Long-term Monitoring of the Great Barrier Reef

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Executive Summary

The Great Barrier Reef World Heritage Area is of immense aesthetic value and great economic importance, supporting tourism and fisheries worth more than $1 billion annually to the Australian economy. Information on status and natural variability of populations is essential for informed management of such an extensive area. The AIMS Long-term Monitoring Program is designed to provide information on population trends in key groups of organisms (particularly crown-of-thorns starfish, corals, algae and reef fishes) on appropriate spatial scales over the length and breadth of the Great Barrier Reef Marine Park (GBRMP). The results contained within this report are intended as a primary source of strategic information for the Great Barrier Reef Marine Park Authority (GBRMPA), the Commonwealth Government agency responsible for the care and development of the GBR World Heritage Area.

Broadscale manta tow surveys have now been carried out in 11 latitudinal sectors spanning the length of the GBR for a continuous period of 14 years (1985-1999) and have played a significant role in our increased understanding of the crown-of-thorns-starfish (COTS) phenomenon. The perimeters of 92 reefs were surveyed using manta tows in the 1999.

Intensive surveys on reefs in six sectors began in the 1993 field season. Coral and fish are surveyed annually on fixed sites within one habitat on each survey reef. Sites on 48 reefs were surveyed in 1999.

This report presents a synthesis of monitoring data collected over the past five years and includes unreported data from the 1999 field season.

Major results are:

Crown-of-thorns starfish

The percentage of reefs on the GBR with outbreaks of COTS is the highest since surveys began. Active or Incipient Outbreaks were observed on 17% of the 92 reefs surveyed in 1999. This compares with 15% in 1998 and 12% in 1997. The highest percentage of reefs with Active Outbreaks recorded previously in the 14 years of surveys was 17% in 1987.

A similar pattern is seen in the overall density of COTS on the GBR. The overall mean number of COTS per tow recorded in 1999 was 0.15. This has declined from 1998 when the mean was 0.23 tow^{-1}. For comparison, the overall mean number of COTS tow^{-1} on the GBR during the last major COTS outbreak in 1989 was 0.87.

Details of the current distribution of COTS are as follows:

- The abundance of COTS is high in the Cooktown/Lizard Is sector but decreased between 1998 and 1999.
- There is evidence of increases in COTS numbers in the Cairns, Innisfail and Townsville sectors. This is consistent with a southward drift and is compatible with the hypothesis

that secondary outbreaks are caused by larvae being transported between reefs by the East Australian Current.

- COTS numbers in the Swain Reefs decreased from the high value in 1998. The latter figure was largely due to a dense population on Horseshoe Reef.
- There were no significant changes in COTS abundance within the other five GBR sectors (no surveys in Cape Grenville sector).

Coral cover

The salient changes on the Great Barrier Reef over the past five years reflect the impact of cyclones and COTS on reef communities and their subsequent recovery from such disturbances. Key results were:

- The highest mean value for cover of living coral on the perimeters of reefs in 1999 (44%) occurred in the Capricorn-Bunker sector. This indicates the extent of recovery from very low cover values after storm activity in 1988.
- Lowest value for reef-wide live coral cover was in the Innisfail sector (13%) in 1999. Many of these reefs have large COTS populations.
- Permanent survey sites on NE faces of reefs in 1999 showed that cover of hard coral was highest in the outer shelf region of the Cooktown/Lizard Is sector (61%) closely followed by reefs in the Capricorn-Bunker sector (60%). These regions have been recovering from storm damage.
- Coral cover on permanent survey sites was lowest in the inshore region of the Cooktown/Lizard Is sector (16%) and Cairns sector (20%) in 1999. The former is probably due to COTS, while the inshore reefs in the Cairns sector were affected by COTS and by coral bleaching.
- Coral cover increased on the permanent survey sites over the past five years in inshore and outer shelf regions of the Cooktown/Lizard Is sector and outer shelf regions of the Capricorn-Bunker sector. Reefs in these regions were damaged by storms a decade ago.
- Coral cover on the permanent survey sites declined over the past five years in the inner region of the Cairns sector and in the mid-shelf region of the Whitsundays. Declines in the Cairns region were due to coral bleaching and COTS. Coral cover declined on mid-shelf reefs in the Whitsundays due to swells from Cyclone Justin in early 1997.
- Coral cover on the permanent survey sites is increasing in the outer shelf region of the Cooktown/Lizard Is sector and in the Capricorn-Bunker sector. Both these regions continue to recover from storm disturbance.
- Coral cover on the permanent survey sites is declining in the inshore region of the Cairns sector, possibly due to COTS.
- The effects of extensive bleaching that was observed early in 1998 developed over a period of months. Coral cover values in 1999 show that the only net losses of coral occurred in survey sites on inshore reefs in the Cairns and Townsville sectors. Most regions of the GBR were not severely affected.

Reef fishes

While many groups of fishes showed significant long term and current trends in various regions, there were only a few instances where a majority of groups showed a consistent trend in a region:

- The majority of larger, more mobile fish taxa showed an increase in abundance over the six years of surveys in the Capricorn-Bunker sector. Several groups, such as surgeonfishes, butterfly fishes and wrasses, continue to increase. Coral cover has increased greatly in this region from very low levels in 1989; the fish assemblages may be changing as the coral communities recover.
- The majority of fish taxa show declining trends in the mid-shelf region of the Cooktown/Lizard Is sector, but are increasing on mid-shelf reefs in the Cairns sector. These trends are not associated with obvious changes in coral cover and have no simple explanation.
- Most damselfish genera are declining on mid-shelf reefs in the Swain Sector. The presence of COTS outbreaks on some of the reefs means that there are divergent trends in coral cover among reefs in the region.
- The majority of groups of reef fishes showed an increase in relative species richness over the time of the surveys in the outer shelf region of the Cooktown/Lizard Is sector and the Capricorn-Bunker sector. These are both regions where coral cover has increased greatly over that time.

Introduction

Background

The Australian Institute of Marine Science set up a long-term monitoring program for the Great Barrier Reef (GBR) in 1992. The program is based on some previous monitoring initiatives on smaller scales and represents the first concerted attempt to assess a range of ecological variables across most of the GBR. In 1993 the Long-Term Monitoring Program (LTMP) became a task in the Cooperative Research Centre for Ecologically Sustainable Use of the Great Barrier Reef.

Scope and limitations of the program

The objective of coral reef monitoring is to detect change. Coral reefs are always changing through natural processes such as recruitment, growth, mortality and disturbance by storms. A major function of the LTMP is to document status and to describe change in reef communities on the GBR. The Great Barrier Reef Marine Park Authority (GBRMPA) is the lead agency for GBR World Heritage Area issues and principal adviser to the Commonwealth Government on care and development of the GBR Marine Park. This information contributes significantly to the GBRMPA's reporting on status of the GBR World Heritage Area as required by the World Heritage Commission of UNESCO. It also allows managers to place small scale, site-specific changes in the context of changes that are observed over much larger scales. This provides some perspective on the importance and significance of site-specific status and change.

The specific 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 GBR Marine Park and with a basis for managing the GBR for ecologically sustainable use.

The program addresses long-term regional change in benthic assemblages, reef fishes and crown-of-thorns starfish on coral reefs of the GBR. It does not address associated habitats: mangroves, seagrass beds and areas of soft substrate between reefs. Intensive sampling of benthic organisms and reef fishes is concentrated in one habitat, the NE face of each survey reef, but the perimeter of each reef is also surveyed by manta tow to give a reef-wide estimate of hard coral cover.

Structure of this report

This report describes changes on a large scale that includes most of the GBR (Section 3) and at regional scales organised by latitude (sector, Section 4). Although data are presented from

1993 to 1999, this report specifically examines trends over the past five years. The period of five years was chosen arbitrarily. It represents a compromise between the biological need to look at periods longer than one year and the increasing complexity of statistical functions required to model variation over long periods.

