little scope for representative sampling of water quality at particular sites over the annual cycle. However the surveys of each sector are made at about the same time each year, arguably making it valid to compare values from the same sectors among years. Any interpretation of comparisons among sectors is complicated by different sectors being sampled at different times during the field season, so differences will necessarily include seasonal effects.

Based on much more extensive, though still episodic, sampling, Furnas and Brodie (1996) were unable to detect long-term trends in any of a similar range of water quality variables. On that basis they aggregated samples collected over several years from defined regions to give broad spatial patterns. Here the LTMP's data are presented in two ways. Samples are aggregated according to the six latitudinal sectors and three shelf positions that are the basis of the general reef sampling scheme (see Section 1). Statistical analysis including all sectors is inappropriate because most stations were sampled only once at differing times of year. The sectors close to Townsville have been sampled more than once per year; these are analysed to look for consistent spatial and temporal patterns. Secondly, the LTMP's data has been reaggregated into the sectors defined by Furnas and Brodie (1996) to allow comparison with their larger data set. Data from stations close to rivers that were categorised as flooding by the Bureau of Meteorology have been excluded because extreme values of many water quality variables are associated with floods following monsoon rains or cyclones.

Study sites

The general sampling design has been described in Section 1. Water samples were taken close to the sample reefs and a number of other sites were sampled in association with the AIMS Biological Oceanography Project. Samples were taken near 50 reefs in 1993-94 and near 67 reefs in 1994-95 (Appendix 2). An additional 188 sets of samples in 1993-94 and 164 sets of samples in 1994-95 were taken at AIMS Bio-oceanography sites. These differed from LTMP sites in that they were samples of GBR lagoon water well away from reefs. Sampling effort by region and season is shown in Table 3.1.

Sampling techniques

Water samples were taken on two occasions at two stations near each survey reef at each annual visit. The two stations were sampled approximately two hours apart and were re-sampled more than 24 hours later. At every station, a sample was taken from both the top and bottom of the water column. Eight samples were collected near each reef during each cruise. Sediment and bio-oceanography stations generally involved sampling just one site at one time.

Full details of the sampling methods for water quality are given in the relevant LTMP Standard Operating Procedure (Devlin and Lourey 1996). Water samples were collected with 8 litre Niskin bottles from two depths, one at 3 m below the surface and the other 3 m above the seabed. *In situ* temperatures were recorded using digital reversing thermometers attached to the Niskin bottles. When taking samples, cloud cover, wind speed, wind direction, tide and water depth were recorded. Water transparency was measured by Secchi disk and presence of surface *Trichodesmium* was noted. On the ship, sub-samples were dispensed from the Niskin bottles into appropriate containers.

Table 3.1. Sampling effort in 1993-94 and 1994-95. Figures are numbers of sites sampled by sector and shelf position.

Sector	Shelf	9/93	10/93	12/93	2/94	3/94	4/94	5/94	9/94	10/94	11/94	2/95	3/95	4/95	5/95
Cape Grenville	Inshore		28			4				14			4		
	Mid					2				4			4		
	Outer		8							6					
Princess Charlotte Bay	Inshore		4							4			2		
	Mid		4							2					
	Outer		4							2					
Cooktown / Lizard Is	Inshore		10							42			2		
	Mid		30							24					
	Outer	4	12							18					
Cairns	Inshore	88			12	10			6	4			28	32	8
	Mid	4			14	2				4			2	34	
	Outer	4			12					4				26	
Innisfail	Inshore	16				8							8		
	Mid	8				4							6		2
	Outer	4													2
Townsville	Inshore	8		24					8				6	32	8
	Mid			16						4	6			26	
	Outer			24										26	
Cape Upstart	Mid			8										4	
Whitsundays	Inshore					12	4				14	36			
	Mid						20					40			
	Outer						8					24			
Pompeys	Inshore										4				
	Mid						2				2	4			
	Outer						2					2			
Swains	Inshore							8			16				
	Mid						4	8			38				
	Outer						4	4			26				
Capricorn/ Bunkers	Outer						8				26				

Processing of samples

1. Nutrient Sub-samples

Collection: Duplicate seawater sub-samples (10 ml) were taken for measurements of total dissolved nutrients, dissolved inorganic nutrients and dissolved silicate. Samples for dissolved nutrient analysis were dispensed from the Niskin bottles (or buckets) into a 50 ml plastic syringe. Approximately 10 ml of seawater was flushed through a 0.45 µm filter (Sartorius Minisart-N™) before the remaining sub-samples were filtered into acid washed, pre-rinsed 10 ml plastic test tubes. Samples for analysis of dissolved phosphorus and nitrogen species were immediately placed in a clean freezer and stored frozen until analysis. Short term storage in this manner has a relatively minor effect on nutrient levels other than ammonium (Ryle and Mueller 1981). Because of the probability of contamination, samples for ammonium analyses need to be very fresh. This was not possible, so levels of ammonium are not included in this report. Samples to be analysed for silicate were stored at room temperature.

Lab Analysis: Dissolved inorganic nutrient and silicate samples were analysed at AIMS. Samples for total dissolved nutrient analyses were thawed and photo-oxidised with UV light for at least 7 hours (Strickland and Parsons 1972). The oxidised samples were then re-frozen until analysis. Analyses of total post-oxidation and un-oxidised inorganic nutrient species were determined by standard wet chemical procedures (Treguer and Le Corre 1975) using 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 sampling process, field blanks of nutrient-free artificial sea water were dispensed and stored in parallel with nutrient samples. To assess the potential levels of contamination during storage, standard and blank nutrient samples were frozen in plastic sample vials and carried during each cruise. Cruise blanks and standards were compared with control blanks and standards stored frozen at AIMS.

2. Suspended solids

Collection: Duplicate 1 litre sub-samples of water were dispensed from the Niskin bottles into rinsed plastic bottles. The sub-samples were then vacuum-filtered through pre-weighed poly-carbonate membrane filters (47 mm, 0.4 µm pore diameter). Filters were stored at room temperature in clean glass scintillation vials.

Lab Analysis: Filter papers were dried overnight in an oven at 60°C and re-weighed to five significant figures. The difference in weights before and after filtration was used to calculate the amount of suspended solids in the sample.

Quality Control: Every 14 filter papers, a field blank was processed. In the laboratory, the samples and the blank filters were processed in parallel. Filter paper blanks were periodically tested for weight changes due to absorbed salt. This involved passing one litre of filtered seawater through them and checking for weight changes.

3. Chlorophyll and phaeophytin

Collection: Sub-samples (100 ml) of water for chlorophyll analyses were collected in pre-rinsed plastic measuring cylinders. Samples were filtered under vacuum onto Whatman™ GF/F glass fibre filter papers (Parsons *et al*. 1984). Prior to filtration, two drops of 5% magnesium carbonate suspension was added to the samples to stabilise the chlorophyll during storage. The filter papers were frozen in aluminium foil pouches until analysis.

Lab Analysis: Pigment 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 the extract volume made up to 10 ml. The sample was then left for 30 min in the dark to allow complete extraction of the chlorophyll pigment. They were then placed in a clinical centrifuge for 10 min. After centrifugation the contents of the plastic tube were poured carefully into a rinsed 10 ml quartz fluorometer cuvette. The red fluorescence emitted from the chlorophyll was measured with a Turner Designs™ 005R fluorometer. Phaeophytin concentration was estimated by taking fluorescence readings before and after acidification of the sample in the cuvette. The fluorescence readings were converted to concentrations of chlorophyll a and phaeophytin (Parsons *et al*. 1984).

Quality Control: During analysis, unused filter papers were analysed every nine samples to correct for any interference caused by fluorescence associated with the filter papers. The fluorometer was standardised spectrophotometrically (Jeffrey and Humphrey 1975) against extracts of pigments from exponentially growing cultures of the diatom *Chaetoceros simplex.*

5. 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. In order to minimise loss due to evaporation, the mouths of the bottles were covered with paraffin film before the lid was replaced. Samples were stored in a cool dark place until processed.

Lab Analysis: Salinity samples were stored under cool conditions (10ºC) but allowed to come to room temperature prior to analysis. Salinities were determined from the conductivity of samples using a Hytech™ 6220 salinometer.

Quality Control: Salinity samples calibrated against IAPSO standards were interspersed with field samples at regular intervals during analyses.

Presentation of data

The data from the LTMP are presented graphically to show spatial and temporal patterns. Data points are mean values for all samples taken at each site/time, that is samples taken within a 24 hour period from all depths at each site. Overall means are also plotted for direct comparison with data of Furnas and Brodie (1996). These authors divide the GBR into coastal (< 20 m deep) and offshore regions and use a slightly different scheme of latitudinal sectors. Data from sectors in the LTMP scheme have been combined to give the best correspondence (Table 3.2). Similarly, inshore sites are taken to correspond to coastal reefs and mid-shelf and offshore sites have been combined to correspond to outer shelf regions of Furnas and Brodie (1996).

Sites in the Cairns, Townsville (here including the Innisfail and Cape Upstart sectors) and the Whitsunday sectors in the central region of the GBR were visited and sampled several times per year by the LTMP. Analyses of variance were used to look for consistent spatial patterns in these sectors. The data were log transformed and analyses were based on Type IV sums of squares because no offshore sites were sampled in the Whitsunday sector 1992-93 (Shaw and Mitchell-Olds 1993). Inshore sites were compared with mid-shelf and offshore sites (combined) using a contrast since cross-shelf gradients in many variables were predicted *a priori*.

Table 3.2. Groupings of AIMS LTMP sectors to correspond approximately to those of Furnas and Brodie (1996).

Sector name in Furnas and Brodie (1996)	Sector name used by LTMP
Shelburne Bay	Cape Grenville
Princess Charlotte Bay	Princess Charlotte Bay
Cooktown	Cooktown/Lizard Is
Cairns	Cairns
Innisfail	Innisfail
Townsville	Townsville and Cape Upstart
Pompey Reefs	Whitsundays and Pompeys
Swain Reefs	Swain Reefs

Results

The geographic spread of the data over three sampling seasons (1992 - 1995) are presented as boxplots in Figures 3.1 - 3.9. The plots are based upon data from a variable number of stations. The Cairns and Townsville sectors have the greatest number of samples since many stations were visited more than once per year. Sectors, shelf positions and years vary both in the mean values and the variability of concentrations. A recurring and predictable pattern for many water quality variables is that concentrations are more variable inshore, particularly adjacent to the Wet Tropics (Cairns and Townsville / Central sectors), while the Swains and Capricorn/Bunker sectors that are mostly exposed to oceanic conditions, show much less variation. Cross-shelf patterns in concentration vary among sectors and between years. Another clear pattern is the high concentrations of chlorophyll in the Whitsundays sector, which includes the Pompey Reefs area, where median values frequently exceed 0.5 mg l^{-1}. Suspended solids tend to decline across the shelf and to be higher in the Cairns, Townsville and Whitsunday sectors. Spatial and temporal patterns are summarised in Table 3.3.

Table 3.3. Summary of patterns for different water quality variables based on simple visual examination of Figs 3.1-3.9.

Salinity	Generally more variable inshore in Cairns, Townsville and Whitsunday sectors. Declining gradient from inshore to offshore in Townsville and Whitsunday sectors in some years.
Suspended Solids	Generally higher and certainly more variable inshore in the Cairns, Townsville and Whitsunday sectors.
Nitrite	Generally low with high values for mid- and outer shelf sites in 1994-95. Variability differs among years. Sectors show different cross-shelf patterns through time.
Nitrate	Evidence of Sector x Year interactions: higher but more variable values offshore in Townsville and Whitsunday sectors, but inshore in Cairns. Sectors show different cross-shelf patterns from year to year.
Dissolved Organic Nitrogen	Median levels vary little, though low in the Swains. No evident cross-shelf pattern.
Dissolved Inorganic Phosphorus	Clear differences among years. High offshore values in the Whitsunday sector in 1994-95. Northern sectors show a greater range. Sectors show different cross-shelf patterns from year to year.
Dissolved Organic Phosphorus	Higher values and more variability inshore in Cairns and Townsville sectors. High values in the Swains in 1992-93.
Silicate	Few data but in most cases variability and levels higher inshore
Chlorophyll a	Median values below 0.5 mg l^{-1} except for consistently high values in Whitsundays sector.

Few consistent patterns were evident in the water quality data from the central area of the GBR. It is evident from Figs 3.1 - 3.9 that there are many interactions: cross-shelf patterns vary among sectors and among years. All the variables showed at least one first-order interaction (Table 3.4). Only one variable, nitrite, showed a marginally significant simple effect of shelf position. A contrast comparing inshore sites with mid-shelf and offshore sites combined found that there was no significant difference in NO_2 concentration between the groups of sites.

Table 3.4. Results of analyses of variance testing for consistent patterns among years, sectors and shelf positions in the Cairns sector, the Townsville sector (including Innisfail and Cape Upstart) and the Whitsundays. All data were log transformed before analysis. "No" indicates no evidence of consistent pattern ($p>0.1$), "M" indicates marginal evidence of consistent pattern ($p = 0.051 - 0.10$), "Yes" indicates evidence of consistent pattern ($p< 0.05$). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation, see Section 1.

Questions	Salinity	Suspended Solids	Nitrite	Nitrate	Diss. Org. Nitrate	Diss. Inorg. Phosphate	Diss. Org. Phosphate	Chlorophyll a
Does the pattern of concentration across the shelf vary between sectors in the different years?	Yes	Yes	No	No	No	No	M	Yes
Sector x Shelf x Year								
Does the average pattern of concentration across the shelf differ between sectors?	(Yes)	(Yes)	No	Yes	No	No	(No)	(No)
Sector x Shelf								
Does the average pattern of concentration across the shelf differ between years?	(Yes)	(No)	No	No	No	Yes	(No)	(No)
Shelf x Year								
Does the average pattern of concentration among sectors differ between years?	(Yes)	(Yes)	M	Yes	Yes	Yes	(Yes)	(Yes)
Sector x Year								
Does the concentration vary among years?	(Yes)	(Yes)	(Yes)	No	(M)	(Yes)	(Yes)	(Yes)
Year								
Does the concentration vary among cross-shelf positions?	(No)	(Yes)	M	(Yes)	(M)	(No)	(M)	(Yes)
Shelf								
Does the concentration vary among sectors?	(Yes)	(No)	(M)	(Yes)	No	(No)	(M)	(Yes)
Sector								

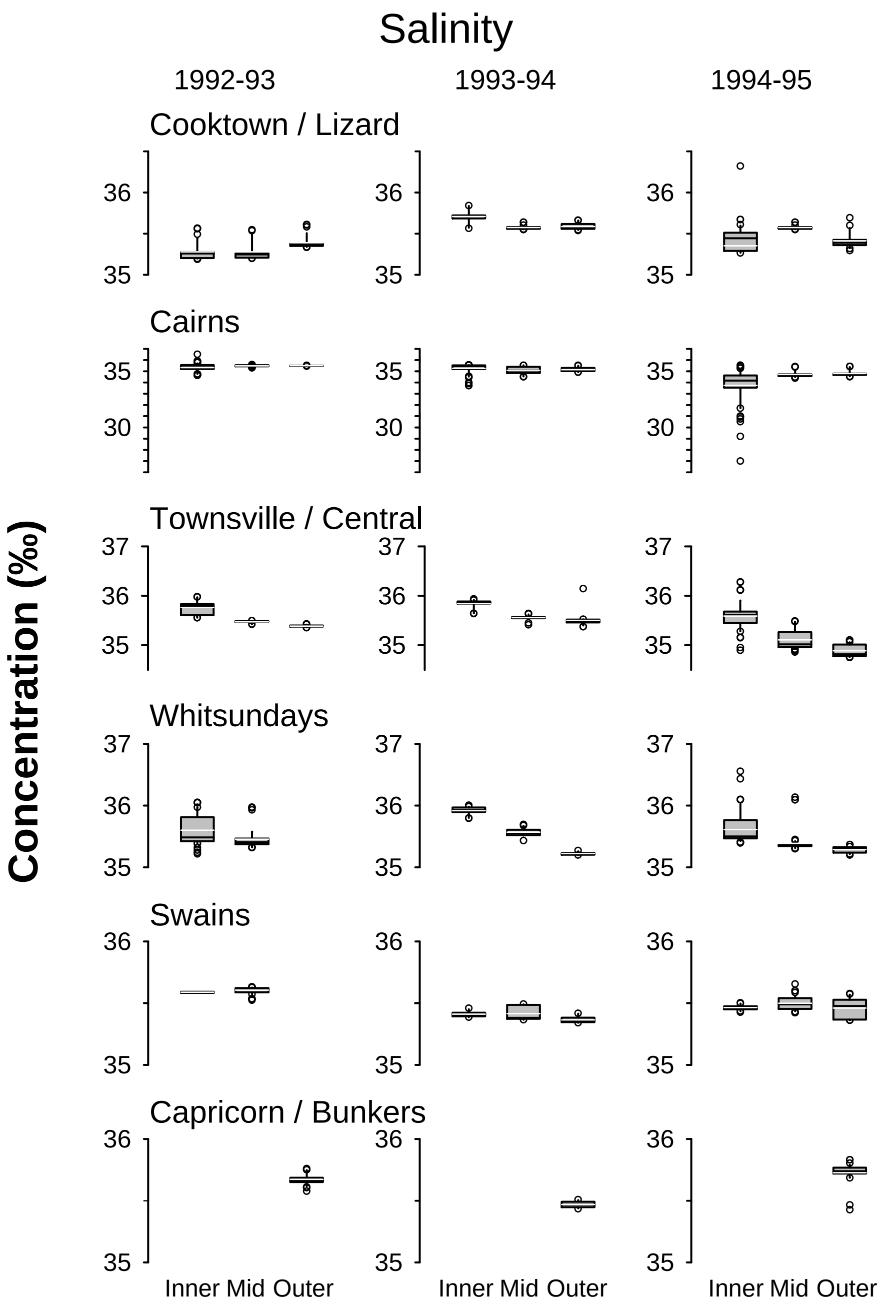


Figure 3.1. The distribution of values for salinity by sector, shelf position and year. Boxplots display the distribution as follows: The range of values of the central 50% of observations (i.e. between the 1st and 3rd quartiles) is shown by the stippled box. The black transverse line marks the median value, the white transverse line marks the mean of value. The vertical lines ("whiskers") beyond the box mark the range of values within 1.5 times the interquartile range (the height of the stippled box) from the 1st and 3rd quartiles. More deviant values are plotted individually. Note that no outer sites were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

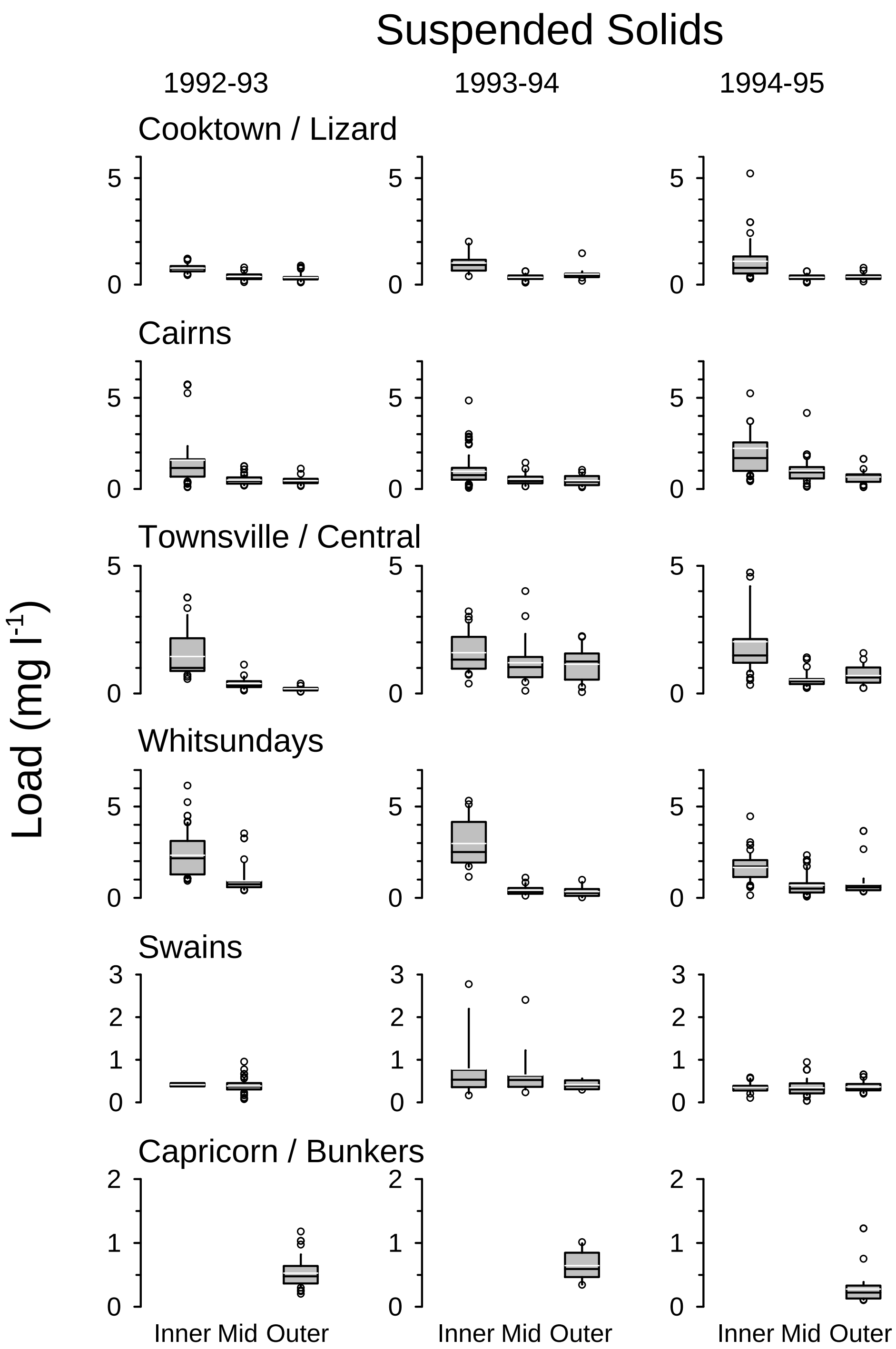


Figure 3.2. The distribution of values for suspended solids by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

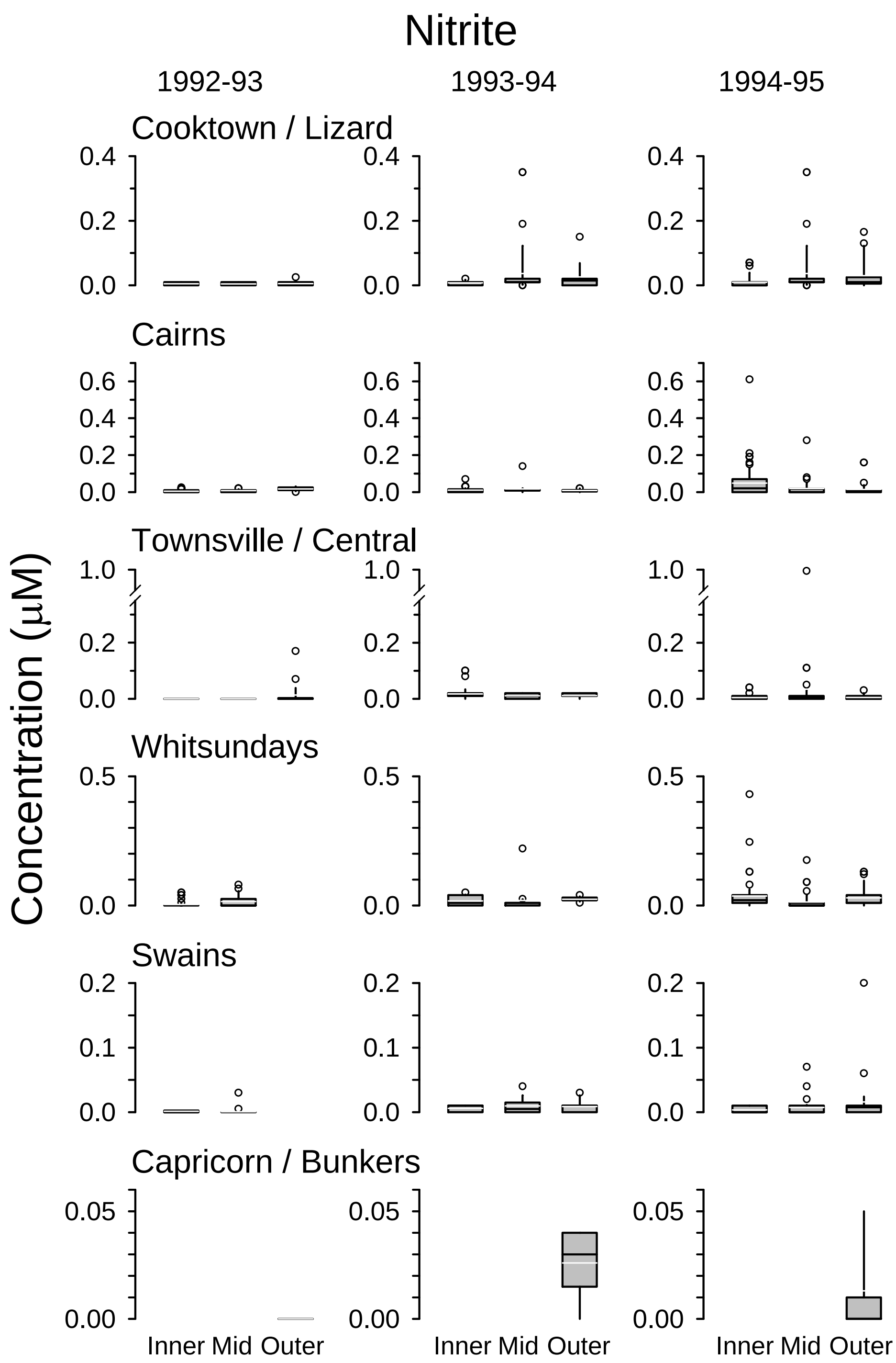


Figure 3.3. The distribution of values for concentration of nitrite by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

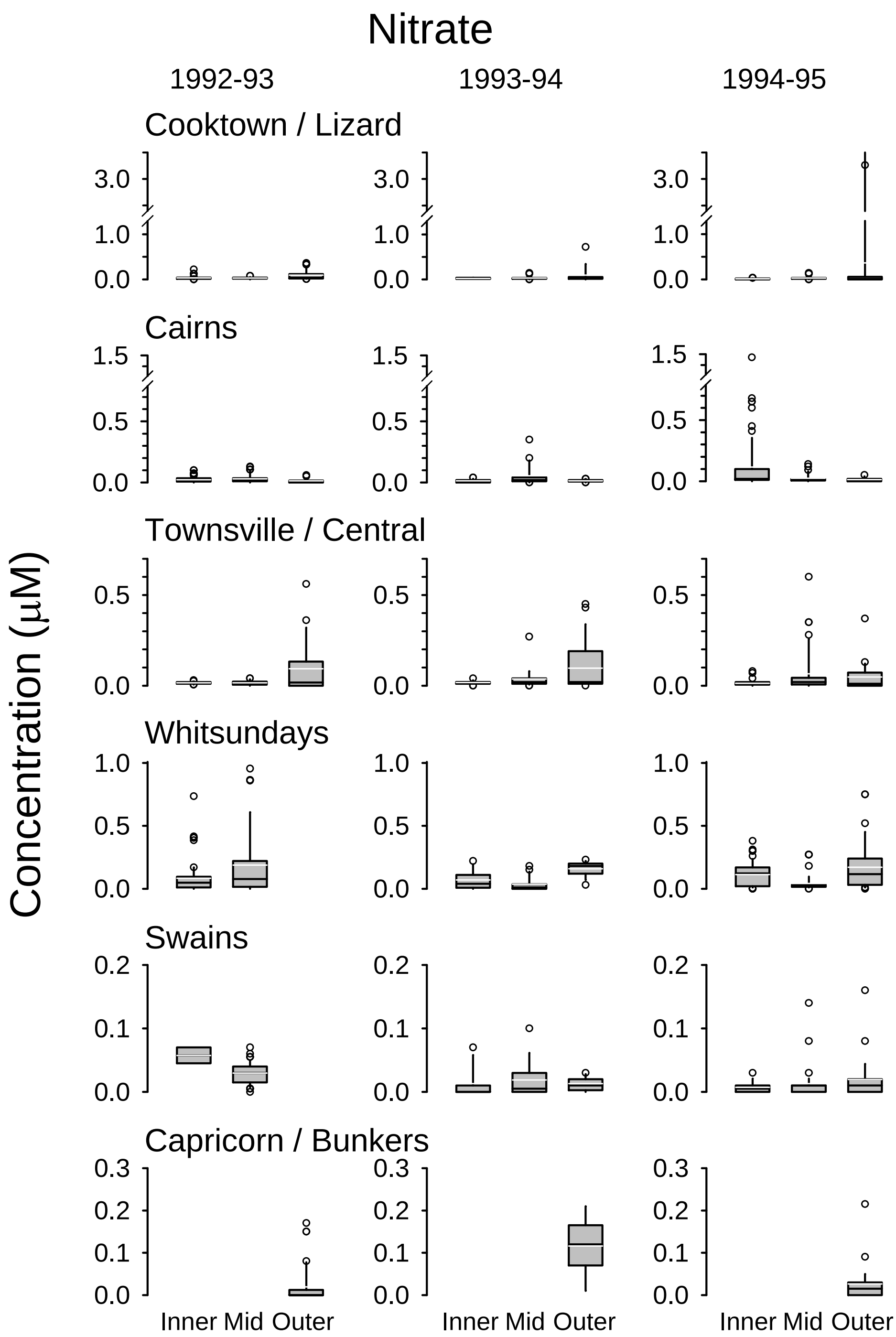


Figure 3.4. The distribution of values for concentration of nitrate by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

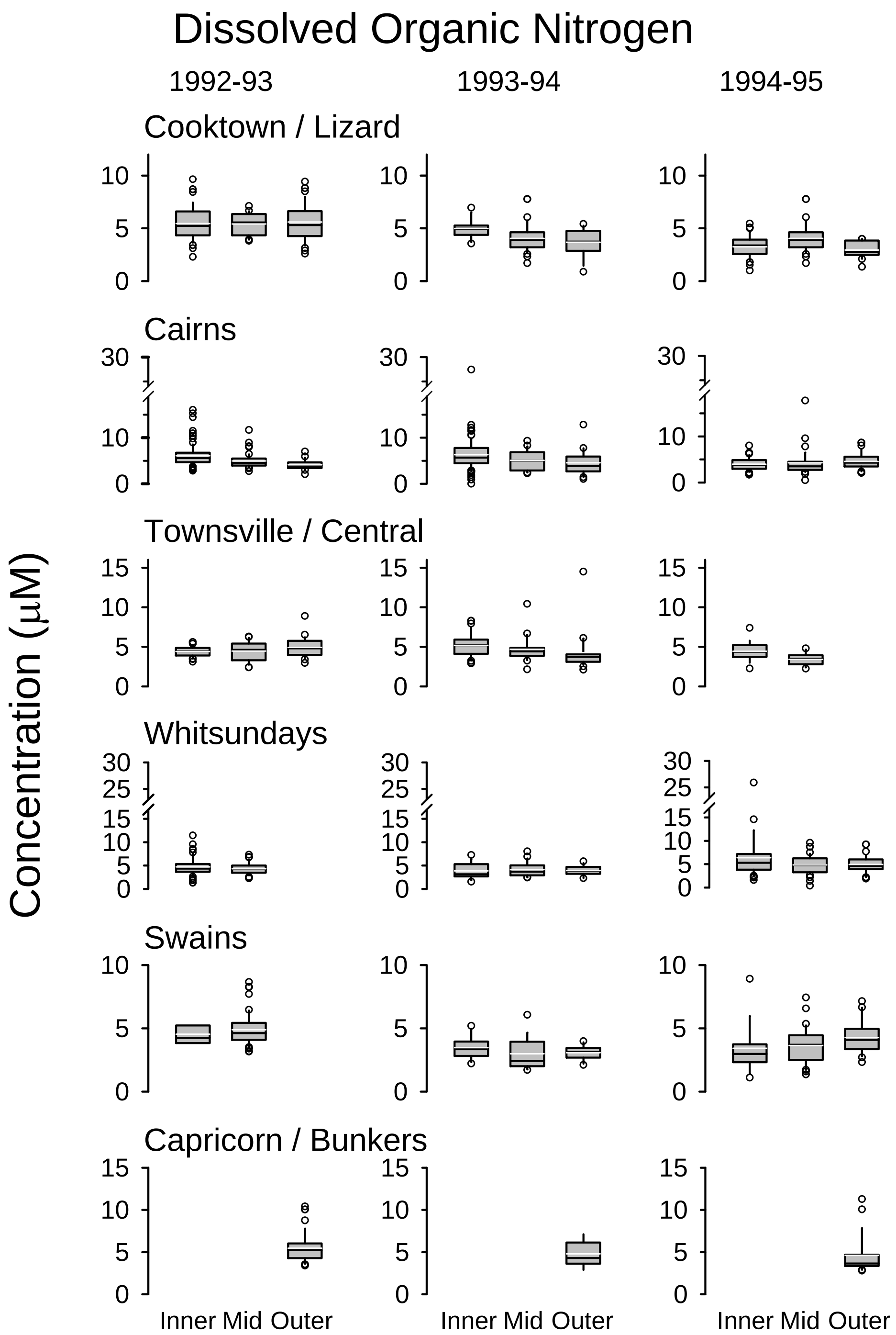


Figure 3.5. The distribution of values for concentration of dissolved organic nitrogen by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

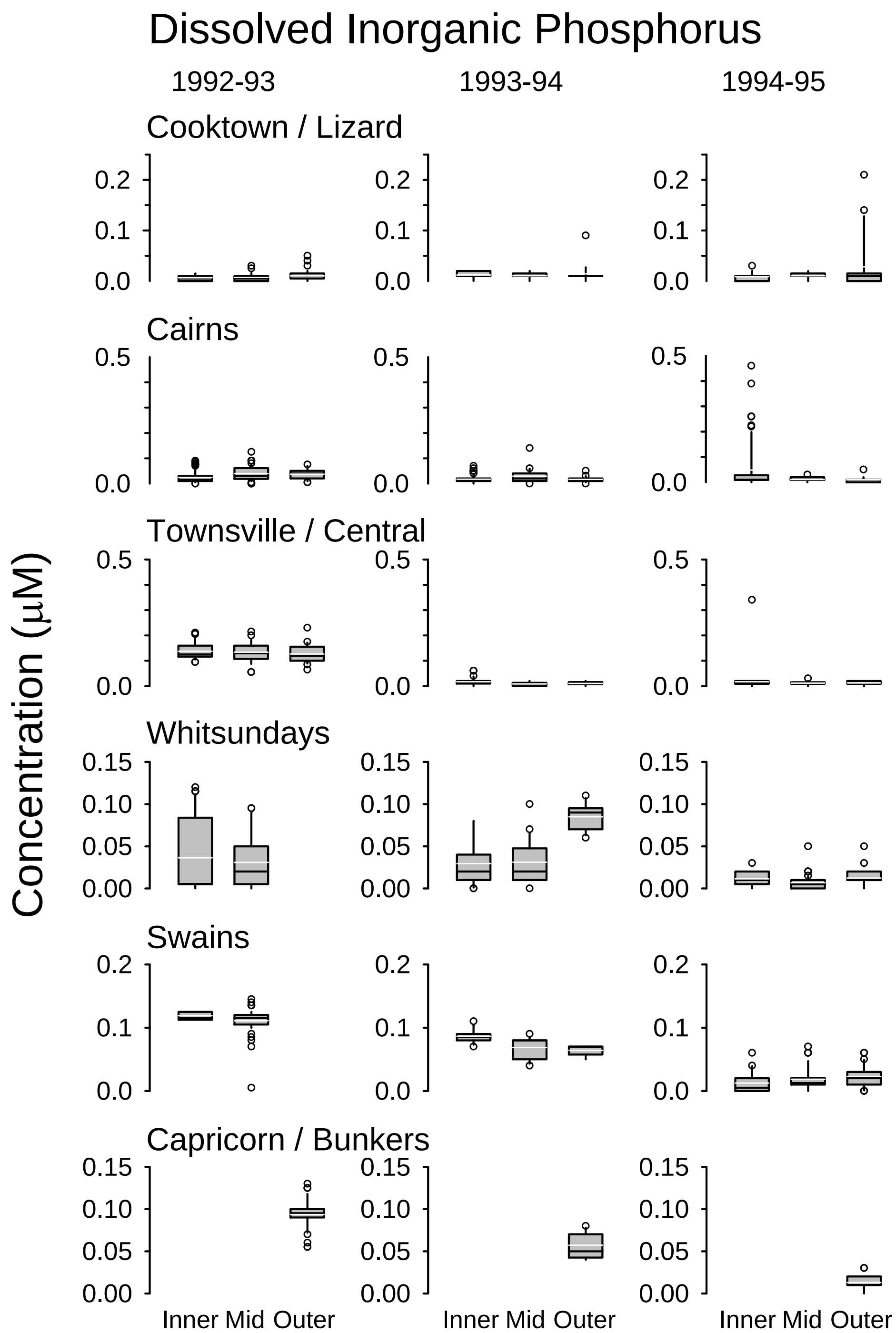


Figure 3.6. The distribution of values for concentration of dissolved inorganic phosphorus by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

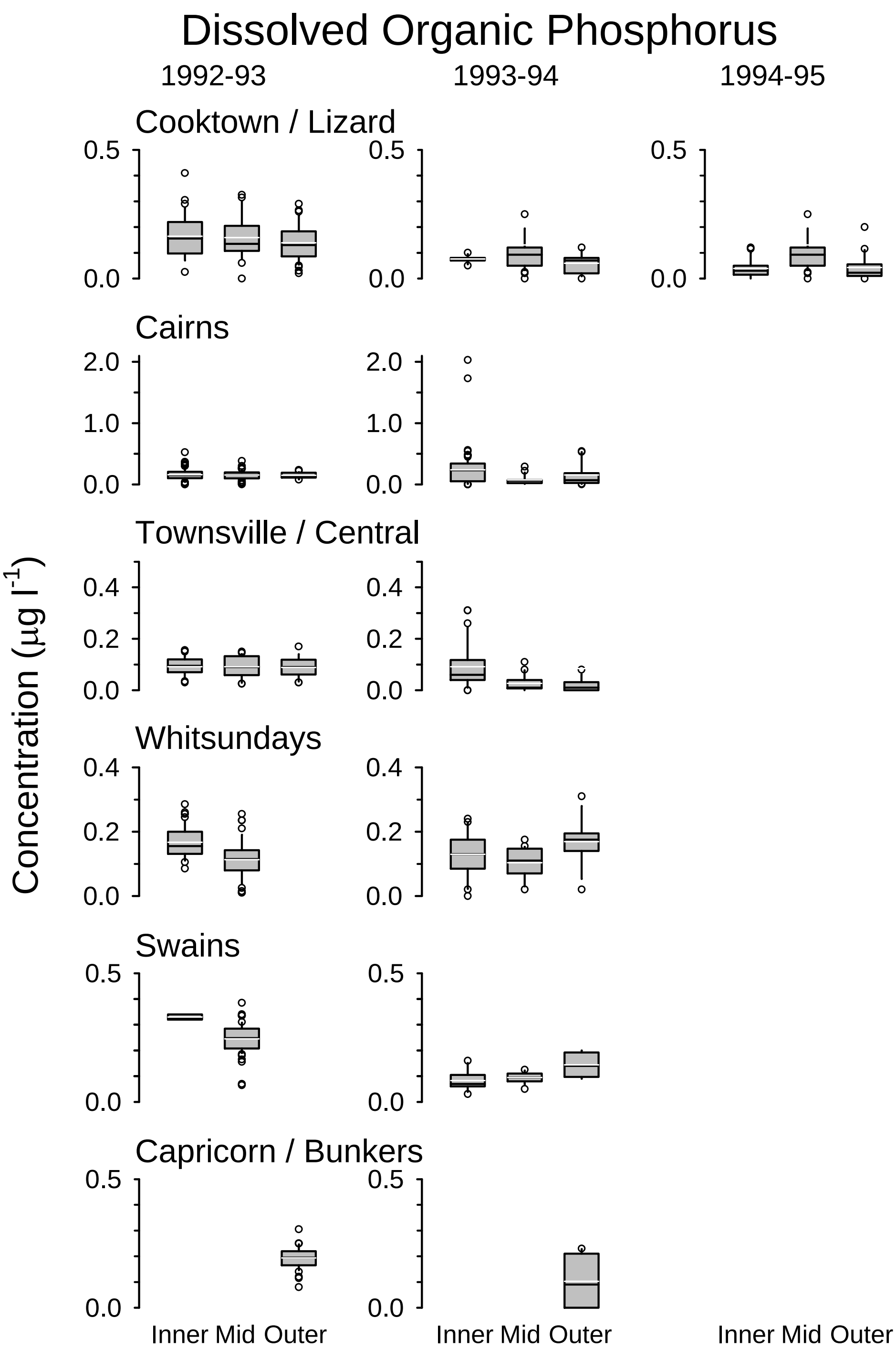


Figure 3.7. The distribution of values for concentration of dissolved organic phosphorus by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Most data from 1994-95 were lost through errors in analysis. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

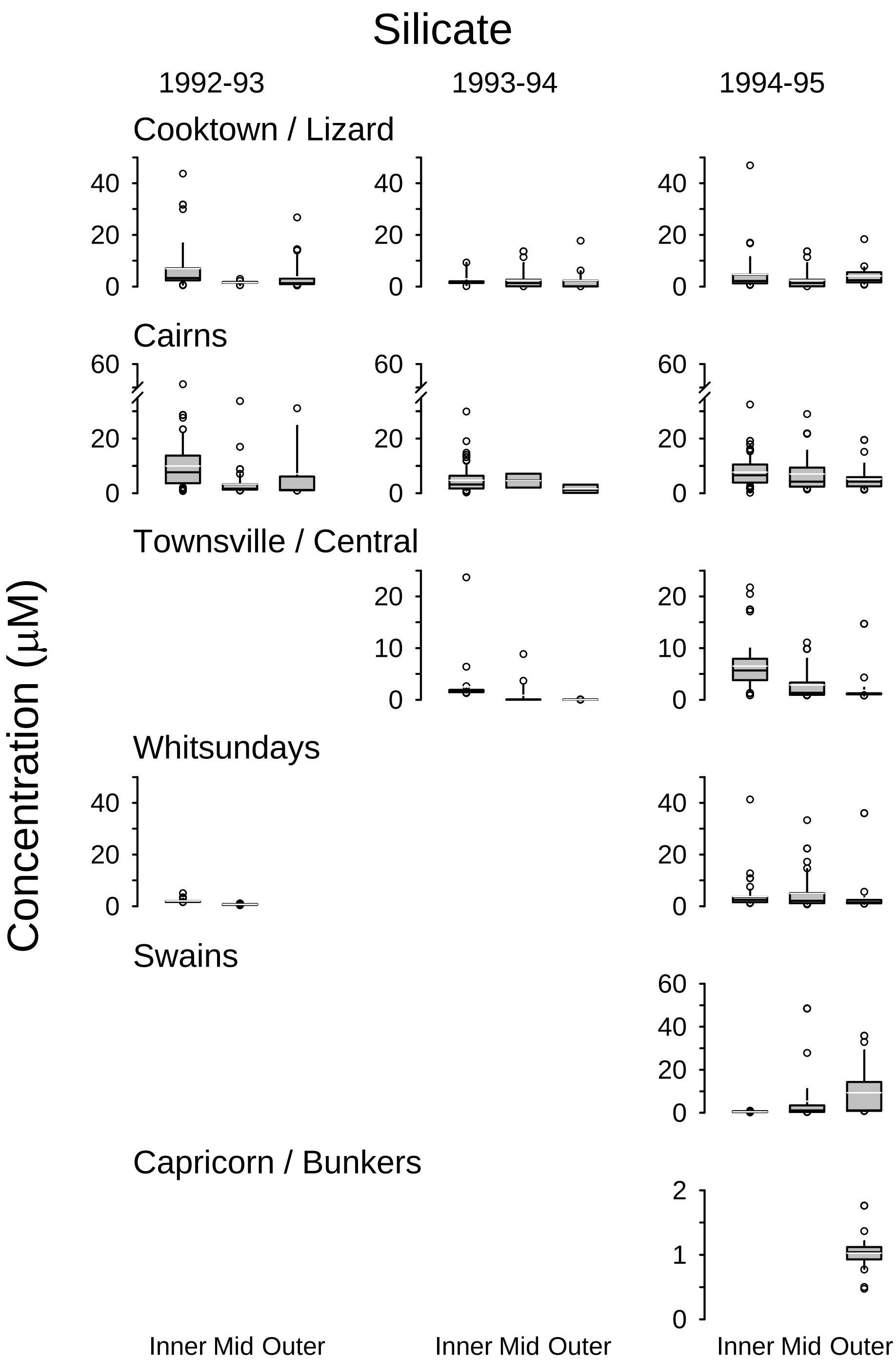


Figure 3.8. The distribution of values for concentration of silicate by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Early data were deleted after finding that freezing led to crystalization and aberrant values. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

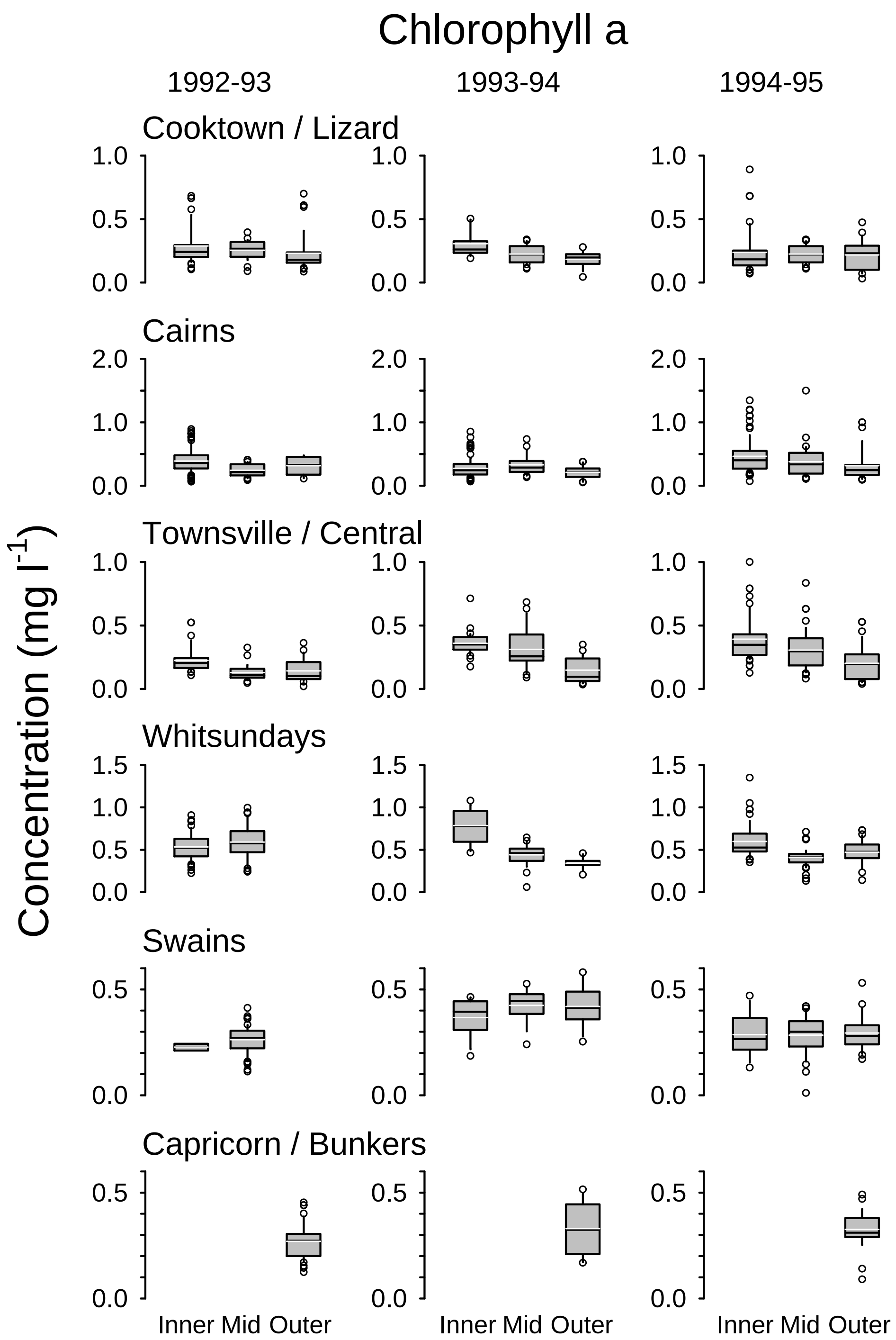


Figure 3.9. The distribution of values for concentration of chlorophyll a by sector, shelf position and year. See caption of Fig. 3.1 for explanation of boxplots. Note that no outer reefs were sampled in the Whitsunday or Swains regions in 1992-93. There are no inner or mid-shelf reefs in the Capricorn / Bunker sector.

COMPARISON WITH ANOTHER STUDY OF GEOGRAPHIC PATTERNS IN WATER QUALITY WITHIN THE GBR

Furnas and Brodie (1996) aggregated data from more than a decade of sampling throughout GBR waters. While they omitted samples associated with cyclonic disturbances, they included data from all seasons. Most of their sampling effort was concentrated in the area between Townsville and Cooktown, so values from those areas are most robust. The LTMP data are similarly distributed geographically. The data of Furnas and Brodie (1996) are compared with those of the LTMP in Fig. 3.10. Only one variable, dissolved inorganic phosphorus, shows a consistent difference in measured concentration between the two data sets though the relative values are fairly consistent. This consistent difference is unlikely to be due to the absence of winter samples in the LTMP data because phosphorus levels were generally lower in winter. Furnas and Brodie (1996) have generally lower values for salinity and higher values for silicate inshore. Both of these could be the result of river outflows and may reflect a different definition of flood conditions between the two sets of samples. Otherwise there are few differences, as would be expected considering the nature of the variables and the limited sampling by the LTMP.

Interpretation

The LTMP shelf-scale sampling of nutrients and other water quality variables, being limited in temporal scope and an adjunct of the sampling of reef biota, cannot provide a robust picture of water quality in GBR waters. The picture that emerges is accurate: it is one of great spatial and temporal variability which indicates a need for much more sampling effort, particularly sampling of the same sites through time, before statements about trends in water quality can be made with confidence. The most cost effective strategy is to integrate these data with other water quality monitoring schemes in the region to obtain as complete a picture as possible with the available resources. This path is being followed.

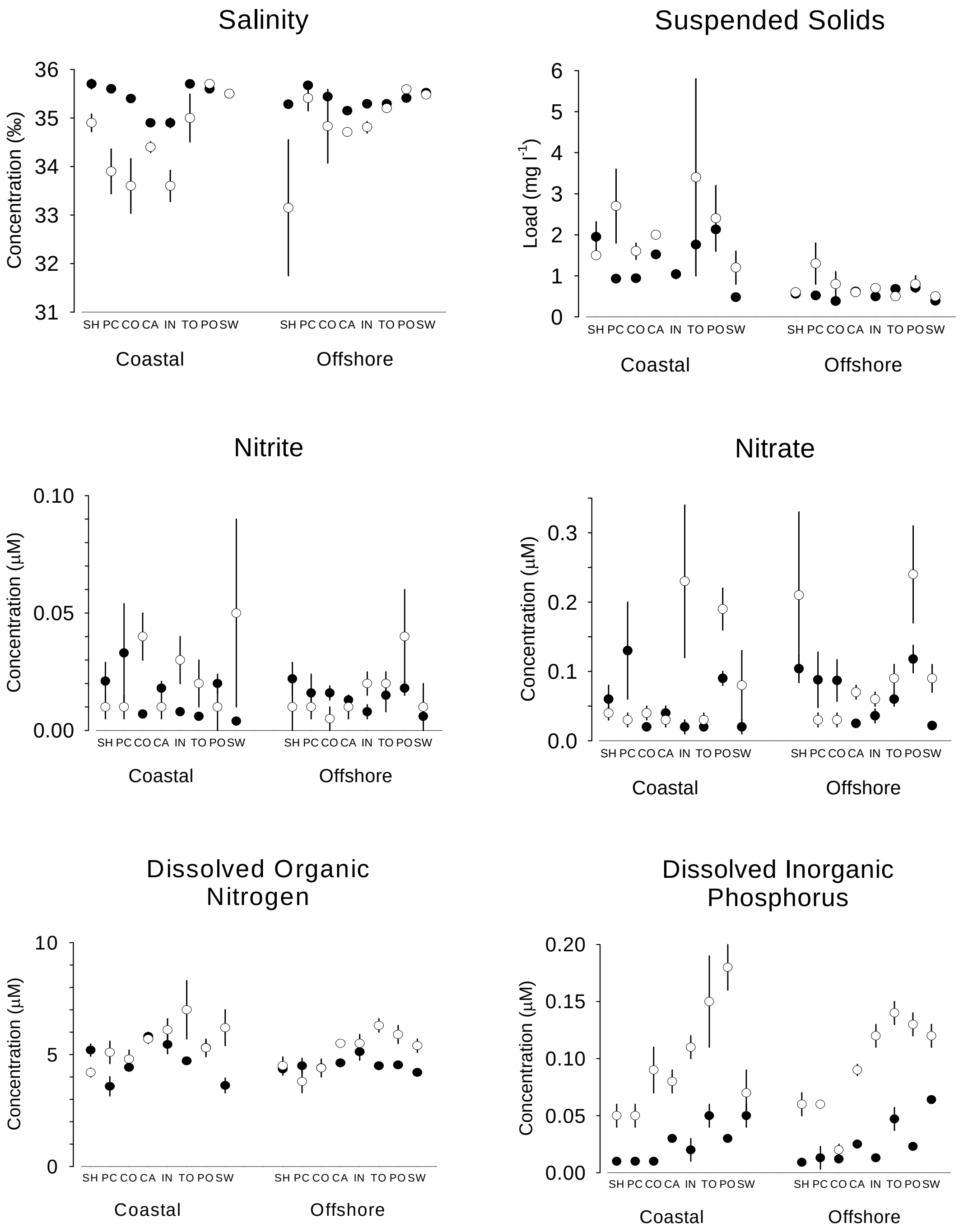


Figure 3.10. Comparison of regional means for three years of water quality data from the LTMP with those of Furnas and Brodie (1996). LTMP data were aggregated geographically according to the scheme of Furnas and Brodie, see Table 3.2. Open circles are values from Furnas and Brodie (Tables 2 and 3), filled circles are from the LTMP. Bars represent standard errors of the means. Sector codes: SH = Shelburne Bay, PC = Princess Charlotte Bay, CO = Cooktown, CA = Cairns, IN = Innisfail, TO = Townsville, PO = Pompey, SW = Swain Reefs.

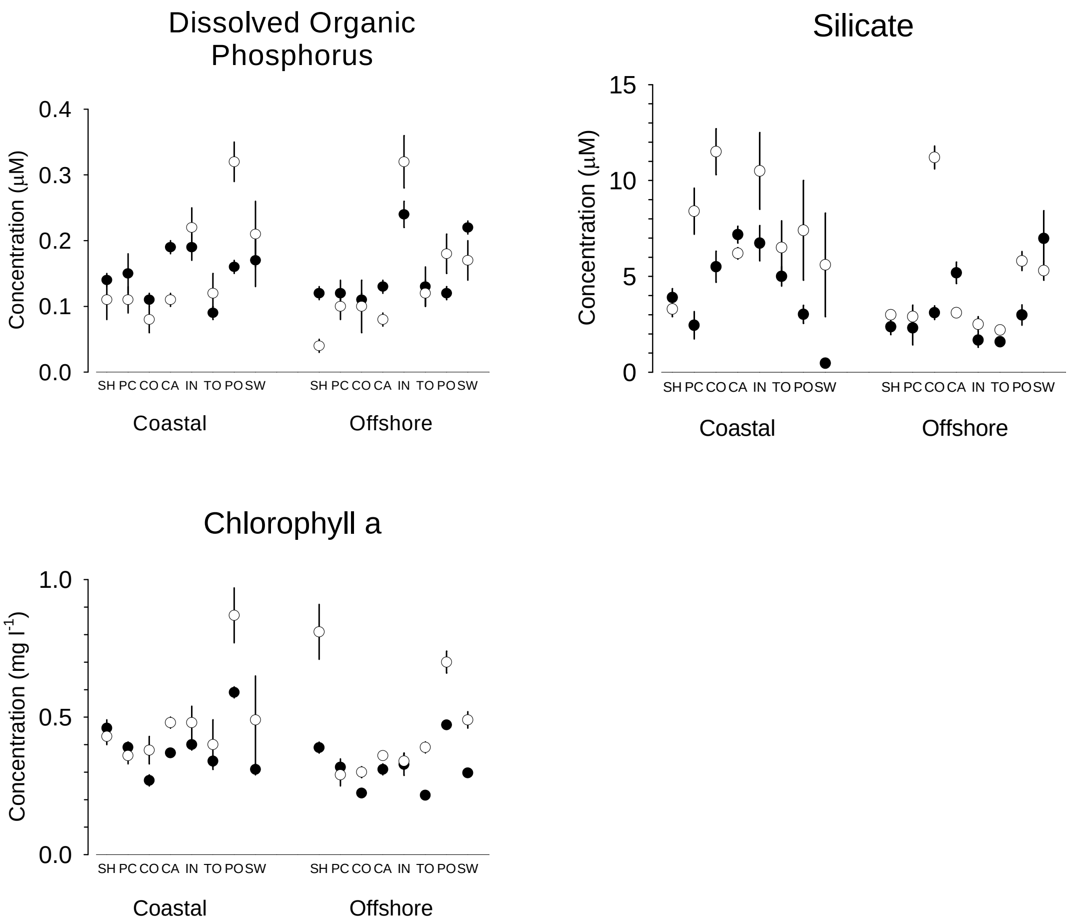


Figure 3.10 continued. Comparison of regional means for three years of water quality data from the LTMP with those of Furnas and Brodie (1996). LTMP data were aggregated geographically according to the scheme of Furnas and Brodie, see Table 3.2. Open circles are values from Furnas and Brodie (Tables 2 and 3), filled circles are from the LTMP. Bars represent standard errors of the means. Sector codes: SH = Shelburne Bay, PC = Princess Charlotte Bay, CO = Cooktown, CA = Cairns, IN = Innisfail, TO = Townsville, PO = Pompey, SW = Swain Reefs.

A DESCRIPTION OF THE GEOGRAPHIC EXTENT OF TWO REGIONAL-SCALE CYCLONIC FLOOD EVENTS AND THEIR ASSOCIATED WATER QUALITY CHANGES

The most dramatic regional-scale changes in water quality are associated with floods following cyclones or monsoonal rain on the mainland (Furnas 1989, Brodie and Furnas 1996). The increased river runoff results in nutrient, phytoplankton and suspended sediment levels far greater than those measured at other times. The broad-scale spatial emphasis of the LTMP is inappropriate for sampling floods which occur episodically in the region of the GBR. The spatial extent of flood plumes is intrinsically interesting in that it defines the area affected by short-lived but extreme conditions which may correlate with deleterious effects on benthos such as coral bleaching (Van Woesik *et al*. 1995). Some macro-algae are able to exploit brief pulses of high nutrients (Schaffelke and Klumpp 1997) and predictable occurrence of such pulses in floods from year to year may define the range of such organisms.

Following Cyclones Sadie and Violet in early 1994 and 1995, heavy rain fell in north Queensland between Townsville (19°16′S) and the Daintree River (16°17′S). The resulting freshwater plumes were readily observable from the air, overlying the inshore waters of the Great Barrier Reef. The plume from Cyclone Sadie formed a single coalesced water mass extending over much of the shelf. In contrast the plumes following Cyclone Violet were restricted to a shallow near-shore band by stronger south-east trade winds following the cyclones.

Methods

Water samples were collected from shelf and coastal waters following each cyclone. Cloud cover, wind speed, wind direction, tide and water depth were recorded at all sampling sites. Water transparency was measured by Secchi disk and the presence of *Trichodesmium* on the surface was noted. Water samples were analysed for salinity, suspended solids, chlorophyll and phaeophytin, dissolved inorganic nutrients (ammonia, nitrate, nitrite and phosphate), dissolved organic nitrogen and phosphorus and in the case of Cyclone Violet, particulate nitrogen and phosphorus. Laboratory procedures follow Devlin and Lourey (1996).

Flood plume monitoring is reactive by nature and because the extent of the plume is always changing, no fixed stations are established. The sampling design is *ad hoc*, governed by extent of plume, location of heaviest rainfall and the availability of vessels.

Water sampling - Cyclone Sadie

The flooding following Cyclone Sadie in February 1994 was largely restricted to coastal watersheds between Cairns and Cooktown. Sampling began 4 February, two days after the main flood peak had occurred.

Water samples were taken along the coastline of the central GBR between the Brook Islands (18°9′S) and the Mulgrave River (17°13′S) (Fig 3.11). The samples were collected at hourly intervals while steaming. Two types of samples were taken: water column samples used three Niskin bottles spaced out over the depth profile and surface samples were taken by bucket. Sub-surface temperatures were recorded with digital reversing thermometers attached to the Niskin bottles.

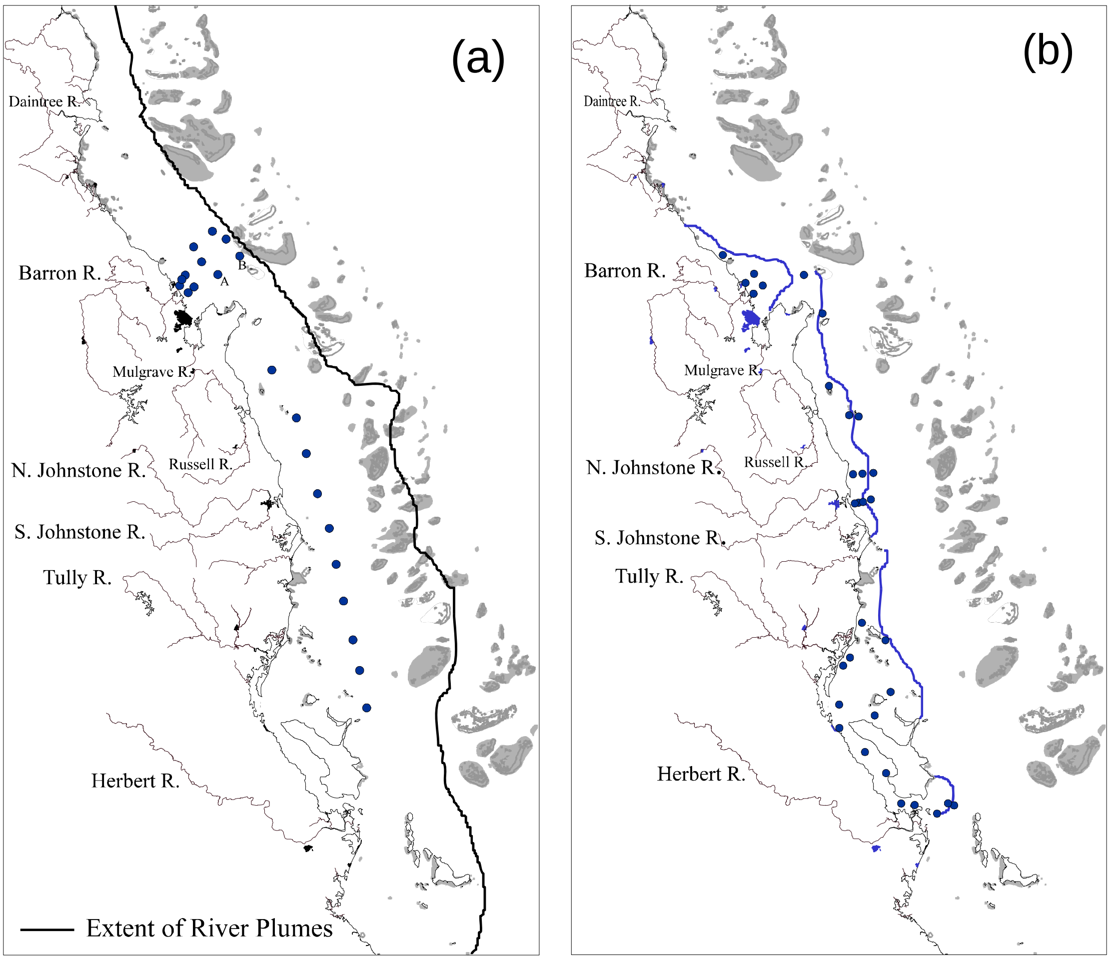


Figure 3.11. Maps of flood plumes following (a) Cyclone Sadie and (b) Cyclone Violet. The offshore extent of the plume is marked by the solid line. Large dots indicate sampling locations.

Water sampling - Cyclone Violet

Two sampling trips were carried out 1 - 2 February 1995, approximately 48 hours after Cyclone Violet had crossed the coast. Water samples associated with the major river plumes were taken at 33 stations by personnel from the Australian Institute of Marine Science, Queensland Department of Environment and Heritage, Department of Primary Industries, James Cook University and Reef Biosearch Pty Ltd (Steven *et al.* 1996). One group of stations was located in the Hinchinbrook Island area, specifically targeting runoff from the Herbert and Tully rivers. A second group spanned the Cairns and Innisfail regions, specifically targeting runoff from the Johnstone, Russell-Mulgrave, and Barron rivers. Sampling procedures were the same as those used following Cyclone Sadie.

Characteristics of the plumes

The plume from Cyclone Sadie was visible for 4-5 days, eventually reaching the outer reefs (Fig. 3.11). The volume of river water discharged (Table 3.5) was moderate compared with other cyclonic events and the ensuing winds (NW - NE at 10 kts) caused relatively little wind-driven sediment resuspension in the lagoon. The apparent lack of a major resuspension event, coupled with the delay before sampling started, may have resulted in the concentrations of dissolved nutrients recorded within this plume (Table 3.6) being lower than in others (Furnas 1989, Brodie and Mitchell 1992).

Table 3.5. Catchment size and mean discharge with average rainfall for recent flood events.

River	Catchment size (km^2)	Mean Annual Discharge (ML x 10^3)	Rainfall during Flood[1] (mm)	
			26 Jan-1 Feb 1994	22 Feb-1 Mar 1995
Daintree	2125	1023	355	417
Barron	2175	884	455	370
Russell-Mulgrave	1475	1617	835	1140
Johnstone	2495	2642	707	905
Tully	1685	3039	754	706
Herbert	10131	3440	577	304

[1](Taylor and Devlin, 1997)

Generally, concentrations of dissolved nutrients and phytoplankton in the plume from Cyclone Sadie were higher than in non-flood periods (Table 3.6), but there was considerable variability among sites and depths. Low concentrations of some dissolved species in the plume suggests that the phytoplankton rapidly acquired the dissolved nutrients, though there was no great increase in chlorophyll concentration (Table 3.6).

The rainfall in the northern catchment area after Cyclone Violet was very similar in duration and intensity to that associated with Cyclone Sadie (Table 3.5). At the time of sampling, the winds were moderate south-easterlies (20 - 25 kts) producing some resuspension in shallow inshore waters (Steven *et al.* 1996). Aerial surveillance on 28 February showed plumes from individual rivers moving in a northerly direction and merging to form a continuous longshore band. The aggregated plume generally lay within 10 km of the coast and impinged on several continental islands (Fig. 3.11).

Water sampling showed variability within the plume resulting from Cyclone Violet reflecting a combination of catchment hydrology, land use, and intensity and duration of rainfall (Steven *et al*. 1996). The Herbert and Tully rivers had higher sediment loads than the other three (Table 3.7), though there may also have been more resuspension. Greatly increased concentrations of nitrate-nitrite, up to 180 times mean concentrations, were also recorded in plumes from these rivers. Many of these inorganic nutrients are taken up rapidly by phytoplankton which could explain the chlorophyll levels 13 times higher than base flow values.

Interpretation

The areal extent of the plumes certainly depends on the direction and strength of the wind and the volume of freshwater coming out of the catchments. Although the amount of rainfall and duration of the events were similar, differences in wind direction and strength influenced the dispersion and movement of the resulting plumes in coastal waters.

Steven *et al*, (1996) present detailed descriptions of nutrient concentrations within these offshore plumes (Tables 3.6, 3.7) and discuss the relation between the variability in plume composition and catchment characteristics, rainfall, wind direction and strength and timing of sampling. Preliminary conclusions are that the composition of plume water varies between events, between days within a single event, with depth and between catchments. The *ad hoc* sampling of these floods makes it difficult to establish the interactions between time, location, catchment hydrology and downstream effects of the catchment. Further, more structured, sampling of such events is needed before these questions are answered.

Table 3.6. Range of values measured inside the plume from Cyclone Sadie in 1994 compared with long term mean concentrations taken from Furnas *et al*. (1995). Values are averages based on location of site proximity to the rivers. The spread of values is taken from depth sampling which consisted of three Niskin bottles spaced out over the depth profile with a surface sample taken by bucket.

Parameter	**Values in river plumes**				**Long-term mean values for GBR Sector**	
	Russell	Johnstone	Tully	Herbert	Cairns	Innisfail
Salinity	35.118	35.26	35.35	29.2	34.7	34.8
Suspended solids (mg/L)	1.73 -2.13	1.43 - 1.29	1.17 - 1.41	2.54 - 1.48	0.6	0.7
SiO_4 (μM)	3.80 -24.6	6.40 - 1.9	2.10 - 5.8	10.80 - 1.6	3.1	2.5
NH_4-N (μM)	0.38 - 1.04	0.33 - 0.06	0.10 -0.44	0.05 - 0.43	0.05	0.07
NO_2+NO_3(μM)	0.04 - 0.04	0.02 - 0.01	0.03 - 0.01	1.21 - 0.14	0.08	0.08
DON (μM)	5.82 - 6.68	4.31 - 6.61	5.69 - 9.21	5.34 - 6.85	5.5	5.5
PO_4-P (μM)	0.02 - 0.06	0.01 - 0.02	0.01 - 0.04	0.01 - 0.05	0.09	0.12
TDP (μM)	0.19 - 0.15	0.01 - 0.03	0.01 - 0.14	0.10 - 0.06	0.08	0.32
Chl a (μg/L)	0.57 - 0.22	0.57 - 0.75	0.60 - 0.93	1.33 - 0.98	0.4	0.34
Phaeophytin (μg/L)	0.28 - 0.13	0.18 - 0.36	0.4 - 0.38	0.60 - 0.45		

Table 3.7. Range of values measured inside the plume from Cyclone Violet in 1995 compared to long term mean concentrations taken from Furnas *et al.* (1995). Values are averages based on location of site proximity to the rivers. Values in table are from surface samples.

Parameter	**Values in river plumes**					**Long-term mean values for GBR Sectors**	
	Barron	Russell	Johnstone	Tully	Herbert	Cairns	Innisfail
Salinity	29.4 - 31.0	13.2 - 27.4	8.6 - 29.6	2.2 - 30.2	4.2 - 33.8	34.7	34.8
Suspended solids (mg/L)	2.2 - 10.7	1.6 - 4.6	1.9 -9.8	4.24 -26.1	5.98 - 46.8	0.6	0.7
SiO_4 (μM)	12.1 - 27.6	27.1 - 86.4	23 - 10 4.6	31.4 -110	7.0 - 111.0	3.1	2.5
NH_4-N (μM)	0.02- 0.4	0.03 - 0.57	0.34 - 1.28	0.6 - 1.33	0.1 - 2.28	0.05	0.07
NO_2+NO_3(μM)	0.24 - 1.2	1.6 - 5.6	1.79 - 13.8	2.31 - 14.4	0.7 - 11.6	0.08	0.08
DON (μM)	5.12 - 9.46	9.2 - 10.87	6.5 - 25.16	6.93 - 26.8	5.30 -24.2	5.5	5.5
PO_4-P (μM)	0.03 - 0.13	0.1 - 0.24	0.08 - 0.32	0.05 - 0.28	0.06 - 0.54	0.09	0.12
TDP (μM)	0.09 - 0.17	0.19 - 0.43	0.12 - 0.34	0.1 - 0.21	0.05 - 1.44	0.08	0.32
Chl a (μg/L)	0.95 - 1.82	0.55 - 0.96	0.78 - 1.88	1.76	0.94 - 3.02	0.4	0.34
Phaeophytin (μg/L)	0.35 - 2.54	0.31 - 0.59	0.27 - 1.01	0.86 - 1.51	0.7 - 1.75		
Particulate N	2.8 - 5.25	2.14 - 10.5	1.9 - 10.54	2.7 - 6.7	1.7 - 8.4		
Particulate P	0.09 - 0.43	0.06 - 0.51	0.2 - 0.46	0.15 - 0.53	0.1 - 0.13		

A COMPARISON OF NUTRIENT STATUS OF SEDIMENTS NEAR THE MOUTHS OF THREE RIVERS WITH CONTRASTING CATCHMENTS

Introduction

Changes in vegetation and land use on the hinterland may affect the water quality of the GBR lagoon in several ways. The catchments of coastal river systems are often cultivated intensively. Land clearing has been estimated to have increased sediment inputs up to five times (Neil and Yu 1996). Large amounts of nitrogen- and phosphorus-based fertilisers are applied and may potentially be leached into rivers whose outflows are a major source of nutrients in the GBR lagoon (Furnas *et al.* 1995). Some authors have suggested that enriched river runoff has caused some regions of the GBR lagoon to become eutrophic (Bell and Gabric 1991; Bell 1991; 1992); others have argued the contrary (Walker 1991) or that the evidence is inconclusive (Kinsey 1991).

A significant fraction of the organic matter and nutrients transported by river systems is likely to be bound in sediments and deposited near to shore (Belperio 1983; Gagan *et al.* 1987). In time this material will be broken down and the constituent nutrients released into the interstitial pore water of the sediment. The nutrients will in turn diffuse into the water column, or be re-suspended by storms and bioturbation. One component of the AIMS Long-term Monitoring Program has been concerned with quantifying the nutrient status of sediments adjacent to three north Queensland rivers with contrasting catchment uses.

The sub-project addressed two questions:

1. Is significant agricultural land use in catchments correlated with elevated levels of nitrogen and phosphorus in associated nearshore bulk sediments and pore waters?
2. How rapidly are nutrients in the sediments released into the overlying water column?

This section of this report deals with the first question; the second is addressed in Lourey *et al*. (in review).

Methods

Sampling design

Samples were taken from cross-shelf transects off the mouths of the Barron, Johnstone and Pascoe Rivers. The Barron and Johnstone Rivers both have catchments with significant agricultural activity. They also have high mean annual flows. The Pascoe River drains an area that is neither heavily cultivated nor populated and so should show minimal anthropogenic effects.

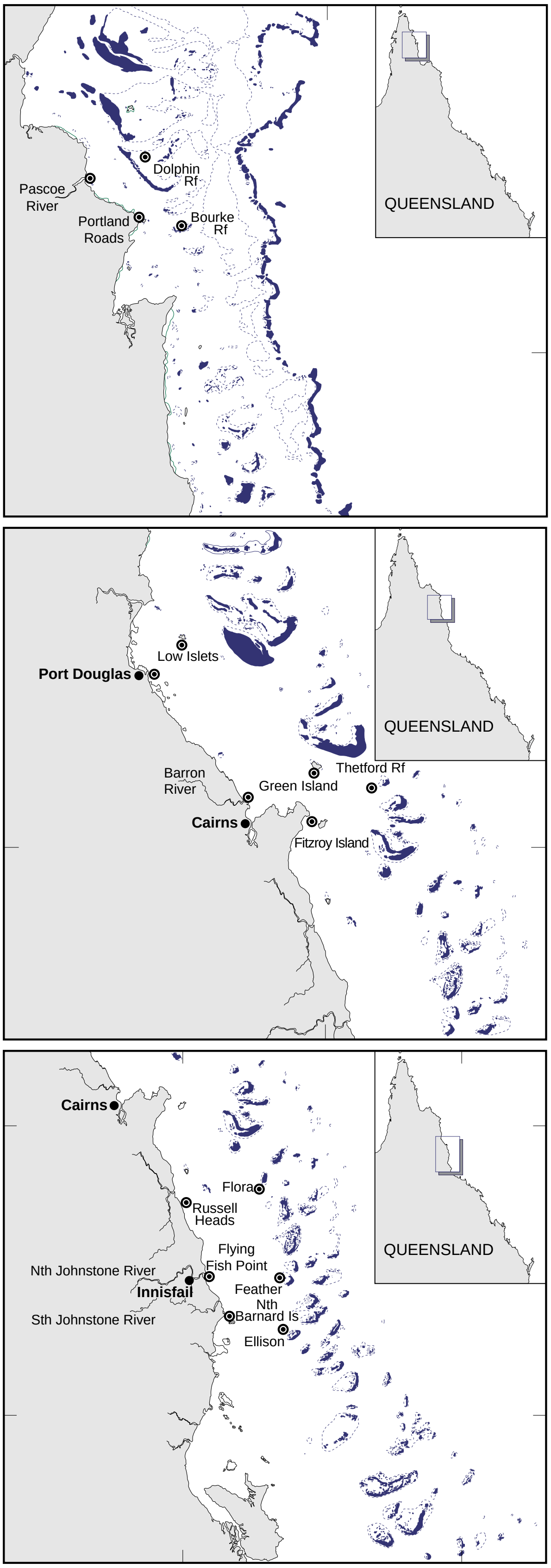


Figure 3.12. Location of the three river systems with contrasting patterns of catchment use. Points indicate sediment sampling sites.

Initial sampling was biannual to assess seasonal differences in sediment nutrients. In the last two years sampling was annual. The Pascoe River was only sampled once in each year in the wet season (Table 3.8).

Six stations were sampled in a grid off each of the Johnstone and Barron Rivers. Four stations were sampled off the Pascoe River. Half of the stations at each river were within 1 km of the shore; the other half were located 20 km offshore, adjacent to reefs along the seaward margin of the GBR lagoon. One cross-shelf transect was situated directly in front of each river mouth. The other two transects were located to the north and south of the river mouth. Fig 3.12 shows the sampling stations for each river system.

Table 3.8. Distribution of sampling effort over the survey period.

Cruise	Sampling Date	Transects surveyed	Season
1	23/11 - 28/11/92	Barron and Johnstone	Dry
2	21/03 - 29/03/93	Barron, Johnstone and Pascoe	Wet
3	14/09 - 21/09/93	Barron and Johnstone	Dry
4	06/03 - 14/03/94	Barron, Johnstone and Pascoe	Wet
5	12/03 -20/03/95	Barron, Johnstone and Pascoe	Wet

Field Sampling

Sediment cores were taken using a modified Bouma boxcorer (0.027 m^2 of seabed) to a sediment depth of 20 cm. Each boxcore was sub-sampled for pore water and solid phase nutrients. Sub-sampling for pore water and solid phase nutrients involved inserting two aluminium cores (7 cm inner diameter) into each box to the depth of maximum penetration. Coring tubes were lined with a tube of PVC which was divided into 2 cm rings. The resulting 2 cm sections were either placed into acid washed petri dishes for pore water extraction or sections of bulk sediment placed into 25 ml plastic vials and frozen for later analysis.

Pore water

Pore water was extracted from sectioned sediment cores using a modified teflon pore water extractor (Robbins and Gustinis 1976). Pore waters were squeezed through 0.4 µm polycarbonate membrane filters under an applied nitrogen pressure of 100 kPa until approximately 10 ml of interstitial water was collected. Samples for total and inorganic nutrient analysis were stored frozen in acid washed plastic vials. Samples for dissolved organic carbon analysis were stored at 4°C in acid washed teflon capped glass vials containing HCl to remove carbonates.

Laboratory analysis

Analyses are described in detail in Lourey (in press). Briefly, samples were analysed for dissolved inorganic nutrient species (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-} and $Si(OH)_4^+$) using a SKALAR™ 20/40 multi-channel segmented flow analyser adapted for low level determinations (Ryle *et al*. 1981). Total dissolved nutrient species were determined using the same apparatus after 8 hr digestion in a La Jolla™ UV photo-oxidation apparatus. The initial inorganic nutrient concentrations were subtracted to derive organic nutrient (DON, DOP) levels.

Solid phase nutrient concentrations were measured in bulk sediment samples. Samples were dried in an oven at 80°C for 24 hr and ground in an agate grinding mill. Total organic carbon was determined using a Beckman Model 915-B Tocamaster™ Total Carbon Analyser using the procedure described by Sandstrom *et al.* (1986). Total carbon and total nitrogen were measured using a Perkin Elmer™ Model 2400 CHN analyser. Total phosphorus was measured using a Varian™ Liberty 220 plasma emission spectrometer after perchloric/nitric acid digestion. Analyses of variance were used to look for consistent patterns associated with the different river catchments, seasons and positions on the continental shelf.

Results

Comparable samples from both the potentially impacted rivers and the control were only taken during the wet season. The only parameters that differed significantly among the three rivers were total dissolved phosphorus and total dissolved carbon. Total dissolved phosphorus was higher in pore waters of sediments near the Pascoe River than in those of the other rivers (Fig. 3.13). This was true both inshore and near the reefs. Total dissolved carbon levels were higher in the Pascoe River area (Fig. 3.13), but the high concentrations only occurred close to the river mouth (river by shelf interaction, Table 3.9, Fig. 3.13).

Table 3.9. Results of analysis of variance to determine the effect of river and shelf position on each parameter for the wet season. "No" indicates no evidence of consistent pattern (p>0.1), "M" indicates marginal evidence of consistent pattern (p = 0.051 - 0.10), "Yes" indicates evidence of consistent pattern (p< 0.05). Parentheses indicate results that are compromised by the results of other tests in the analyses.