Changes at the scale of individual reefs, as presented in the preceding report (Sweatman et al. 1998) are now available on the Institute's web site:

http://www.aims.gov.au.

This report also includes sections on two special topics: Section 5 deals with the effect of the large-scale bleaching on reefs of the GBR. Section 6 gives a preliminary description of the effects of Tropical Cyclone Rona that crossed the GBR north of Cairns in January 1999.

Methods

Program design

The AIMS Long-term Monitoring Program is designed to detect changes over time in reef communities at a regional scale. Regions in this context refer to the combinations of three positions across the shelf (inshore, mid-shelf, outer shelf) at six latitudes (sectors). Surveys by the Long-term Monitoring Program involve three "tasks": manta tow surveys for crown-of-thorns starfish (COTS) and reef-wide coral cover, surveys of sessile benthic organisms using video and visual counts of reef fishes. The data that are collected are listed in Table 2.1.

Table 2.1: 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 cover of hard and soft coral, dead coral, other incidental observations (e.g. coral bleaching, Drupella, giant clams, reef aesthetics)
Benthic Organisms	Video transects at selected sites in one reef habitat	Per cent cover of all identifiable sessile benthic organisms
Fishes	Visual surveys of fish at selected sites in one reef habitat	Counts of most mobile and non-cryptic fish species (see Appendix C)

Selection of reefs

Initially, 52 "core" reefs were selected for annual survey. The reefs were widely distributed throughout the GBR and spanned variations in the composition of coral and fish communities (Done 1982, Williams 1982), which are known to be greater across the GBR from the coast to the Coral Sea, than they are along its length.

The sample reefs were selected within six of the 11 cross-shelf sectors (Fig. 2.1) that had been identified for manta-tow surveys for COTS (Bainbridge et al. 1994). Where possible, three or more reefs were selected in each of three zones of the continental shelf: inshore, mid-shelf and outer shelf, in each sector.

There are no inshore or mid-shelf reefs in the Capricorn-Bunker sector. Also, the innermost reefs in the Swains are more than 100 km from the mainland and so are not subject to coastal influences. These inner Swains reefs have been grouped with mid-shelf reefs in this report.

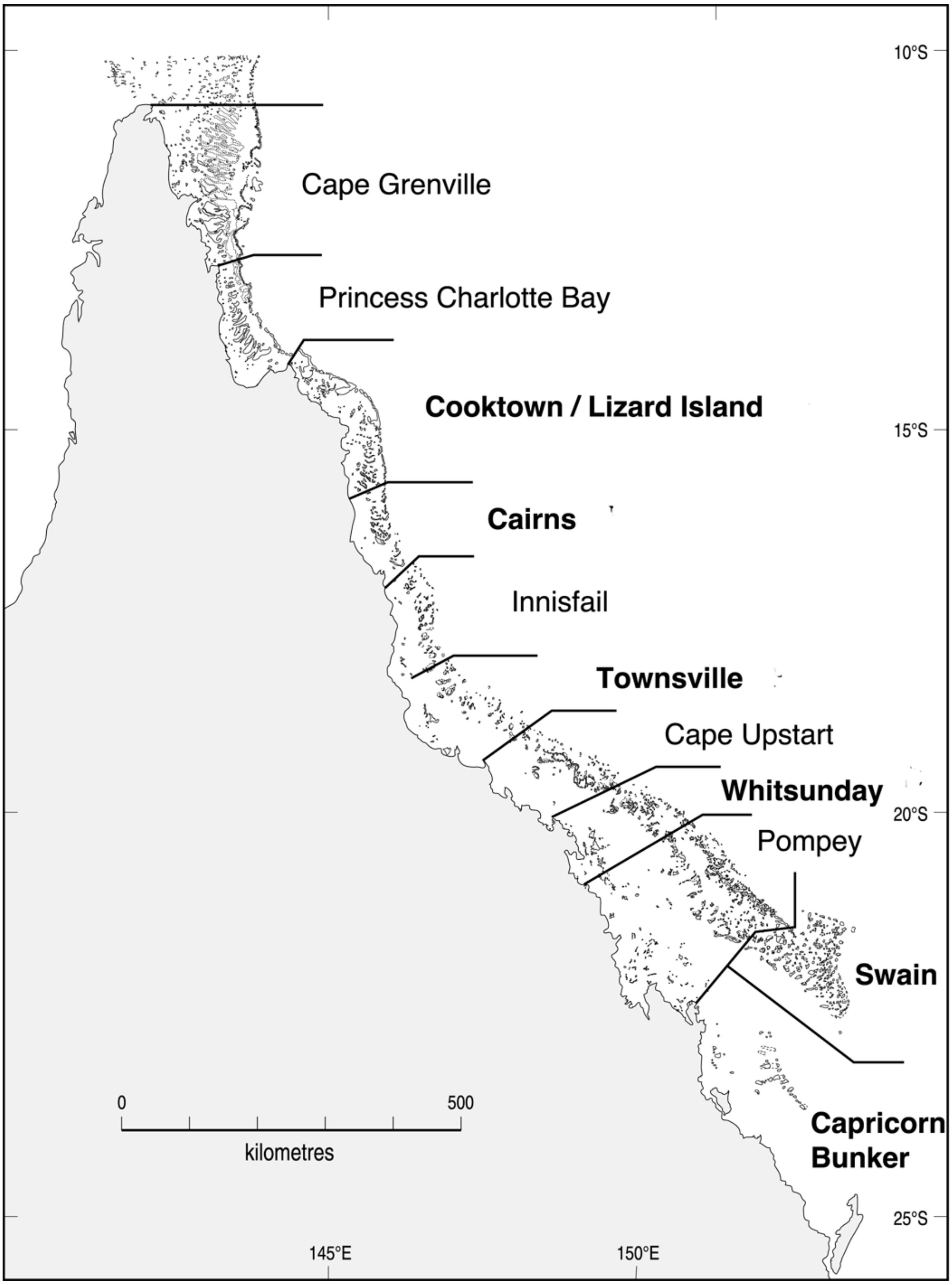


Figure 2.1 Map of the GBR showing the locations of latitudinal sectors. The six sectors where LTMP core survey reefs are located are shown in bold face type.

The core survey reefs were chosen from the reefs within each shelf position for logistical and historical reasons. Because of the non-biological nature of the selection criteria, the survey reefs are likely to be representative of the reefs in each of the regions. The number of core survey reefs has since been reduced to 48 because some reefs could not be sampled reliably on a regular basis.

An additional 55 reefs from the 11 sectors are scheduled to be surveyed annually using manta tow only. Some of these reefs are to be surveyed every year (key reefs); others are surveyed every third year (cycle reefs). These manta tow reefs take second priority and the full set of surveys is rarely completed because of bad weather and limited ship time. Maps and a full listing are given in Appendices A and B.

Sampling methods

The core survey reefs are sampled in two stages (Fig. 2.2). The entire perimeter of each reef is surveyed using manta tows. Fishes and benthic organisms are surveyed intensively at three sites in a habitat that is standardised across reefs. The sites are located in the first stretch of continuous reef (excluding vertical drop-offs) to be encountered when following the perimeter from the back reef zone towards the front reef in a clockwise direction. The sites are usually situated on the north east flank of the reef (Fig. 2.2). Sites are separated by at least 250 m where possible.

There are five 50 m transects within each site. These are permanently marked with a star picket at each end and lengths of reinforcing rod at 10 m intervals. Transects run parallel to the reef crest at about 6-9 m depth (Fig. 2.2). Transects were initially laid haphazardly, roughly following depth contours with 10 - 40 m between them.