	Total				Porewater		
Questions	Carbonate	Organic carbon	Nitrogen	Phosphorus	Tot. Diss. Nitrogen	Tot. Diss. Phosphorus	Diss. Organic Nitrogen
Do the samples from each combination of river and shelf position vary? *Differences among samples within River x Shelf comb.s*	Yes	Yes	Yes	Yes	No	No	No
Does the pattern of concentration across the shelf vary among rivers? *River x Shelf interaction*	No	No	No	No	No	No	Yes
Does the average pattern of concentration vary across the shelf? *Main effect of shelf*	Yes	No	No	Yes	No	M	(Yes)
Does the average pattern of concentration vary among rivers? *Main effect of river*	No	No	No	No	No	Yes	(Yes)

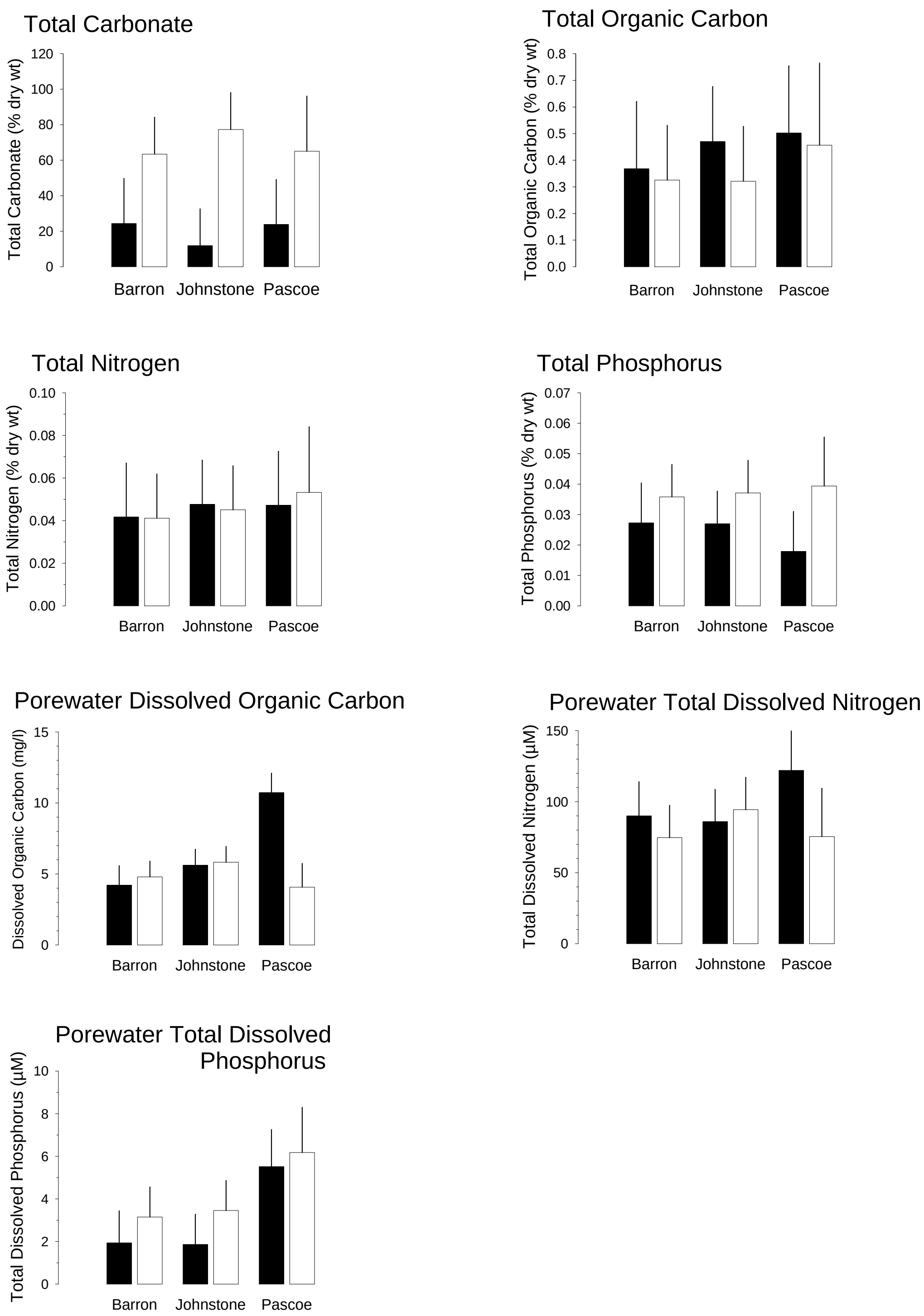


Figure 3.13. Differences among rivers in mean concentrations of nutrients in the wet season (±95% confidence limits). Filled bars = inshore sites, unfilled bars = mid-shelf sites.

Interpretation

Nutrient status of bulk sediments and porewaters near river mouths did not appear to reflect obvious differences in catchment use for agriculture. While a correlation was anticipated, the delivery of nutrients to coastal sediments is complex and there are numerous processes that could disrupt any relationship. For example, much of the dissolved nutrients will be assimilated by phytoplankton. The proportion of the total input that reaches the sediment may be variable depending on the phytoplankton community. Dissolved nutrients do not always reach the coastal zone: Pailles *et al.* (1993) found that total phosphorus concentrations in sediments of the Johnstone River were lower in sites adjacent to rainforest than in sites with agricultural influences. However, much of the phosphate lost from agricultural land under normal flow conditions appeared to be trapped in the saltwater/freshwater mixing zone of the estuary as a result of flocculation, so little of the phosphorus entered the coastal zone. This is unlikely to apply in this case because, as described in the previous subsection, at least two cyclones affected the area during the study. While Cyclone Sadie principally affected rivers north of Cairns (which should have included the Barron River) prior to 1994 samples, Cyclone Violet caused both the Johnstone and Barron Rivers to flood six weeks before the 1995 sampling. These floods would be likely to have remobilised the estuarine sediments and discharged them into the near-shore environment.

The large differences among sampling stations show that spatial variability of chemical parameters in sediments was high. This high level of natural heterogeneity made it difficult to determine fine scale differences in pore water composition since the variation between sites separated by a few kilometres is as great as that among the rivers. The variability in sediment chemistry may result from a number of different factors. For instance, sediments differ in their adsorption potential for phosphorus (Pailles and Moody 1992; Alongi *et al*. 1992; Pailles *et al*. 1993). Release of bound nutrients depends on diagenetic processes for their initial conversion to dissolved interstitial species, while release into the water column depends on diffusion and re-suspension, with finer sediments being more likely to be resuspended than coarse materials (Callender 1982).

DISCUSSION

Given the constrained sampling of water quality within the LTMP, any picture of temporal and spatial variation must be incomplete and would form an unreliable basis for explaining variation in assemblages of benthic organisms and fishes. Whether water quality has changed over the long term due to human activity and if so, what are the impacts on the biota of the GBR, remain major questions for managers of the marine park. The most obvious effects might be expected where conditions are most extreme: within range of flood plumes from rivers. The two flood events described here differ considerably qualitatively and in their spatial extent. Many more plumes will need to be sampled before it will be possible to relate the likely extent and intensity of such flood plumes to variation in the assemblages of benthic animals and fishes.

Sampling of sediments near river mouths represents a crude attempt to relate sediment nutrient levels to patterns of catchment use. The sub-project found no correlation but this is inconclusive: sampling needs to be matched to processes by which nutrients enter the sediments and to the dynamics of their release into the water column. Since most runoff is associated with cyclonic flood events, catchment differences should be most evident in wet years. A conclusive study will require considerably more information on processes, combined with more sophisticated sampling effort over a longer time.

4. Fishes

Hugh Sweatman, Angus Thompson, Alistair Cheal and Dan Ryan

INTRODUCTION

Reef fishes are a salient part of the fauna of coral reefs and include species of commercial importance. A few groups, notably coral feeding butterfly fishes, have been advocated as indicators of reef health (e.g. Crosby and Reese 1996). This section is principally concerned with the results of fish surveys in 1993-94 and 1994-95, being the second phase of setting up the sampling scheme and the first full set of samples. The main objectives of the Section are:

- To re-examine spatial patterns in the fish assemblages as described in the first AIMS Status Report (Halford *et al*. 1995) using data from the full set of sample reefs.
- To examine spatial patterns of species richness in selected groups.
- To look at the magnitude and distribution of changes in fish assemblages within and between reefs.

METHODS

Study sites

The sampling design has been described in Section 1. Thirty-three reefs were sampled 1992-93, 32 reefs in 1993-94 and 49 were sampled in 1994-95 (Appendix 2). These were visited between September and May in each survey year. At each sample reef there are three sites, each consisting of a series of five 50 m transects. These were haphazardly located in the first instance, but then permanently marked. For analysis of geographic patterns, the counts have been summed over 250 m of transects, giving estimates of density from three sites in the one area of each reef. This reduces variability in counts of mobile organisms such as fishes whose abundances on 50 m transects are likely to vary between successive counts on the same day because of movement.

Sampling techniques

Full details of the sampling method are given in the Standard Operating Procedure (Halford and Thompson 1996). Fishes of 191 species (Appendix 3) were censused visually on the five transects at each site on each reef. The samples covered by this report are the first, second and third years of the AIMS Long-term Monitoring Program and represent a time of evolution and modification of the original sampling design, in light of practical experience. While modifications to a long term program must be minimised if data are to be comparable between years, it became clear that the initial transect width of 10 m for larger, more mobile species was not practical in conditions of low visibility that are frequently encountered on inshore reefs. In the first two years, poor visibility meant that it was not possible to survey larger fishes on some inshore reefs: in some cases the transect width had to be reduced to 6 m. The 2 m transect width for pomacentrids was also problematic because of the number of large schools of planktivorous pomacentrids encountered, since these greatly increased sampling time and also increased the likelihood of overlooking rarer species. In the third year of sampling (1994-95) the transect widths were reduced to 5 m and 1 m respectively. Summary counts of the different taxa in each year are given in Appendix 4.

WHAT ARE THE GEOGRAPHIC PATTERNS IN THE ABUNDANCE OF FISHES?

Sampling of both corals and fishes in a variety of habitats in transects across the continental shelf in the central GBR has demonstrated that there are often clear cross-shelf patterns (Done 1982, Russ 1984, Williams 1982; Williams and Hatcher 1983). Williams (1983) found that north-south variability was less than cross-shelf variability in reef fish assemblages on cross-shelf transects at five latitudes. Williams (1991) has reviewed knowledge of the patterns in the distribution of fishes on various scales from the GBR. The main aim of this section is to compare the patterns of abundance described by Halford *et al*. (1995), which were based on a subset of the survey reefs, with the patterns of abundance based on the full sampling design.

Analyses

Two analyses of variance (ANOVAs), each consisting of a series of contrasts, were used to examine whether there is systematic geographic variation in abundance of the groups that can be attributed to latitude or cross-shelf position. The geographic distribution of reefs along the GBR complicates such analyses: while the four northern sectors differ in the extent that outer shelf reefs form a barrier, there are generally identifiable inshore, mid-shelf and outer shelf reefs, subject to progressively less coastal and more oceanic influences respectively. The Swains sector reefs can be expected to show a different pattern, for, while the oceanic influence decreases from outer Swain reefs to inner ones, coastal influences will be much less on Swain reefs closest to the coast than for instance, inshore reefs of the Whitsunday sector (Fig. 1.1). The channel between the inner Swain reefs and the coast allows considerable fetch the influence of the SE tradewinds means that the most sheltered reefs in the Swains may in fact be mid-shelf reefs. Finally, all the reefs in the Capricorn/Bunker sector are outer shelf reefs. The contrasts were chosen to reflect these patterns, looking for homogeneity among the four northern sectors, comparing these with the Swains and treating the Capricorn Bunker reefs separately in a comparison with only outer shelf reefs in other sectors. As discussed in Section 1, the contrasts form a logical sequence and significant interactions in particular complicate the interpretation of subsequent tests for main effects. Tests that require careful interpretation are indicated in the summary tables by the use of parentheses. All data were transformed $\log_{10}(x + 1)$ prior to analysis.

Results

For initial presentation, larger, more mobile species have been grouped by family (Fig. 4.1). The hypotheses and the results of ANOVAs are given in Tables 4.1 and 4.2 and the results are summarised by family in Table 4.3. None of the families of larger fishes showed significant variation among the four most northerly sectors in the pattern of distribution across the shelf, though the Pomacentridae as a family did show such differences. Scaridae and *Zanclus* showed different cross-shelf patterns of abundance in the Swains when compared to the four northern sectors. Lethrinidae, Lutjanidae, Scaridae and Serranidae were present in different numbers in different sectors. Five families (Acanthuridae, Lethrinidae, Lutjanidae, Serranidae and Siganidae) were unevenly distributed across the shelf in consistent ways. Abundances varied more with latitude when only the relatively homogeneous outer shelf reefs were considered (Table 4.2, Fig. 4.1). Seven of the ten families showed differences in abundance among sectors excluding the Capricorn/Bunker reefs. The remaining three (Chaetodontidae, Labridae and *Zanclus*) showed lower abundances on Capricorn/ Bunker reefs compared with outer shelf reefs in other sectors.

When the Pomacentridae are divided into genera, much more variation in abundances is evident (Fig. 4.2). Nine of the 12 genera (*Acanthochromis*, *Amblyglyphidodon*, *Chromis*, *Chrysiptera*, *Neoglyphidodon*, *Pomacentrus* and *Stegastes*) showed significantly different patterns of abundance across the shelf in different sectors, *Plectroglyphidodon* showed evidence of differences in abundance across the shelf (Table 4.4). Once again, when only outer shelf reefs are considered, nine of the 12 showed differences among sectors when the Capricorn/Bunker reefs were excluded and no additional genera showed different abundances on the Capricorn/Bunker reefs compared with the five other sectors (Table 4.5). Most genera were less abundant in the Capricorn/Bunker reefs than on other outer shelf reefs, with the notable exception of the genus *Pomacentrus* (Fig. 4.2). Results are summarised by genus in Table 4.6.

Proportions of variance (Table 4.7) are a measure of the scale of patchiness of the distribution of fish taxa and hence give an indication of where sampling effort should be concentrated. With the exception of the family Acanthuridae and the genus *Pomacentrus*, all taxa were most patchy at the level of the 50 m transect, so there was substantial variation among transects within a site on a reef. The abundances of some common genera such as *Amblyglyphidodon, Chromis, Chrysiptera* and *Pomacentrus* showed considerable additional variation among reefs. The maximum proportion of variance due to differences among sites within reefs was only about 25%. These values for proportions of variance support a sampling scheme that visits many reefs and includes more transects within sites than sites within reefs.

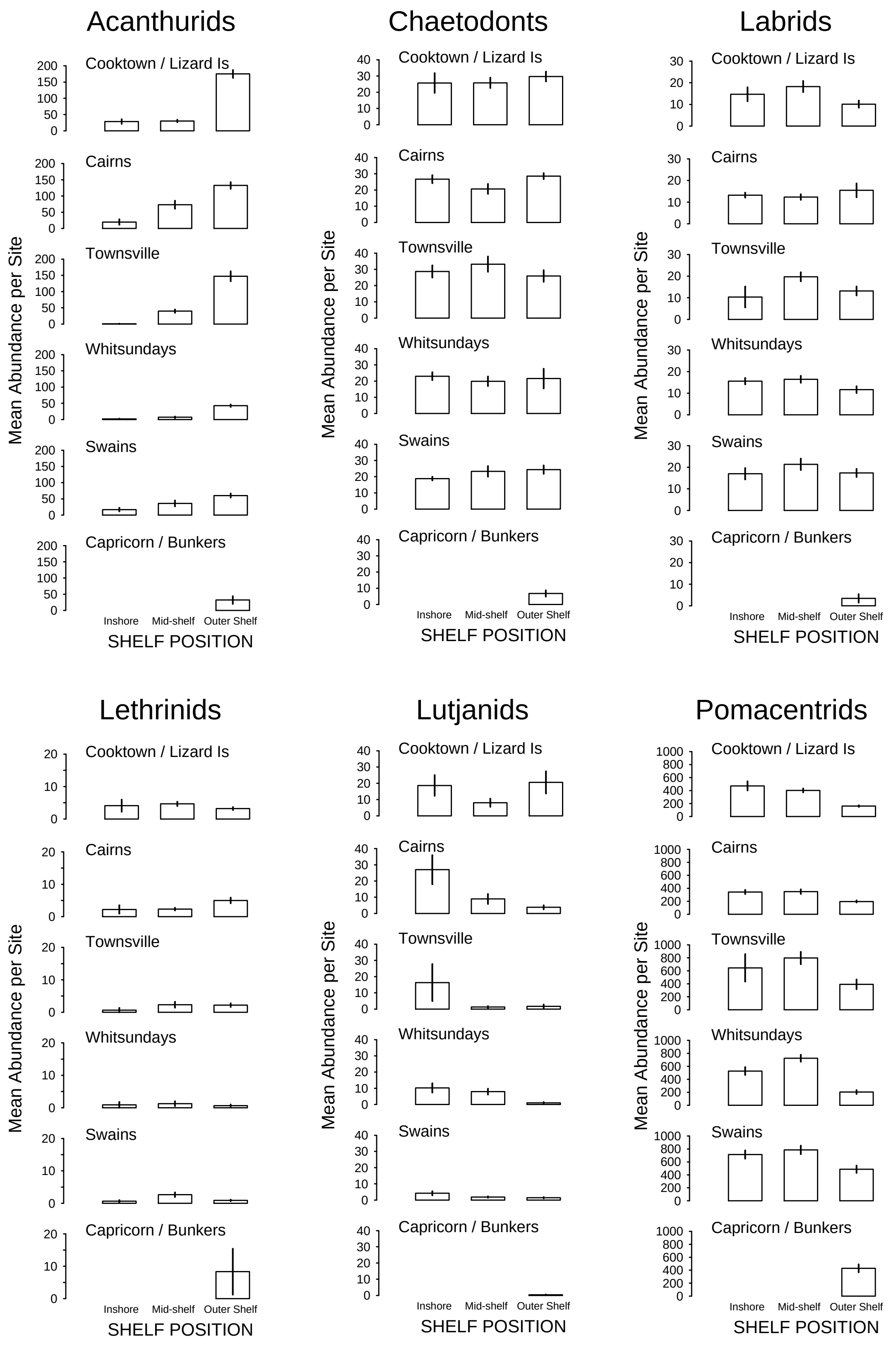


Figure 4.1. Mean number of individuals per site for nine families of larger fish in 1994-95 counted on 5 m wide transects and pomacentrids counted on 1 m wide transects. Error bars are S.E.s.

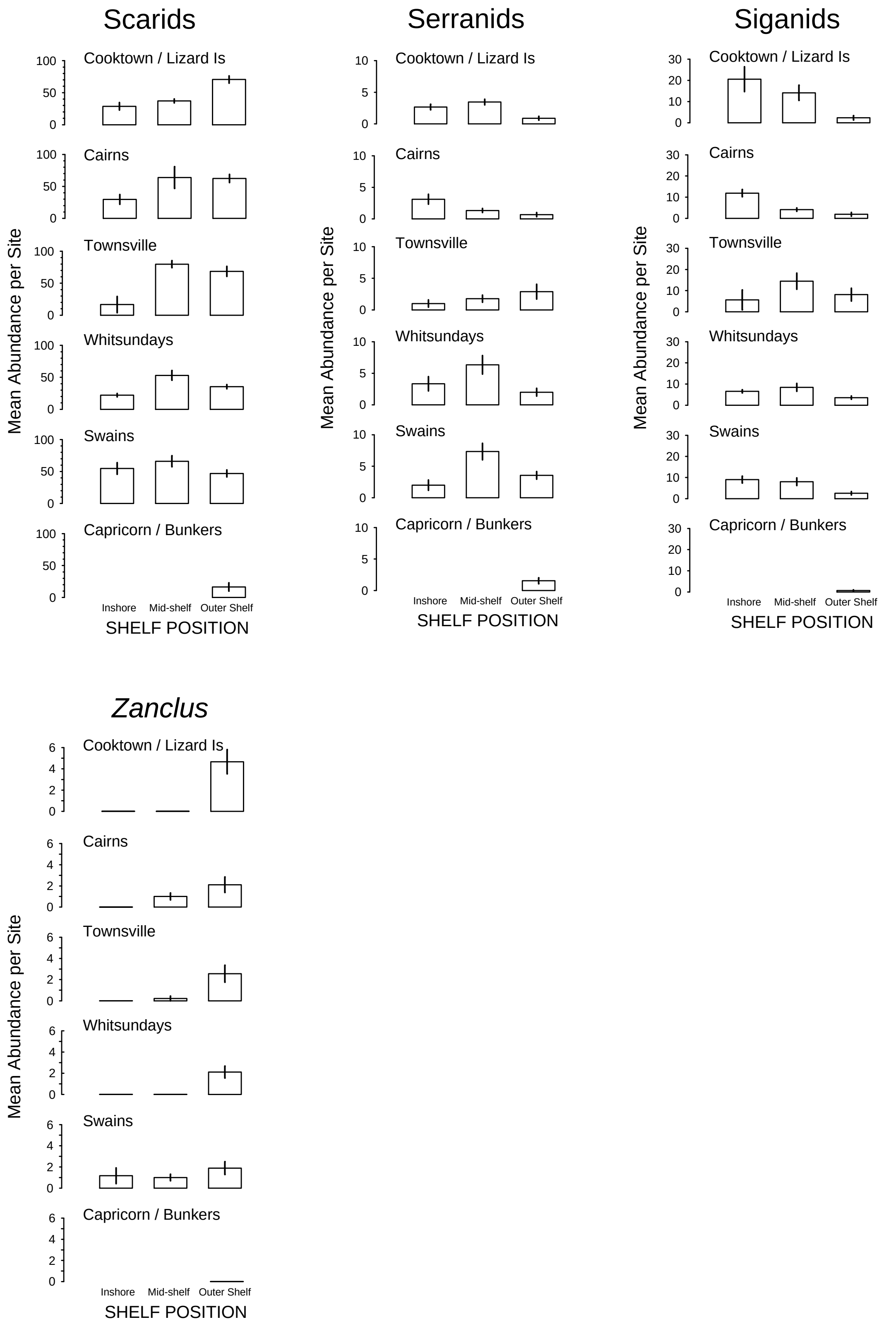


Figure 4.1 continued. Mean number of individuals per site for nine families of larger fish in 1994-95 counted on 5 m wide transects. Error bars are S.E.s.

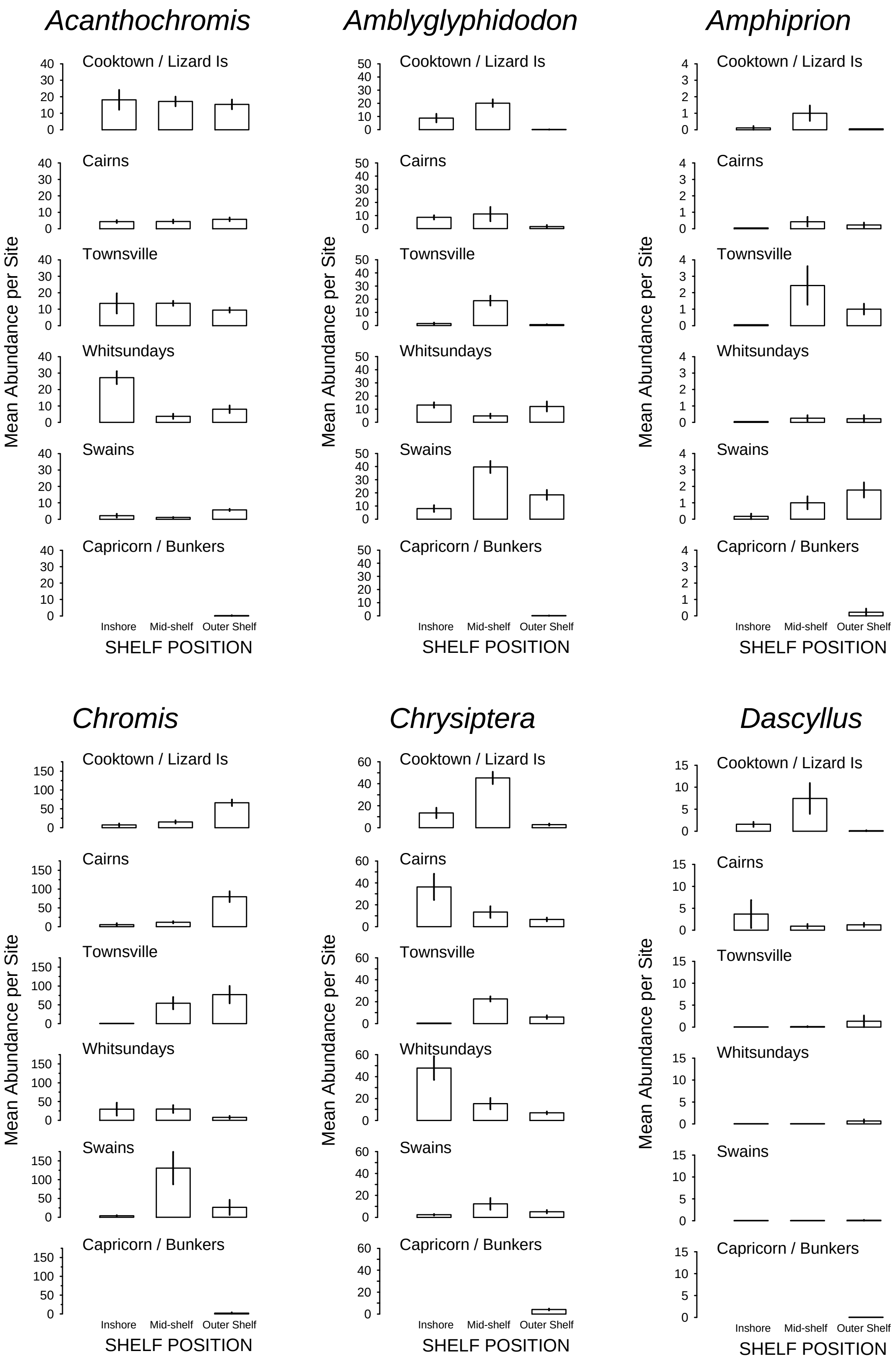


Figure 4.2. Mean number of individuals per site for 12 genera of pomacentrids in 1994-95 counted on 1 m wide transects. Error bars are S.E.s.

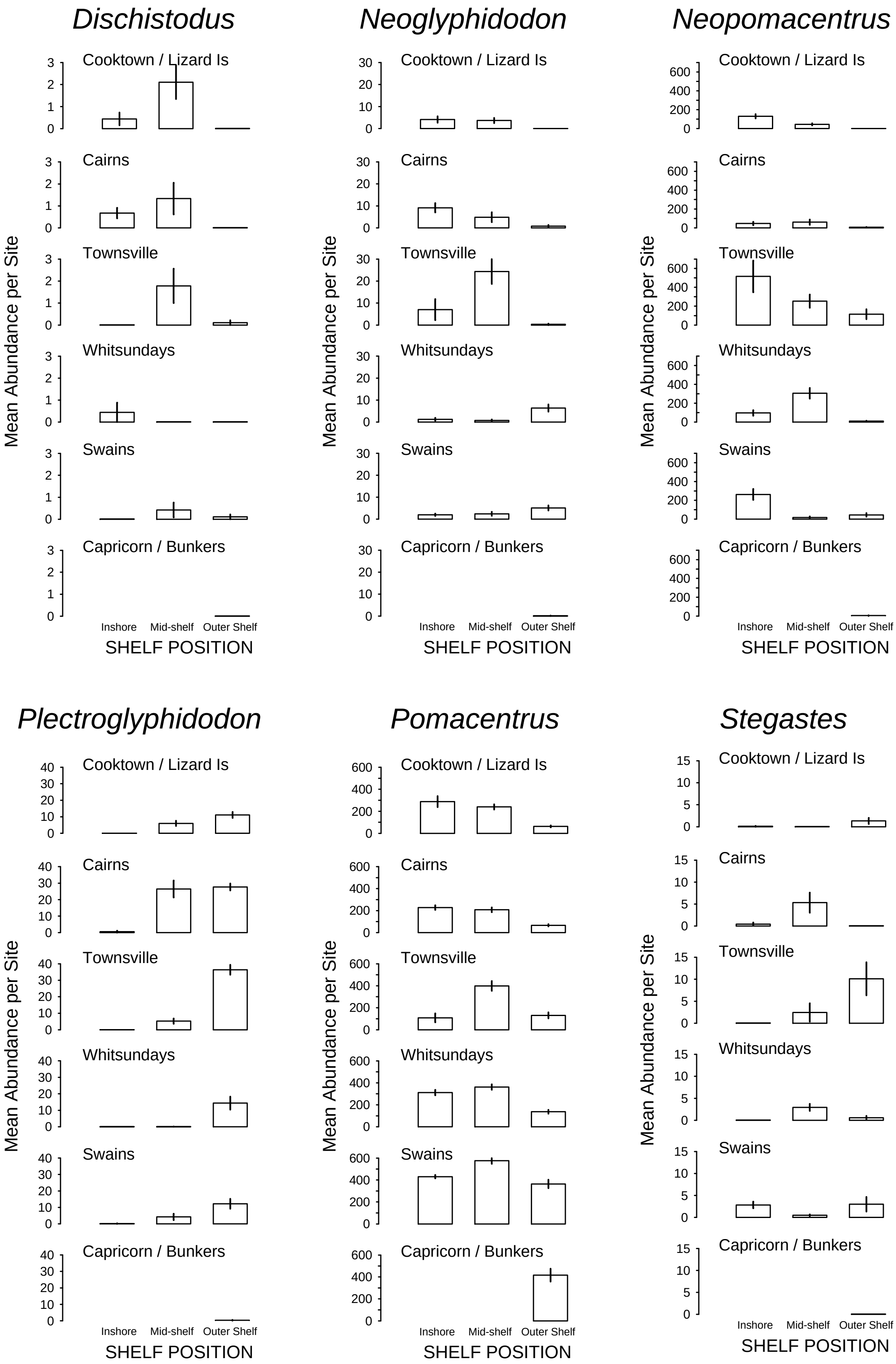


Figure 4.2 continued**.** Mean number of individuals per site for 12 genera of pomacentrids in 1994-95 counted on 1 m wide transects. Error bars are S.E.s.

Table 4.1. Results of analyses of variance and contrasts on abundances of larger fishes to examine whether there is systematic geographic variation in abundance of the groups that can be attributed to latitude or cross-shelf position. Data from all sectors except the Capricorn Bunker sector (omitted because there are only outer shelf reefs). Fishes were grouped by family and abundances were summed to the site level, giving three values per reef. All values transformed $\log_{10}(x+1)$ before analysis. Note that Pomacentrids were counted on narrower transects than other families (see methods). "No" indicates no evidence of consistent pattern ($p>0.1$), "M" indicates marginal evidence of consistent pattern ($p = 0.051 - 0.10$), "Yes" indicates evidence of consistent pattern ($p< 0.05$). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation.

Questions	**Acanthurids**	**Chaetodontids**	**Labrids**	**Lethrinids**	**Lutjanids**	**Pomacentrids**	**Scarids**	**Serranids**	**Siganids**	***Zanclus***
Does the pattern of abundance across the shelf vary among the 4 northern sectors? *(Sector by cross-shelf interaction in 4 northern sectors)*	No	No	No	No	No	Yes	No	No	No	No
Does the pattern of abundance across the shelf in the Swains differ from that in the 4 northern sectors? *(Interaction contrast sector by cross-shelf interaction, Swains vs 4 northern sectors)*	No	No	No	No	No	(No)	M	No	No	M
Does abundance vary among the 4 northern sectors (averaged across the shelf)? *(Sector effect, 4 northern sectors)*	No	No	No	Yes	No	(M)	No	No	No	No
Does abundance vary between the Swains and the 4 northern sectors (averaged across the shelf)? *(Sector effect, contrast Swains vs 4 northern sectors)*	No	No	No	(No)	M	(Yes)	(M)	M	No	(No)
Does abundance vary between inshore and mid-shelf reefs (averaged over the 4 northern sectors and Swains)? *(Cross-shelf effect 1, 5 northern sectors)*	Yes	No	No	Yes	Yes	(Yes)	(Yes)	No	No	(No)
Does abundance vary between outer shelf reefs and other reefs (averaged over the 4 northern sectors and Swains)? *(Cross-shelf effect 2, 5 northern sectors)*	(Yes)	No	No	(No)	(Yes)	(Yes)	(M)	(M)	Yes	(Yes)

Table 4.2. Results of analyses of variance and contrasts on abundances of larger fishes to examine whether there is systematic geographic variation in abundance of the groups that can be attributed to latitude. Data from outer shelf reefs only. Fishes were grouped by family and abundances were summed to the site level, giving three values per reef. All values transformed $\log_{10}(x+1)$ before analysis. "No" indicates no evidence of consistent pattern (p>0.1), "M" indicates marginal evidence of consistent pattern (p = 0.051 - 0.10), "Yes" indicates evidence of consistent pattern (p< 0.05). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation.

Questions	**Acanthurids**	**Chaetodontids**	**Labrids**	**Lethrinids**	**Lutjanids**	**Pomacentrids**	**Scarids**	**Serranids**	**Siganids**	***Zanclus***
Do abundances on outer shelf reefs vary among the 5 northern sectors?	Yes	No	No	Yes	Yes	Yes	M	Yes	M	No
Do abundances on outer shelf reefs differ between the Capricorn/ Bunkers and the other sectors. *(Contrast Capricorn/Bunkers vs 5 northern sectors)*	(Yes)	Yes	Yes	(No)	(Yes)	(Yes)	(Yes)	(No)	(Yes)	Yes

Table 4.3. Summary of statistically significant geographic patterns in abundance for fishes grouped by family (see Fig 4.1).

Acanthurids	• Consistent cross-shelf patterns with lower abundances inshore and higher abundances on outer shelf reefs • Abundances on outer shelf reefs vary among 5 northern sectors but are lowest in the Capricorn/ Bunkers
Chaetodontids	• No clear patterns in overall abundance in 5 northern sectors or across shelf • Abundances on outer shelf reefs similar in all sectors except the Capricorn/ Bunkers where abundances are lower
Labrids	• No clear patterns in overall abundance in 5 northern sectors or across shelf • Abundances on outer shelf reefs similar in all sectors except the Capricorn/ Bunkers where abundances are lower
Lethrinids	• Overall mean abundance varies among 4 northern sectors • Overall mean abundance is lower on inshore reefs • Abundance on outer shelf reefs varies among 5 northern sectors
Lutjanids	• Overall abundance in Swains less than in the 4 northern sectors • Consistent cross-shelf patterns with higher abundances inshore and lower abundances on outer shelf reefs • Abundances on outer shelf reefs vary among 5 northern sectors • Abundances on Capricorn/ Bunker reefs are lower than average for outer shelf reefs in other sectors
Pomacentrids	• Pattern of abundance across the shelf varies among 4 northern sectors • Overall mean abundances vary among sectors though cross-shelf patterns also vary. • Overall mean abundance highest on mid-shelf reefs, though cross-shelf patterns vary among sectors • Abundances on outer shelf reefs vary among 5 northern sectors • Abundances on Capricorn/ Bunker reefs are higher than average for outer shelf reefs in other sectors
Scarids	• Pattern of abundance across the shelf differs between the Swains and the 4 northern sectors • Overall mean abundances highest in the Swains though cross-shelf patterns also vary among sectors. • Overall mean abundances lowest on inshore reefs though cross-shelf patterns also vary among sectors. • Abundances on outer shelf reefs vary among 5 northern sectors • Abundances on Capricorn/ Bunker reefs are lower than average for outer shelf reefs in other sectors
Serranids	• Higher overall abundance in the Swains than in 4 northern sectors • Overall mean abundance is lowest on outer shelf reefs • Abundances on outer shelf reefs vary among 5 northern sectors
Siganids	• No clear differences in overall abundance among the 5 northern sectors • Overall abundance is highest on inshore and mid-shelf reefs • Abundances on outer shelf reefs vary among 5 northern sectors • Abundances on Capricorn/ Bunker reefs are lower than average for outer shelf reefs in other sectors
Zanclus	• Pattern of abundance across the shelf differs between the Swains and the 4 northern sectors • Overall abundance is highest on outer shelf reefs • No clear differences in abundance on outer shelf reefs of 5 northern sectors,

	but absent from Capricorn/ Bunkers

Table 4.4. Results of analyses of variance and contrasts on abundances of pomacentrid fishes to examine whether there is systematic geographic variation in abundance of the groups that can be attributed to latitude. Data from all sectors except the Capricorn Bunker sector (omitted because there are only outer shelf reefs). Fishes were grouped by genus and abundances were summed to the site level, giving three values per reef. All values transformed $\log_{10}(x+1)$ before analysis. "No" indicates no evidence of consistent pattern ($p>0.1$), "M" indicates marginal evidence of consistent pattern ($p = 0.051 - 0.10$), "Yes" indicates evidence of consistent pattern ($p< 0.05$). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation. Shading indicates that the data violated the assumption of homogeneity of variances and so analyses are unreliable.

Questions	*Acanthochromis*	*Amblyglyphidodon*	*Amphiprion*	*Chromis*	*Chrysiptera*	*Dascyllus*	*Dischistodus*	*Neoglyphidodon*	*Neopomacentrus*	*Plectroglyphidodon*	*Pomacentrus*	*Stegastes*
Does the pattern of abundance across the shelf vary among the 4 northern sectors? *(Sector by cross-shelf interaction in 4 northern sectors)*	Yes	Yes	No	Yes	Yes	No	No	Yes	No	No	Yes	Yes
Does the pattern of abundance across the shelf in the Swains differ from that in the 4 northern sectors? *(Interaction contrast sector by cross-shelf interaction, Swains vs 4 northern sectors)*	(No)	(No)	Yes	(No)	(No)	No	No	(No)	Yes	No	(No)	(Yes)
Does abundance vary among the 4 northern sectors (averaged across the shelf)? *(Sector effect, 4 northern sectors)*	(No)	(No)	Yes	(No)	(No)	No	No	(No)	Yes	M	(No)	(No)
Does abundance vary between the Swains and the 4 northern sectors (averaged across the shelf)? *(Sector effect, contrast Swains vs 4 northern sectors)*	(Yes)	(Yes)	(Yes)	(No)	(M)	No	No	(No)	(No)	(No)	(Yes)	(No)
Does abundance vary between inshore and midshelf reefs (averaged over the 4 northern sectors and Swains)? *(Cross-shelf effect 1, 5 northern sectors)*	(No)	(Yes)	(Yes)	(Yes)	(M)	No	Yes	(No)	(M)	Yes	(Yes)	(No)
Does abundance vary between outer shelf reefs and other reefs (averaged over the 4 northern sectors and Swains)?*(Cross-shelf effect 2, 5 northern sectors)*	(Yes)	(Yes)	(No)	(No)	(No)	No	(No)	(No)	(Yes)	(Yes)	(Yes)	(No)

Table 4.5. Results of analyses of variance and contrasts on abundances of pomacentrid fishes to examine whether there is systematic geographic variation in abundance of the groups that can be attributed to latitude or cross-shelf position. Data from outer shelf reefs only. Fishes were grouped by genus and abundances were summed to the site level, giving three values per reef. All values transformed $\log_{10}(x+1)$ before analysis. "No" indicates no evidence of consistent pattern ($p>0.1$), "Yes" indicates evidence of consistent pattern ($p< 0.05$). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation. Shading indicates that the data violated the assumption of homogeneity of variances and so analyses are unreliable.

Questions	*Acanthochromis*	*Amblyglyphidodon*	*Amphiprion*	*Chromis*	*Chrysiptera*	*Dascyllus*	*Dischistodus*	*Neoglyphidodon*	*Neopomacentrus*	*Plectroglyphidodon*	*Pomacentrus*	*Stegastes*
Do abundances on outer shelf reefs vary among the 5 northern sectors?	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes
Do abundances on outer shelf reefs differ between the Capricorn/ Bunkers and the other sectors *(Contrast Capricorn/Bunkers vs 5 northern sectors)*	(Yes)	(Yes)	(No)	(Yes)	No	No	No	(Yes)	(No)	(Yes)	(Yes)	(Yes)

Table 4.6. Summary of statistically significant geographic patterns in abundance for pomacentrid fishes grouped by genus (see Fig 4.2). Shading indicates tests that are unreliable due to inequality of variances.

Acanthochromis	• Relative abundance across the shelf varies among 4 northern sectors • Mean abundance in the Swains is lower than the overall mean for 4 northern sectors • Overall mean abundance is higher on inshore reefs but relative abundance across the shelf varies among sectors • Abundance on outer shelf reefs varies among sectors
Amblyglyphidodon	• Relative abundance across the shelf varies among 4 northern sectors • Mean abundance in the Swains is higher than the overall mean for 4 northern sectors • Overall mean abundance is highest on mid-shelf reefs but relative abundance across the shelf varies among sectors • Abundance on outer shelf reefs varies among sectors
Amphiprion	• Relative abundance across the shelf differs in the Swains compared with 4 northern sectors • Overall mean abundance varies among 4 northern sectors • Mean abundance in the Swains is higher than the overall mean for 4 northern sectors • Overall mean abundance is lowest on inshore reefs but relative abundance across the shelf varies among sectors • Abundance on outer shelf reefs varies among sectors
Chromis	• Relative abundance across the shelf varies among 4 northern sectors • Overall mean abundance is lowest on inshore reefs but relative abundance across the shelf varies among sectors • Abundance on outer shelf reefs varies among sectors
Chrysiptera	• Relative abundance across the shelf varies among 4 northern sectors • Mean abundance in the Swains is lower than the overall mean for 4 northern sectors • Overall mean abundance is highest on mid-shelf reefs but relative abundance across the shelf varies among sectors • No differences in abundance on outer shelf reefs among sectors
Dascyllus	• No clear geographic patterns in abundance
Dischistodus	• No clear differences in abundance among sectors • Abundances generally lower on inner than mid-shelf reefs • No differences in abundance on outer shelf reefs among sectors
Neoglyphidodon	• Relative abundance across the shelf varies among 4 northern sectors • Abundance on outer shelf reefs varies among sectors
Neopomacentrus	• Relative abundance across the shelf differs in the Swains compared with 4 northern sectors • Overall mean abundance varies among 4 northern sectors • Overall mean abundance decreases from inshore to outer shelf reefs but relative abundance across the shelf varies among sectors • Abundance on outer shelf reefs varies among sectors
Plectroglyphidodon	• Overall abundance varies among 4 northern sectors • Overall mean abundance increases from inshore to outer shelf reefs • Abundance on outer shelf reefs varies among sectors
Pomacentrus	• Relative abundance across the shelf varies among 4 northern sectors • Overall mean abundance in the Swains is higher than for the 4 northern sectors but relative abundance across the shelf varies among sectors • Overall mean abundance is highest inshore and lowest on outer shelf reefs but relative abundance across the shelf varies among sectors • Abundance on outer shelf reefs varies among sectors and is highest on the Capricorn/ Bunker reefs
Stegastes	• Relative abundance across the shelf varies among sectors • Abundance on outer shelf reefs varies among sectors

Table 4.7. Proportional components of variance for families and genera (expressed as percentage of the total) manifest at each scale of sampling. Values are based on the 1994-95 sampling of the complete set of reefs. For interpretation, a high value for "reef" relative to "site" indicates that mean abundances vary more among reefs than among sites within each reef, etc.

	Percentage of total Variance		
	Reef	**Site**	**Transect**
Families			
Acanthurids	65.8	9.5	24.7
Chaetodonts	23.4	9.7	66.9
Labrids	13.4	14.2	72.4
Lethrinids	5.9	5.0	89.1
Lutjanids	5.6	24.0	70.4
Pomacentrids	23.8	24.7	51.5
Scarids	21.3	22.5	56.2
Serranids	15.1	1.2	83.8
Siganids	14.6	12.6	72.8
Zanclus	13.7	0.0	86.3
Genera			
Acanthochromis	17.3	12.1	70.6
Amblyglyphidodon	37.5	13.6	49.0
Amphiprion	2.1	0.0	97.9
Chromis	36.9	14.3	48.8
Chrysiptera	43.6	8.0	48.4
Dascyllus	2.8	25.2	72.0
Dischistodus	23.8	2.1	74.2
Neoglyphidodon	33.5	16.1	50.4
Neopomacentrus	23.4	12.7	63.9
Plectroglyphidodon	28.7	16.1	55.1
Pomacentrus	42.6	17.3	40.1
Stegastes	19.1	21.0	59.9

Interpretation

Halford *et al*. (1995) gave a summary of the spatial patterns in the distribution of fish species on 33 of the Program's study reefs sampled in 1992-93. Reefs were categorised by latitude (sector) and shelf position. Survey of the full set of 49 reefs in 1994-95 allows reconsideration of these results with a more complete data set. The geographic patterns as shown by figures 4.4 - 4.9 of Halford *et al*. (1995) are similar to those in Figs 4.1 and 4.2 but there are fewer statistically significant differences (compare Tables 4.3 and 4.4 in Halford *et al*. [1995] with Tables 4.1, 4.2, 4.4 and 4.5 in this section). This presumably means that the larger numbers of sample reefs lead to greater variation in the abundance of taxa among the reefs in the cross-shelf positions in the different sectors.

Comparing these results with those of Halford *et al*. (1995), groups showing clearly different patterns in 1994-95 compared with 1992-93 include:

For families:

- Acanthuridae only showed clear variation in abundance among sectors when outer shelf reefs alone were considered.
- Chaetodontidae did not show any clear variation in abundance across the shelf or among sectors, except for lower numbers in the Capricorn/Bunkers compared with outer shelf reefs in other sectors.
- The restricted number of species from the Labridae (Appendix 3) showed little difference in abundance across the shelf and among sectors, except for lower numbers in the Capricorn Bunkers compared with outer shelf reefs in other sectors.
- Lethrinidae and Lutjanidae showed patterns of abundance similar to those in the previous study (Fig. 4.1) but fewer of the differences were statistically significant.

For Pomacentrid genera:

- The cross-shelf pattern of abundance of nine of the twelve genera varied among the 5 northern sectors (Fig 4.2, Table 4.4).

ARE THERE DISTINCT COMMUNITIES OF FISHES?

Multivariate ordinations provide a way to summarise geographic patterns in communities by considering the distributions of numerous taxa simultaneously. Here we use principal components ordinations (using presence/absence of species having more than two individuals on at least three reefs). Groups of reefs that support similar assemblages when the distributions of many species are considered simultaneously should map close together. As expected from the univariate analyses, there are indications of relatively strong cross-shelf patterns (inshore, mid- and outer shelf reefs form groups with limited overlap, Fig. 4.3) and weaker latitudinal ones (reefs from different sectors are somewhat intermingled, Fig. 4.3).

These analyses have followed the established approach of looking for cross-shelf and latitudinal patterns. Several taxa show consistent cross-shelf patterns (Figs 4.1 and 4.2), but while there are differences among sectors, few taxa show a consistent latitudinal trend that might, for instance, indicate that climatic variables drive the distribution. Cross-shelf position is also the sum of a number of factors balancing coastal and oceanic influences. Even a cursory look at a map indicates that the breadth of the continental shelf, which should be inversely related to terrestrial influence, and the integrity of the barrier of seaward reefs (that might exclude oceanic influences) do not vary in a simple fashion along the length of the GBR.

Methods

In order to refine the sector-by-shelf position categorisation so as to reflect the underlying process more closely, each sample reef was categorised subjectively according to two other characteristics (Table 4.8):

1. Exposure: a subjective three level classification relating exposure to wave energy, based on the degree that reefs are sheltered from the prevailing SE tradewinds as judged from charts.
2. Slope: four level factor relating to the estimated average angle of the reef slope.

When the same ordinations are re-plotted with the reefs categorised by exposure (Fig. 4.4), the separation of exposure categories is more distinct than the separation by shelf position (Fig. 4.3). Categorisation by slope did not produce clear groupings.

Factor analysis was used to see if the abundances of fish species on reefs could be used to identify general factors that contribute to fish distribution. Each species was then tested to see if presence or absence on a reef was related to the exposure scale (contingency table, exact probabilities found by monte carlo simulation). When species showed non-random distributions among exposure categories, the corresponding loadings of that species on the first three factors were examined.

Results

In this way, three assemblages of species were identified: those that occur in sheltered conditions (preponderance on sheltered reefs and large positive loading on Factor 1), those that occur in exposed conditions (preponderance on exposed reefs and large negative loading on Factor 1) and the rest showing no preference (Tables 4.9 and 4.10).

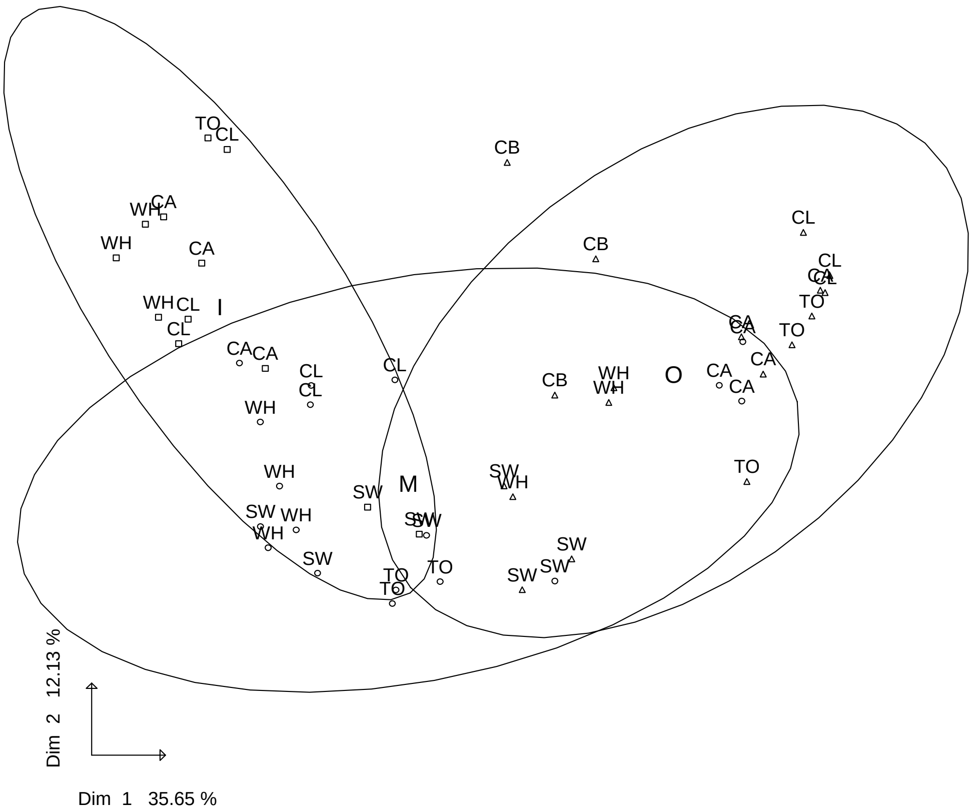


Figure 4.3. Principal component plots showing grouping of reefs by shelf position. Plots are based on abundances of all species present as more than two individuals on three or more reefs in 1994-95. All data column centred to account for differences in abundance among species and transformed $\log_{10}(x+1)$. Ellipses are “confidence ellipses” which will on average include 80% of points in a group if the data are multivariate normal. Sector codes: CL = Cooktown-Lizard, CA =Cairns, TO = Townsville, WH = Whitsundays, SW = Swains and CB = Capricorn-Bunkers.

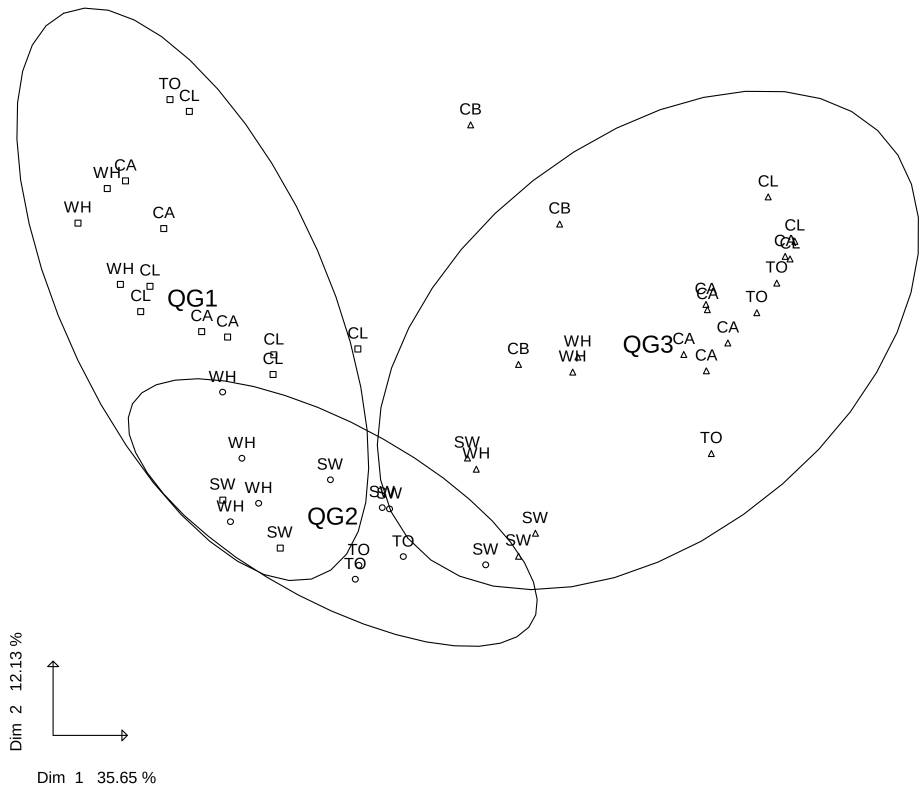


Figure 4.4. Principal component plots showing groupings by exposure. Plots are based on abundances of all species present as more than two individuals on three or more reefs in 1994-95. All data column centred to account for differences in abundance among species and transformed $\log_{10}(x+1)$. Ellipses are "confidence ellipses" which will on average include 80% of points in a group if the data are multivariate normal. Sector codes: CL = Cooktown-Lizard, CA =Cairns, TO = Townsville, WH = Whitsundays, SW = Swains and CB = Capricorn-Bunkers.

Table 4.8. Descriptions of categories used in refining categorisation of reefs other than by sector and shelf-position.

Category	Description
Exposure	
Low	No swell and moderate chop.
Moderate	Slight influence of swell and moderate to heavy chop
High	Exposed to full swell.
Slope	
Broken	Slope has varied structure with large areas of unconsolidated substrate.
Flat	Slope generally consolidated with a gradient < 20°.
Moderate	Generally consolidated with a gradient 21 - 60°.
Steep	Generally consolidated with a gradient > 60°.

Table 4.9. Larger species categorised by exposure regime and latitude on the basis of exact tests. Columns represent species common to each exposure regime given in column headings, [N] denotes species with a largely northern distribution.

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

Table 4.10. Pomacentrids categorised by exposure regime and latitude on the basis of exact tests. Columns represent species common to each exposure regime given in column headings, [N] denotes species with a largely northern distribution, [S] denotes species with a largely southern distribution.

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

There is also a weaker effect of latitude (Fig. 4.5) related to Factor 3. Three groups with different distributions by latitude emerge among the pomacentrids. Only three species show predominantly southern distributions, eight show northern distributions and the rest show little effect of latitude (Table 4.10). The latitudinal effect is even weaker in the larger taxa, with most of the species showing no discernible effect of latitude (Table 4.9). Although weak, this gradient is reasonably distinct in the ordinations (Fig. 4.5).

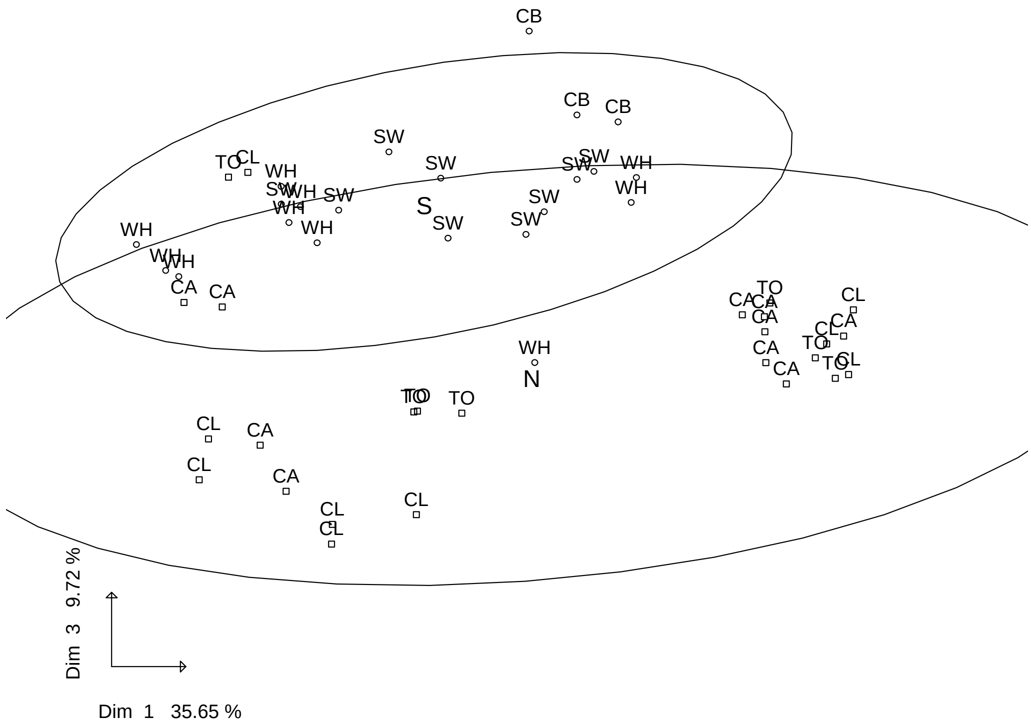


Figure 4.5. Principal component plots showing groupings by latitude. Plots are based on abundances of all species present as more than two individuals on three or more reefs in 1994-95. All data column centred to account for differences in abundance among species and transformed $\log_{10}(x+1)$. Ellipses are "confidence ellipses" which will on average include 80% of points in a group if the data are multivariate normal. Reefs in northern sectors indicated by squares, reefs in southern sectors indicated by circles. Sector codes: CL = Cooktown-Lizard, CA = Cairns, TO = Townsville, WH = Whitsundays, SW = Swains and CB = Capricorn-Bunkers.

Interpretation

The relatively clear separation of reefs when categorised by the exposure scale in Table 4.8 implies that exposure to wave energy or to its correlate, oceanic rather than coastal water bodies, is a major forcing factor for cross-shelf distributions. The identification of "communities" is not meant to imply that the assemblages of fish species interact to produce a self-perpetuating community structure. The species may all be responding independently to attributes of the benthos (which correlate with exposure), or their larvae may have restricted pelagic habitat requirements. Prevailing water quality may allow them to colonise some sites on a regular basis but reach others only rarely (Williams 1991).

WHAT ARE THE GEOGRAPHIC PATTERNS IN THE DIVERSITY OF FISHES?

Biodiversity is an important conservation value and is one of the simplest characteristics of assemblages that might indicate changes in ecosystem function in response to environmental stress. Numerous measures of biodiversity have been proposed, but species richness (number of species present) is simple to interpret and is widely used.

Analyses

Because only a circumscribed list of species was counted (Appendix 3), total species richness based on these data is likely to be a biased estimate of the true figure. Only when most of the species in a taxon that occur on the GBR were on the circumscribed list were those taxa included. These included pomacentrids, scarids, siganids and the genera *Acanthurus* and *Chaetodon.*

The numbers of species from these taxa present on each reef in the 1994-95 season were recorded. Two analyses of variance similar to those used in the previous section were used to examine whether there is systematic geographic variation in mean numbers of species of each group present on each reef that can be attributed to latitude or cross-shelf position. Once again each analysis consisted of a series of contrasts similar to those used before, though the analyses of numbers of species per reef had fewer degrees of freedom than analyses based on abundances at sites.

Results

All the selected taxa showed uneven geographical patterns of species richness (Fig. 4.6, Tables 4.11 and 4.12). These are summarised in Table 4.13. Variable numbers of species of the diverse pomacentrids were present in cross-shelf positions in different sectors. All other groups showed relatively consistent cross-shelf patterns, but the patterns varied among groups. *Acanthurus* spp., *Chaetodon* spp. and scarids were more diverse on mid-shelf and outer shelf reefs while the siganids were more diverse on inshore and mid-shelf reefs. The numbers of the *Acanthurus* spp. and *Chaetodon* spp. varied among the five northern sectors. The pomacentrids and *Chaetodon* spp. were less diverse in the Capricorn/Bunker group compared with other outer shelf reefs. There were fewer species belonging to two taxa, the genera *Acanthurus* and *Chaetodon*, on the Capricorn/ Bunker reefs than on outer shelf reefs in other sectors.

Interpretation

It is not surprising that different taxa show different patterns of diversity because the groups have substantially different ecologies. Even among the siganids, scarids and *Acanthurus* spp. that are largely herbivorous, Russ (1984) has previously described differences in abundances across the GBR lagoon near Townsville.

The Capricorn/Bunker reefs experienced a dramatic decline in hard coral cover in 1989 (Miller *et al*. 1991, Doherty *et al*. 1997) and still have low average values (Fig. 5.1, Table 5.3). Large scale increases in dead coral do not generally lead to an increase in abundance of herbivorous fishes associated with the turf algae growing on dead coral skeletons (Williams 1986) and this is true for the abundance of acanthurids and the richness of *Acanthurus* spp. in this case. Butterfly fishes have been found to respond to a decline in living coral cover (Williams 1986). There were lower densities of chaetodontids in the Capricorn/Bunker reefs (Fig. 4.2) and the number of species in the genus *Chaetodon* was also lower (Fig. 4.6). Not only were there fewer species but there was a smaller proportion of specialist coralivores (Table 4.14), though the difference was not statistically significant. The most appropriate comparison is with the assemblages on outer shelf reefs of the Swains, the next most southerly sector. Only one species, the generalist *Chaetodon lunula*, was recorded in the Capricorn/Bunkers but not in the Swains, while eight species that were present in the Swains, including six specialist coralivores, were not recorded on the Capricorn/Bunker reefs. This difference in the chaetodontids is possibly related to the major decline in hard coral cover.

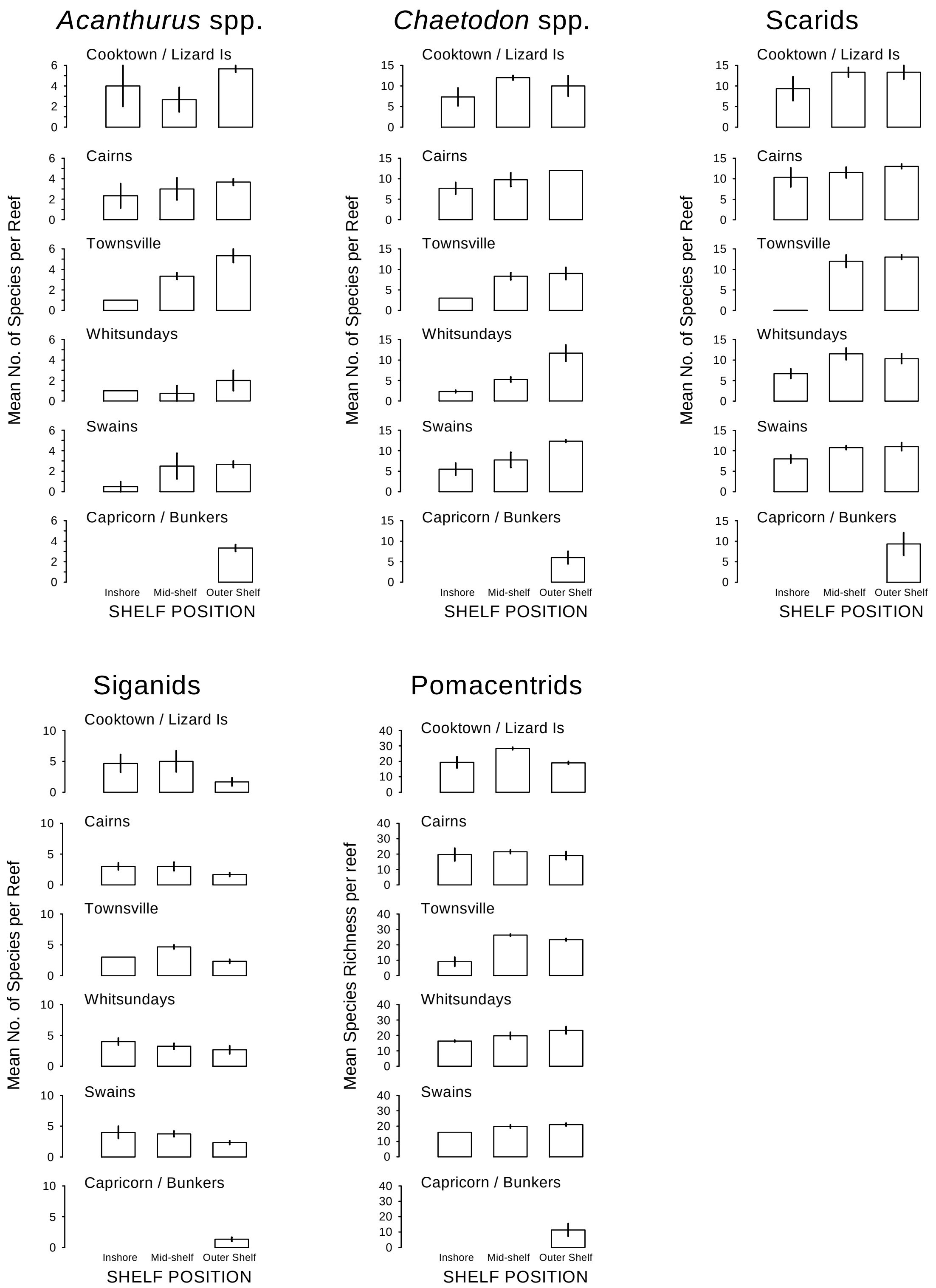


Figure 4.6. Mean species richness (number of species present) per reef in 1994-95 displayed by sector and shelf position for two genera and three families. Error bars are standard errors. Note that these figures are based on a prescribed list of species on NE outer slopes. There are no inner- or mid-shelf sample reefs in the Capricorn/Bunker sector.

Table 4.11. Results of analyses of variance and contrasts on species richness of selected families of fishes to examine whether there is systematic geographic variation in species richness within the groups that can be attributed to latitude or cross-shelf position. Data from all sectors except the Capricorn Bunker sector (omitted because there are only outer shelf reefs) were the number of species in each family recorded from each reef. Note that Pomacentrids were counted on narrower transects than other families (see methods). "No" indicates no evidence of consistent pattern (p>0.1), "Yes" indicates evidence of consistent pattern (p< 0.05). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation.

Questions	*Acanthurus* spp	*Chaetodon* spp.	Pomacentrids	Scarids
Does the pattern of species richness across the shelf vary among the 4 northern sectors? *(Sector by cross-shelf interaction in 4 northern sectors)*	No	No	Yes	No
Does the pattern of species richness across the shelf in the Swains differ from that in the 4 northern sectors? *(Sector by cross-shelf interaction contrast, Swains vs 4 northern sectors)*	No	No	(No)	No
Does species richness vary among the 4 northern sectors (averaged across the shelf)? *(Sector effect, 4 northern sectors)*	No	No	(Yes)	No
Does species richness vary between the Swains and the 4 northern sectors (averaged across the shelf)? *(Sector effect, contrast Swains vs 4 northern sectors)*	Yes	Yes	(No)	No
Does species richness vary between inshore and midshelf reefs (averaged over the 4 northern sectors and Swains)? *(Cross-shelf effect 1, 5 northern sectors)*	No	Yes	(No)	Yes
Does species richness vary between outer shelf reefs and other reefs (averaged over the 4 northern sectors and Swains)?*(Cross-shelf effect 2, 5 northern sectors)*	Yes	(Yes)	(No)	(Yes)

Table 4.12. Results of analyses of variance and contrasts on species richness of five taxa examining whether there is systematic geographic variation in species richness of the groups that can be attributed to latitude. "No" indicates no evidence of consistent pattern (p>0.1), "Yes" indicates evidence of consistent pattern (p< 0.05). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation.

Questions	*Acanthurus* spp	*Chaetodon* spp.	Pomacentrids	Scarids
Does the number of species on outer shelf reefs vary among the 5 northern sectors?	Yes	No	No	No
Does the number of species on outer shelf reefs differ between the Capricorn/ Bunkers and the other sectors. *(Contrast Capricorn/ Bunkers vs 5 northern sectors)*	(No)	Yes	Yes	No

Table 4.13. Summary of statistically significant geographic patterns in species richness for five taxa.

***Acanthurus* spp.**	Average species richness lower in the Swains than the overall mean for the 4 northern sectors Species richness increases from inshore to outer shelf reefs Species richness on outer reefs varies among sectors
***Chaetodon* spp.**	Average species richness lower in the Swains than the overall mean for the 4 northern sectors Species richness increases offshore Species richness is lower on Capricorn/Bunker reefs than the average of offshore reefs in other sectors
Pomacentrids	Cross-shelf pattern of species richness varies among sectors Overall mean species richness varies among sectors Species richness is higher on Capricorn/Bunker reefs than the average of offshore reefs in other sectors
Scarids	Species richness increases offshore No differences in abundance on outer reefs among sectors
Siganids	Species richness decreases offshore No differences in abundance on outer reefs among sectors

Table 4.14. Proportion of Chaetodon spp. that are specialised hard coral feeders recorded on reefs of the Capricorn/Bunker group compared with those on the outer reefs of the Swains. Data on feeding categories from Anderson *et al*. (1981) and Myers (1991). Fisher's exact test (species with unknown feeding habits excluded) p=0.176 (one tailed).

Feeding category	Capricorn/Bunkers	Outer Swains
Hard coral feeders	2	8
More generalised feeders	7	8
Unknown	2	2

WHAT CHANGES OCCURRED IN FISH ASSEMBLAGES IN THE THREE YEARS OF SAMPLING?

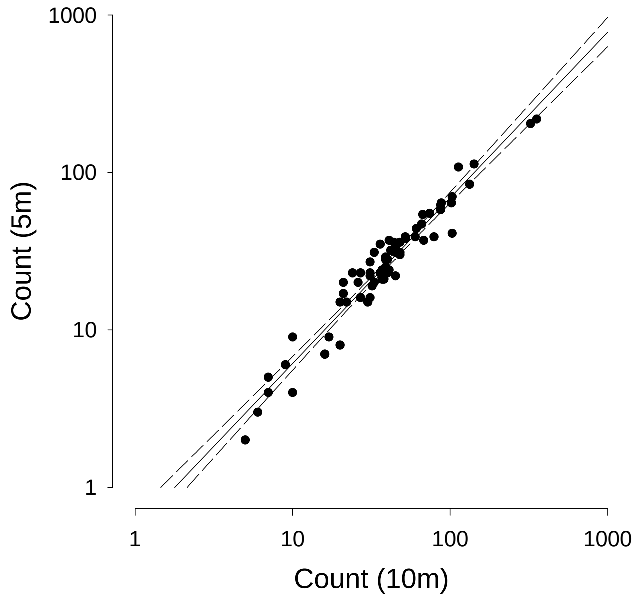
A prime function of long term monitoring is to assess change in populations. This section looks at which taxa changed significantly on 14 study reefs that were visited in all of the first three years. Larger species have once again been grouped into families and pomacentrids have been grouped into genera: this is necessary to increase the power of the analyses but complicates interpretation. Groups that show changes require further examination to see which species are responsible.
Before counts from the third survey year can be compared with those from preceding years, when the original wider transects were used, a correction factor was needed. In addition, any analysis of changes should be followed by estimates of how much change could have been detected.

Estimation of correction factors for revised transect widths

In order to estimate correction factors to allow comparison of data from the initial broad transects with those from the narrower ones, a special set of counts was made on LTMP sampling sites at three reefs near Townsville. These reefs varied in shelf position (Rib and Davies Reefs are mid-shelf reefs, Myrmidon is an outer shelf reef) and live coral cover (27-60%). Sampling was carefully designed to make simultaneous counts using the different transect widths and to minimise inter-observer bias.

For a correction factor to have generality, the relationship between abundance estimates from 5 m and 10 m, and 1 m and 2 m wide transects should not be influenced by density of fish and so should be linear over a broad range of densities. Secondly, this linear relationship should not vary significantly among reefs (which would indicate variation with habitat type) or among fish taxa (reflecting general differences in behaviour). Data were pooled to family level for larger mobile fishes and to genus level for pomacentrid species so as to obtain adequate sample sizes. A correction factor is only relevant if density estimates for taxa differ between the two transect widths. Four families (Acanthuridae, Chaetodontidae, Labridae and Scaridae) and five pomacentrid genera (*Acanthochromis*, *Amblyglyphidodon*, *Neoglyphidodon*, *Plectroglyphidodon* and *Pomacentrus*) showed such differences and were used in the calculation for the 5 m vs 10 m, and 1 m vs 2 m comparisons respectively. Figures 4.7A and 4.7B show the linear relationships based on the subsets of families and genera. These gave the correction factors in Table 4.15 which were applied to these taxa in the analyses which follow.

A



B

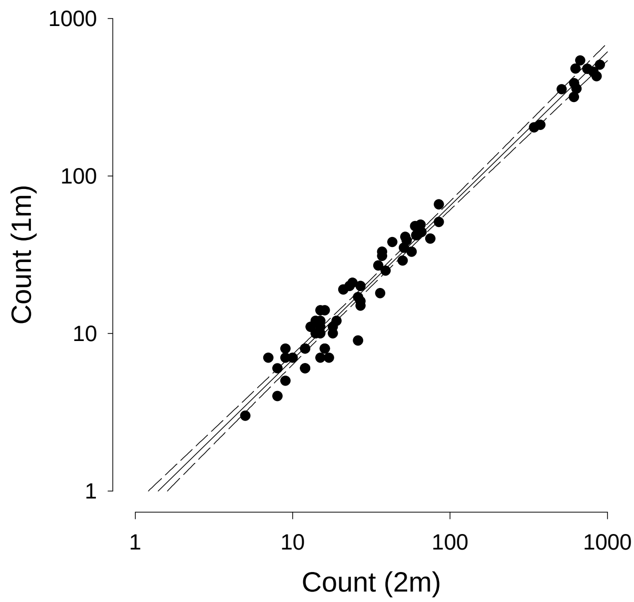


Figure 4.7. Relationship (A) between counts of the five most abundant families of larger, non-pomacentrid fish made simultaneously on transects 5 and 10 m wide ($r^2 = 0.946$)and (B) between simultaneous counts of the eight most abundant genera of pomacentrid fish on transects 1 and 2 m wide ($r^2 = 0.961$). Dashed lines are 95% confidence limits.

Table 4.15. Correction factors and 95% confidence intervals from simultaneous counts on transects of different widths. These values have been retransformed from logarithmic to linear scale.

Transect widths	Correction Factor	95% Confidence interval
5 vs 10 m	0.662	0.628 - 0.697
1 vs 2 m	0.661	0.627 - 0.698

Analyses

Contrasts were used to test for differences in abundance between years and to look for linear trends in abundance of each of the selected taxa on each reef. The Type I error rate was set at 0.1 for these contrasts following the Precautionary Principle. Taxa that occurred at average densities of less than 3 individuals per site on a reef were considered too rare to test.

As a measure of the power of the analysis, "detectable differences" were estimated for each taxon, giving an estimate of the population changes that would be statistically significant. This involved iteration, incrementing the change in numbers over the two years and testing for significance using the standard error for the linear contrast and the appropriate degrees of freedom in the equivalent of a t-test.

Results

Ninety-two taxon-reef combinations were common enough to test and 20 showed significant ($\alpha < 0.1$) linear trends; that is more than twice the number that would be expected with an error rate of 0.1. Ten of these increased in density and 10 declined. Mean counts for taxa showing linear trends over the three years are plotted in Fig. 4.8 and tests are summarised in Table 4.16. Some of these taxa also showed quadratic trends and others showed only quadratic but not linear trends. With three data points, quadratic trends alone do not indicate any easily interpretable population process so are not considered further.

Special attention is given to taxa showing decreasing trends in the period as this may indicate a need for management intervention. Since most taxa in these analyses were represented by more than one species, the changes in numbers of the constituent species were examined. Species vary in abundance and the absolute and proportional changes differed. The most likely pattern would involve some individual species increasing and others decreasing, with the overall trend for the taxon being driven by changes in one or two abundant species. In fact there was remarkable consistency in the direction of changes: when a taxon showed an overall decline, most of the constituent species declined (Tables 4.17 and 4.18). The same was true on three reefs (Table 4.16) where the speciose pomacentrids showed an increase (Table 4.18).

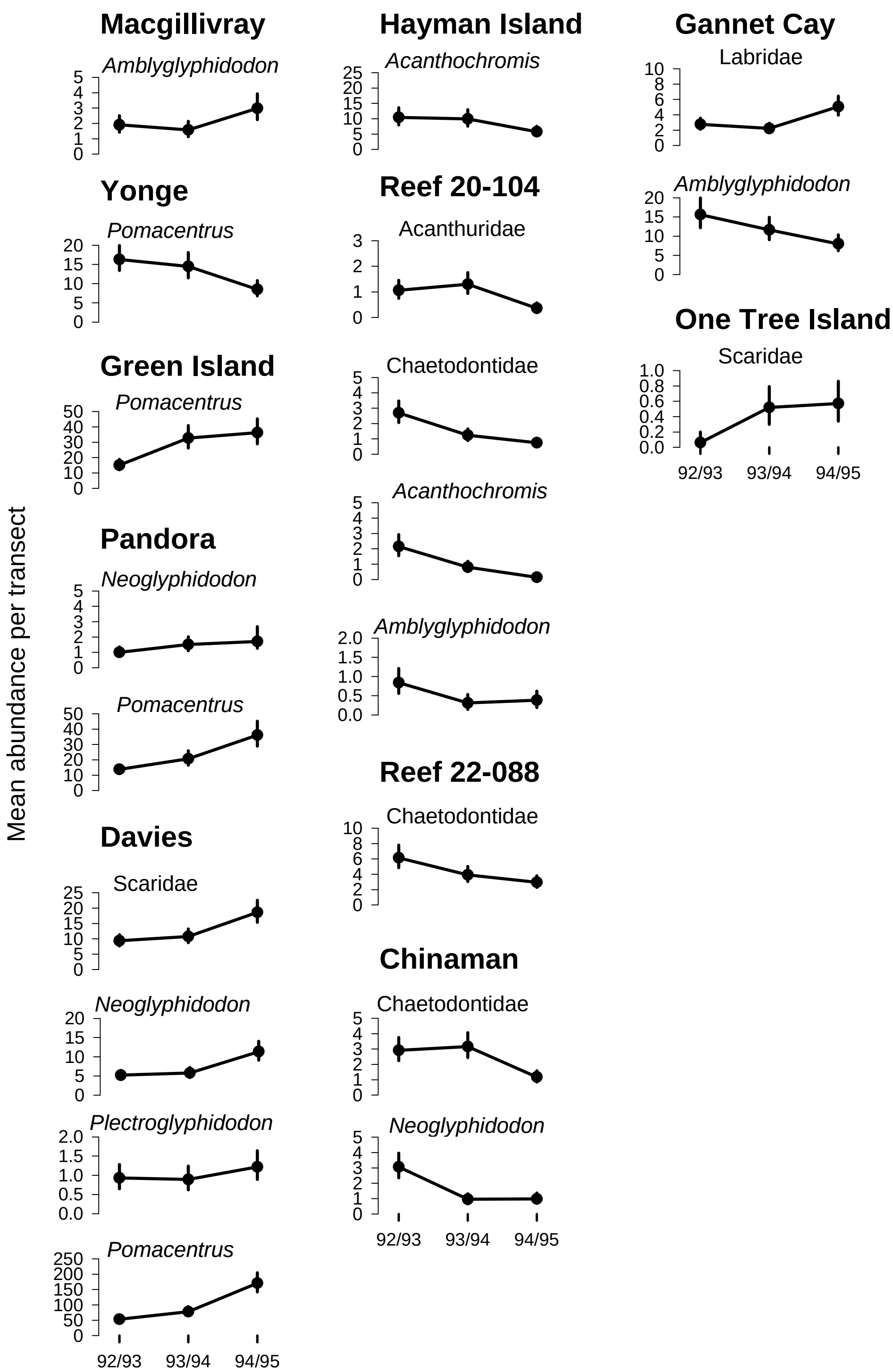


Figure 4.8. Abundances of fish taxa from 14 reefs surveyed in all of the first three years that showed significant linear trends. Values are mean abundances per transect with standard errors.

Table 4.16. Schematic indicating taxa that showed significant changes in abundance on 14 reefs surveyed in each of the first three years. Direction of the arrows indicates increases (⇧) or declines (⇩), number of arrows indicates significance level: ⇧ = 0.10 > p > 0.05, ⇧⇧ = 0.05 > p >0.01, ⇧⇧⇧ = p < 0.01. Shaded areas indicate reefs where taxa were too rare to test.

	Sector	Cooktown/ Lizard		Cairns			Townsville			Whitsundays		Swains			Capricorn / Bunkers
	Shelf	Mid-shelf	Outer	Inner	Mid-shelf	Mid-shelf	Inner	Mid-shelf	Outer	Inner	Mid-shelf	Inner	Mid-shelf	Mid-shelf	Outer
	Reef	Macgillivray	Yonge	Green Is.	Hastings	Michaelmas	Pandora	Davies	Myrmidon	Hayman	20104	22088	Chinaman	Gannet Cay	One Tree Is.
Families	Acanthurids										⇩⇩⇩				
	Chaetodontids										⇩⇩⇩	⇩⇩	⇩⇩⇩		
	Labrids													⇧⇧	
	Scarids							⇧							⇧⇧
Genera	*Acanthochromis*									⇩	⇩⇩⇩				
	Amblyglyphidodon	⇧									⇩⇩			⇩⇩	
	Neoglyphidodon						⇧⇧	⇧⇧⇧					⇩⇩⇩		
	Plectroglyphidodon							⇧⇧							
	Pomacentrus		⇩⇩⇩	⇧⇧⇧			⇧⇧⇧	⇧⇧⇧							

Table 4.17. Absolute changes in abundance of individual species belonging to families that showed significant overall declines in abundance on reefs surveyed in all three years. Negative values indicate declines in abundance. Dashes indicate that the species did not occur.