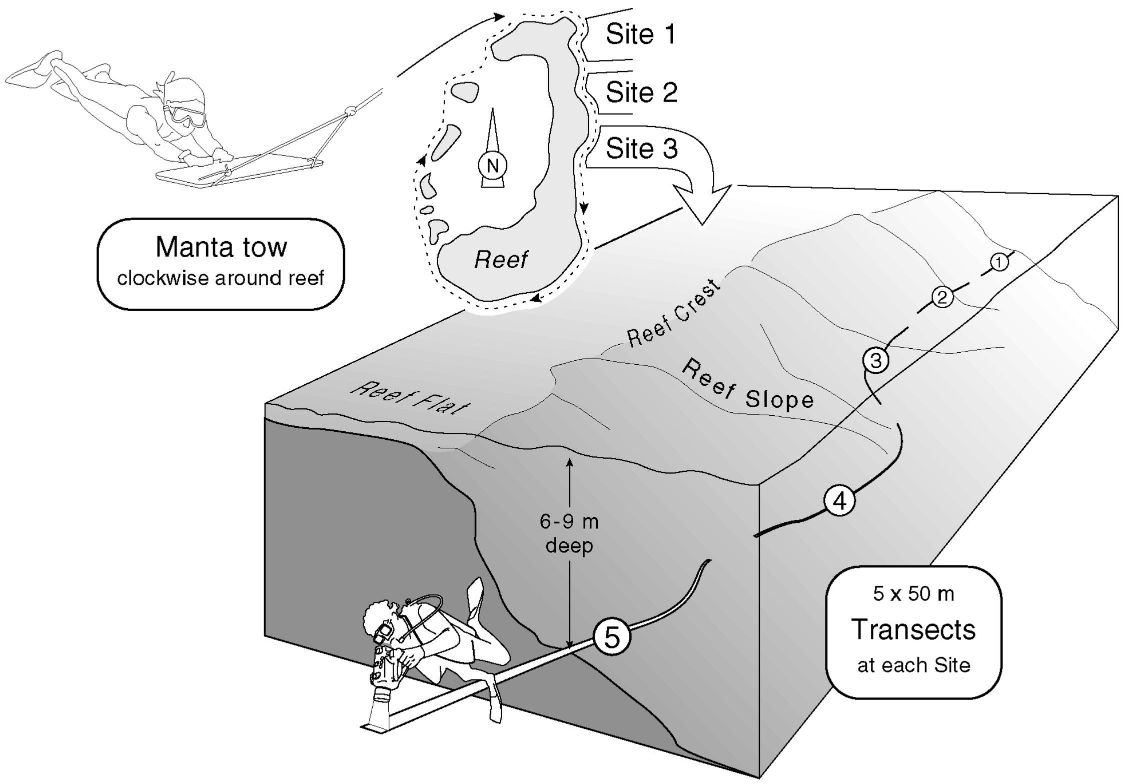


Figure 2.2: Schematic arrangement of sampling effort on a core survey reef.

Surveys are made between September of one year and May of the next year. The reefs in each sector are surveyed at about the same time each year in a series of five or six cruises that alternate to the north and the south of Townsville. Some reefs near Cairns were sampled twice in early 1999 to assess the impact of Tropical Cyclone Rona in that sector (Section 6).

In this report, **annual surveys are referred to by the year in which the field season ended**: thus surveys made between October 1998 and May 1999 are referred to as 1999 surveys.

Forty-eight core reefs were sampled for fish and/or benthos in 1998-99 (Appendix B). Forty-four of these were also surveyed by manta tow; four inshore reefs could not be surveyed because of poor visibility. A further 48 reefs were surveyed by manta tow alone in 1998-99 (Appendix B).

Quality control

It is important to maintain consistency in the way data are collected and processed, so that differences that appear over time reflect differences in the populations of reef organisms rather than changes in sampling. 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 2.2). These document current methods of data collection and processing in considerable detail. They are reviewed at least every two years and updated as necessary. Current SOPs are available in electronic form via the AIMS web page (www.aims.gov.au).

Table 2.2: Titles of standard operating procedures and related documents.

Broadscale surveys	Bass DK and Miller IR (1996) Crown-of-thorns starfish and coral surveys using the manta tow and SCUBA search techniques. Standard Operating Procedure No. 1, AIMS, Townsville. 38 pp. (Available at www.aims.gov.au)
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. (Available at www.aims.gov.au)
Data handling	Baker VJ and Coleman G (in press) A guide to the Reef Monitoring database. Standard Operating Procedure No. 6, AIMS, Townsville.

Data storage and access

Data are entered using a number of purpose-designed data entry and checking programs. All data are held in an Oracle™ database at AIMS. The structure of the database is described in Baker and Coleman (in press).

Methods for individual tasks

Broadscale surveys

AIMS began broadscale surveys of the Great Barrier Reef in the mid-1980s. These surveys were incorporated into the LTMP in 1992. The primary objective of the broadscale surveys is to detect and monitor populations of COTS on the Great Barrier Reef. Manta tow surveys also provide estimates of per cent cover of soft corals and living and dead coral, allowing assessment of the impact of COTS outbreaks and other large-scale disturbances. This report presents coral cover and COTS data from 13 years of broadscale surveys on the GBR.

Sampling techniques

Broadscale surveys use the manta tow technique as described by Bass and Miller (1996) and English et al. (1997). At each reef, two teams work in opposite directions around the reef to survey about half the perimeter each. A team consists of a boat driver and an observer who is towed behind the boat on a manta board. At two-minute intervals the boat stops, allowing the observer to record the data for that tow (Table 2.3). Current practice differs from the documented method in that cover of soft coral is estimated in place of sand and rubble. This was instigated in the 1998 field season.

Quality control

Quality control is in two stages. First, all observers are trained before participating in the broadscale surveys (see Bass and Miller 1996). Secondly, on each sampling trip, some reefs are surveyed by two observers following the same towpath. This gives a measure of the variability between observers, which is necessary because the precision of observers varies continually (Moran and De'ath 1992). When observers show signs of bias (Miller and Müller 1997) they are retrained.

Data handling and analysis

Per cent cover of living coral, dead coral and soft coral is calculated from the manta tow results by representing each cover category by the mid-point of its range. Coral cover, the number of COTS per reef and the average number of COTS per tow are used to assess the outbreak status of each reef (Fernandes 1991; Moran and De'ath 1992). There are four categories: Active Outbreak (AO); Incipient Outbreak (IO), Recovering (RE); or No recent Outbreak (NO). In concept, an Active Outbreak occurs when starfish densities reach levels where loss of coral tissue through starfish feeding is estimated to be faster than the growth of the coral. Definitions of outbreaks have evolved over the time that surveys have been made. Initially, reefs with active outbreaks were those where >40 COTS were recorded over

Table 2.3: Primary variables recorded every 2 minutes during a manta tow survey. See Bass and Miller (1996) 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%
Dead coral		1- = >0-5%
Soft coral		1+ = >5-10%
		2- = >10-20%
		2+ = >20-30%
		3- = >30-40%
		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

the whole reef and >30% of coral was dead. 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. After 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 (Lassig and Engelhardt 1995, Engelhardt et al. 1997). This represents a starfish density that is highly likely to cause net decline in corals. In this report the criterion of 0.22 COTS per tow is referred to as "Incipient outbreak" level.

Reefs which fit the following criteria were chosen to estimate the regional trends:

reefs must have been surveyed at least four times, reefs must also have been surveyed within three years of both the start (1986) and the end (1999) of the surveys.

An exception was made in the case of the inshore region of the Cape Grenville sector where one reef which had only been surveyed three times was included to provide an adequate sample. At least three reefs from each region were required for the analysis.

Regional trends in coral cover and COTS populations were determined over a five-year period. Trends were only calculated for those regions where a minimum of three reefs was sampled in each of the five survey years. Simple (quadratic) curves were fitted to the annual estimates of mean reef-wide coral cover and mean number of COTS/tow from reefs in each region. Data were transformed using the empirical logit transformation (see Appendix I). For ease of interpretation these data have been back transformed on the provided plots.