SPECIES	20104	22088	Chinaman
Acanthurus lineatus	0	-	-
Ctenochaetus (grouped)	-5	-	-
Naso tuberosus	-1	-	-
Naso unicornis	-12	-	-
Chaetodon aureofasciatus	-2	-24	-
Chaetodon auriga	-4	0	0
Chaetodon baronessa	-	-7	-
Chaetodon ephippium	-2	0	-
Chaetodon flavirostris	-2	-4	-7
Chaetodon kleinii	-	-	0
Chaetodon lineolatus	-2	-1	1
Chaetodon melannotus	-	-	-2
Chaetodon ornatissimus	-	-2	2
Chaetodon pelewensis	-	-2	-7
Chaetodon plebeius	-	-8	-6
Chaetodon rainfordi	-19	-22	-2
Chaetodon speculum	-	2	-
Chaetodon trifascialis	-	-2	-1
Chaetodon trifasciatus	1	-8	-1
Chaetodon ulietensis	-	-	-2
Chaetodon unimaculatus	-	-	-1
Chaetodon vagabundus	-	0	-1
Chelmon rostratus	-10	0	-
Forcipiger flavissimus	-	5	-2
Forcipiger longirostrus	-	-2	-4

Table 14.18. Absolute changes in abundance of individual species belonging to pomacentrid genera that showed significant overall changes in abundance on reefs surveyed in all three years. Negative values indicate declines in abundance. Dashes indicate that the species did not occur.

	Declining					*Increasing*		
SPECIES	Yonge	Hayman	20104	Chinaman	Gannet	Green	Pandora	Davies
Acanthochromis polyacanthus	-	-107	-55	-	-	-	-	-
Amblyglyphidodon curacao	-	-	-42	-	-226	-	-	-
Amblyglyphidodon leucogaster	-	-	-2	-	0	-	-	-
Neoglyphidodon melas	-	-	-	-52	-	-	-	-
Neoglyphidodon nigroris	-	-	-	0	-	-	-	-
Neoglyphidodon polyacanthus	-	-	-	-1	-	-	-	-
Pomacentrus amboinensis	-	-	-	-	-	-	2	26
Pomacentrus bankanensis	-73	-	-	-	-	11	-	-1
Pomacentrus brachialis	-	-	-	-	-	104	19	2
Pomacentrus chrysurus	-	-	-	-	-	1	-	-
Pomacentrus coelestis	-44	-	-	-	-	4	-	2
Pomacentrus grammnorhyncus	-	-	-	-	-	2	-	-2
Pomacentrus lepidogenys	-87	-	-	-	-	40	-	635
Pomacentrus moluccensis	-	-	-	-	-	277	287	432
Pomacentrus nagasakiensis	-	-	-	-	-	5	-	1
Pomacentrus philippinus	-16	-	-	-	-	-	-	14
Pomacentrus taeniometapon	-	-	-	-	-	51	133	-
Pomacentrus vaiuli	-	-	-	-	-	-	-	1
Pomacentrus wardi	-	-	-	-	-	12	94	43

Table 4.19. Estimated annual changes in abundance of fishes required to give a significant linear trend based on three annual surveys of 14 reefs, with α = 0.05 and β = 0.2. Standard errors based on log transformed data.

	Detectable annual proportional changes	
TAXON	Decrease	Increase
Families		
Acanthurids	0.29	0.40
Chaetodontids	0.27	0.36
Labrids	0.29	0.41
Lethrinids	0.31	0.46
Lutjanids	0.29	0.41
Pomacentrids	0.26	0.34
Scarids	0.31	0.44
Serranids		
Siganids	0.32	0.47
Zanclids	0.19	0.24
Genera		
Acanthochromis	0.30	0.43
Amblyglyphidodon	0.25	0.34
Amphiprion[1]	--	--
Chromis	0.35	0.53
Chrysiptera	0.29	0.40
Dascyllus[1]	--	--
Dischistodus[1]	--	--
Neoglyphidodon	0.23	0.30
Neopomacentrus	0.52	1.07
Plectroglyphidodon	0.18	0.22
Pomacentrus	0.26	0.35
Stegastes	0.21	0.26

[1] Detection requires > eightfold change

Three reefs (Table 4.16) showed declines in the numbers of chaetodonts which are salient fishes, many of which feed on living hard coral. Only one of these reefs, 22-088, showed a decline in hard coral cover (Fig. 5.6) perhaps due to the active COTS outbreak (see Swains Sector in Section 2).

The 14 reefs for which three annual counts have been made are widely dispersed and a formal test for geographic patterns of change was not possible though this will be a focus in analyses of subsequent years' data. Few patterns emerge from Table 4.16 except that on Reef 20-104, all four taxa showing significant trends out of seven taxa that could be tested showed declines, while four out of nine increased on Davies Reef.

Estimates of the power of the monitoring program are given in Table 4.19. Among the families, detectable differences were smallest for *Zanclus* and chaetodonts as well as the smaller pomacentrids. They were greatest for siganids, scarids and lethrinids, all of which tend to occur in groups. Among the pomacentrid genera, detectable differences were smallest for territorial herbivores (*Stegastes* and *Plectroglyphidodon*) and greatest for schooling planktivores (*Neopomacentrus* and *Chromis*).

Interpretation

Many reef fishes are quite long lived and recruitment levels vary markedly from year to year, so populations of reef fishes are frequently dominated by distinct cohorts from irregular years of high recruitment (eg Doherty and Fowler 1994). In such systems, a pattern of gradual decline in abundance of species from year to year may occur during intervals between recruitment pulses. Information on geographic variation in recruitment is confined to a very few species but there are examples showing consistent latitudinal differences over time and consistent differences among reefs for one species while other species show entirely different spatial and temporal patterns (Doherty 1991). Since most of the taxa in this analysis include several species, consistent changes across all species seem unlikely to occur by chance. In summary, gradual declines and rapid increases in numbers of individual species are a feature of reef fish population dynamics, but synchronised large declines in a number of species are likely to be due to stresses.

Reef 20-104 showed the most consistent declines among the 14 reefs, but the locations of the sites and transects were also changed prior to the second year's sampling. The changes involved abandonment of the initial Site 1, renaming the initial Site 2 as Site 1 and the initial Site 3 as Site 2 and selecting a new site as Site 3. Name changes not withstanding, the transects in two of the sites were sampled in all three years and these also showed a declining trend. This suggests that the apparent decline was not due simply to the relocation of sites.

There are two alternative explanations for the consistent trends in the species that are grouped into taxa: either they were all affected by environmental changes or there is a sampling artefact because an observer showed positive or negative bias towards all members of a taxon in one annual visit. Stringent training of observers and annual cross-calibration exercises are intended to minimise the risk of such bias. A consistent trend over several years would not arise from observer bias without an underlying population trend. Counts from the reefs showing trends will be closely examined in future surveys.

DISCUSSION

Few fish families showed distinct distribution patterns across the continental shelf or with latitude. This does not mean that fish assemblages are substantially the same all over the GBR because the net distribution of families is the result of the distributions of the constituent species, which are unlikely to be exactly the same. The multivariate biplots (Figs 4.3 - 4.5) that are based on individual species' distributions show evidence of cross-shelf and some latitudinal patterns.

The number of families that showed clear patterns was less than in a previous analysis based on fewer sample reefs (Halford *et al*. 1995). This is presumably because adding reefs within the sector-shelf combinations adds habitat variability and hence variability in fish assemblages as well. Previous studies that have emphasised cross-shelf patterns have been based mainly on transects within one sector; the broader picture appears to be more complex. Incorporation of an index of exposure clarified the pattern based on ordination of fish assemblages from all sample reefs. This crude index may correlate with a number of factors that may cause the patterns of fish distribution. Smaller site-attached species may correlate with the benthic assemblages which respond to wave energy.

The interpretation of linear trends in fish assemblages is restricted by the limited number of reefs for which there are data. An additional complication is the use of a correction factor which can only be used with some species and gives estimated values. These problems will decline as the time series extends. The observation that the majority of species in families or genera seem to vary together requires investigation with a larger data set.

5. Corals and Sessile Benthos

Hugh Sweatman, Rachelle Ninio, Kate Osborne and Dan Ryan

INTRODUCTION

Benthic organisms such as scleractinians and coralline algae build the framework of reefs. They provide micro-habitats for different life stages of many other reef organisms and corals in particular are important to the aesthetic appeal of reefs to tourists. The status of benthic organisms is directly related to the economic and conservation value of reefs. This Section presents the results from surveys of the benthic communities from the initial 1992-93 season to the 1994-95 season. A previous status report (Christie *et al.* 1995) described geographic variation in benthic assemblages using a subset of the full sampling design: 34 reefs that were surveyed during the first year of the AIMS Long-term Monitoring Program. A survey of the full set of reefs within one year was attempted for the first time in the third year of the project. In this Section, the spatial patterns for a more extensive set of 48 reefs will be described and compared with those described previously.

A primary objective of the Long-term Monitoring Program is to detect changes in reef assemblages through time. Although 48 reefs were not surveyed in a single year until 1994-95, a subset of 14 reefs was surveyed in all three years. Patterns of change are examined in these reefs. This report focuses on change in hard coral cover for two reasons. First, hard corals form an important part of the structure of coral reefs and hard coral cover is often taken as an indicator of overall reef status since it indicates potential for reef growth. Second, hard corals are a "benthic group" that can be recognised with confidence in video transects. In order to gain a more general view, trends in the entire benthic community are also examined.

METHODS

Study sites

The sampling design has been described in Section 1. The benthos was surveyed on the same areas as were fishes (Section 4). Thirty-three reefs were sampled in 1992-93, 32 reefs in 1993-94 and 48 were sampled in 1994-95 (Appendix 2). These were visited between September and May in each survey year. At each sample reef there are three sites, each consisting of a series of five 50 m transects. These were haphazardly located in the first instance, but then permanently marked. For analysis of geographic patterns, mean cover estimates were based on 250 m of transects, giving estimates of cover from three sites on each reef.

Sampling Techniques

A 25 cm wide swathe along each transect was recorded using a Hi-8 video camera held 25-30 cm above the substrate. Percentage cover of corals and other benthic categories were estimated using a point sampling technique, in which approximately 150 systematically dispersed points are sampled per video transect. Details of the video survey and sampling techniques can be found in Christie *et al*. (1996). Corals were identified to the greatest taxonomic detail achievable. For the purposes of analysis here, all benthic records were subsequently assigned to two different classifications: "benthic groups" and "benthic life-forms" as shown in Table 5.1. Under "benthic groups," sample points are categorised into very broad classes of benthic organisms. The "benthic life-forms" scheme is an extension of the "benthic groups" scheme in that the category "hard corals" is subdivided into a number of distinct growth forms.

Table 5.1. Categories of benthic organisms used in this section: benthic groups and benthic life-forms

BENTHIC GROUP	BENTHIC LIFE-FORM
Abiotic	
Soft coral	Soft coral
Hard coral	Branching Encrusting Foliose Massive Sub-massive Solitary mushroom Branching *Acropora* spp. Tabulate *Acropora* spp. Encrusting *Acropora* spp. Corymbose *Acropora* spp.
Macro-algae	Macro-algae *Halimeda* spp.
Turf algae	Turf algae
Coralline algae	Coralline algae
Sponge	Sponge
Other	*Millepora* spp.
Indeterminate	

Two general questions were addressed:

- What are the geographic patterns in cover of benthic organisms on the GBR?
- What changes have occurred in benthic assemblages in the duration of the study?

WHAT ARE THE GEOGRAPHIC PATTERNS IN COVER OF BENTHIC ORGANISMS ON THE GBR?

Done (1982) has described variation in coral communities in the central section of the GBR from inshore reefs to the Flinders Reefs in the Coral Sea. Using abundance categories for species, inshore, mid-shelf and outer reefs supported different assemblages of hard corals , both on their fronts and flanks. Christie *et al*. (1995) described benthic assemblages in terms of benthic groups both across the shelf and latitudinally on a subset of the Long-term Monitoring Program's sample reefs and found that patterns varied among the groups. These descriptions are extended here to include the full sampling design and also by subdividing the hard corals into life-forms.

Analyses

As in the case of fish assemblages (Section 4) two analyses of variance, each consisting of a series of contrasts, were used to examine whether there is systematic geographic variation in abundance of the benthic groups that can be attributed to latitude or cross-shelf position. The geographic distribution of reefs along the GBR complicates such analyses: in the four northern sectors there are generally identifiable inner-, mid- and outer shelf reefs, subject to progressively less coastal and more oceanic influences respectively. If terrestrial influences are important then Swains sector reefs can be expected to show a different pattern, for while the oceanic influence decreases from outer Swain reefs to inner ones, coastal influences will be much less on inner Swain reefs than for instance, inner reefs of the Whitsunday sector. Reefs of the Swains sector were distinguished from the rest for this reason. Finally, all the reefs in the Capricorn/Bunker sector are outer shelf reefs, leading to a separate analysis involving only outer shelf reefs from each sector. Percentage cover values for sites within reefs surveyed in the 1994-95 season were transformed using the empirical logit transformation (McCullagh and Nelder 1989) prior to analysis.

Multivariate ordinations provide a way to summarise geographic patterns in communities by considering the cover values of numerous taxa simultaneously for each reef. Here we use principal components biplots of log transformed, column-centred percent cover values. As well as being classified by sector and shelf position, reefs were also categorised by exposure according to the same subjective scale that was used for fish assemblages in Section 4 (see Table 4.8).

Results

Hard coral and turf algae cover most of the substratum at the sites on a majority of reefs. Mean percentage cover values for benthic groups are displayed by sector and shelf position in Fig. 5.1. The results of the analyses of variance are summarised in Tables 5.2 and 5.3 and a summary of the distributional trends for benthic groups is given in Table 5.4. Though there was no clear cross-shelf pattern in total hard coral, there were differences in mean percentage cover among sectors, with the highest cover in the Townsville sector (Fig. 5.1, Table 5.2). Turf algae accounted for more of the cover on inshore and mid-shelf reefs and there were also differences in the average cover among sectors, with highest values in the Cooktown/Lizard Is. sector (Fig. 5.1, Table 5.2). The Capricorn/Bunker reefs had significantly less hard coral and significantly more turf algal cover than other outer shelf reefs (Fig. 5.1, Table 5.3). Coralline algae were generally found on outer shelf reefs and were not recorded on inshore reefs other than the inner Swain reefs. Soft corals tended to be most common on outer shelf reefs and least common on mid-shelf reefs. Among outer shelf reefs their occurrence was lowest on the Capricorn/Bunker reefs. Abiotic substrata, principally sand and rubble, were more common on inshore reefs. Other small components of the benthos were macro-algae that showed no clear regional patterns, but varied among sites in regions where they did occur, and sponges that covered a very small proportion of the substratum except on outer reefs of the Whitsunday sector (Fig. 5.1). The category "other" includes a diverse range of organisms: *Millepora*, spp., tunicates and hydroids. Summary data for percent cover of benthic groups on each reef in each survey are given in Appendix 5.

Components of variance give a measure of the variability of cover of benthic groups at various spatial scales (Table 5.5). This indicates how sampling effort should be allocated. Most benthic groups showed greater variation in cover among reefs than among sites within a reef or transects within a site on a reef. No benthic groups showed greatest variation among sites within reefs (max. 26.6%). There was most variation among transects in four benthic groups: abiotic substrates, other categories, sponges and turf algae. Abiotic substrates and turf algae also showed significant variation among reefs (Table 5.5). Sponges are generally rare and occur in significant numbers in few locations notably the Whitsunday outer shelf reefs (Fig. 5.1). The diversity of the "other" category makes it hard to generalise. These values for proportions of variance support a sampling scheme that visits many reefs and includes more transects within sites than sites within reefs. The values are similar to those reported in Christie *et al*. (1995) from a reduced set of sample reefs.

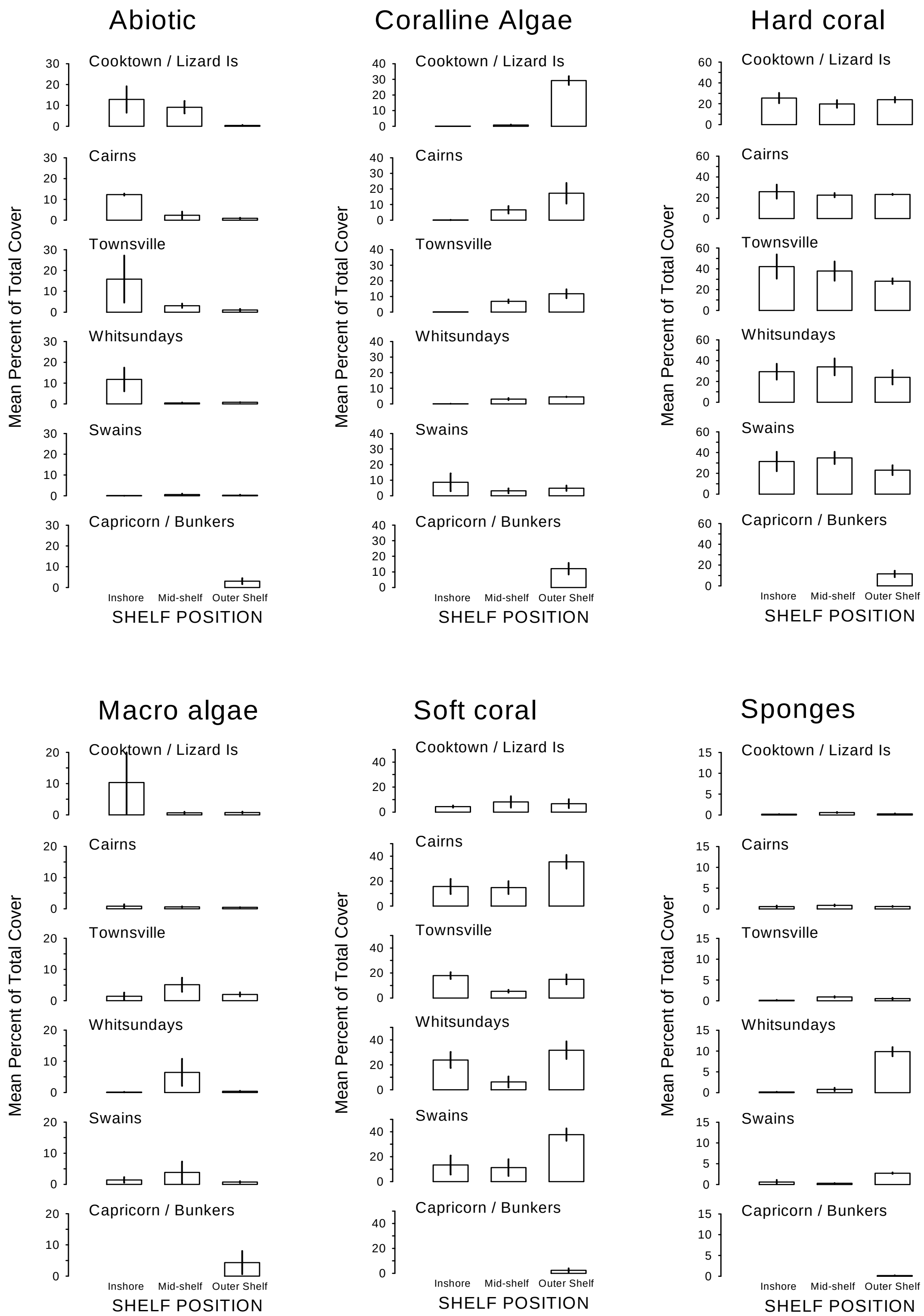


Figure 5.1. Mean percentage cover per site in 1994-95 for sessile benthic assemblages categorised into benthic groups. Error bars are S.E.s.

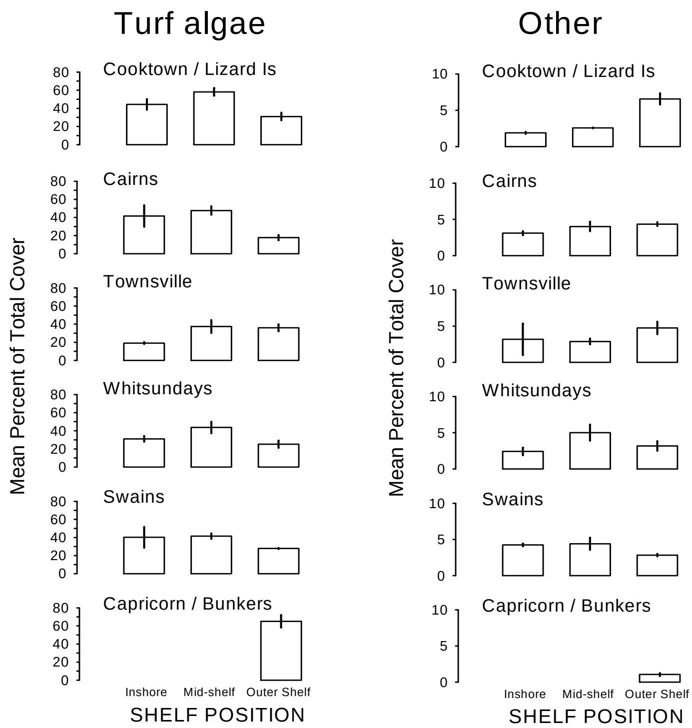


Figure 5.1 continued**.** Mean percentage cover per site in 1994-95 for sessile benthic assemblages categorised into benthic groups. Error bars are S.E.s.

Table 5.2. Results of analyses of variance and contrasts to examine systematic geographic variation in coverage of the benthic groups that can be attributed to latitude or cross-shelf position. Data from all sectors except the Capricorn Bunker sector (omitted because there are only outer shelf reefs). Data are means of percentage cover per site, giving three values per reef. Empirical logit transform was applied before analysis. "No" indicates no evidence of consistent pattern (p>0.1), "M" indicates marginal evidence of consistent pattern (p = 0.051 - 0.10), "Yes" indicates evidence of consistent pattern (p< 0.05). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation, see Section 1.

Questions	**Abiotic**	**Coralline Algae**	**Hard coral**	**Macro-algae**	**Soft coral**	**Sponges**	**Turf Algae**	**Other**
Does the pattern of coverage across the shelf vary among the 4 northern sectors? *(Sector by cross-shelf interaction in 4 northern sectors)*	No	No	No	No	No	Yes	No	M
Does the pattern of coverage across the shelf in the Swains differ from that in the 4 northern sectors? *(Interaction contrast sector by cross-shelf interaction, Swains vs 4 northern sectors)*	No	Yes	No	No	No	(M)	No	(No)
Does coverage vary among the 4 northern sectors (averaged across the shelf)? *(Sector effect, 4 northern sectors)*	No	No	Yes	No	M	(M)	Yes	(No)
Does coverage vary between the Swains and the 4 northern sectors (averaged across the shelf)? (Sector effect, contrast Swains vs 4 northern sectors)	Yes	(Yes)	(No)	No	(No)	(Yes)	(No)	(No)
Does coverage vary between inner and mid-shelf reefs (averaged over the 4 northern sectors and Swains)? *(Cross-shelf effect 1: 5 northern sectors)*	Yes	(Yes)	No	No	No	(Yes)	No	(No)
Does coverage vary between outer shelf reefs and other reefs (averaged over the 4 northern sectors and Swains)? *(Cross-shelf effect 2: 5 northern sectors)*	(Yes)	(Yes)	No	No	Yes	(Yes)	M	(No)

Table 5.3. Results of analyses of variance and contrasts to examine systematic variation in coverage of the benthic groups on outer shelf reefs that can be attributed to latitude. Data are means of percentage cover per site, giving three values per reef. Empirical logit transform was applied before analysis. "No" indicates no evidence of consistent pattern ($p>0.1$), "M" indicates marginal evidence of consistent pattern ($p = 0.051 - 0.10$), "Yes" indicates evidence of consistent pattern ($p< 0.05$). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation, see Section 1.

Questions	Abiotic	Coralline Algae	Hard coral	Macro-algae	Soft coral	Sponges	Turf Algae	Other
Does coverage vary among outer shelf reefs of the 5 northern sectors?	No	Yes	No	No	Yes	Yes	M	Yes
Does coverage on outer shelf reefs differ between the Capricorn/ Bunkers and the other sectors. *(Contrast Capricorn/Bunkers vs 5 northern sectors)*	No	(No)	Yes	No	(Yes)	(Yes)	(Yes)	(No)

Table 5.4. Summary of statistically significant geographic patterns in cover of benthic groups.

Abiotic	• Lower average cover in the Swains than in other sectors. • Cover generally higher on inshore reefs. • No differences in cover on outer shelf reefs among sectors.
Coralline algae	• Mean cover lower overall in the Swains. • Generally higher cover on outer shelf reefs in northern sectors, but high on mid-shelf reefs in the Swains. • Variation among sectors in cover on outer shelf reefs
Hard coral	• Differences in average cover among sectors, highest in Townsville sector. • Lower cover in Capricorn/Bunkers than on outer shelf reefs in other sectors.
Macro-algae	• No clear patterns of cover by sector or shelf position, but very variable
Soft corals	• Differences in average cover among sectors, being generally low in Cooktown/Lizard Is. and Townsville sectors. • Clear differences in cover on outer shelf reefs among sectors, but no trend with latitude.
Sponges	• Generally low cover except on outer shelf reefs in the Whitsundays sector.
Turf algae	• Differences in average cover among sectors, with more in the north. • Average cover tends to be lower on outer shelf reefs. • Higher cover on reefs in Capricorn/Bunkers than on outer shelf reefs in other sectors.
Other	• Pattern of cover across the shelf differs among sectors, with higher cover on outer shelf reefs in the north and mid-shelf reefs in Whitsundays and Swains. • Varies among 5 northern sectors. • Cover on outer shelf reefs in Capricorn/ Bunkers is not different from the overall mean for other sectors

Table 5.5. Proportional components of variance, expressed as percentage of total variance manifest at each scale of sampling for benthic groups based on data from 1994-95 surveys of the complete set of reefs. For interpretation, a high value for "reef" relative to "site" indicates that mean percent cover varies more among reefs than among sites within each reef, etc.

	Percentage of total variance		
	Reef	Site	Transect
Benthic Group			
Abiotic substrates	32.1	13.7	54.2
Coralline algae	52.4	3.7	43.8
Hard corals	42.9	25.2	31.9
Macro-algae	54.7	19.4	25.9
Other	13.2	16.6	70.2
Soft corals	52.7	17.6	29.7
Sponges	11.6	4.8	83.6
Turf algae	33.2	26.6	40.2

Abundance of hard corals, subdivided into life-form categories are shown in Fig. 5.2, the results of analyses are given in Tables 5.6 to 5.9 and distribution trends are summarised by life-form in Tables 5.10. The most important life-forms in terms of percentage cover were encrusting corals, foliose corals, massive and sub-massive corals and branching, corymbose and tabulate *Acropora* spp. The cover of encrusting corals was greater in the high-energy Swains sector. Foliose corals were more important on inshore reefs than on mid-shelf or outer reefs. The cover of massive corals in different shelf positions varied among sectors, being high on outer reefs near Townsville, but mid-shelf reefs in the Cooktown/ Lizard Is sector. Sub-massive corals showed no clear patterns other than having low cover on the Capricorn/ Bunker reefs. Branching *Acropora* spp. show no pattern and only exceed 5% cover in the mid-shelf Swains due to the large thickets at Gannet Cay. Corymbose *Acropora* spp. tend to be found on mid-shelf reefs. Tabulate *Acropora* spp. show different cross-shelf patterns in different sectors, being most common on mid-shelf reefs of the Townsville sector.

Biplots can show up broadscale patterns as reefs with similar communities should map close together, while the overlaid vectors indicate which groups are responsible for separations. Biplots confirm the findings of the other analyses: there is no evidence of a consistent north-south pattern in assemblages, shown by the extensive overlap of the confidence ellipses for the northern and southern sectors (Fig. 5.3). Grouping reefs by sectors showed very little pattern. When the reefs are grouped by shelf position (Fig. 5.4) there is some separation between inner and outer reefs along Dimension 1, with inner reefs having more "abiotic" substrata and outer reefs having more coralline algae. When the reefs are grouped according to exposure categories (Table 4.8), low exposure reefs appear quite distinct from those in the medium and high exposure categories (Fig 5.5), once again along Dimension 1.

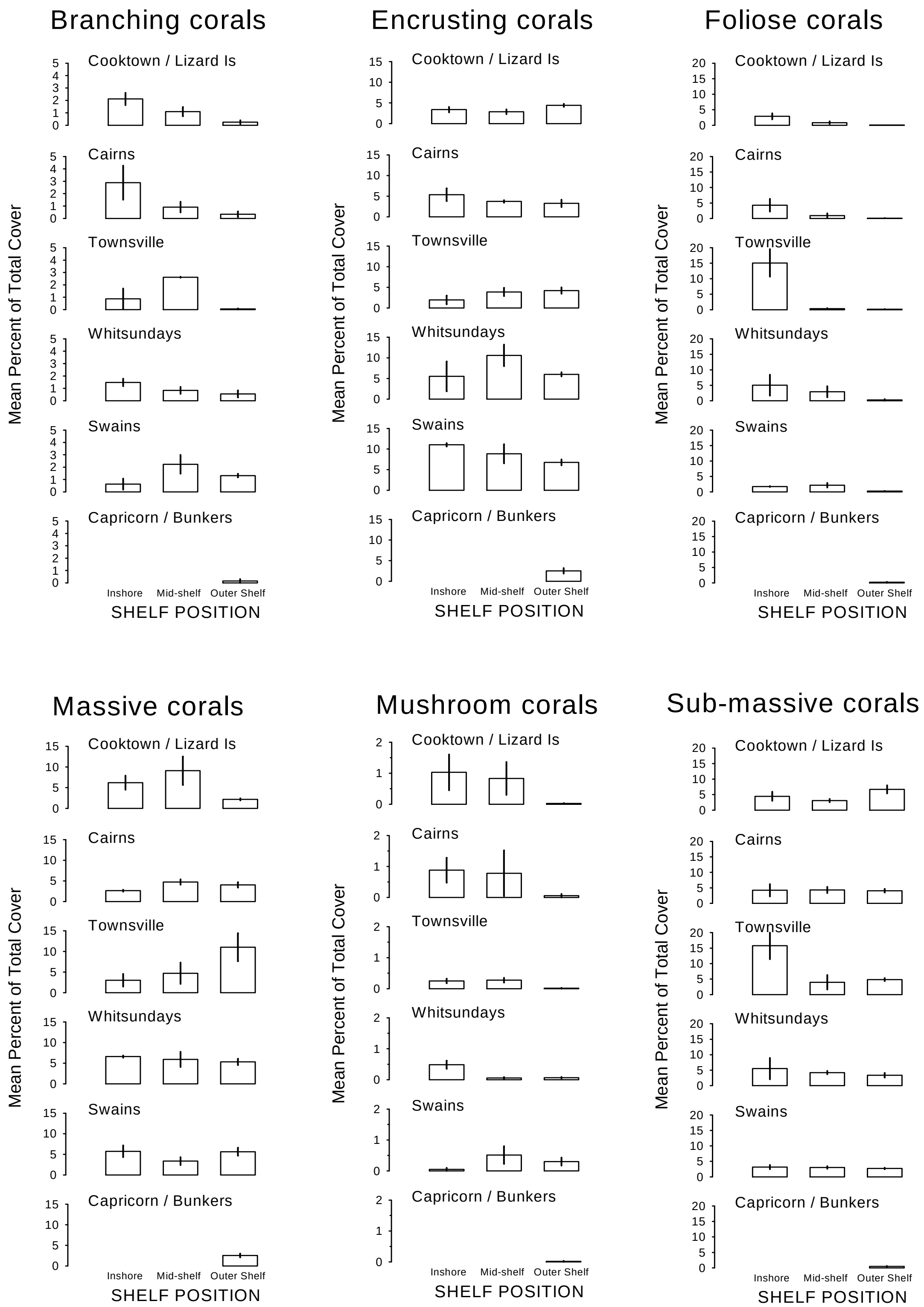


Figure 5.2. Mean percentage cover per site in 1994-95 for assemblages of hard coral (including *Millepora*) categorised into life-forms. Error bars are standard errors.

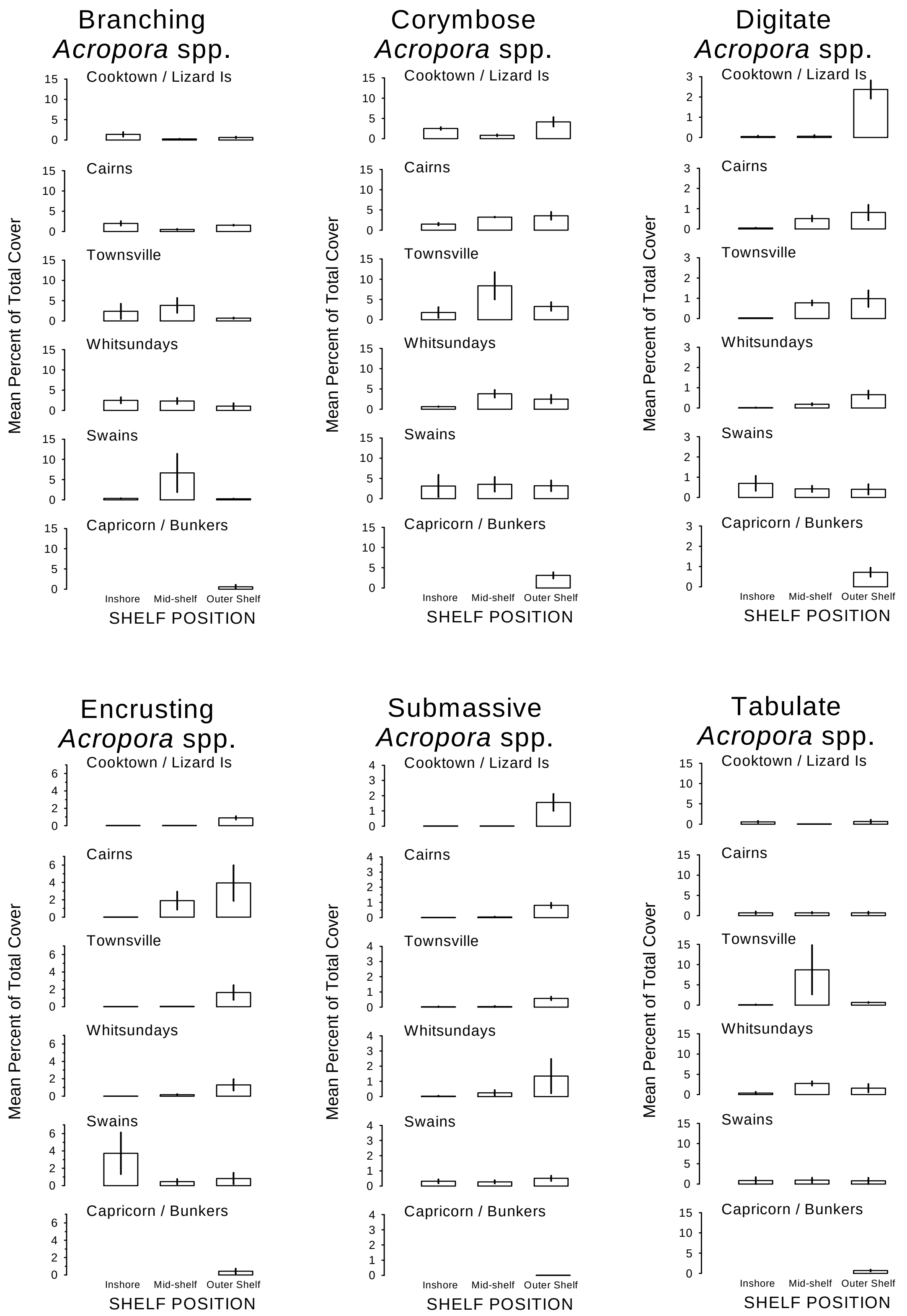


Figure 5.2 continued. Mean percentage cover per site in 1994-95 for assemblages of hard coral (including *Millepora*) categorised into life-forms. Error bars are standard errors.

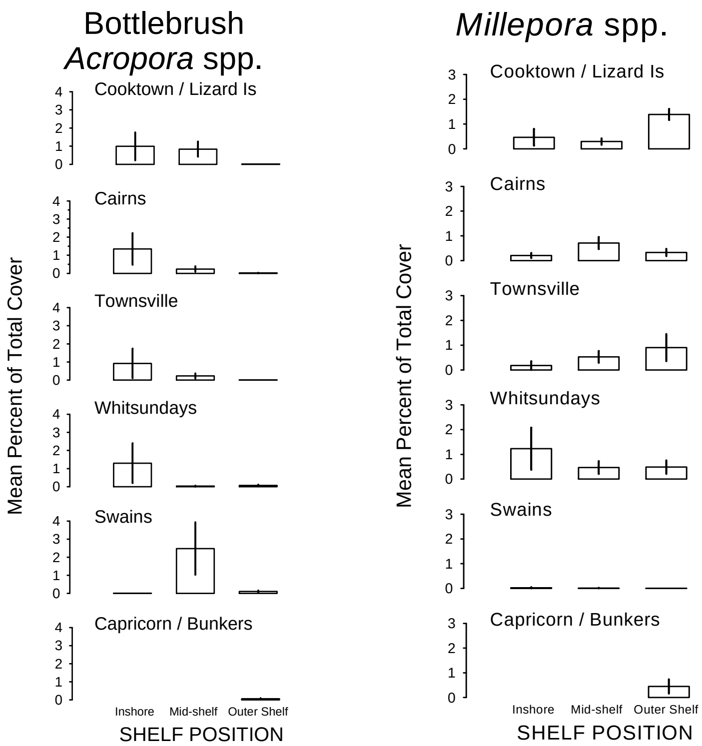


Figure 5.2 continued**.** Mean percentage cover per site in 1994-95 for assemblages of hard coral (including *Millepora*) categorised into life-forms. Error bars are standard errors.

Table 5.6. Results of analyses of variance and contrasts on percentage cover of the benthic life-forms (excluding *Acropora* spp.) to examine whether there is systematic geographic variation in percentage cover of the life-forms that can be attributed to latitude or cross-shelf position. Data from all sectors except the Capricorn Bunker sector (omitted because there are only outer shelf reefs). Data are means of percentage cover per site, giving three values per reef. Empirical logit transform was applied before analysis. "No" indicates no evidence of consistent pattern (p>0.1), "M" indicates marginal evidence of consistent pattern (p = 0.051 - 0.10), "Yes" indicates evidence of consistent pattern (p< 0.05). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation, see Section 1.

Questions	**Branching corals**	**Encrusting corals**	**Foliose corals**	**Massive corals**	**Mushroom corals**	**Sub-massive corals**	***Millepora* spp.**
Does the pattern of coverage across the shelf vary among the 4 northern sectors? *(Sector by cross-shelf interaction in 4 northern sectors)*	No	No	No	M	No	No	No
Does the pattern of coverage across the shelf in the Swains differ from that in the 4 northern sectors? *(Interaction contrast sector by cross-shelf interaction, Swains vs 4 northern sectors)*	M	No	No	(No)	M	No	No
Does coverage vary among the 4 northern sectors (averaged across the shelf)? *(Sector effect, 4 northern sectors)*	No	No	No	(No)	No	No	No
Does coverage vary between the Swains and the 4 northern sectors (averaged across the shelf)? *(Sector effect, contrast Swains vs 4 northern sectors)*	(No)	Yes	No	(No)	(No)	No	Yes
Does coverage vary between inner and midshelf reefs (averaged over the 4 northern sectors and Swains)?*(Cross-shelf effect 1: 5 northern sectors)*	(No)	No	M	(No)	(No)	No	No
Does coverage vary between outer shelf reefs and other reefs (averaged over the 4 northern sectors and Swains)?*(Cross-shelf effect 2: 5 northern sectors)*	(Yes)	No	(Yes)	(M)	(No)	No	No

Table 5.7. Results of analyses of variance and contrasts to examine whether there is systematic variation in cover of the benthic life-forms (excluding *Acropora* spp.) on outer shelf reefs that can be attributed to latitude. Data are means of percentage cover per site, giving three values per reef. Empirical logit transform was applied before analysis. "No" indicates no evidence of consistent pattern ($p>0.1$), "M" indicates marginal evidence of consistent pattern ($p = 0.051 - 0.10$), "Yes" indicates evidence of consistent pattern ($p< 0.05$). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation, see Section 1.

Questions	**Branching corals**	**Encrusting corals**	**Foliose corals**	**Massive corals**	**Mushroom corals**	**Sub-massive corals**	***Millepora* spp.**
Does coverage vary among outer shelf reefs of the 5 northern sectors?	No	M	M	Yes	M	M	No
Does coverage on outer shelf reefs differ between the Capricorn/ Bunkers and the other sectors *(Contrast Capricorn/Bunkers vs 5 northern sectors)*	M	(Yes)	(No)	(No)	(No)	(Yes)	No

Table 5.8. Results of analyses of variance and contrasts on percentage cover of the benthic life-forms of *Acropora* spp. to examine whether there is systematic geographic variation in percentage cover of the life-forms of *Acropora* spp. that can be attributed to latitude or cross-shelf position. Data from all sectors except the Capricorn Bunker sector (omitted because there are only outer shelf reefs). Data are means of percentage cover per site, giving three values per reef. Empirical logit transform was applied before analysis. "No" indicates no evidence of consistent pattern (p>0.1), "M" indicates marginal evidence of consistent pattern (p = 0.051 - 0.10), "Yes" indicates evidence of consistent pattern (p< 0.05). Parentheses indicate where the results of preceding contrasts must also be considered in interpretation, see Section 1. Shading indicates that the data violated the assumption of homogeneity of variances and so analyses are unreliable.

Questions	*Ac. branching*	*Ac. digitate*	*Ac. encrusting*	*Ac. corymbose*	*Ac. sub-massive*	*Ac. tabulate*	*Ac. bottlebrush*
Does the pattern of coverage across the shelf vary among the 4 northern sectors? (Sector by cross-shelf interaction in 4 northern sectors)	No	Yes	No	No	No	Yes	No
Does the pattern of coverage across the shelf in the Swains differ from that in the 4 northern sectors? (Interaction contrast Sector by cross-shelf interaction, Swains vs 4 northern sectors)	No	(No)	No	No	No	(No)	No
Does coverage vary among the 4 northern sectors (averaged across the shelf)? (Sector effect, 4 northern sectors)	No	(No)	No	No	No	(No)	No
Does coverage vary between the Swains and the 4 northern sectors (averaged across the shelf)? (Sector effect, contrast Swains vs 4 northern sectors)	No	(M)	Yes	No	No	(No)	No
Does coverage vary between Inner and Midshelf reefs (averaged over the 4 northern sectors and Swains)? (Cross-shelf effect 1, 5 northern sectors)	No	(M)	No	M	No	(Yes)	No
Does coverage vary between Outer shelf reefs and other reefs (averaged over the 4 northern sectors and Swains)? (Cross-shelf effect 2, 5 northern sectors)	No	(Yes)	Yes	(No)	Yes	(No)	M

Table 5.9. Results of analyses of variance and contrasts to examine whether there is systematic variation in coverage of the benthic life-forms of *Acropora* spp. on outer shelf reefs that can be attributed to latitude. Data are means of percentage cover per site, giving three values per reef. Empirical logit transform was applied before analysis. "No" indicates no evidence of consistent pattern (p>0.1), "M" indicates marginal evidence of consistent pattern (p = 0.051 - 0.10), "Yes" indicates evidence of consistent pattern (p< 0.05). Shading indicates that the data violated the assumption of homogeneity of variances and so analyses are unreliable.

Questions	***Ac. branching***	***Ac. digitate***	***Ac. encrusting***	***Ac. corymbose***	***Ac. sub-massive***	***Ac. tabulate***	***Ac. bottlebrush***
Does coverage vary among outer shelf reefs the 5 northern sectors?	No	No	No	No	No	No	No
Does coverage on outer shelf reefs differ between the Capricorn/ Bunkers and the other sectors (Contrast Capricorn/Bunkers vs 5 northern sectors)	No	No	M	No	Yes	No	No

Table 5.10. Summary of statistically significant geographic patterns in occurrence of benthic life-forms. Shading indicates that the data violated the assumption of homogeneity of variances and so analyses are unreliable.

Branching corals	• Pattern of cover across the shelf differs between the Swains and 4 northern sectors • Cover tends to be lower on outer shelf reefs • Lower cover on Capricorn/Bunker reefs than on outer shelf reefs in other sectors
Encrusting corals	• Higher average cover in the Swains than in other sectors • Cover on outer shelf reefs varies among sectors • Low cover on Capricorn/Bunker reefs
Foliose corals	• Higher average cover on inshore reefs. • Cover on outer shelf reefs varies among sectors, but is very low.
Massive corals	• Pattern of cover across the shelf varies among sectors • Cover on outer shelf reefs varies among sectors
Mushroom corals	• Pattern of cover across the shelf differs between the Swains and 4 northern sectors (but low percentage cover and variable) • Cover on outer shelf reefs varies among sectors, but is very low.
Sub-massive corals	• No clear patterns of cover by sector or shelf-position, but very variable. • Cover on outer shelf reefs varies among sectors • Cover on Capricorn/ Bunker reefs lower than the mean of outer reefs in other sectors.
Branching *Acropora*	• No clear patterns of cover by sector or shelf-position.
Bottlebrush *Acropora*	• Low percentage cover everywhere but very rare on outer shelf reefs
Corymbose *Acropora*	• No clear pattern of cover by sector • Cover tends to be higher on mid-shelf reefs
Digitate *Acropora*	• Pattern of cover across the shelf differs among sectors. • Overall mean cover in the Swains is higher than the overall mean for northern sectors, but values very low. • Overall mean cover is higher on outer shelf reefs, but values very low.
Encrusting *Acropora*	• Pattern of cover across the shelf differs between sectors: high values on outer shelf reefs except in the Swains • Lower cover on Capricorn/Bunker reefs than on outer shelf reefs in other sectors
Sub-massive *Acropora*	• Cover tends to be higher on outer shelf reefs • Not recorded on Capricorn/Bunker reefs
Tabulate *Acropora*	• Pattern of cover across the shelf varies among sectors, with generally low percentage cover except on mid-shelf reefs in the Townsville sector
Millepora	• No clear patterns in cover with shelf-position, but not recorded in the Swains. • Very low cover values in general.

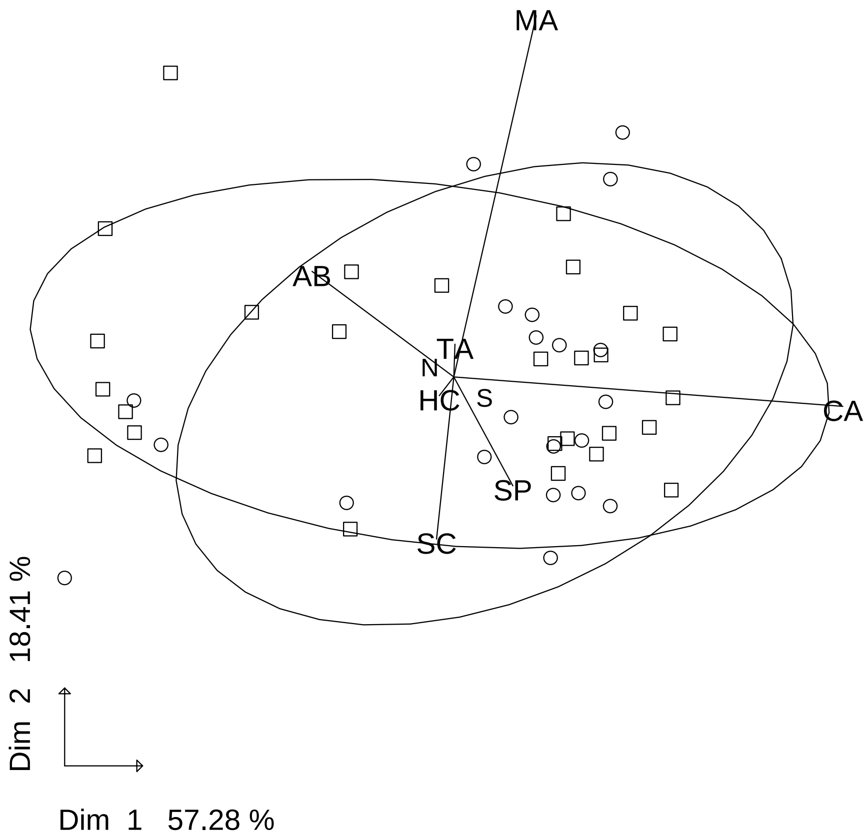


Figure 5.3. Projection of ordinations of benthic assemblages of 48 reefs in multivariate space, based on "benthic groups". Dimensions 1 and 2 are the first two principal components. Reefs are categorised by latitude: squares represent reefs in the three northern sectors, circles represent reefs in the three southern sectors. Vectors represent variation in the data associated with particular benthic groups. See Section 1 for notes on interpreting biplots. Ellipses are 80% confidence zones. AB = abiotic substrate, CA = coralline algae, HC = hard coral, MA = macro-algae, SC = soft coral, SP = sponge, TA = turf algae.

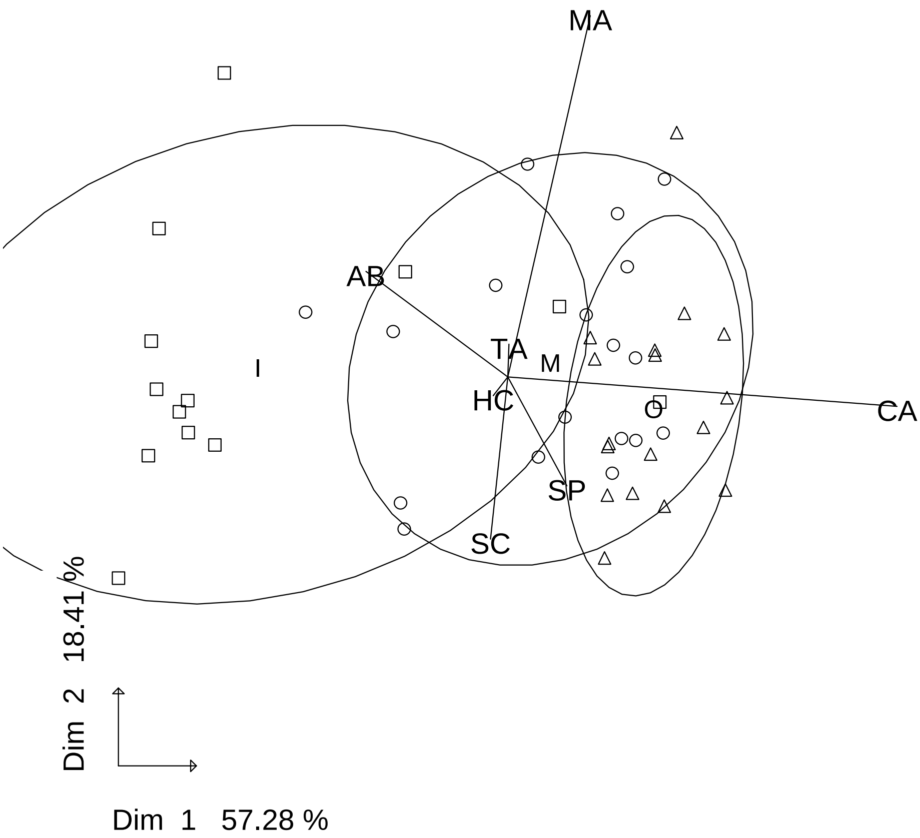


Figure 5.4. Projection of ordinations of benthic assemblages of 48 reefs in multivariate space, based on "benthic groups". Dimensions 1 and 2 are the first two principal components. Reefs are categorised by shelf position: squares represent inshore reefs, circles represent mid-shelf reefs and triangles represent outer shelf reefs. Vectors represent variation in the data associated with particular benthic groups. See Section 1 for notes on interpreting biplots. Ellipses are 80% confidence zones. AB = abiotic substrate, CA = coralline algae, HC = hard coral, MA = macro-algae, SC = soft coral, SP = sponge, TA = turf algae.

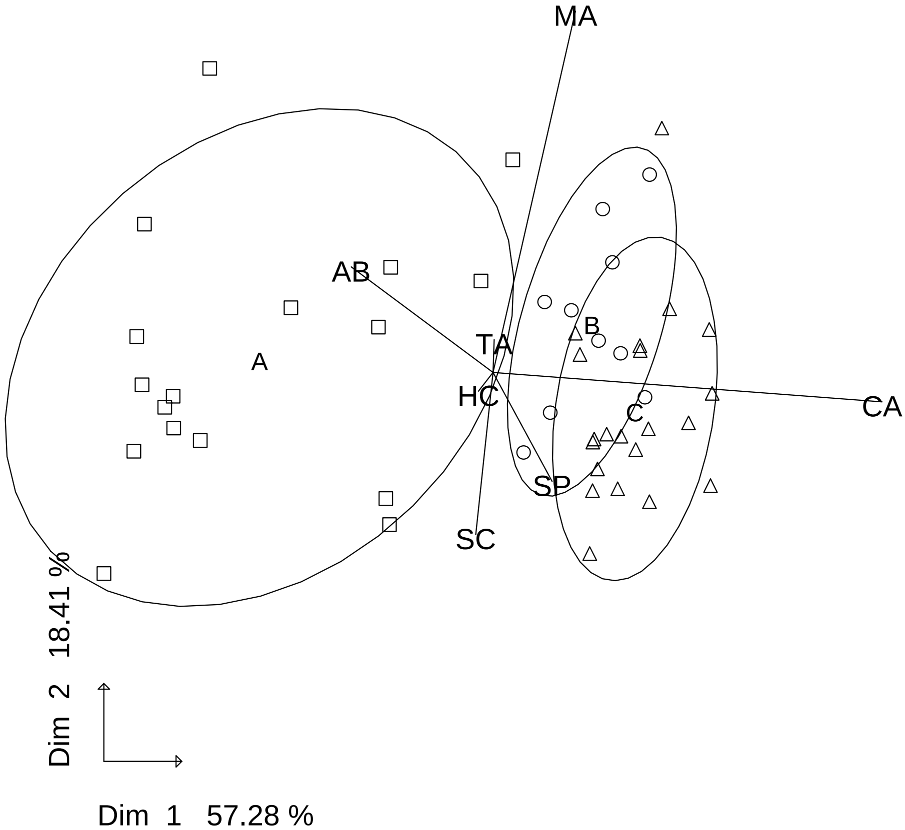


Figure 5.5. Projection of ordinations of benthic assemblages of 48 reefs in multivariate space, based on "benthic groups". Dimensions 1 and 2 are the first two principal components. Reefs are categorised by exposure (see Table 4.8) : square symbols represent reefs with low exposure, circles represent reefs with intermediate exposure and triangles represent exposed reefs. Vectors represent variation in the data associated with particular benthic groups. See Section 1 for notes on interpreting biplots. Ellipses are 80% confidence zones. AB = abiotic substrate, CA = coralline algae, HC = hard coral, MA = macro-algae, SC = soft coral, SP = sponge, TA = turf algae.

Interpretation

Hard coral is a major structural component of reefs, so hard coral cover is sometimes considered an indicator of the ability of a reef to grow and is taken as an index of reef condition. Considering the benthic group "hard coral," the only patterns that emerge are that there are some differences in average coral cover among the northern sectors. Looking at the life-forms that are aggregated under the heading of hard coral, it is clear that these vary much more in their distributions. While the video images do not allow many corals to be identified reliably to species, the distribution of individual species would presumably be more complex. The highest values for cover of the benthic group "hard coral" are found in the Townsville sector. Foliose and sub-massive forms are especially abundant on inshore reefs in the Townsville sector, while tabulate and corymbose *Acropora* spp. are most abundant on the mid-shelf reefs. The high values in the Townsville sector are due in part to the development of assemblages dominated by fast-growing *Acropora* spp. after the reefs there were damaged by *Acanthaster planci* in the mid 1980s.

These patterns conform broadly to those described from a subset of the sample reefs by Christie *et al*. (1995). Obvious differences include the distribution of hard corals, turf algae and macro-algae. Christie *et al*. (1995) reported that the Capricorn/ Bunker reefs had significantly lower cover of hard corals than the other sectors. This remained true in comparison to other outer shelf reefs (Table 5.2), but there were also significant differences in average cover of hard coral among the four northern sectors (Fig. 5.1). Macro-algae showed no coherent pattern over the full set of reefs. Christie *et al*. (1995) reported high overall mean values in the Townsville and Whitsunday sectors which did not hold when the full sampling design was considered. The general pattern of high macro-algal cover on mid-shelf reefs was disrupted by very high cover values on Decapolis Reef, an inshore reef in the Cooktown/Lizard Is sector. When the full design was surveyed, cover of turf algae was generally lower on outer reefs than on reefs in other shelf positions. The "other organisms" category also varied in the cross-shelf pattern of cover among the northern sectors in these results and in Christie *et al*. (1995), but the patterns were substantially different. Reefs where Christie *et al*. (1995) recorded the highest values, the mid-shelf reefs in the Cooktown-Lizard Is and Townsville sectors and outer shelf reefs in the Whitsundays, ranked relatively low in the full sampling design. The "other organisms" category is so heterogeneous that no biologically interpretable pattern would be expected.

The biplots suggest that benthic assemblages form more distinct groups on the basis of exposure than on strict shelf position. This implies that exposure to wave energy or its correlate, oceanic water quality, is a major forcing factor for cross-shelf distributions. Note that exposed reefs correspond closely to the outer shelf reefs, while mid-shelf and inner shelf positions do not correspond so closely to moderate and low exposure categories respectively. This is presumably due to the variable extent that outer shelf reefs form a barrier preventing oceanic influences from penetrating into the GBR lagoon.

WHAT CHANGES HAVE OCCURRED IN BENTHIC ASSEMBLAGES IN THE DURATION OF THE STUDY?

Introduction

Benthic assemblages are changing continuously at a variety of scales. Most of the foreseeable impacts, especially those requiring management response such as water quality changes, oil spills or crown-of-thorns starfish, are likely to affect a whole reef as sampled by the Long-term Monitoring Program, that is, all transects within all three sites.

Analyses

Two approaches were used to study change. Considering hard coral cover, the average values for coral cover for the 14 reefs that were sampled in each of the first three years were subject to a repeated measures analysis of variance. Each reef was then examined for linear and quadratic trends in hard coral cover using contrasts. As for fish taxa, a Type I error rate of 0.1 was used following the Precautionary Principle. Second, changes in cover of the benthic groups on the 14 reefs between the first and the third visit were displayed graphically as principal components biplots. Values for change were log transformed and column-centred.

An important part of any study of change is an assessment of the ability of sampling to detect change: the statistical power of the sampling scheme. Detectable differences were estimated for the benthic groups, based on variance estimates from the 14 reefs sampled in all three years.

Results

As expected, the overall analysis showed that there were differences in coral cover between successive surveys on some reefs. Focussing on changes on individual reefs using contrasts, eight of the 14 reefs showed significant linear trends (or both linear and quadratic trends) in cover of hard coral in the first three years of sampling (Fig. 5.6). Reefs that showed significant quadratic components to change, but without significant linear trends, were not considered further. This was because, with only three data points, annual change with no net direction does not indicate any simple population process requiring management action. Two of the eight reefs showed significant declines in coral cover, these were Reef 22-088 and Gannet Cay. With the exception of Pandora Reef and possibly Davies Reef, the other reefs had low initial cover of hard coral.

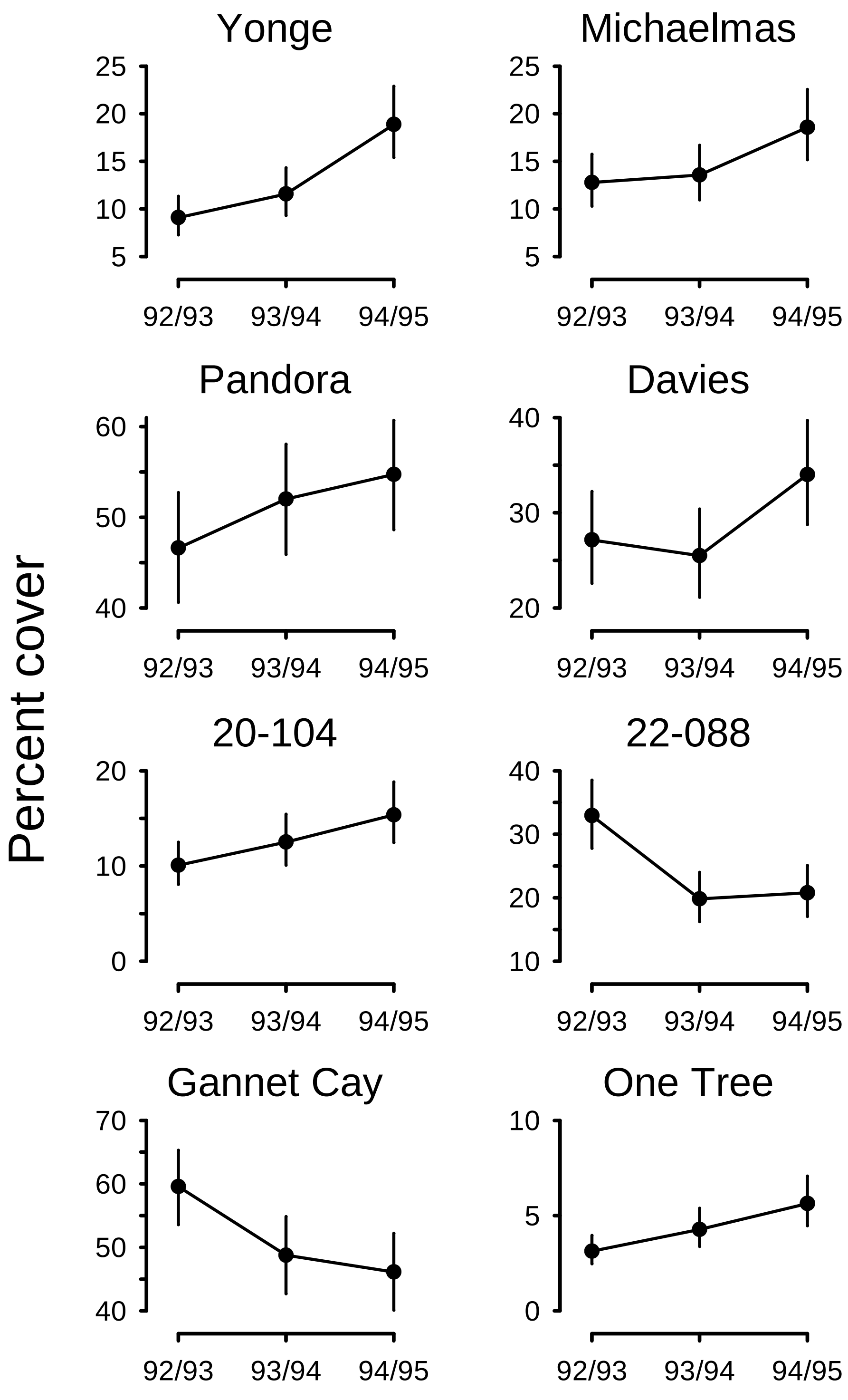


Figure 5.6. Patterns of change in hard coral cover on reefs that were sampled in all three years and showed significant linear trends in mean percent cover of hard coral. Error bars are S.E.s.

Use of the logit transformation complicates the presentation of estimates of the changes (in percentage of total cover) that could have been detected because detectable differences are expressed as odds ratios, whose numerical values are asymmetric and depend on the initial percentage cover of the organisms under consideration. Based on the 14 reefs that were censused in all three years, the logit transformed differences that could be detected ($\alpha = 0.1$) with 80% certainty are given in Table 5.11. In order to apply these to a particular reef, the values of detectable change (increase and decrease) must be read from the Y axis in Fig. 5.7, interpolating a value from the curves for logit-transformed detectable differences and for the pre-existing percentage cover (X axis in Fig 5.7). For example, a reef with 35% cover of hard coral (transformed detectable difference = 0.38 [$0.2 < 0.38 < 0.6$]) would show a statistically significant ($p<0.10$) change if that cover increased by approximately 9% (to 44%) or decreased by about 8% (to 27%), indicated by the drop-lines in Fig. 5.7. For macro-algae (transformed detectable difference = 1.52), the equivalent figures would be an increase of 36% or a decrease of 24%.

Table 5.11. Detectable differences in mean cover of benthic groups on a reef in successive years, (α= 0.1), logit transformed data. These must be used in conjunction with Fig. 5.7

Benthic Group	Detectable Difference (logit scale)
Abiotic	2.106
Coralline algae	1.387
Hard coral	0.377
Macro-algae	1.521
Other	1.790
Soft corals	0.816
Sponges	2.329
Turf algae	0.449

The multivariate approach shows that there were large changes in benthos on a number of reefs, but not in any coherent direction (Fig. 5.8). Reefs 22-088 and Gannet Cay both showed a decline in hard coral as described above. Gannet Cay reef showed a notable increase in turf algal cover, which was true to a lesser extent on Reef 22-088. Davies Reef and Reef 20-104 both also showed increases in cover of algal turf. The cover of coralline algae showed a complementary decline at Davies Reef, while at 20-104 the decline was in macro-algae. One Tree Reef showed the opposite pattern: an increase in cover of macro-algae and a decrease in cover of turf algae. Chinaman Reef showed a decline in cover of turf algae in favour of soft corals. At Yonge Reef, cover of hard coral increased and there was a decline in cover of coralline algae.

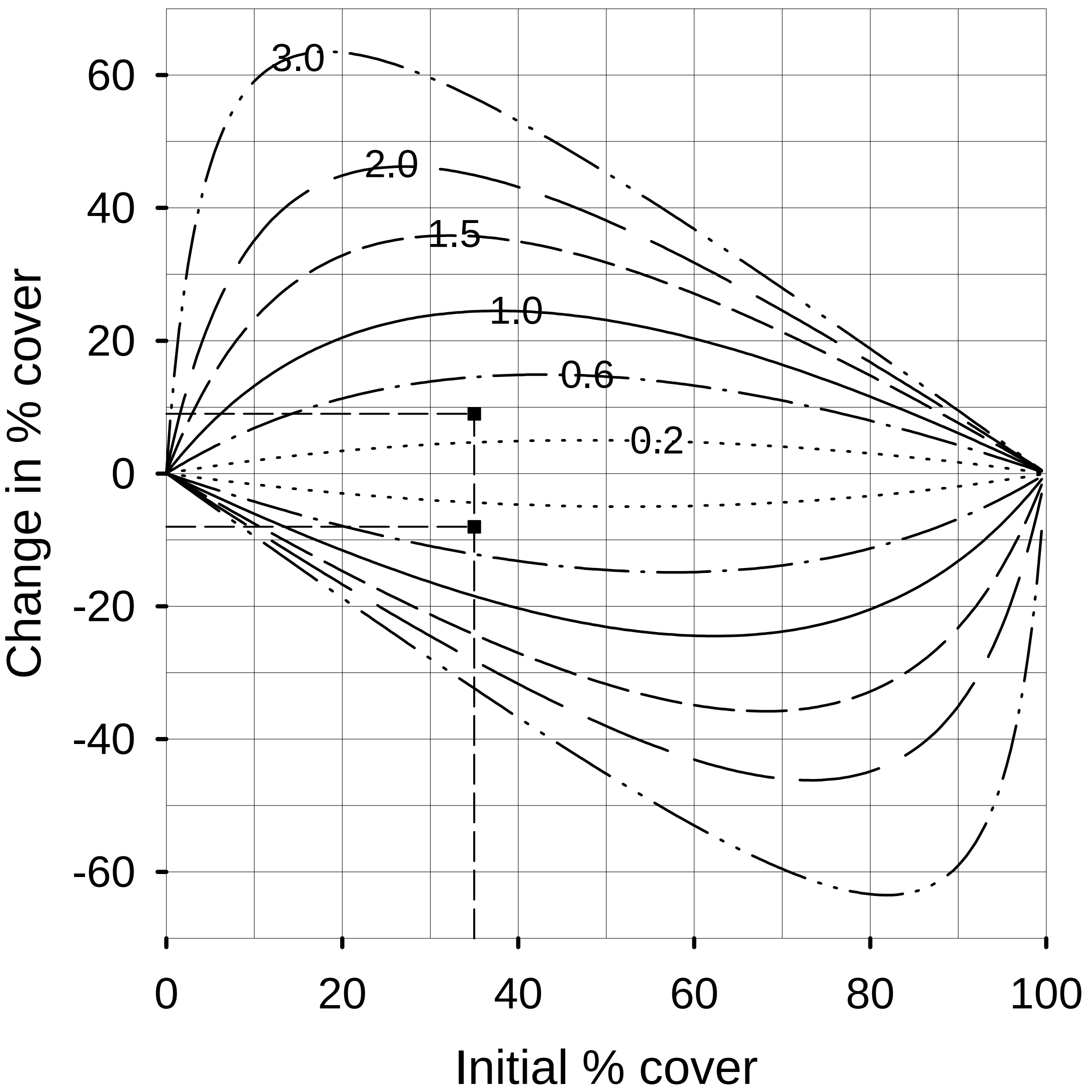


Figure 5.7. Curves for estimation of detectable changes between years for logit transformed data. The set of curves for positive change are labelled with detectable difference values (see Table 5.11); the same line styles denote the corresponding curves for negative change. Estimates of detectable changes in percent cover are read from the Y axis using the starting cover value on the X axis and interpolating from the curves for logit-transformed detectable differences. See text for example.

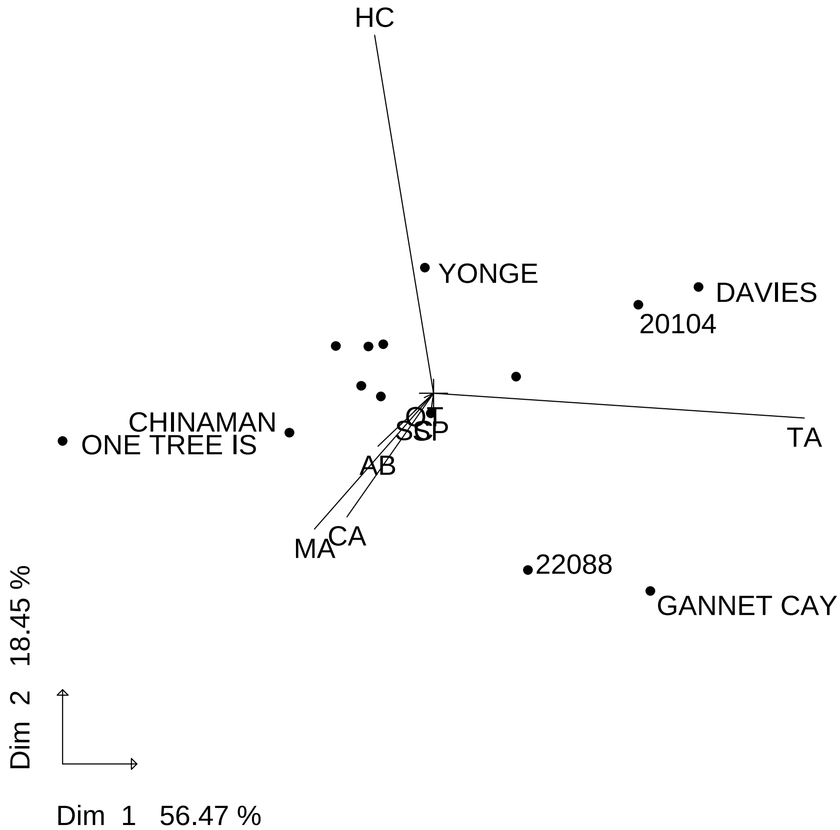


Figure 5.8. Projection of ordinations of change between 1992-93 samples and 1994-95 samples of benthic assemblages of 14 reefs in multivariate space, based on "benthic groups". Dimensions 1 and 2 are the first two principal components. Vectors represent variation in the data associated with particular benthic groups. See Section 1 for notes on interpreting biplots. AB = abiotic substrate, CA = coralline algae, HC = hard coral, MA = macro-algae, SC = soft coral, SP = sponge, TA = turf algae.

Interpretation

In the absence of disturbance, corals would be expected to grow and increase the percentage of surface covered. The net rate of growth in coral cover is 3 - 5% per year (see example in Fig. 5.6). Coral species differ in their growth rates so the rate of increase in coral cover is likely to vary with the location of the reef since this affects the species composition of assemblages, with the conditions for growth in terms of water quality and with the reef's stage of regeneration after disturbance. These aspects will be explored in more detail in the next report.

Based on estimates of variance from the 14 reefs that were sampled in all three years, the power of the sampling scheme to detect changes in benthic cover from year to year seems to be acceptable for hard corals. The average cover of hard corals on reefs surveyed in 1994-95 was 27.2%. Values extracted from Fig. 5.7 are estimates and so cannot be taken too literally, but changes of the order of 10% in hard coral cover from year to year on average reefs should be detected in 80% of cases with Type I error rate of 10%. The power to detect change in cover of other benthic groups is lower. Clearly only very large changes in assemblages of sponges could be detected with the current sampling design.

There are two identifiable reasons for the changes in benthic assemblages: the declines in hard coral cover at Gannet Cay and 22-088 are consistent with crown-of-thorns starfish outbreaks. Both these reefs have had elevated populations of crown-of-thorns starfish. Gannet Cay reef had an active outbreak since 1989, while 22-088 is a large reef which had numerous *A. planci* in one or more localised patches since the first survey in 1992. The Capricorn/Bunker reefs suffered a dramatic reduction in coral cover in the late 1980s (Miller *et al*. 1991, Doherty *et al*. 1997), apparently due to sub-cyclonic storm damage. An increase in cover of macro-algae as occurred at One Tree Reef is sometimes an indicator of reef degradation and of a long-term shift to algal domination (Hatcher *et al*. 1989, Done 1992). In this case, the increased cover of macro-algae (principally *Halimeda* spp.) was still only 11.8%, which was marginally greater than cover of hard coral (8.1%) while turf algae covered 53%. Several taxa of fishes declined in abundance on Reef 20-104 over the three years of the study (Section 4). It is noticeable that coral cover increased at a steady rate (Fig. 5.6), site relocations not withstanding.

DISCUSSION

Biogeographic patterns based on 48 reefs are more likely to be representative of the overall pattern than those based on a subset of those reefs. It is important to stress that these data concern assemblages on the north-east corners of reefs. There is no evidence that the same patterns hold true for the benthic assemblages in other reef zones, for instance in back-reef areas. As a cautionary point, coral cover on reefs in the Capricorn/Bunker group remained comparatively low, though the cover at One Tree Island Reef increased over the three years (Fig. 5.6). Long term observations using the manta tow method have pointed to a major reduction in coral cover in the Capricorn/ Bunker Section in 1988 (Fig 2.12) which could not be attributed to crown-of-thorns starfish activity or any major cyclones (Miller *et al*. 1991). This is an example of an unidentified disturbance that has had a noticeable effect on reef assemblages for years. It raises the possibility that other aspects of the biogeographic patterns described here may also be due to regions being in transient stages of recovery following undocumented large-scale disturbances. The suggestion that outbreaks of crown-of-thorns starfish progress from north to south down the GBR over a number of years as larvae are transported by prevailing summer currents (Reichelt *et al*. 1990) implies that there may be regional differences in the stage of recovery that overlies any latitudinal differences in assemblages. The LTMP should be able to document this with the current outbreaks of *A. planci*.

Reassuringly, the two reefs showing a significant decline in hard coral cover over the three years also provide evidence of the mechanism: they have had outbreaks of *A. planci*. However, when the annual changes on the fourteen reefs are examined, six reefs showed a net decrease between the first and second surveys. Coral cover declined on two reefs (Gannet Cay and Chinaman Reef in the Swains) between the second and third surveys. In the absence of disturbance hard corals should grow and cover should increase by a few percent per year. This mean rate of growth will depend on the mix of fast and slow-growing corals in assemblages and some spatial patterns in assemblage composition have been described here. While there is a clear need to examine the geographic patterns in mean growth rates, no corals should show a decrease in cover in the absence of disturbance. It is a matter of priority to collect information on agents of disturbance that might cause a decline in mean coral cover over all sites at a reef. Only one of these, the crown-of-thorns starfish, is monitored within the current sampling; information on cyclones, storms, bleaching and oil spills must be integrated to aid interpretation.

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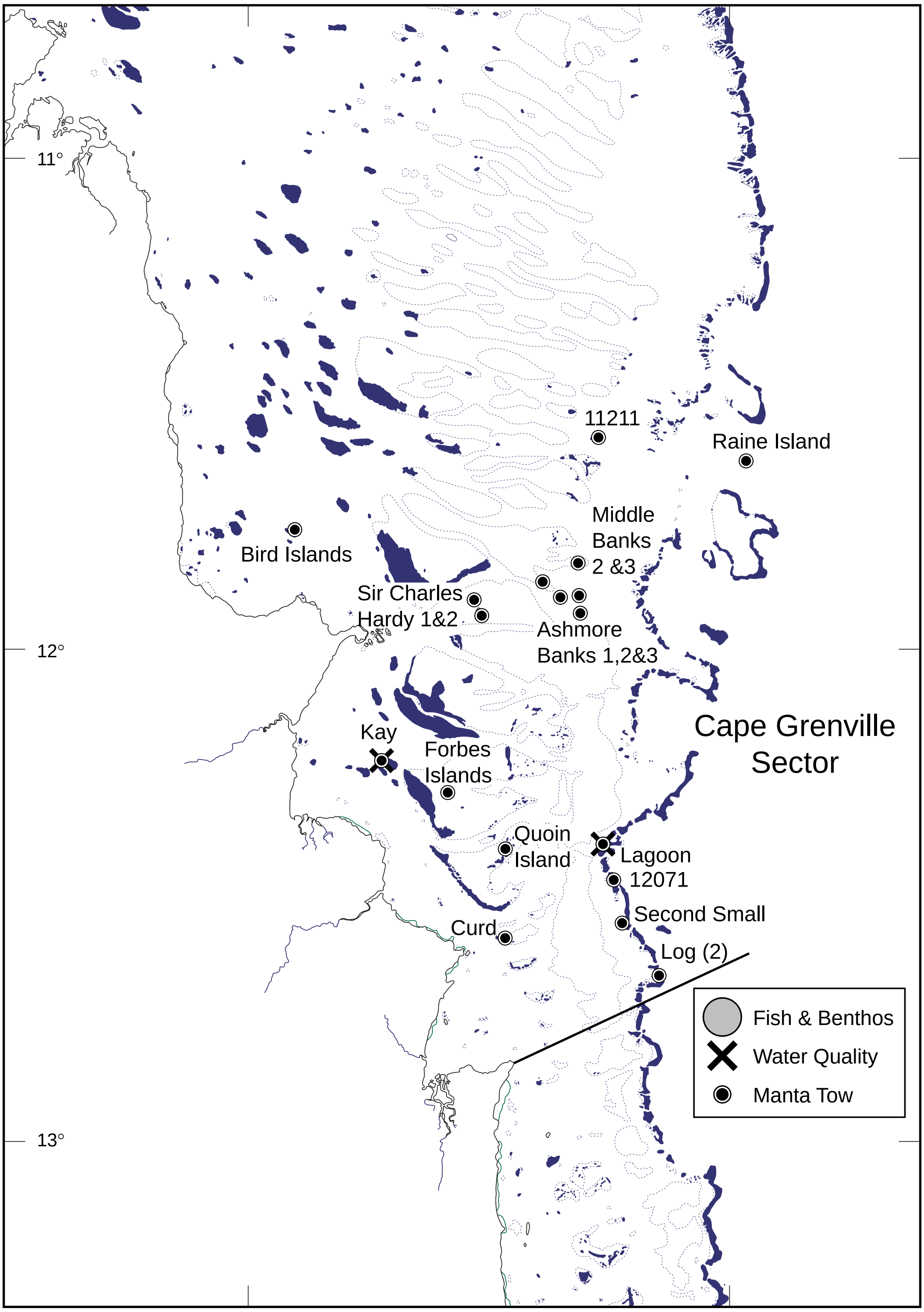
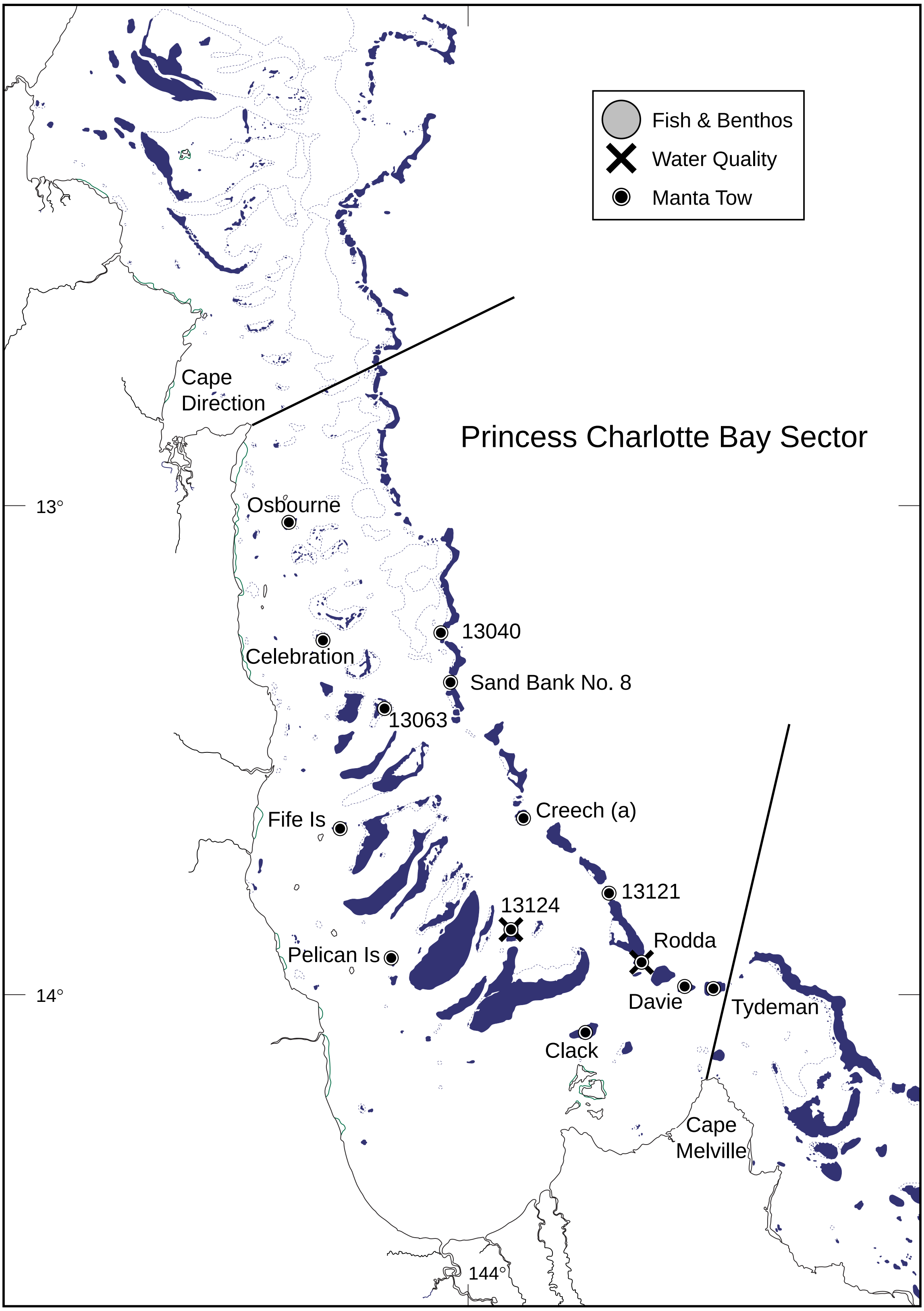
7. Appendices