Linear models were used to fit simple (quadratic) curves to the sequence of observations of median coral cover (reef-wide coral cover) and mean numbers of COTS per tow from each reef. The fitted values from these curves for individual reefs were then used to estimate regional means. A similar linear model was fitted to the regional means and then used to estimate the overall trend over time and the current trend for each region. See Appendix I for a more technical explanation.

Sessile benthos

Sampling techniques

Benthic organisms were surveyed on the five marked transects within each site on the core reefs. A 25 cm wide swathe was recorded along each 50 m transect using a Hi-8 video camera held 25-30 cm above the substrate. Per cent cover of corals and other benthic categories were estimated using a point sampling technique, in which approximately 200 systematically-dispersed points were sampled from each video transect. Details of the video survey and sampling techniques can be found in the SOP (Christie et al. 1996). Corals were identified to the greatest taxonomic detail achievable, but aggregated for analysis. Analysis concentrated on three major components of the benthic community: hard corals, soft corals and algae. The hard corals were then divided into the dominant families: Acroporidae, Faviidae, Pocilloporidae and Poritidae. The Acroporidae were further subdivided into Montipora spp., tabulate Acropora spp. and other Acropora spp. (see Table 2.4).

Quality control

Quality control involves training new observers to use the video camera effectively in the field followed by initial training in identifying organisms in the recordings and an on-going program monitoring agreement between all observers. A second on-going program checks field identifications against identifications in the recordings.

Table 2.4: Explanation of benthic categories.

Major Benthic Group	
Hard Corals	Order Scleractinia
Soft Corals	Subclass Alcyonaria
Algae	Macro-algae and turf algae
Major Benthic Families	
Acroporidae	Family Acroporidae
Faviidae	Family Faviidae
Pocilloporidae	Family Pocilloporidae
Poritidae	Family Poritidae
Acroporidae Groups	
Montipora	Genus Montipora
Acropora tabulate	Genus Acropora tabulate life-form
Acropora other	Genus Acropora, non-tabulate life-forms

Data handling and analysis

For each category of benthic organisms, the mean values (based on the five transects) for per cent cover at each site in each year were used to estimate temporal trends in cover of benthic organisms at each reef. Annual cover values were transformed using the empirical logit transformation before analysis (see Appendix I). A linear model was then used to fit a simple (quadratic) curve to the transformed annual values for per cent cover. This model was then used to estimate (1) the overall trend (over the pastfive annual surveys) and (2) the current trend for each core survey reef.

Regional trends in per cent cover over time were estimated using a similar procedure except that the linear model was fitted to transformed annual estimates of overall mean cover on each reef in the region. See Appendix I for a more technical explanation.

Reef fishes

Sampling technique

Fishes of 191 species (Appendix C) were counted on the five 50 m transects at three sites on each reef. Because the surveys span the annual recruitment season, 0+ individuals are excluded from counts. Full details of the sampling method are given in the SOP (Halford and Thompson 1996).

Quality control

All observers cross-calibrate their counts each year during training before the field season. Estimating the cut point for 0+ individuals is particularly important.

Counts are entered into a database at the end of each day's diving using specially written programs that trap simple errors. When data for all the transects on a reef have been entered, the new data are compared with counts from previous years using a linear model to check for unlikely values. This allows observers to check for misidentifications.

Data handling and analyses

Counts have been summed over the five transects, giving estimates of abundance from three sites in the one area of each reef. As in previous Status Reports (Oliver et al. 1995, Sweatman 1997, Sweatman et al. 1998), larger species have been grouped into families and pomacentrid fishes have been grouped into genera. This increases the power of the analyses, but complicates interpretation.

To look at trends in abundance of fishes on individual reefs, the corrected abundances for the five transects in each site were summed and log transformed [ln(x + 1)] to reduce the influence of abundant taxa. A linear model was then used to fit a simple (quadratic) curve to the transformed annual estimates of abundance. This model was then used to estimate the overall trend (over the past five annual surveys) and current trend for each core survey reef. A taxon was considered too rare to test if it did not occur on that reef at an average density of 15 individuals or more (one per transect) in any year.

Regional trends in abundance over time were estimated using a similar procedure except that the linear model was fitted to transformed annual estimates of mean abundance per site for each reef in the region. See Appendix I for a technical explanation. A taxon was considered too rare to test if it did not occur at an average density of 15 individuals or more (one per transect) on any reef in the region in any year.

Species richness refers to the mean number of species (from the prescribed list Appendix C) recorded on each reef in a region. The list in Appendix C includes most scarids, chaetodontids and pomacentrids, as well as surgeonfishes of the family Acanthuridae that occur on the GBR. Values are mainly useful for comparison with other regions within the program.

Reefs of the Great Barrier Reef: General Trends

Trends in numbers of organisms in regions of the GBR depend on the history of large-scale disturbances and the time that has been available for recovery. There were no large or persistent cyclones in the GBR province since the previous set of surveys, so most of the declines are due to crown-of-thorns starfish activity.

The analyses (Section 2, Appendix I) of abundances of fishes and per cent cover of benthic organisms on individual reefs identify two types of trends, general trends over the past five annual surveys, and current trends, those evident at the 1999 survey. Note that the analyses for current trends are less powerful than those for average trends (Appendix I). Trends for the GBR are summarised here by considering the proportions of core survey reefs in each sector that show increasing, decreasing, or no significant trends in cover of hard coral and abundance of reef fishes.

The crown-of-thorns starfish (COTS), *Acanthaster planci*, is an important cause of coral mortality when populations build up to outbreak levels. AIMS staff have been monitoring COTS populations since 1986. The results of these surveys are summarised in Fig. 3.1. Populations of the starfish have decreased in the Cooktown/Lizard Is sector, but are increasing in the Innisfail and Townsville sectors. This is consistent with observations of previous waves of outbreaks, where the incidence of reefs with new active outbreaks moves south over time. This is presumably associated with the southward transport of larvae due to the East Australian Current. There are also three reefs with active outbreaks in the Swains sector. This sector is an exception to the general pattern in that populations persist there. COTS numbers on all three Swain reefs have decreased from the notably high values recorded in 1998.

The most obvious regional trend in hard coral cover is the continuing increase in coral cover on sites in the Capricorn-Bunkers sector (Fig. 3.2). These sites were largely denuded of coral in 1988, but now have some of the highest coral cover values of any region. The substantial proportion of reefs with declining trends in the past five years in Cairns and Townsville sectors is mainly made up of inshore reefs that were affected by bleaching in 1998. The 1999 surveys also allowed assessment of the effects of coral bleaching on coral cover at sites across much of the GBR. Except on some inshore reefs in the Cairns and Townsville sectors, effects on hard coral cover on the majority of survey sites were limited (Section 5). Declining trends on Whitsunday reefs over five years are due to coral loss associated with Cyclone Justin in 1997. There are fewer significant current trends; the results in the Swains reflect the coral loss and recovery associated with COTS on individual reefs.

There has been a general increasing trend in families of larger, more mobile reef fishes in the Capricorn-Bunkers over the past five years, associated with the increasing coral cover. A number of families have declined in abundance in the Townsville sector, principally on outer shelf reefs (Fig. 3.3). The families involved include herbivores and carnivores. No clear causes can be identified.

Several genera of damselfishes have been increasing in abundance over the past five years in the south and the Cairns and Cooktown/Lizard Is sectors in the north (Fig. 3.4). The increases in the Capricorn-Bunkers have been associated with the increase in coral cover and these are slowing. Several genera have been increasing on inshore and outer-shelf reefs in the Cooktown/Lizard Is sector. Coral cover has been increasing in abundance on outer-shelf reefs, but there is no simple explanation for increases on inshore reefs. Several genera increased in abundance in each region of the Cairns sector and these increases are continuing. In the Swains sector, the damselfish genera that showed any trend all showed declines over the past five years in both regions. The genera currently show declining trends are mainly on the mid-shelf reefs, the region where COTS are active.

Explanation of summary plots

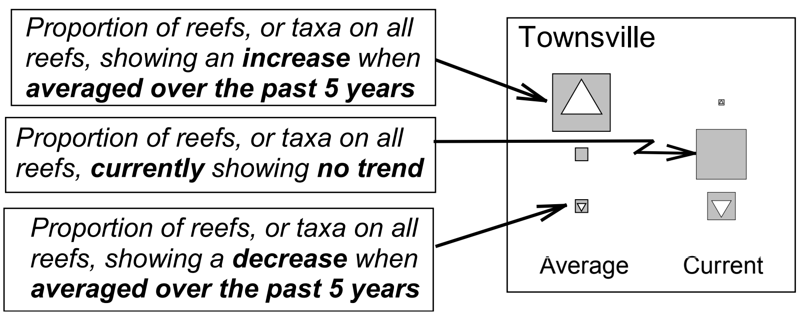
Trends in reef-wide cover of hard coral and in COTS are represented by conventional line graphs and histograms (Fig. 3.1).

The trends in hard coral cover and in fishes on reefs in each sector are represented by two sets of plots. The left hand set of squares concerns the average trends over the past five years; right hand set concerns current trends. Dimensions of the three filled squares reflect the proportion of taxa on survey reefs in each sector showing significant ($p<0.1$) increasing trends, decreasing trends or no significant trend. Arrowheads within the squares indicate direction of trend.

For hard coral cover (Fig. 3.2), the dimensions of the squares represent the proportion of reefs in each sector showing each trend (sum = No. of reefs). For fishes (Fig. 3.3, 3.4), the dimensions of the squares represent the proportion of all taxa on all reefs in the sector that showed each trend (sum = No. of fish taxa x No. of reefs).

Taxa that were too rare to allow a trend to be estimated were omitted.

An annotated example:



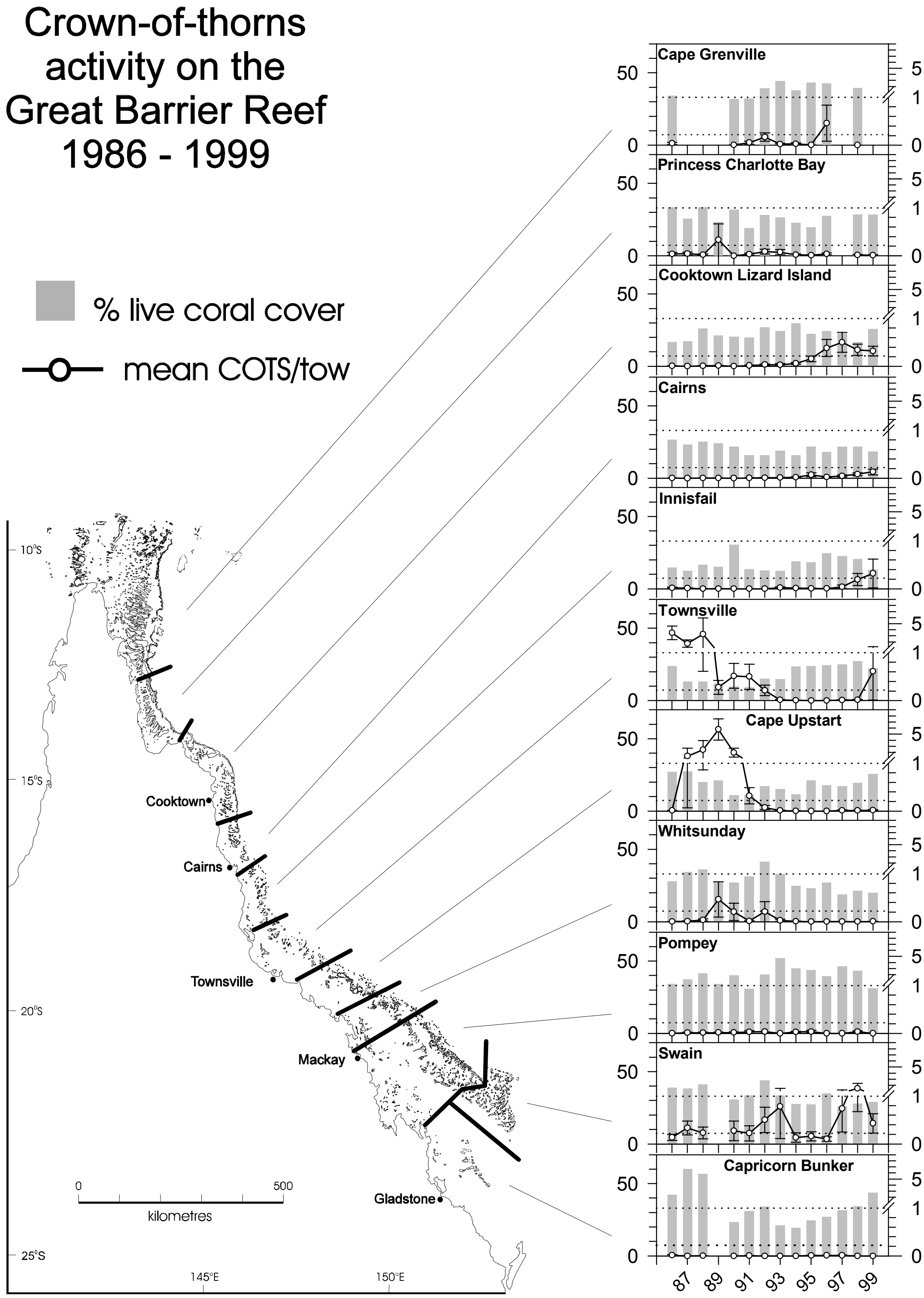


Figure 3.1 Summary of COTS populations and reef-wide coral cover on the GBR since 1986. Bar charts show mean live coral cover in each year (left hand axis); line plots show COTS abundances (mean COTS per tow ± SE) in each year (right hand axis). Lower dotted line = Incipient outbreak level (0.22 COTS per tow), upper dotted line = Active outbreak level (1.0 COTS per tow).