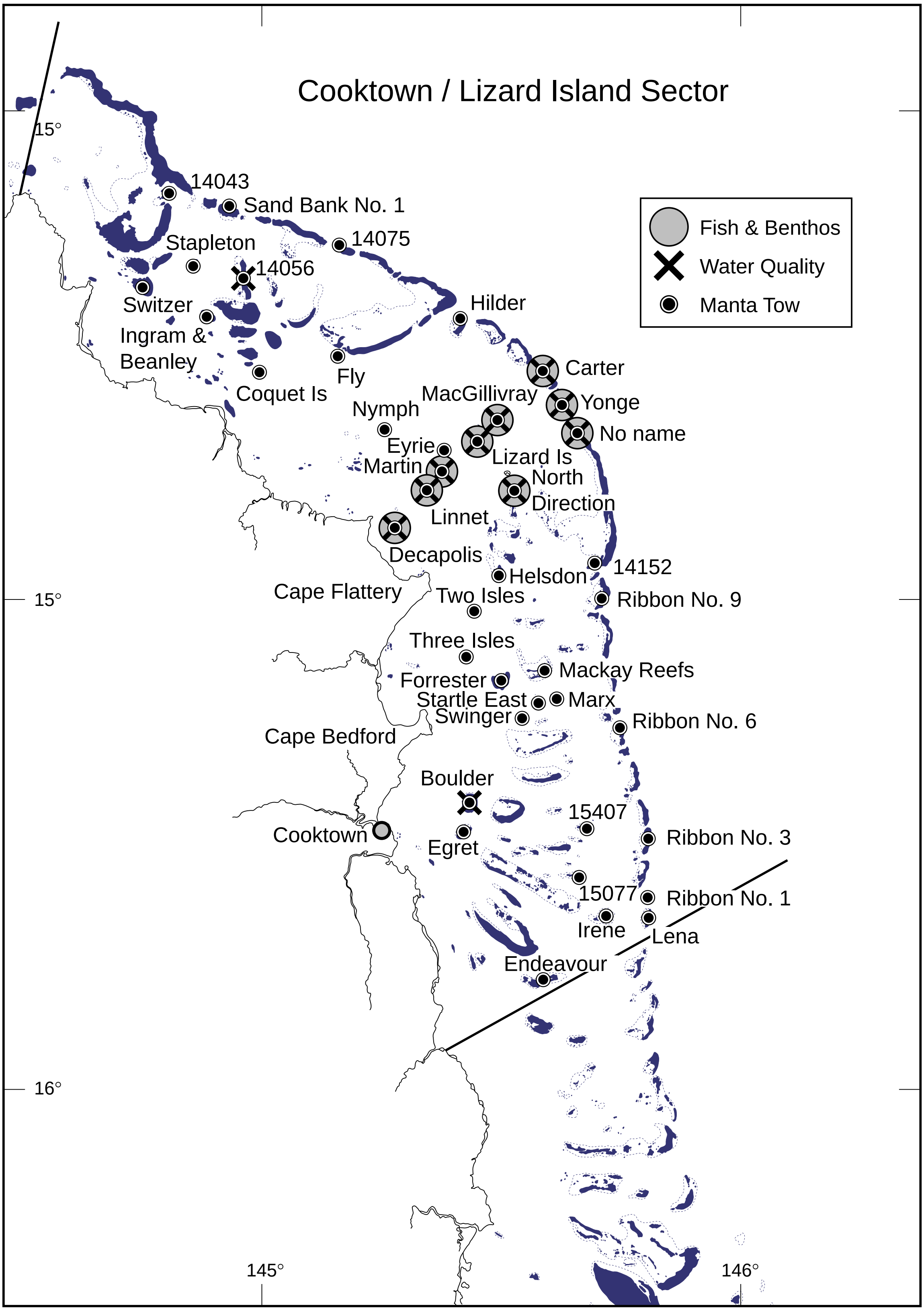
Appendix 1

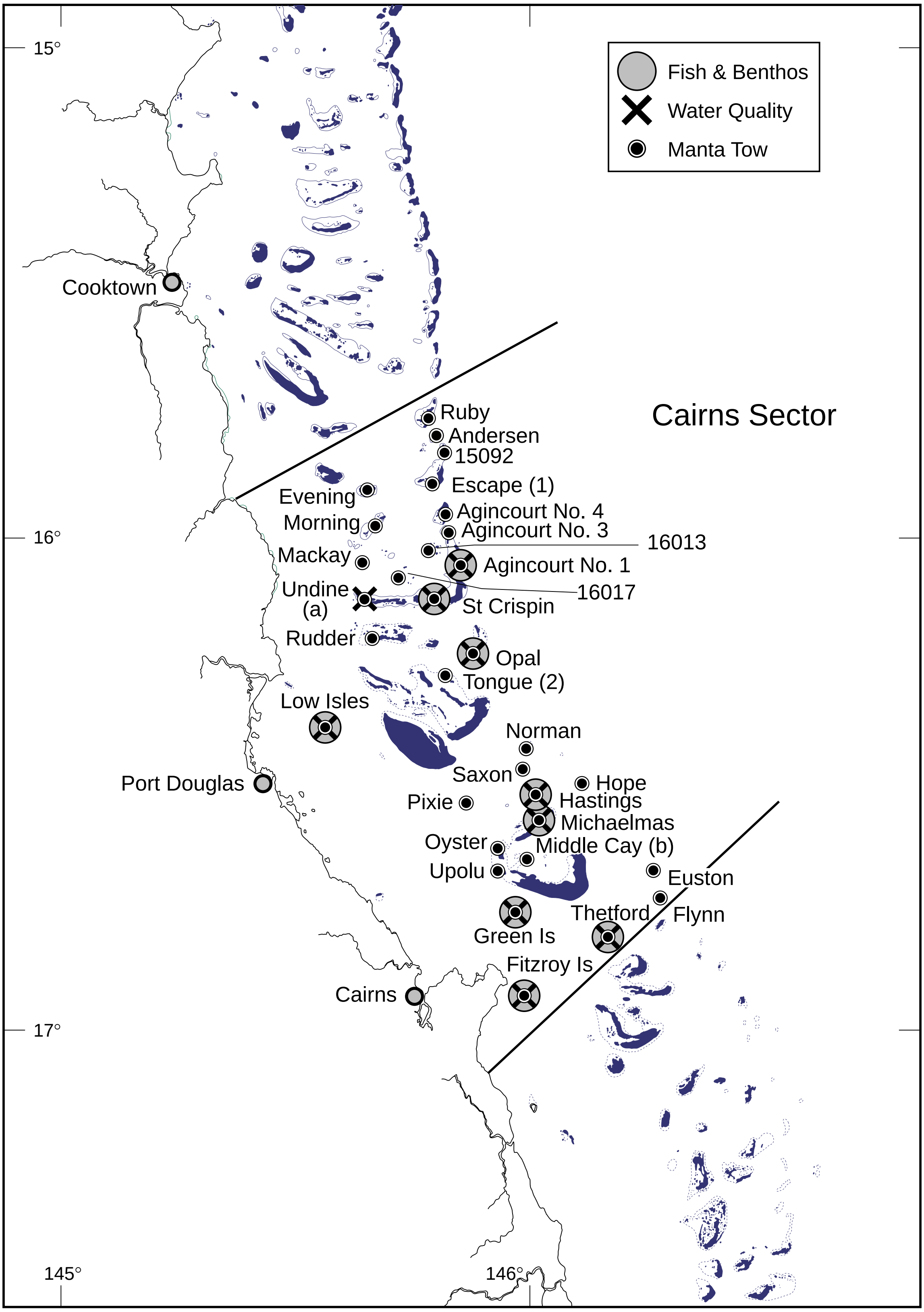
Locations of survey reefs and the types of samples taken.



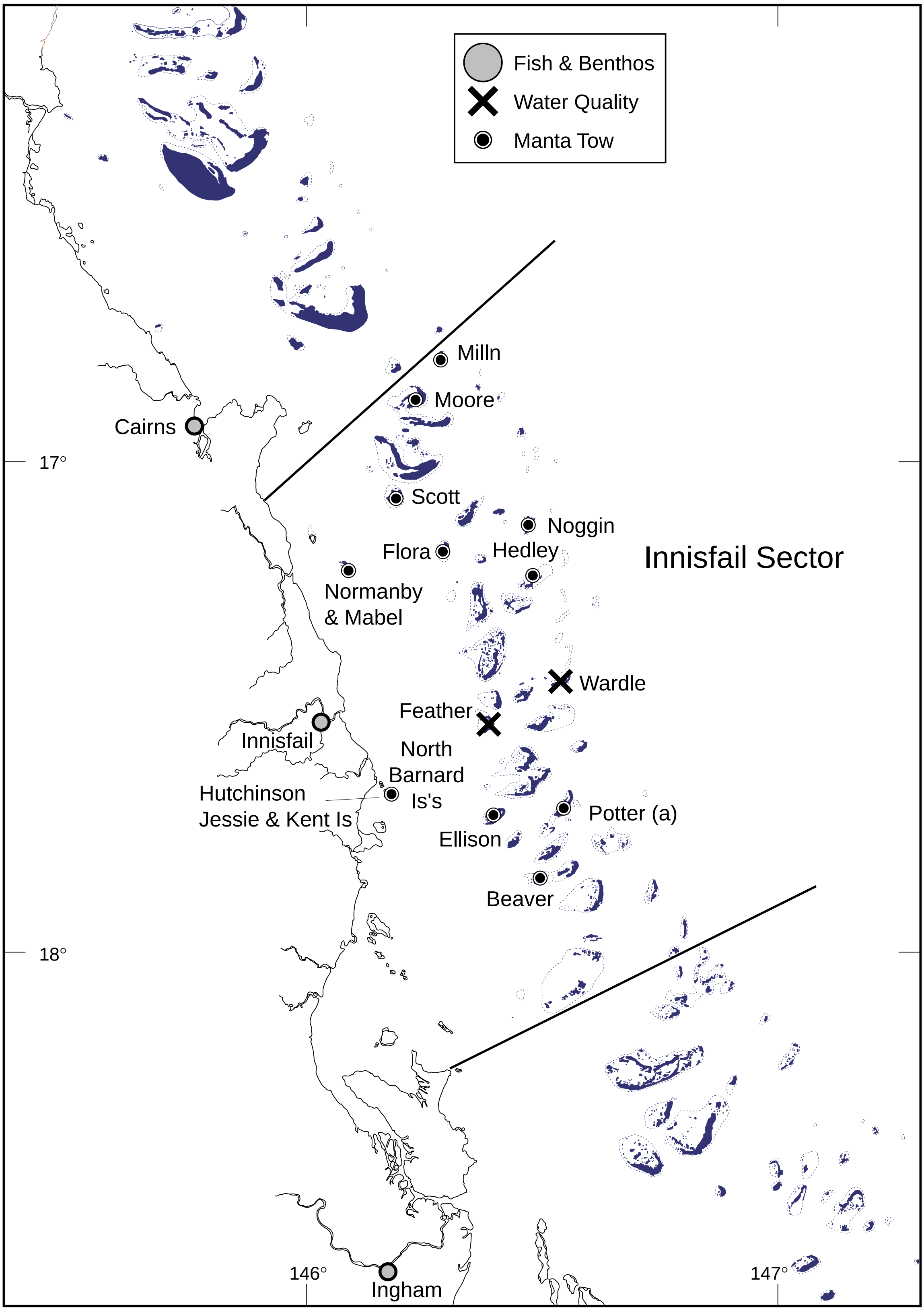


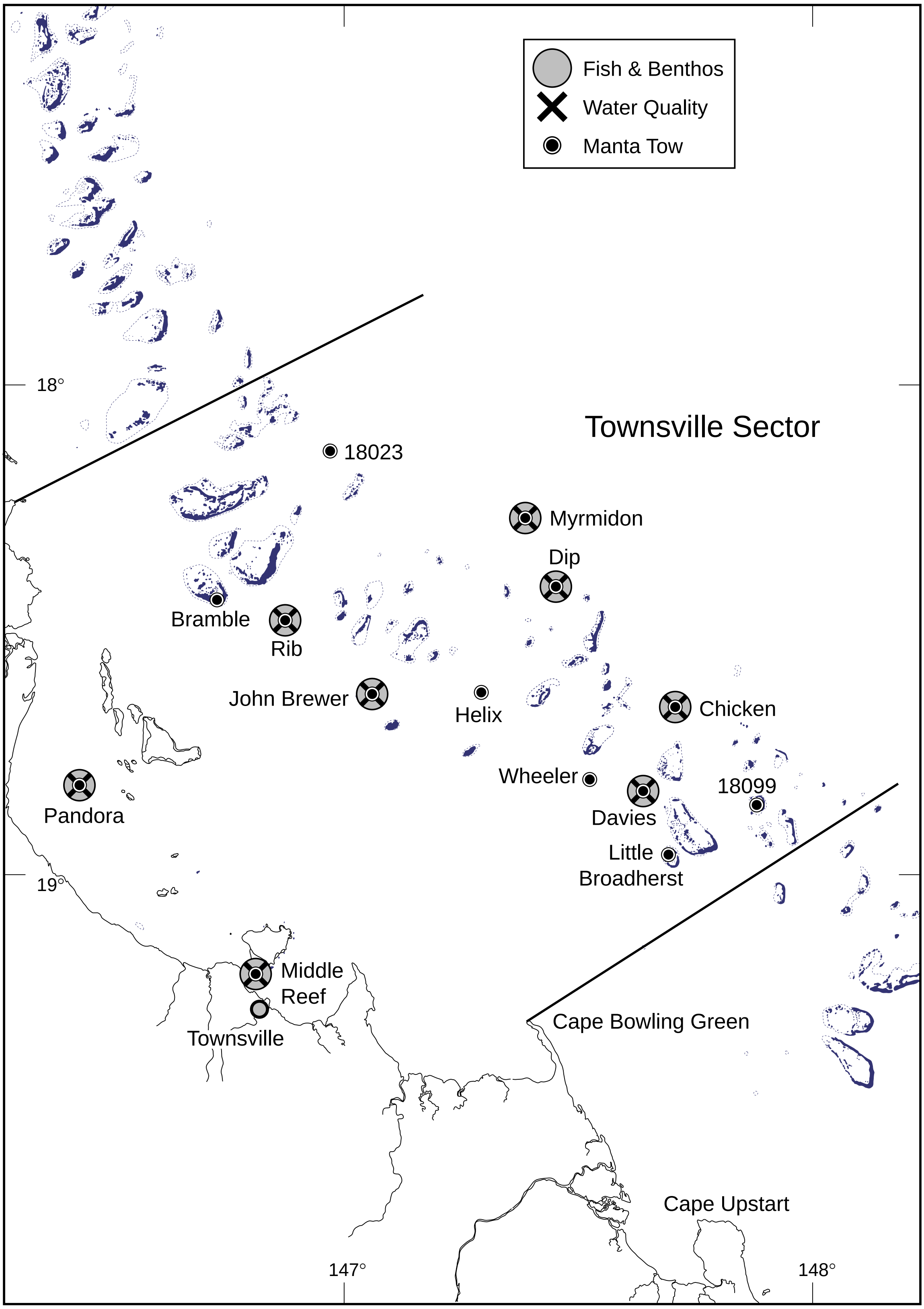
Fish & Benthos
Water Quality
Manta Tow
Princess Charlotte Bay Sector
Cape Direction
13°
Osbourne
13040
Celebration
Sand Bank No. 8
13063
Creech (a)
Fife Is
13121
13124
Rodda
Pelican Is
Davie
Tydeman
14°
Clack
Cape Melville
144°

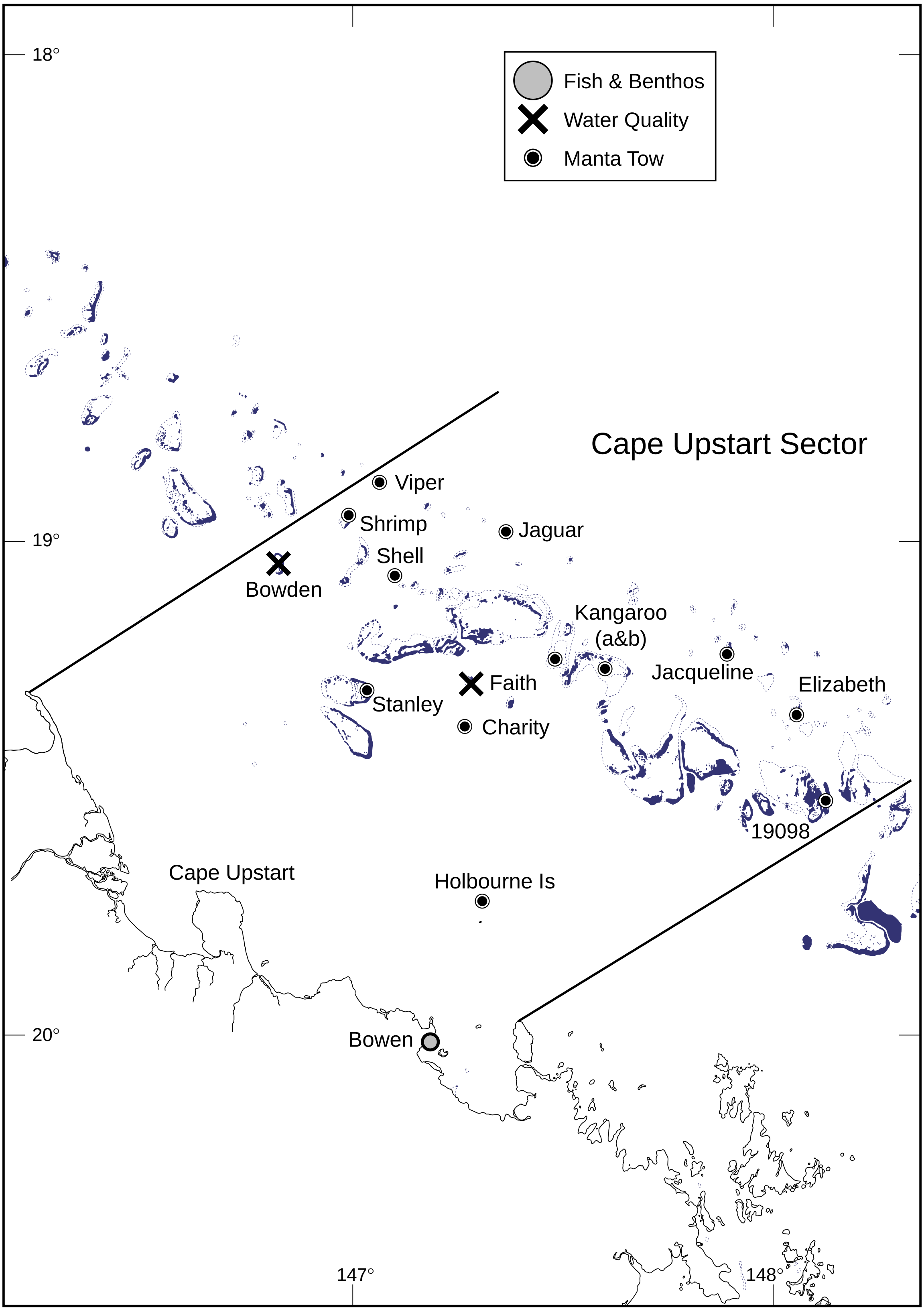

Cooktown / Lizard Island Sector
Fish & Benthos
Water Quality
Manta Tow
15°
15°
16°
145°
146°
14043
Sand Bank No. 1
Stapleton
14075
14056
Switzer
Ingram &
Beanley
Hilder
Fly
Coquet Is
Carter
MacGillivray
Yonge
Nymph
No name
Eyrie
Martin
Lizard Is
North
Direction
Linnet
Decapolis
14152
Helsdon
Cape Flattery
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

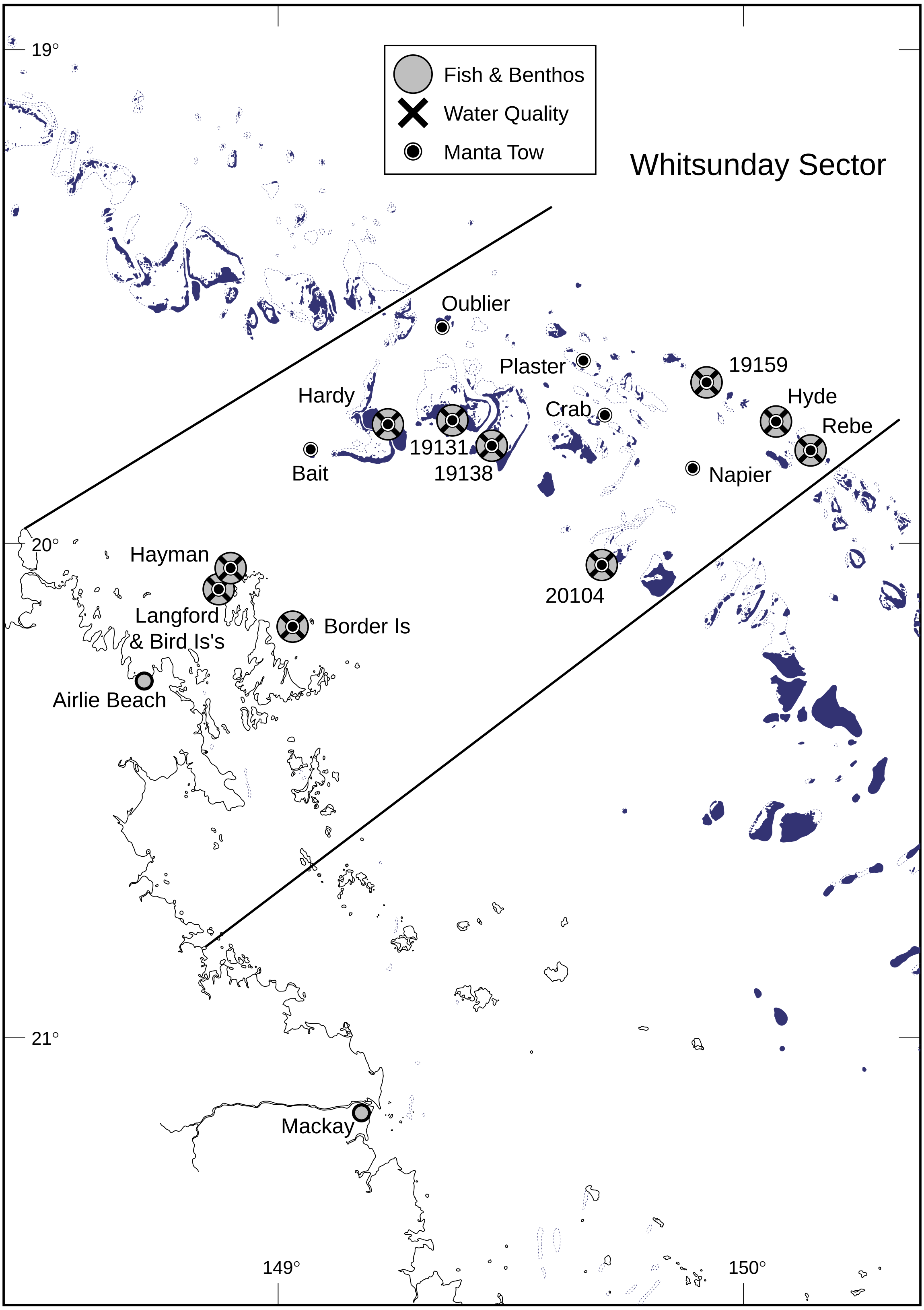


15°
16°
17°
145°
146°
Fish & Benthos
Water Quality
Manta Tow
Cairns Sector
Cooktown
Ruby
Andersen
15092
Escape (1)
Evening
Morning
Agincourt No. 4
Agincourt No. 3
16013
Mackay
Agincourt No. 1
Undine
(a)
16017
St Crispin
Rudder
Opal
Tongue (2)
Low Isles
Norman
Saxon
Hope
Port Douglas
Hastings
Pixie
Michaelmas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

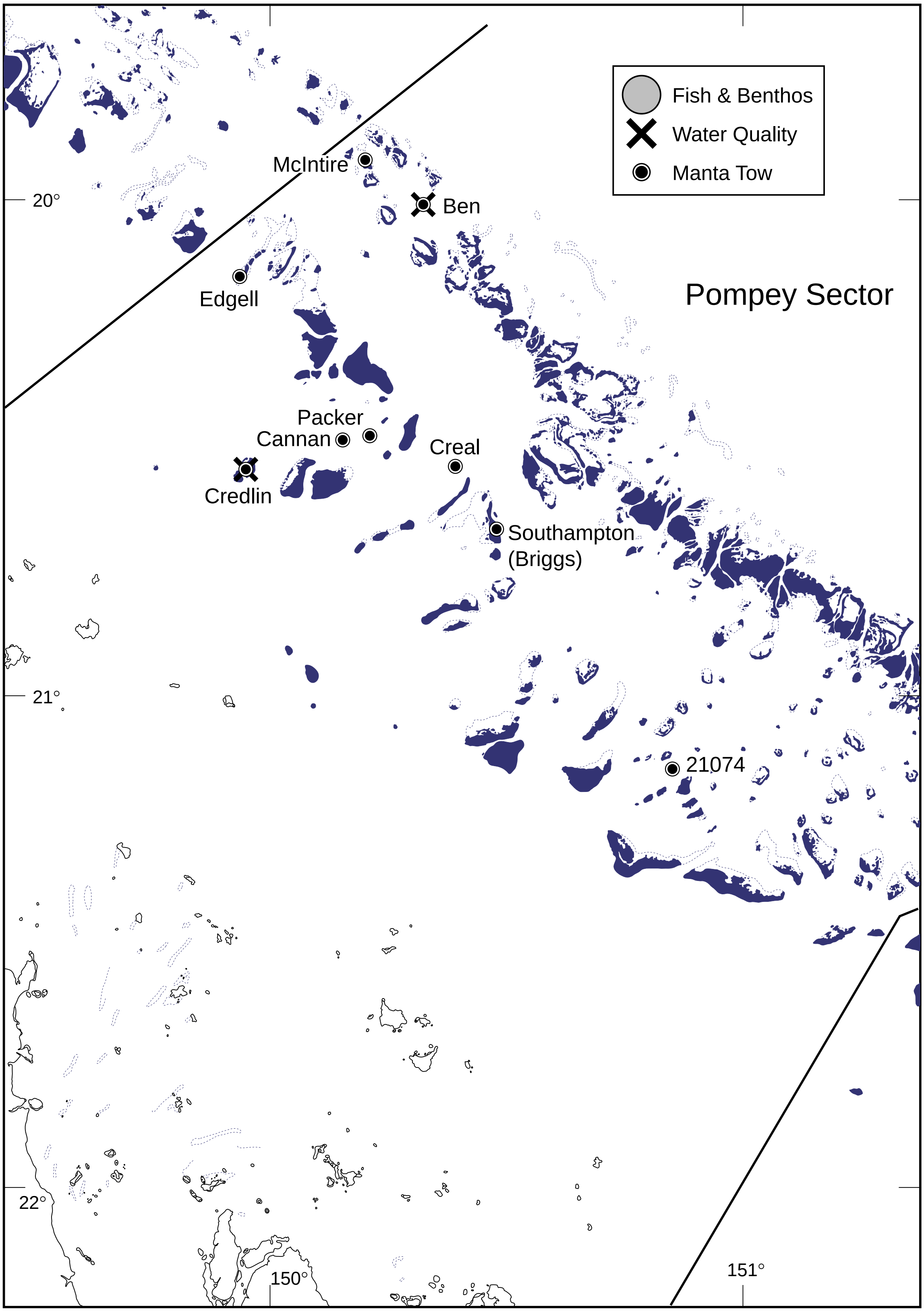

Fish & Benthos
Water Quality
Manta Tow
Milln
Moore
Cairns
17°
Scott
Noggin
Flora
Hedley
Innisfail Sector
Normanby
& Mabel
Wardle
Feather
Innisfail
North
Barnard
Is's
Hutchinson
Jessie & Kent Is
Potter (a)
Ellison
Beaver
18°
146°
Ingham
147°


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

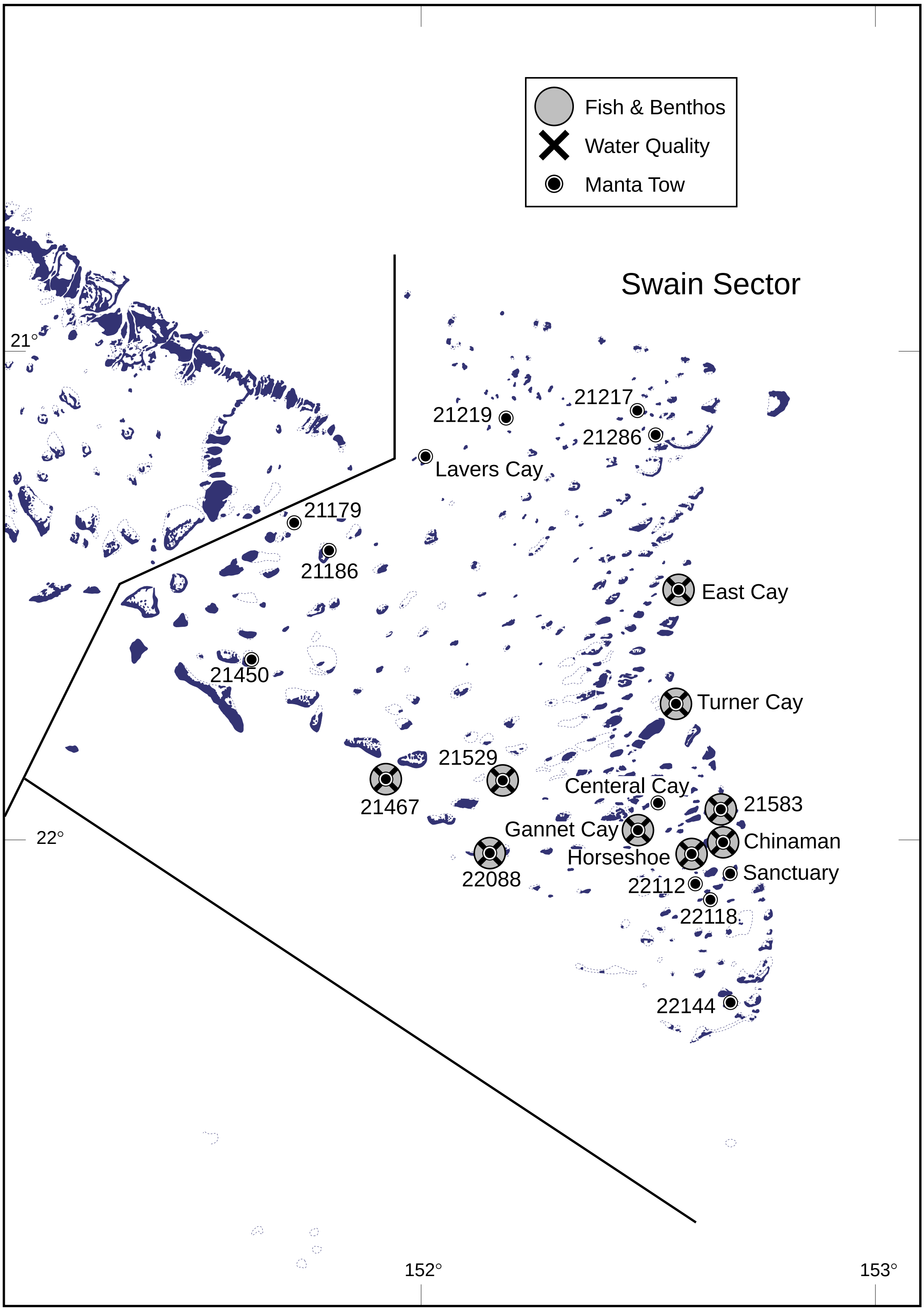

18°
Fish & Benthos
Water Quality
Manta Tow
Cape Upstart Sector
Viper
Shrimp
Jaguar
19°
Shell
Bowden
Kangaroo
(a&b)
Jacqueline
Elizabeth
Faith
Stanley
Charity
19098
Cape Upstart
Holbourne Is
20°
Bowen
147°
148°



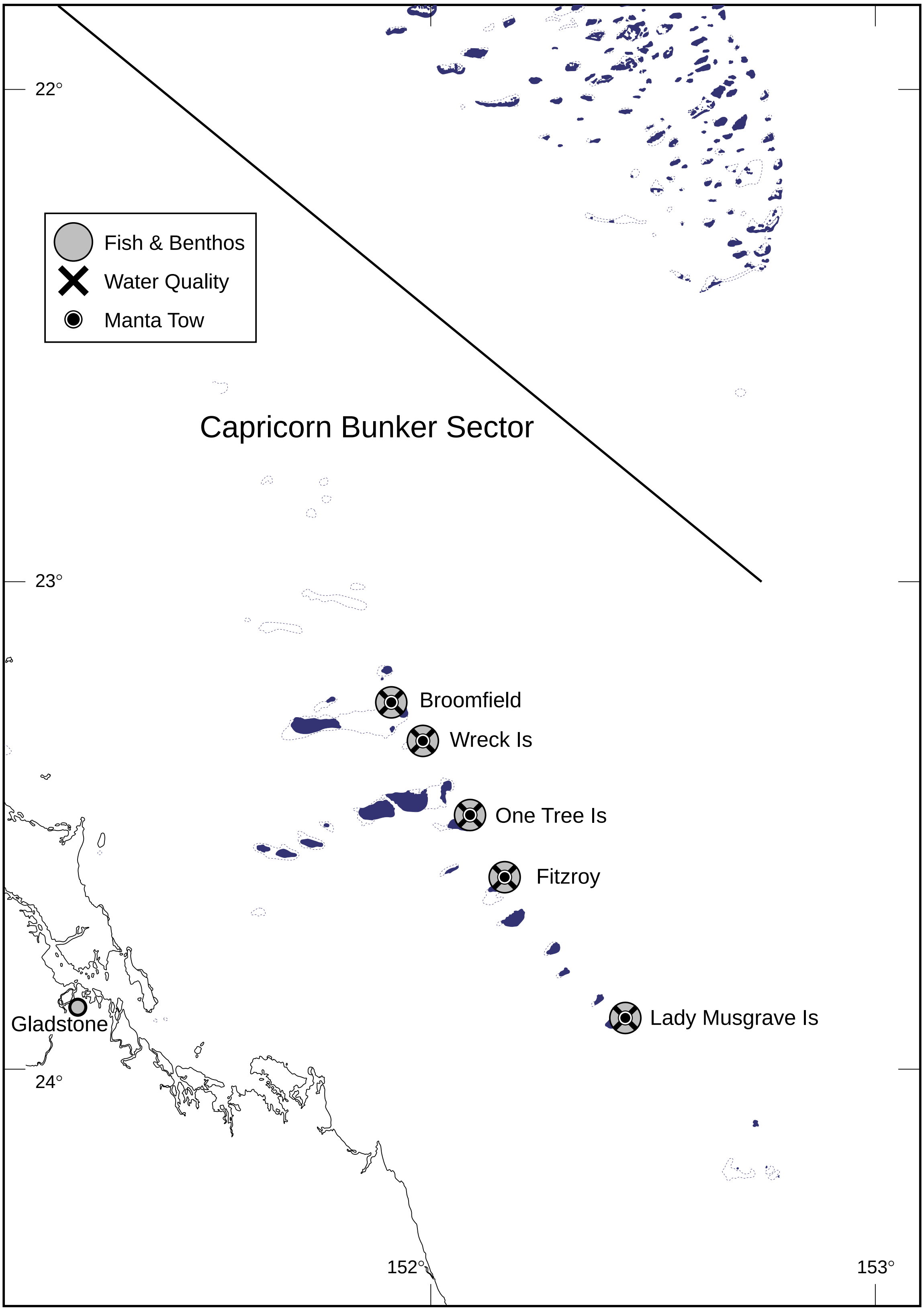
Fish & Benthos
Water Quality
Manta Tow
Whitsunday Sector
19°
20°
21°
149°
150°
Oublier
Plaster
19159
Hardy
Crab
Hyde
Rebe
19131
19138
Bait
Napier
Hayman
20104
Langford
& Bird Is's
Border Is
Airlie Beach
Mackay



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
East Cay
21450
Turner Cay
21529
21467
Centeral Cay
21583
Gannet Cay
Chinaman
Horseshoe
Sanctuary
22088
22112
22118
22144



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

APPENDIX 2

Summary of reefs surveyed in the first 3 years of the LTMP. Reefs in bold type are the core sampling reefs. Reef ID refers to the GBRMPA Gazetteer. Sampling codes:
B = benthos, **F** = reef fishes, **f** = small fish species only, **M** = manta tow, **W** = water samples.