Summary of trends in hard coral cover, 1994-99

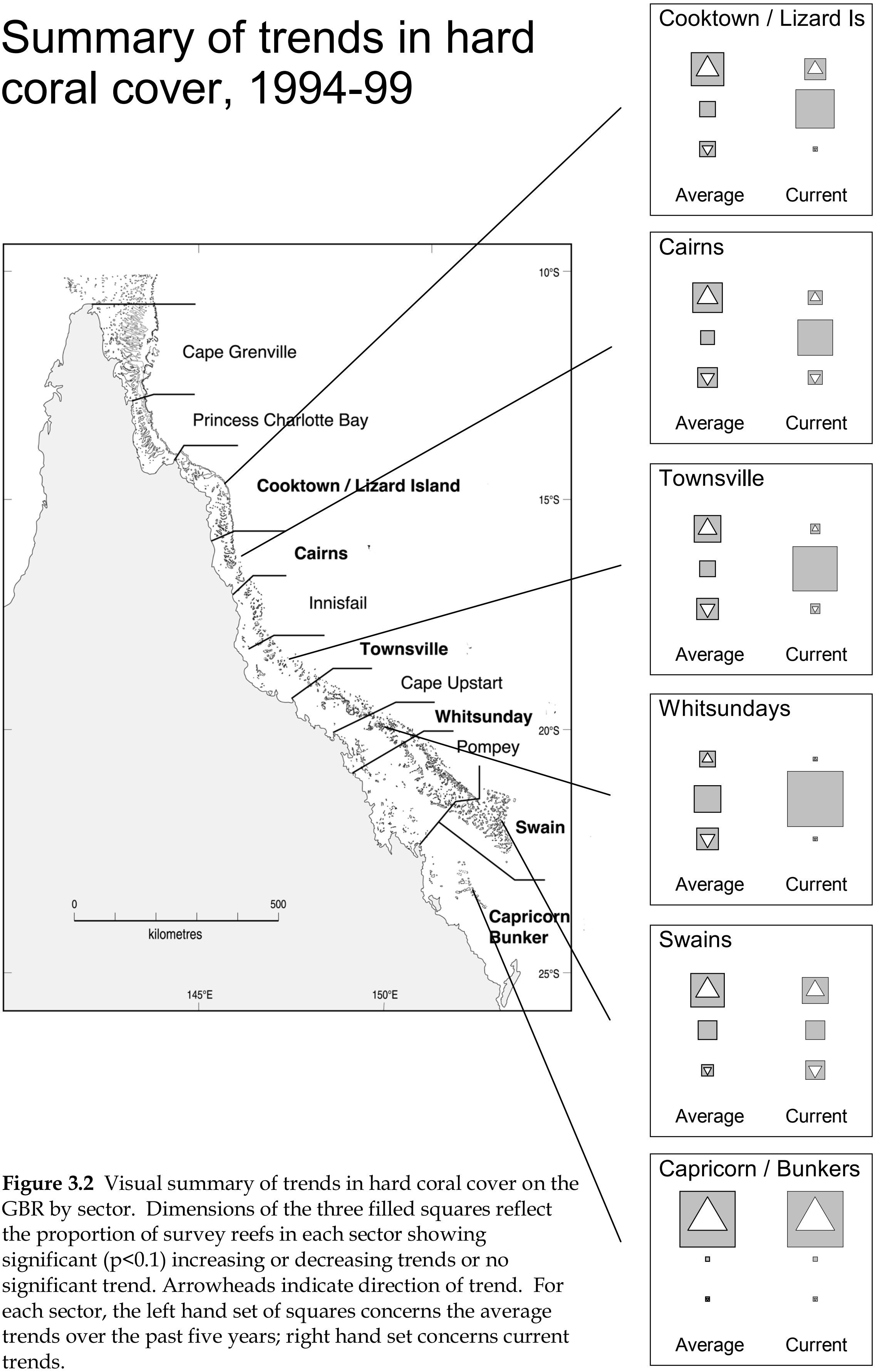
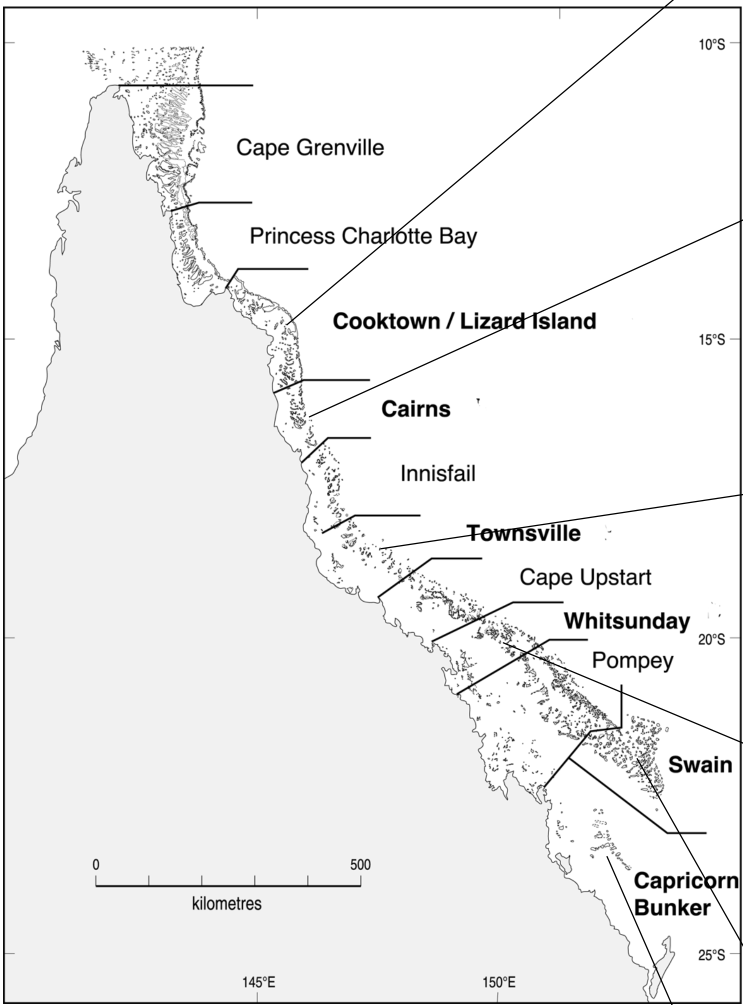


Figure 3.2 Visual summary of trends in hard coral cover on the GBR by sector. Dimensions of the three filled squares reflect the proportion of survey reefs in each sector showing significant ($p<0.1$) increasing or decreasing trends or no significant trend. Arrowheads indicate direction of trend. For each sector, the left hand set of squares concerns the average trends over the past five years; right hand set concerns current trends.

Summary of trends in abundance of larger fishes, 1994-99



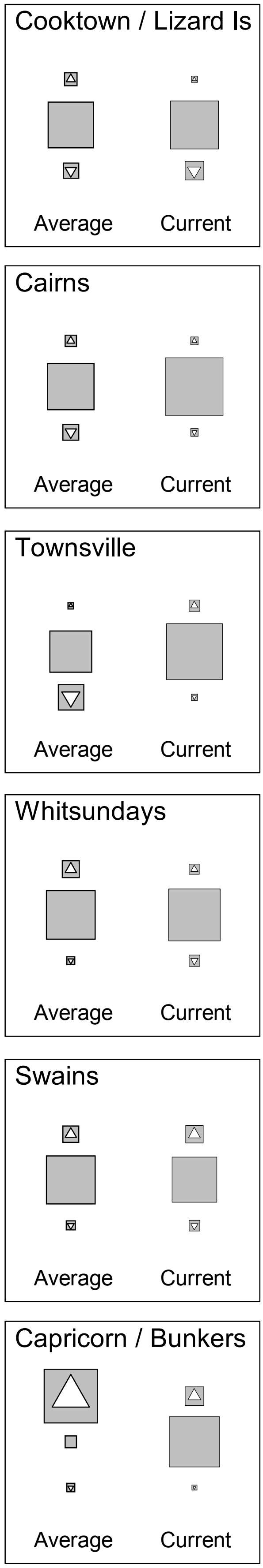
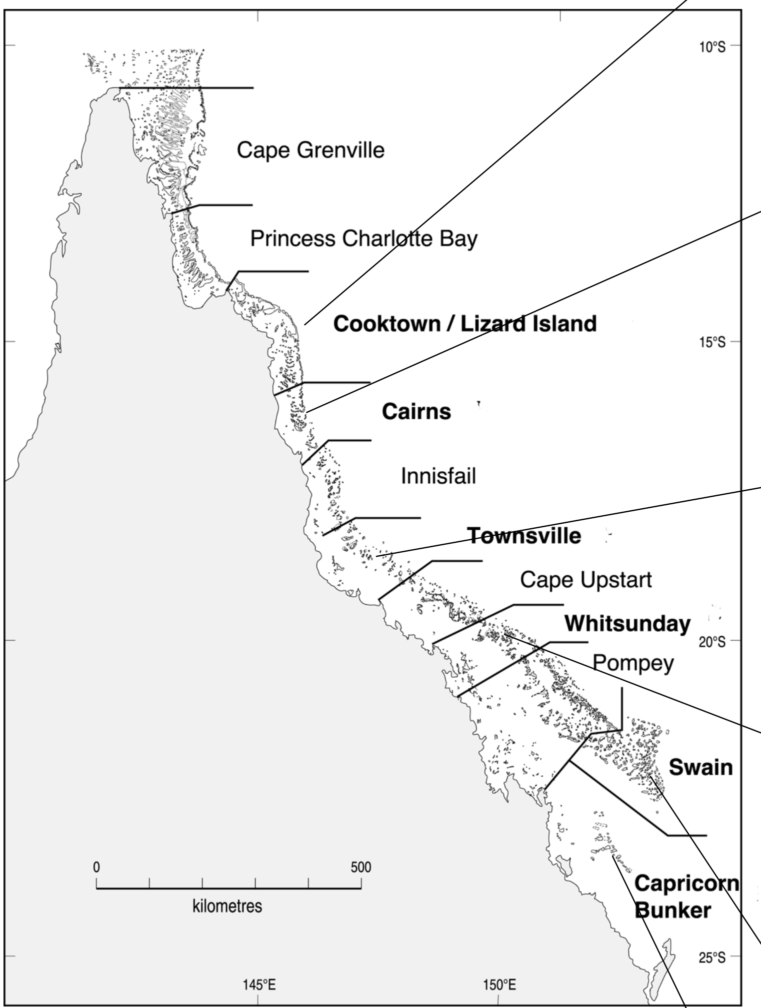


Figure 3.3 Visual summary of trends in abundance of larger reef fishes on the GBR by sector. Dimensions of each set of three filled squares reflect the number of families of larger fishes showing significant (p<0.1) increasing or decreasing trends or no significant trend on each reef, summed over all survey reefs in each sector and expressed as a proportion. Arrowheads indicate direction of trend. For each sector, the left hand set concerns the average trends over the past five years; right hand set concerns current trends. Families that were too rare to test have been omitted.

Summary of trends in abundance of damselfishes, 1994-99



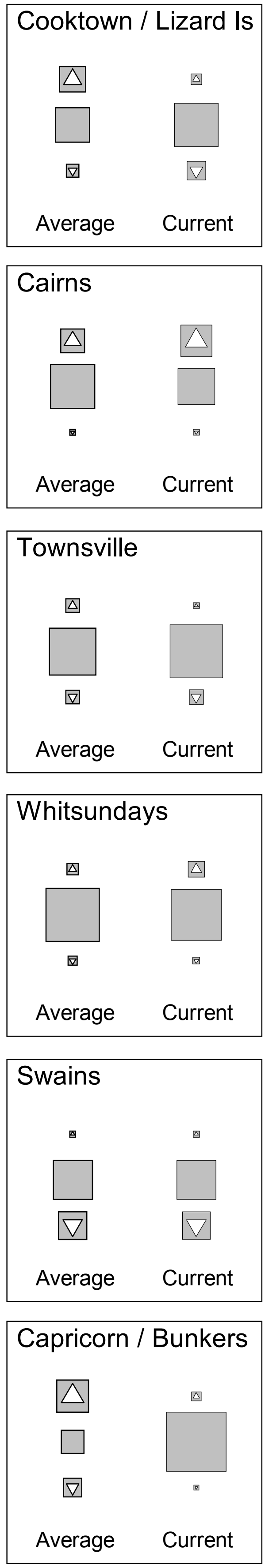


Figure 3.4 Visual summary of trends in abundance of damselfishes on the GBR by sector. Dimensions of each set of three filled squares reflect the number of damselfish genera showing significant ($p<0.1$) increasing or decreasing trends or no significant trend on each reef, summed over all survey reefs in each sector and expressed as a proportion. Arrowheads indicate direction of trend. For each sector, the left hand set concerns the average trends over the past five years; right hand set concerns current trends. Genera that were too rare to test have been omitted.

Reefs of the Great Barrier Reef: Regional Status and Trends

Introduction

The AIMS Long-term Monitoring Program is designed to provide estimates of regional status where the term "region" refers to each combination of sector (latitude) and position on the continental shelf (inshore, mid-shelf, outer shelf).

This section of the report considers status in terms of mean abundances or cover values for major groups of organisms, as well as the past and current trends in those values. These are presented sector by sector from north to south. Mean values for regions are given in Appendices E and F. Similar information about each survey reef is available on the AIMS website.

Analyses and their interpretation have been described in Section 2 and are given in detail in Appendix I.

Several facts need to be borne in mind when reading the regional summaries:

1. The summaries draw on the three components of the LTMP and these differ in the areas of the individual reefs that are sampled and in the length of the time since surveys were started:
   - Fishes and benthic organisms have been sampled on permanent sites on the NE faces of all the core sample reefs since 1995. Earlier surveys did not include all core reefs in each year.
   - Regional species richness for fishes is based on the total numbers of prescribed species recorded on the permanent sites on each reef in each survey. This measure is only useful on a comparative basis. These data differ from the others in that only the past four years of surveys are included, see Section 2.
   - The entire perimeters of most of the core reefs and of a large number of additional reefs have been surveyed using manta tows at varying intervals since the mid-1980s. Manta tows provide information on coral cover and population densities of crown-of-thorns starfish, *Acanthaster planci,* (COTS).
2. The statistical model (Appendix I) requires a sequence of observations from several reefs in each region; this condition was not always fulfilled. Some reefs that have been surveyed were not included because they have not been sampled frequently enough to allow trends to be estimated. Similarly, some regions have been omitted because too few reefs within them had been surveyed adequately. The reefs that were included in the analyses are indicated in Appendix B, with a few exceptions that are mentioned in the text.
3. Estimates of the magnitude of changes that would have been detected - the statistical power of the tests - are given in Appendix I.

Per cent cover refers to the absolute value: the percentage of the total substrate that is covered by a certain taxon.

Explanation of the sector status pages

This section of the report summarises data on each latitudinal sector and, within these sectors, each region (inshore, mid-shelf and outer shelf) that was surveyed in the 1999 field season. All sectors have information concerning reef-wide hard coral cover and COTS populations collected by manta tow from at least one region. Core sectors also have fish abundance and benthic cover information collected from fixed transects on core survey reefs in each region.

The symbols on the first page (sectors surveyed by manta tow only) or first opening (core sectors) for each sector summarise the regional trends for the variables over the past five years. For interpretation, the steepness and direction of slope of the line to the left of the vertical tick mark indicates the strength and direction (respectively) of the **average trend** on reefs in a region over the past five years. The line to the right of the vertical tick mark represents the strength and direction of the **current trend** at the 1999 survey, based on the past five years. Marginally significant trends ($0.1 > p > 0.01$) are indicated by broken lines. When neither the average trend nor the current trend was even marginally significant, the cell was left blank. A star (★) indicates that the data were insufficient to detect a trend with any certainty. Roman numerals identify summaries of trends in the following variables:

(i) Reef-wide hard coral cover and COTS populations collected via manta tow surveys.

(ii) Benthic cover of the main groups of benthic organisms, principal families of hard corals and three groups within the family Acroporidae.

(iii) Fish abundances (mean number per site) of eight families of larger, more mobile species and of eight genera of site-attached damselfishes.

(iv) Fish species richness for selected taxa based on numbers of species per reef.

The plots on subsequent pages show for each region distribution of the variables described below and the fitted trend line. Again the plots are categorised by shelf position. In each case, all of the available time-series for each region is shown, while the trend line is only fitted to the past five years. Plots, identified by letters, summarise the following variables:

A Reef-wide hard coral cover and COTS populations collected by manta tow surveys.

B Benthic cover of the main groups of benthic organisms.

C Benthic cover of the principal families of hard corals.

D Benthic cover of three groups within the family Acroporidae.