Sector	Shelf position	Reef ID	Reef Name	Year surveyed		
				92/93	93/94	94/95
Cape Grenville	Inshore	11-167	BIRD IS'S		M	
		12-010	KAY	MW	MW	MW
		12-102	CURD	M		
	Mid-shelf	11-184	SIR CHARLES HARDY (1 & 2)	MW	W	W
		11-211	11-211			M
		11-222	MIDDLE BANKS (2 & 3)			M
		11-237	ASHMORE BANKS (1, 2 & 3)			M
		12-016	FORBES IS'S	M		
		12-027	QUOIN IS		M	
	Outer Shelf	11-243	RAINE IS			M
		12-061	LAGOON	MW	MW	MW
		12-071	12-071	M		
		12-098	SECOND SMALL		M	
		12-107	LOG (2)		M	
Princess Charlotte Bay	Inshore	13-006	OSBORNE	M		
		13-081	FIFE IS			M
		13-107	PELICAN IS			M
		14-017	CLACK	W	MW	W
	Mid-shelf	13-041	CELEBRATION		M	
		13-063	13-063	M		
		13-124	13-124	MW	MW	MW
	Outer Shelf	13-040	13-040		M	
		13-056	SAND BANK NO.8	M		
		13-118	CREECH (A)			M
		13-121	13-121		M	
		13-127	RODDA	MW	MW	MW
		13-130	DAVIE			M
		13-133	TYDEMAN	M		
Cooktown / Lizard Is	Inshore	14-097	COQUET IS	M		
		14-123	**MARTIN**	**MFBW**		**MFB**
		14-126	**LINNET**	**MFBW**		**MFBW**
		14-131	**DECAPOLIS**		**FBW**	**FBW**
		15-002	TWO ISLES	M		
		15-005	THREE ISLES		M	
		15-012	BOULDER	MW	MW	MW
		15-013	EGRET	M		

Sector	Shelf position	Reef ID	Reef Name	Year surveyed		
				92/93	93/94	94/95
Cooktown / Lizard Is	Mid-shelf	14-054	STAPLETON IT			M
		14-056	14-056	M		
		14-061	SWITZER			M
		14-064	INGRAM AND BEANLEY IS'S		M	
		14-109	FLY	W	M	
		14-114	**MACGILLIVRAY**	**MFBW**	**MFBW**	**MFBW**
		14-115	NYMPH IS		M	
		14-116	**LIZARD IS**		**MFBW**	**MFBW**
		14-118	EYRIE			M
		14-135	HELSDON	M		
		14-143	**NORTH DIRECTION IS**		**MFBW**	**MFBW**
		15-009	FORRESTER		M	
		15-024	MACKAY REEFS			M
		15-027	MARX		M	
		15-028	STARTLE (EAST)			M
		15-030	SWINGER			M
		15-047	15-047	M		
		15-077	15-077			M
		15-084	IRENE		M	
		15-089	ENDEAVOUR	M		
	Outer Shelf	14-045	SAND BANK NO.1	M		
		14-075	14-075			M
		14-085	HILDER		M	
		14-137	**CARTER**	**MFBW**		**MFBW**
		14-138	**YONGE**	**MFBW**	**MFBW**	**MFBW**
		14-139	**NO NAME**		**MFBW**	**MFBW**
		14-152	14-152		M	
		14-154	RIBBON NO.9	M		
		15-032	RIBBON NO.6		M	
		15-050	RIBBON NO.3			M
		15-080	RIBBON NO.1			M
		15-085	LENA		M	
Cairns	Inshore	**16-028**	**LOW ISLETS**	**MFBW**	**W**	**FBW**
		16-049	**GREEN IS**	**MFBW**	**MFBW**	**MFBW**
		16-054	**FITZROY IS**		**MFBW**	**MFBW**
	Mid-shelf	15-095	EVENING			M
		15-098	MORNING	M		
		16-013	16-013 (A, B & C)			M
		16-015	**MACKAY**	**MFBW**		**MFBW**
		16-017	16-017		M	
		16-020	UNDINE (A)	MW	MW	MW
		16-023	RUDDER	M		
		16-026	TONGUE (2)	M		
		16-032	SAXON	M		
		16-040	PIXIE	M		
		16-043	OYSTER (A)	M		
		16-044	MIDDLE CAY (B)		M	
		16-046	UPOLU CAY			M
		16-057	**HASTINGS**	**MFBW**	**MFBW**	**MFBW**
		16-060	**MICHAELMAS**	**MFBW**	**MFBW**	**MFBW**
		16-068	**THETFORD**		**MFBW**	**MFBW**

Sector	Shelf position	Reef ID	Reef Name	Year surveyed		
				92/93	93/94	94/95
Cairns	Outer Shelf	15-088	RUBY	M		
		15-090	ANDERSEN		M	
		15-092	15-092			M
		15-094	ESCAPE (1)		M	
		15-096	AGINCOURT NO.4	M		
		15-099	**AGINCOURT NO.1**		**MFBW**	**MFBW**
		15-099	AGINCOURT NO.3		M	
		16-019	**ST. CRISPIN**	**MFBW**		**FBW**
		16-025	**OPAL (2)**			**MFBW**
		16-030	NORMAN	W	W	MW
		16-063	EUSTON		W	MW
		16-065	FLYNN		M	M
Innisfail	Inshore	17-012	NORMANBY AND MABEL IS'S	M		
		17-043	HUTCHISON IS			M
		17-043	JESSIE AND KENT IS'S			M
	Mid-shelf	16-067	MILLN		M	
		16-071	MOORE		M	
		17-004	SCOTT			M
		17-010	FLORA	M		
		17-034	FEATHER	W	M	MW
		17-044	ELLISON		M	
		17-051	BEAVER		M	
	Outer Shelf	17-008	NOGGIN			M
		17-014	HEDLEY		M	
		17-032	WARDLE		MW	MW
		17-059	POTTER (A)			M
Townsville	Inshore	**18-051**	**PANDORA**	**FBW**	**FBW**	**FBW**
		19-011	**MIDDLE**	**fBW**	**B**	**fBW**
	Mid-shelf	18-029	BRAMBLE		M	
		18-032	**RIB**		**MFBW**	**MFBW**
		18-075	**JOHN BREWER**	**MFBW**		**MFBW**
		18-076	HELIX	M		
		18-095	WHEELER			M
		18-096	**DAVIES**	**MFBW**	**MFBW**	**MFBW**
		18-099	18-099			M
		18-106	LITTLE BROADHURST	M		
	Outer Shelf	18-023	18-023		M	
		18-034	**MYRMIDON**	**MFBW**	**MFBW**	**MFBW**
		18-039	**DIP**	**MFBW**		**MFBW**
		18-086	**CHICKEN**		**MFBW**	**MFBW**
Cape Upstart	Inshore	19-103	HOLBOURNE IS			M
	Mid-shelf	18-118	SHRIMP		M	
		19-019	BOWDEN	M	MW	MW
		19-028	SHELL		M	
		19-044	FAITH	M	MW	MW
		19-045	STANLEY	M		
		19-047	CHARITY		M	
		19-063	KANGAROO (A & B)	M		
		19-082	ELIZABETH			M
		19-098	19-098			M

Sector	Shelf position	Reef ID	Reef Name	Year surveyed		
				92/93	93/94	94/95
Cape Upstart	Outer Shelf	18-112	VIPER	M		
		18-120	JAGUAR	M		
		19-061	JACQUELINE			M
Whitsundays	Inshore	**20-014**	**HAYMAN IS**	**MFBW**	**MFBW**	**MFBW**
		20-019	**LANGFORD AND BIRD IS'S**	**MFBW**		**MFBW**
		20-067	**BORDER IS (A)**		**FBW**	**MFBW**
	Mid-shelf	**19-131**	**19-131**		**MFBW**	**MFBW**
		19-135	**HARDY**	**MFBW**		**MFBW**
		19-137	BAIT	M		
		19-138	**19-138**	**MFBW**	**MFBW**	**MFBW**
		19-147	PLASTER		M	
		19-177	CRAB			M
		19-195	NAPIER	M		
		20-104	**20-104**	**MFBW**	**MFBW**	**MFBW**
	Outer Shelf	**19-159**	**19-159**	**MFB**		**MFBW**
		19-207	**HYDE**	**MFB**	**MFBW**	**MFBW**
		19-209	**REBE**		**MFBW**	**MFBW**
Pompeys	Mid-shelf	19-219	MCINTYRE		M	
		20-112	EDGELL		M	
		20-144	CANNAN	M		
		20-145	PACKER		M	
		20-287	CREDLIN	MW	MW	MW
		20-297	CREAL		M	
		20-299	SOUTHAMPTON (BRIGGS)			M
		21-074	21-074			M
	Outer Shelf	20-113	BEN		MW	MW
Swains	Inshore	**21-467**	**21-467**		**MFBW**	**MFBW**
		22-088	**22-088**	**MFBW**	**MFBW**	**MFBW**
	Mid-shelf	21-179	21-179			M
		21-186	21-186			M
		21-217	21-217		M	
		21-219	21-219		M	
		21-235	LAVER'S CAY		M	
		21-286	21-286		M	
		21-450	21-450			M
		21-529	**21-529**	**MFBW**		**MFBW**
		21-556	**GANNET CAY**	**MFBW**	**MFBW**	**MFBW**
		21-577	CENTRAL	M		
		22-102	**CHINAMAN**	**MFBW**	**MFBW**	**MFBW**
		22-104	**HORSESHOE**	**MFBW**		**MFBW**
		22109	SANCTUARY	M		
		22-112	22-112	M		
		22-118	22-118	M		
		22-144	22-144	M		
	Outer Shelf	**21-305**	**EAST CAY**		**MFBW**	**MFBW**
		21-562	**TURNER CAY**		**MFBW**	**MFBW**
		21-583	**21-583**			**MFW**
Capricorn / Bunker Group	Outer Shelf	**23-048**	**BROOMFIELD**	**MFBW**		**MFBW**
		23-051	**WRECK IS**	**MFBW**		
		23-055	**ONE TREE IS**	**MFBW**	**MFBW**	**MFBW**
		23-077	**FITZROY**		**MFBW**	
		23-082	**LADY MUSGRAVE IS**	**MFBW**	**M**	**MFBW**

APPENDIX 3

A. List of larger, more mobile fish species that would be counted on 10 or 5 m wide transects.

Acanthuridae
Acanthurus albipectoralis
Acanthurus blochii
Acanthurus dussumieri
Acanthurus grammoptilus
Acanthurus lineatus
Acanthurus maculiceps
Acanthurus mata
Acanthurus nigricans
Acanthurus nigricauda
Acanthurus nigrofuscus
Acanthurus nigroris
Acanthurus olivaceus
Acanthurus pyropherus
Acanthurus spp.
Acanthurus triostegus
Acanthurus xanthopterus
Ctenochaetus (grouped)
Naso annulatus/brevirostris
Naso lituratus
Naso tuberosus
Naso unicornus
Paracanthurus hepatus
Zebrasoma scopas
Zebrasoma veliferum

Chaetodontidae
Chaetodon aureofasciatus
Chaetodon auriga
Chaetodon baronessa
Chaetodon bennetti
Chaetodon citrinellus
Chaetodon ephippium
Chaetodon flavirostris
Chaetodon kleinii
Chaetodon lineolatus
Chaetodon lunula
Chaetodon melannotus
Chaetodon meyerii
Chaetodon ocellicaudus
Chaetodon ornatissimus
Chaetodon pelewensis
Chaetodon plebeius
Chaetodon punctatofasciatus
Chaetodon rafflesi
Chaetodon rainfordi
Chaetodon reticulatus
Chaetodon speculum

Chaetodontidae (cont)
Chaetodon trifascialis
Chaetodon trifasciatus
Chaetodon ulietensis
Chaetodon unimaculatus
Chaetodon vagabundus
Chelmon rostratus
Forcipiger flavissimus
Forcipiger longirostrus
Hemitaurichthys polylepis

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

Lethrinidae
Lethrinus atkinsoni
Lethrinus harak
Lethrinus laticaudus
Lethrinus lentjan
Lethrinus miniatus
Lethrinus nebulosus
Lethrinus obsoletus
Lethrinus olivaceus
Lethrinus ornatus
Lethrinus xanthochilus
Monotaxis grandoculis

Lutjanidae
Lutjanus adetti
Lutjanus argentimaculatus
Lutjanus bohar
Lutjanus carponotatus
Lutjanus fulviflamma
Lutjanus fulvus
Lutjanus gibbus
Lutjanus kasmira
Lutjanus lutjanus
Lutjanus monostigma
Lutjanus quinquelineatus
Lutjanus russelli

Lutjanidae (cont)
Lutjanus vittus
Macolor (grouped)

Scaridae
Bolbometapon muricatum
Cetoscarus bicolor
Hipposcarus longiceps
Calotomus carolinus
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
Scarus spp.

Serranidae
Plectropomus areolatus
Plectropomus laevis
Plectropomus leopardus
Plectropomus maculatus
Variola louti

Siganidae
Siganus argenteus
Siganus corallinus
Siganus doliatus
Siganus javus
Siganus lineatus
Siganus puellus
Siganus punctatissimus
Siganus punctatus
Siganus vulpinus

Zanclidae
Zanclus cornutus

B. List of damselfish species that would be counted on 2 or 1 m wide transects.

Acanthochromis polyacanthus
Amblyglyphidodon curacao
Amblyglyphidodon leucogaster
Amphiprion akindynos
Amphiprion chrysopterus
Amphiprion clarkii
Amphiprion melanopus
Amphiprion perideraion
Chromis acares
Chromis agilis
Chromis amboinensis
Chromis atripectoralis
Chromis atripes
Chromis chrysura
Chromis flavomaculata
Chromis iomelas
Chromis lepidolepis
Chromis margaritifer
Chromis nitida
Chromis retrofasciatus
Chromis ternatensis
Chromis vanderbilti
Chromis viridis
Chromis weberi
Chromis xanthura
Chrysiptera flavipinnis
Chrysiptera rex
Chrysiptera rollandi
Chrysiptera talboti
Dascyllus aruanus
Dascyllus reticulatus
Dascyllus trimaculatus
Dischistodus melanotus
Dischistodus perspicillatus
Dischistodus prosopotaenia
Dischistodus pseudochrysopoecilus
Hemiglyphidodon plagiometopon
Neoglyphidodon melas
Neoglyphidodon nigroris
Neoglyphidodon polyacanthus
Neopomacentrus azysron
Neopomacentrus bankieri
Neopomacentrus cyanomos
Plectroglyphidodon dickii
Plectroglyphidodon johnstonianus
Plectroglyphidodon lacrymatus
Pomacentrus amboinensis
Pomacentrus australis
Pomacentrus bankanensis
Pomacentrus brachialis
Pomacentrus chrysurus
Pomacentrus coelestis
Pomacentrus grammnorhyncus
Pomacentrus lepidogenys
Pomacentrus moluccensis
Pomacentrus nagasakiensis
Pomacentrus philippinus
Pomacentrus taeniometapon
Pomacentrus vaiuli
Pomacentrus wardi
Pomachromis richardsoni
Premnas biaculeatus
Stegastes apicalis
Stegastes fasciolatus
Stegastes nigricans

APPENDIX 4: SUMMARY COUNTS OF THE DIFFERENT FISH TAXA RECORDED ON REEFS IN EACH SURVEY YEAR

A. Numbers of larger, mobile fishes recorded on reefs in 1993-94 surveys. Sum from all transects at all sites on each reef.

Reef	Reef ID No	Sector	Shelf position	Acanthur-idae	Chaetodon-tidae	Labridae	Lethrinidae	Lutjanidae	Scaridae	Serranidae	Siganidae	Zanclidae
Decapolis	14-131	CL	I	5	26	14	2	38	15	15	67	0
Macgillivray	14-114	CL	M	119	119	56	31	114	148	13	34	2
Lizard Is	14-116	CL	M	117	110	66	20	19	104	15	52	0
North Direction Is	14-143	CL	M	88	133	69	20	21	150	16	64	2
Yonge	14-138	CL	O	789	129	57	22	31	346	3	1	22
No Name	14-139	CL	O	888	185	44	32	100	372	8	13	30
Green Is	16-049	CA	I	159	113	87	8	170	186	7	52	0
Fitzroy Is	16-054	CA	I	23	88	78	2	76	37	1	45	0
Hastings	16-057	CA	M	384	100	48	13	9	191	2	21	6
Michaelmas	16-060	CA	M	315	84	32	8	147	117	7	25	6
Thetford	16-068	CA	M	373	41	59	3	15	284	5	16	11
Agincourt No.1	15-099	CA	O	729	125	46	25	15	488	1	17	15
Pandora	18-051	TO	I	7	144	67	4	43	50	21	32	0
Rib	18-032	TO	M	156	124	47	1	1	222	3	47	0
Davies	18-096	TO	M	107	94	50	2	4	276	13	34	2
Myrmidon	18-034	TO	O	194	100	24	2	1	115	3	0	6
Chicken	18-086	TO	O	212	69	43	5	2	156	13	11	1
Hayman Is	20-014	WH	I	24	92	45	0	15	54	8	41	0
Border Is (A)	20-067	WH	I	4	84	29	0	61	51	23	36	0
19131	19-131	WH	M	83	140	62	5	19	324	41	130	0
19138	19-138	WH	M	47	105	100	10	19	355	25	47	2
20104	20-104	WH	M	40	35	75	18	52	232	26	44	0
Hyde	19-207	WH	O	300	110	50	7	9	195	9	27	8
Rebe	19-209	WH	O	392	77	44	1	2	213	7	21	7
21467	21-467	SW	I	25	89	63	0	34	109	21	67	1
22088	22-088	SW	I	116	99	58	9	15	241	16	37	24
Gannet Cay	21-556	SW	M	60	139	61	25	20	415	104	73	6
Chinaman	22-102	SW	M	273	89	85	9	12	223	36	23	9
East Cay	21-305	SW	O	171	103	58	3	1	90	8	10	19
Turner Cay	21-562	SW	O	290	108	66	4	0	206	14	13	3
One Tree Is	23-055	CB	O	27	3	1	28	0	29	3	0	0
Fitzroy	23-077	CB	O	23	53	6	0	24	10	11	2	2

B. Numbers of larger, mobile fishes recorded on reefs in 1994-95 surveys. Sum from all transects at all sites on each reef.

Reef	Reef ID No	Sector	Shelf position	Acanthur-idae	Chaetodon-tidae	Labridae	Lethrinidae	Lutjanidae	Scaridae	Serranidae	Siganidae	Zanclidae
Martin	14-123	CL	I	144	86	51	21	66	107	8	50	0
Linnet	14-126	CL	I	111	117	64	0	83	131	5	113	0
Decapolis	14-131	CL	I	1	28	17	16	19	20	11	22	0
Macgillivray	14-114	CL	M	86	82	60	13	42	101	8	12	0
Lizard Is	14-116	CL	M	111	74	29	11	21	109	11	52	0
North Direction Is	14-143	CL	M	74	76	75	18	9	124	12	63	0
Carter	14-137	CL	O	634	110	24	10	129	183	3	1	23
Yonge	14-138	CL	O	495	68	34	9	11	223	2	4	8
No Name	14-139	CL	O	446	89	33	10	45	229	3	16	11
Low Islets	16-028	CA	I	2	73	27	0	53	41	7	29	0
Green Is	16-049	CA	I	156	87	44	14	75	173	17	50	0
Fitzroy Is	16-054	CA	I	20	80	48	6	115	53	4	28	0
Mackay	16-015	CA	M	22	89	53	6	39	147	7	24	4
Hastings	16-057	CA	M	336	65	31	12	31	97	3	9	3
Michaelmas	16-060	CA	M	247	62	29	5	7	123	3	7	0
Thetford	16-068	CA	M	271	32	35	5	30	398	3	9	5
Agincourt No.1	15-099	CA	O	496	78	51	18	12	182	2	3	13
St. Crispin	16-019	CA	O	323	95	68	19	13	251	3	11	2
Opal (2)	16-025	CA	O	374	84	20	8	9	129	1	3	4
Pandora	18-051	TO	I	2	86	31	2	49	50	3	17	0
Rib	18-032	TO	M	143	145	48	11	1	200	3	23	0
John Brewer	18-075	TO	M	129	80	70	6	5	256	4	59	2
Davies	18-096	TO	M	86	74	59	4	5	262	9	48	0
Myrmidon	18-034	TO	O	357	108	30	6	1	161	1	6	16
Dip	18-039	TO	O	494	57	47	8	10	170	3	18	3
Chicken	18-086	TO	O	473	68	41	6	4	286	22	49	4
Hayman Is	20-014	WH	I	8	63	50	0	29	62	2	15	0
Langford & Bird Is	20-019	WH	I	5	87	54	8	21	80	7	25	0
Border Is (A)	20-067	WH	I	2	57	36	0	42	56	21	19	0

B continued. Numbers of larger, mobile fishes recorded on reefs in 1994-95 surveys. Sum from all transects at all sites on each reef.

Reef	Reef ID No	Sector	Shelf position	Acanthur-idae	Chaetodon-tidae	Labridae	Lethrinidae	Lutjanidae	Scaridae	Serranidae	Siganidae	Zanclidae
19131	19-131	WH	M	0	75	34	0	10	72	12	8	0
Hardy	19-135	WH	M	55	80	50	12	45	200	39	29	0
19138	19-138	WH	M	19	64	59	2	14	216	13	44	0
20104	20-104	WH	M	9	19	54	1	26	148	12	20	0
19159	19-159	WH	O	104	126	45	5	5	86	9	8	9
Hyde	19-207	WH	O	132	40	36	1	0	112	2	17	2
Rebe	19-209	WH	O	147	28	24	0	4	120	7	7	8
21467	21-467	SW	I	15	61	49	3	19	118	4	33	0
22088	22-088	SW	I	86	52	53	1	6	211	8	21	7
21529	21-529	SW	M	6	65	44	14	8	139	33	24	0
Gannet Cay	21-556	SW	M	36	88	91	11	5	254	28	37	3
Chinaman	22-102	SW	M	188	27	61	5	2	209	18	12	4
Horseshoe	22-104	SW	M	201	99	60	2	7	191	9	23	5
East Cay	21-305	SW	O	146	71	36	2	3	101	12	6	12
Turner Cay	21-562	SW	O	158	77	55	1	4	152	7	2	4
21583	21-583	SW	O	238	71	65	5	6	170	13	15	1
Broomfield	23-048	CB	O	126	35	20	71	2	65	9	2	0
One Tree Is	23-055	CB	O	11	10	1	3	0	17	4	2	0
Lady Musgrave Is	23-082	CB	O	152	16	10	1	1	66	1	2	0

C. Numbers of damselfishes recorded on reefs in 1993-94 surveys. Sum from all transects at all sites on each reef.

Reef	Reef ID No.	Sector	Shelf	*Acanthochromis*	*Amblyglyphidodon*	*Amphiprion*	*Chromis*	*Chrysiptera*	*Dascyllus*	*Dischistodus*	*Hemiglyphidodon*	*Neoglyphidodon*	*Neopomacentrus*	*Plectroglyphidodon*	*Pomacentrus*	*Pomachromis*	*Premnas*	*Stegastes*	All
Decapolis	14-131	CL	I	6	2	0	0	9	0	0	0	8	459	0	433	0	0	0	917
Macgillivray	14-114	CL	M	83	44	0	193	165	19	5	0	10	175	33	748	0	3	0	1478
Lizard Is	14-116	CL	M	85	76	2	100	107	22	2	0	9	273	35	403	0	0	0	1114
North Direction Is	14-143	CL	M	61	92	7	49	263	10	37	1	15	92	14	401	0	3	0	1045
Yonge	14-138	CL	O	64	0	0	646	63	0	0	0	0	0	57	357	42	0	1	1230
No Name	14-139	CL	O	110	0	0	251	28	1	0	0	1	8	38	515	1	0	6	959
Green Is	16-049	CA	I	15	56	0	57	148	36	6	0	10	50	4	771	0	0	1	1154
Fitzroy Is	16-054	CA	I	28	53	0	0	17	0	0	0	69	338	0	679	0	0	3	1187
Hastings	16-057	CA	M	12	7	2	51	22	9	0	0	0	61	125	386	0	0	47	722
Michaelmas	16-060	CA	M	21	11	4	108	19	0	0	0	1	328	103	597	0	0	11	1203
Thetford	16-068	CA	M	50	10	7	39	23	4	0	0	2	101	103	684	0	0	6	1029
Agincourt No.1	15-099	CA	O	11	0	0	222	28	0	0	0	0	10	150	187	0	0	0	608
Pandora	18-051	TO	I	74	13	0	0	1	0	0	0	60	1178	0	518	0	0	0	1844
Rib	18-032	TO	M	54	40	6	240	57	1	6	0	50	1510	37	1525	0	0	2	3528
Davies	18-096	TO	M	53	96	20	28	142	0	0	0	140	809	33	2229	0	0	0	3550
Myrmidon	18-034	TO	O	29	5	2	214	2	3	0	0	0	0	106	209	3	0	5	578
Chicken	18-086	TO	O	61	0	2	51	62	0	0	0	3	803	129	965	0	0	59	2135
Hayman Is	20-014	WH	I	257	89	0	23	82	1	0	0	17	483	0	2276	0	0	1	3229
Border Is (A)	20-067	WH	I	102	70	0	430	475	0	0	0	5	1375	0	1749	0	0	0	4206
19131	19-131	WH	M	31	6	3	28	35	0	0	0	2	3382	0	3164	0	0	18	6669
19138	19-138	WH	M	39	33	4	238	59	0	0	0	3	1521	0	3320	0	0	33	5250
20104	20-104	WH	M	31	13	1	53	128	0	0	0	10	1901	0	1824	0	0	24	3985
Hyde	19-207	WH	O	45	33	5	16	57	8	0	0	33	7	45	682	0	0	0	931
Rebe	19-209	WH	O	51	18	2	19	39	6	0	0	17	144	53	726	0	0	1	1076
21467	21-467	SW	I	9	9	0	27	6	0	0	0	16	2117	1	2167	0	0	2	4354
22088	22-088	SW	I	2	48	6	0	5	0	0	0	1	354	1	1863	0	0	8	2288
Gannet Cay	21-556	SW	M	3	333	4	3101	27	0	2	0	12	2	2	2465	0	0	3	5954
Chinaman	22-102	SW	M	13	73	5	147	5	0	0	0	29	242	41	2648	0	0	1	3204
East Cay	21-305	SW	O	29	142	2	11	35	0	0	0	28	77	34	1528	0	0	8	1894
Turner Cay	21-562	SW	O	18	69	8	24	21	0	0	0	20	41	48	1976	0	0	19	2244
One Tree Is	23-055	CB	O	0	0	0	0	25	0	0	0	0	0	0	3501	0	0	0	3526
Fitzroy	23-077	CB	O	0	0	2	7	26	0	0	0	0	7	4	4422	0	0	0	4468

D. Numbers of damselfishes recorded on reefs in 1994-195 surveys. Sum from all transects at all sites on each reef.

Reef	Reef ID No.	Sector	Shelf	*Acantho-chromis*	*Amblygly-phidodon*	*Amphip-rion*	*Chromis*	*Chrysip-tera*	*Dascyllus*	*Dischist-odus*	*Hemigly-phidodon*	*Neoglyphi-dodon*	*Neopoma-centrus*	*Plectrogly-phidodon*	*Poma-centrus*	*Poma-chromis*	*Premnas*	*Stegastes*	All
Macgillivray	14-114	CL	M	53	49	0	69	113	10	3	0	6	123	24	529	0	4	0	983
Lizard Is	14-116	CL	M	68	57	5	31	113	51	1	0	13	197	18	938	0	0	0	1492
Martin	14-123	CL	I	49	21	0	25	72	7	4	0	12	518	0	1151	0	0	1	1860
Linnet	14-126	CL	I	106	57	1	40	44	7	0	0	21	260	0	1104	0	0	0	1640
Decapolis	14-131	CL	I	8	1	0	0	5	0	0	0	4	398	0	333	0	0	0	749
Carter	14-137	CL	O	39	1	0	170	7	0	0	0	0	0	19	151	6	0	4	397
Yonge	14-138	CL	O	31	0	0	226	15	0	0	0	0	0	47	144	3	0	5	471
No Name	14-139	CL	O	68	0	0	198	3	1	0	0	0	0	34	271	1	0	3	579
North Direction Is	14-143	CL	M	33	75	4	36	182	6	15	1	14	80	12	689	0	3	0	1150
Agincourt No.1	15-099	CA	O	16	0	0	263	35	0	0	0	0	0	89	194	0	0	0	597
Mackay	16-015	CA	M	22	120	0	6	122	6	16	1	52	24	3	951	0	0	0	1323
St. Crispin	16-019	CA	O	13	13	1	191	4	5	0	0	1	0	86	284	7	0	0	605
Opal (2)	16-025	CA	O	22	1	1	263	21	6	0	0	6	50	74	118	0	0	0	562
Low Islets	16-028	CA	I	14	10	0	0	49	3	3	0	32	159	0	848	0	0	0	1118
Green Is	16-049	CA	I	17	35	0	49	241	30	2	0	4	53	5	569	0	0	1	1006
Fitzroy Is	16-054	CA	I	8	32	0	0	37	0	1	0	46	204	0	629	0	0	3	960
Hastings	16-057	CA	M	16	4	3	50	5	3	0	0	0	95	117	429	0	0	51	773
Michaelmas	16-060	CA	M	4	4	2	49	14	0	0	0	2	547	79	610	0	0	6	1317
Thetford	16-068	CA	M	11	5	0	36	19	2	0	0	4	61	118	498	0	0	7	761
Rib	18-032	TO	M	39	55	0	338	52	0	6	0	41	670	15	868	0	0	0	2084
Myrmidon	18-034	TO	O	27	5	1	371	4	12	0	0	0	64	115	194	7	0	5	805
Dip	18-039	TO	O	22	0	4	237	15	0	1	0	0	73	90	270	33	0	34	779
Pandora	18-051	TO	I	73	9	0	0	0	0	0	0	41	2490	0	576	0	0	0	3189
John Brewer	18-075	TO	M	37	33	6	43	68	1	9	0	62	761	16	1083	0	0	22	2141
Chicken	18-086	TO	O	36	1	4	84	35	0	0	0	3	897	122	714	0	0	52	1948
Davies	18-096	TO	M	46	82	16	108	83	0	1	0	116	852	16	1634	0	0	0	2954
Middle	19-011	TO	I	8	0	0	0	0	0	0	0	1	604	0	72	0	0	0	685
19131	19-131	WH	M	3	5	0	15	15	0	0	0	0	1720	0	936	0	0	5	2699
Hardy	19-135	WH	M	32	4	2	80	22	0	0	0	5	573	1	1291	0	0	4	2014
19138	19-138	WH	M	5	38	1	126	24	0	0	0	0	695	0	1309	0	0	15	2213
19159	19-159	WH	O	21	80	2	46	28	3	0	0	33	68	72	552	0	0	4	909

D continued. Numbers of damselfishes recorded on reefs in 1994-195 surveys. Sum from all transects at all sites on each reef.

Reef	Reef ID No.	Sector	Shelf	*Acantho-chromis*	*Amblygly-phidodon*	*Amphip-rion*	*Chromis*	*Chrysip-tera*	*Dascyllus*	*Dischist-odus*	*Hemigly-phidodon*	*Neoglyphi-dodon*	*Neopoma-centrus*	*Plectrogly-phidodon*	*Poma-centrus*	*Poma-chromis*	*Premnas*	*Stegastes*	All
Hyde	19-207	WH	O	21	15	0	14	21	1	0	0	15	5	21	375	2	0	0	490
Rebe	19-209	WH	O	30	13	0	11	13	2	0	0	9	14	36	307	0	0	1	436
Hayman Is	20-014	WH	I	118	51	0	2	53	0	0	0	2	226	0	1135	0	0	0	1587
Langford & Bird Is	20-019	WH	I	57	28	0	5	119	0	4	0	9	44	0	741	0	0	0	1007
Border Is (A)	20-067	WH	I	70	39	0	261	258	0	0	0	0	598	0	927	0	0	0	2153
20104	20-104	WH	M	4	11	0	141	123	0	0	0	4	669	0	803	0	0	11	1766
East Cay	21-305	SW	O	20	61	3	0	28	0	1	0	20	36	24	723	0	0	5	921
21467	21-467	SW	I	11	12	0	18	7	0	0	0	6	1136	1	1304	0	0	6	2501
21529	21-529	SW	M	3	125	2	470	122	0	1	0	5	1	1	2025	0	0	2	2757
Gannet Cay	21-556	SW	M	3	157	3	1004	15	0	4	0	2	10	3	1835	0	0	2	3038
Turner Cay	21-562	SW	O	16	69	5	51	12	0	0	0	21	54	43	1175	0	0	22	1468
21583	21-583	SW	O	15	36	8	185	6	1	0	0	5	316	43	1381	0	0	0	1996
22088	22-088	SW	I	2	36	1	4	7	0	0	0	6	442	0	1276	0	0	11	1785
Chinaman	22-102	SW	M	6	69	5	95	3	0	0	0	20	184	44	1660	0	0	1	2087
Horseshoe	22-104	SW	M	1	125	2	2	7	0	0	0	2	13	3	1388	0	0	1	1544
Broomfield	23-048	CB	O	2	1	0	18	13	0	0	0	1	44	3	1565	0	0	0	1647
One Tree Is	23-055	CB	O	0	0	0	0	14	0	0	0	0	0	0	1256	0	0	0	1270
Lady Musgrave Is	23-082	CB	O	0	0	2	2	10	0	0	0	0	5	0	925	0	0	0	944

APPENDIX 5: PERCENTAGE COVER OF BENTHIC GROUPS RECORDED ON REEFS IN EACH SURVEY YEAR

A. Percentage cover of benthic groups recorded on reefs in 1993-94 surveys. Mean values from all sites on each reef.

Reef	Reef ID No.	Sector	Shelf position	Percentage cover of: Abiotic substrates	Coralline algae	Hard coral	Macro-algae	Soft coral	Sponges	Turf algae	Other	Unidentified
Decapolis	14-131	CL	I	19.5	0.0	20.8	30.9	6.1	0.0	34.1	1.1	1.6
Macgillivray	14-114	CL	M	29.0	4.7	23.3	1.5	5.9	0.9	39.4	2.1	2.6
Lizard Is	14-116	CL	M	6.7	10.9	17.0	0.0	18.5	1.5	44.3	1.9	3.4
North Direction Is	14-143	CL	M	20.9	9.1	21.1	0.8	2.8	1.0	44.5	1.3	3.6
Yonge	14-138	CL	O	2.3	45.0	12.4	1.7	5.0	1.1	27.7	2.3	7.4
No Name	14-139	CL	O	1.7	38.1	21.0	0.9	11.6	1.6	17.2	3.3	8.1
Green Is	16-049	CA	I	20.8	1.6	8.9	2.3	8.3	1.5	61.7	1.9	1.3
Fitzroy Is	16-054	CA	I	16.5	0.7	24.2	1.2	21.5	1.0	35.4	1.2	2.6
Hastings	16-057	CA	M	0.9	6.9	20.2	1.3	10.9	1.3	60.2	2.3	1.3
Michaelmas	16-060	CA	M	5.3	9.1	15.5	2.1	25.8	2.2	38.8	4.2	4.2
Thetford	16-068	CA	M	4.2	14.4	15.8	2.2	14.3	0.8	48.5	1.8	2.8
Agincourt No.1	15-099	CA	O	2.4	31.6	17.7	1.2	22.4	1.1	23.4	1.1	2.9
Pandora	18-051	TO	I	7.6	0.0	51.9	0.0	19.6	0.0	18.7	3.4	2.5
Rib	18-032	TO	M	10.3	7.8	38.0	2.3	6.2	2.3	33.5	1.0	3.0
Davies	18-096	TO	M	4.5	6.1	26.3	9.8	2.8	2.0	47.8	2.7	3.7
Myrmidon	18-034	TO	O	7.7	6.4	29.8	1.0	24.6	0.7	27.8	2.1	5.3
Chicken	18-086	TO	O	1.7	8.5	30.2	1.3	9.5	0.7	46.8	1.8	2.7
Hayman Is	20-014	WH	I	9.1	0.7	39.5	0.0	14.6	1.4	33.0	3.9	1.6
Border Is (A)	20-067	WH	I	16.7	0.8	25.0	0.0	33.3	2.2	23.1	2.2	1.5
19131	19-131	WH	M	2.2	3.0	56.7	1.5	1.4	1.0	32.8	5.7	2.9
19138	19-138	WH	M	5.3	8.6	26.2	0.8	3.8	1.1	55.9	1.8	4.5
20104	20-104	WH	M	4.3	8.9	13.6	23.6	2.9	1.2	44.6	3.5	2.9
Hyde	19-207	WH	O	2.3	8.5	16.4	1.5	47.5	10.5	12.9	1.9	3.4
Rebe	19-209	WH	O	1.6	7.4	17.9	0.7	30.7	11.4	31.9	2.2	1.2
21467	21-467	SW	I	1.8	12.7	34.4	1.5	22.7	0.7	25.6	1.9	2.7
22088	22-088	SW	I	1.7	22.1	21.4	0.7	6.6	1.7	44.6	1.8	2.9
Gannet Cay	21-556	SW	M	3.4	6.6	48.8	0.0	4.6	0.0	36.8	0.6	3.8
Chinaman	22-102	SW	M	1.9	18.2	22.6	0.0	27.1	0.7	29.3	1.9	2.0
East Cay	21-305	SW	O	3.3	6.2	16.8	1.9	50.8	3.6	20.6	1.0	1.9
Turner Cay	21-562	SW	O	1.0	13.3	27.5	0.6	36.6	1.9	19.9	1.4	1.7
One Tree Is	23-055	CB	O	7.7	32.9	6.5	2.2	1.9	1.4	50.9	0.8	1.1
Fitzroy	23-077	CB	O	4.0	29.1	19.7	1.1	8.8	1.5	35.7	1.3	3.6

B. Percentage cover of benthic groups recorded on reefs in 1994-95 surveys. Mean values from all sites on each reef.

Reef	Reef ID No.	Sector	Shelf position	Percentage cover of Abiotic substrates	Coralline algae	Hard coral	Macro-algae	Soft coral	Sponges	Turf algae	Other	Unidentified
Martin	14-123	CL	I	23.8	0.0	23.1	1.3	5.7	0.9	45.1	1.7	2.6
Linnet	14-126	CL	I	2.2	0.0	35.2	0.7	5.7	0.6	54.2	2.1	1.9
Decapolis	14-131	CL	I	14.0	0.0	19.5	32.8	4.3	1.0	39.0	1.3	1.9
Macgillivray	14-114	CL	M	14.5	0.9	26.5	1.3	6.2	1.0	49.7	1.8	1.9
Lizard Is	14-116	CL	M	4.4	0.9	13.8	0.6	18.2	1.3	60.7	1.9	1.8
North Direction Is	14-143	CL	M	9.5	3.0	19.1	2.1	2.6	1.1	64.0	1.1	2.5
Carter	14-137	CL	O	0.8	32.5	23.1	1.2	2.5	0.0	33.1	4.0	4.9
Yonge	14-138	CL	O	1.5	31.5	19.6	0.8	4.5	0.9	37.1	3.1	4.6
No Name	14-139	CL	O	1.7	23.6	28.7	1.7	13.8	0.9	22.8	3.2	6.9
Low Islets	16-028	CA	I	13.6	0.0	34.5	3.3	17.2	0.8	31.6	1.9	2.5
Green Is	16-049	CA	I	11.8	1.3	12.4	2.6	6.2	1.6	65.6	1.8	2.2
Fitzroy Is	16-054	CA	I	12.7	0.0	30.5	0.6	25.5	0.6	27.6	1.1	3.0
Mackay	16-015	CA	M	8.7	0.7	27.9	2.6	5.4	1.5	54.3	1.2	2.2
Hastings	16-057	CA	M	3.1	6.8	23.9	1.0	9.6	1.4	54.5	2.0	2.7
Michaelmas	16-060	CA	M	3.2	8.4	19.4	1.2	29.8	1.7	33.7	2.6	4.1
Thetford	16-068	CA	M	2.6	11.3	18.6	0.7	16.0	0.6	48.2	1.5	3.6
Agincourt No.1	15-099	CA	O	1.2	30.2	23.5	0.7	24.6	1.3	15.9	1.0	3.8
St. Crispin	16-019	CA	O	2.9	8.1	22.0	1.1	39.4	0.7	23.4	3.1	2.8
Opal (2)	16-025	CA	O	2.8	13.3	24.0	1.1	42.8	1.1	13.8	2.2	2.0
Pandora	18-051	TO	I	4.9	0.0	53.9	0.8	17.7	1.2	20.2	4.7	2.1
Middle	19-011	TO	I	27.2	0.0	30.4	4.4	21.3	0.7	18.1	2.1	1.4
Rib	18-032	TO	M	2.5	8.2	55.4	1.4	6.4	1.8	23.0	0.6	2.8
John Brewer	18-075	TO	M	7.3	8.0	23.8	10.2	6.7	2.7	46.0	1.7	2.8
Davies	18-096	TO	M	3.0	4.6	34.2	9.2	3.1	1.1	43.3	1.2	1.7
Myrmidon	18-034	TO	O	4.2	6.8	30.7	1.6	24.4	1.1	28.4	3.0	3.0
Dip	18-039	TO	O	2.9	16.9	22.7	3.4	11.3	1.2	38.4	2.1	2.4
Chicken	18-086	TO	O	2.6	11.4	31.1	1.6	11.1	1.0	41.2	1.4	1.9
Hayman Is	20-014	WH	I	4.1	0.0	44.0	2.0	14.5	2.0	31.4	4.4	2.0
Langford & Bird Is	20-019	WH	I	22.6	0.7	18.2	0.7	20.9	0.6	36.5	1.0	1.7

B continued. Percentage cover of benthic groups recorded on reefs in 1994-95 surveys. Mean values from all sites on each reef.

Reef	Reef ID No.	Sector	Shelf position	Percentage cover of Abiotic substrates	Coralline algae	Hard coral	Macro-algae	Soft coral	Sponges	Turf algae	Other	Unidentified
Border Is (A)	20-067	WH	I	9.5	0.0	26.0	0.0	36.3	0.9	25.3	1.3	3.2
19131	19-131	WH	M	2.4	2.6	56.1	0.6	1.9	1.0	32.5	3.7	3.7
Hardy	19-135	WH	M	2.5	2.8	30.7	7.1	19.9	2.3	33.4	3.5	3.0
19138	19-138	WH	M	2.1	4.9	32.7	1.7	2.2	1.0	58.6	1.4	1.1
20104	20-104	WH	M	1.0	5.3	16.4	19.0	2.5	1.3	50.1	2.3	4.8
19159	19-159	WH	O	2.9	4.9	37.9	0.8	20.0	9.6	23.6	2.6	3.2
Hyde	19-207	WH	O	1.2	5.1	17.6	1.1	46.0	10.5	19.0	2.0	1.8
Rebe	19-209	WH	O	1.9	4.8	16.4	1.2	33.6	11.4	32.9	1.2	2.7
21467	21-467	SW	I	2.9	2.9	40.8	4.4	21.1	0.7	28.6	2.3	2.2
22088	22-088	SW	I	2.4	14.4	22.0	1.0	5.7	1.9	51.9	1.7	1.8
21529	21-529	SW	M	3.6	1.6	28.7	14.3	3.2	1.1	47.3	0.8	3.8
Gannet Cay	21-556	SW	M	1.5	1.5	46.2	0.7	4.3	1.5	46.7	1.1	2.0
Chinaman	22-102	SW	M	2.7	7.2	21.1	1.3	31.2	1.3	34.8	0.8	5.0
Horseshoe	22-104	SW	M	2.8	4.1	43.6	1.0	8.1	0.7	37.2	1.6	4.3
East Cay	21-305	SW	O	2.0	3.1	18.3	1.8	44.1	3.6	28.4	0.7	3.1
Turner Cay	21-562	SW	O	1.3	6.6	27.9	1.1	33.0	3.5	27.2	0.7	2.3
Broomfield	23-048	CB	O	4.5	6.1	17.8	1.4	6.6	1.4	64.7	2.1	1.1
One Tree Is	23-055	CB	O	5.6	18.7	8.6	11.8	2.3	0.7	53.1	2.1	1.2
Lady Musgrave Is	23-082	CB	O	1.6	11.8	8.6	0.9	1.4	0.7	77.3	1.5	1.0

8. Abbreviations

AIMS	Australian Institute of Marine Science
ANOVA	Analysis of variance
COTS	Crown-of-thorns starfish
DON	Dissolved organic nitrogen
DOP	Dissolved organic phosphorus
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
LTMP	Long-term Monitoring Program
OU	Observational Unit
SE	Standard error
SOP	Standard Operating Procedure