E, F Abundances of fish belonging to eight families of larger, more mobile species (mean number per site).

G, H Abundances of fish belonging to eight genera of site-attached damselfishes (mean number per site).

The legends for plots of means and fitted trend lines include information on the significance and direction of the trends. Where the five-year average or the current trend is significant, this is coded in symbols beside the variable names in the figure legends. The symbol before the slash mark (/) gives the direction of the average trend over the preceding five years; the symbol after the slash mark gives the current trend. A plus sign (+) indicates a significant increasing trend, a minus sign (-) indicates a significant decreasing trend and a dot (.)

indicates no significant trend. Thus “+/.” would indicate that the abundance or cover has increased significantly over the preceding five years but there is currently no significant trend. “-/-“ would indicate that the abundance or cover has decreased significantly over the preceding five years and is currently decreasing.

Summaries by sector

Cape Grenville Sector

No reefs in the Cape Grenville sector were surveyed in 1999.

Princess Charlotte Bay Sector

This sector was surveyed in October 1998.

Summary

The limited information from this sector does not reveal any notable changes in coral cover or significant populations of COTS.

Geography

The outer reefs in this sector form a substantial wall against the influences of the Coral Sea. The mid-shelf reefs are very large.

Bleaching

Reefs in this sector were surveyed in 1998 and 1999. No bleaching was recorded during broadscale surveys on either occasion. Note that reefs were surveyed in October when sea temperatures are generally too low to induce coral bleaching.

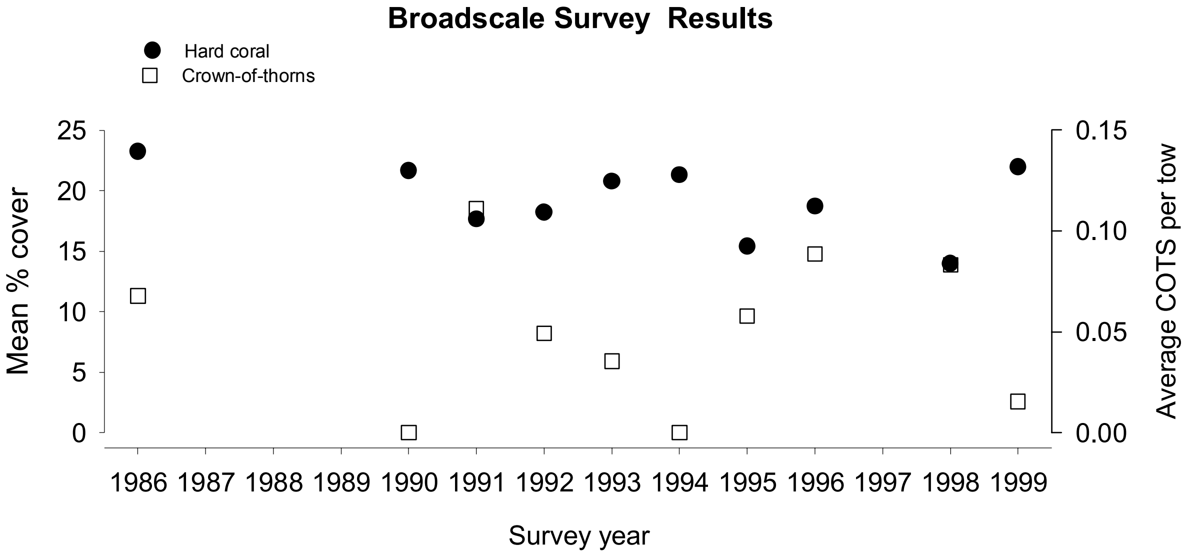
Figure 4.1 Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Princess Charlotte Bay Sector.

	Mid	Outer
Crown-of-thorns starfish		
Hard Coral		

Princess Charlotte Bay Sector Mid-Shelf Reefs

Only two mid-shelf reefs were surveyed in this sector in 1999. Too few reefs have been surveyed in recent years to estimate trends for the region reliably. Coral cover remains moderate on reefs that were surveyed (Fig 4.2). A few COTS were observed on Reef 13-063. COTS have been observed in most previous surveys, but at well below outbreak densities.

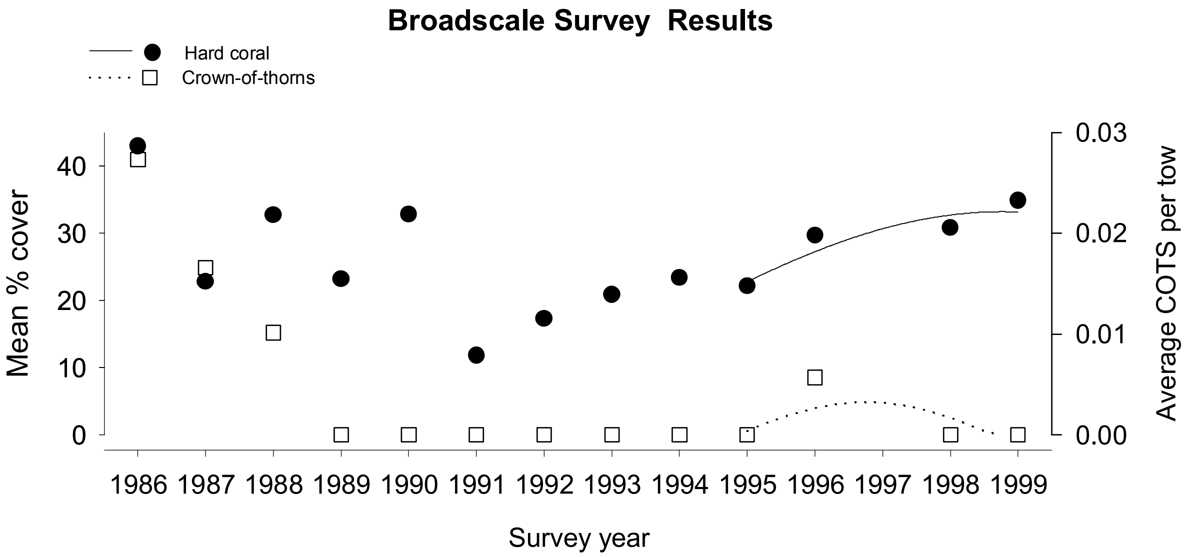
Figure 4.2 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Princess Charlotte Bay Sector Outer Shelf Reefs

No COTS were observed on any of the three outer shelf reefs surveyed in 1999. Coral cover has remained at moderate levels over the past five years (Fig. 4.3)

Figure 4.3 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Cooktown / Lizard Island Sector

This sector was surveyed in October 1998.

Summary

Surveys in recent years have shown an increase in COTS numbers on inner and mid-shelf reefs. Surveys in 1999 indicate the COTS numbers may have peaked on inshore reefs and are currently declining on mid-shelf reefs. Perhaps reflecting this trend, coral cover no longer appears to be declining on either inner or mid-shelf reefs. In the absence of COTS and other major disturbance, coral cover on outer shelf reefs continues to increase. There have been considerable changes in fish populations in the sector. On outer shelf reefs these may be associated with the increase in hard coral cover. Changes in fish populations on mid-shelf reefs do not correspond to changes in coral cover.

Geography

The offshore reefs in this sector form a wall and represent a substantial barrier to influences from the Coral Sea, both in terms of wave energy and exchange of water.

Bleaching

This sector is surveyed in October each year, when sea surface temperatures are generally too low to cause mass bleaching. Over the past three years, bleaching was only recorded at a very low level in October 1998. Bleaching was most common on inshore reefs, particularly the front and flanks of Turtle Group B, the southern flank of Linnet Reef and the front of Martin Reef. Some bleaching was observed on the backs of Helsdon and Rosser Reefs in the mid-shelf region. No bleaching was recorded on outer shelf reefs in this sector.

Figure 4.4(i) Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Cooktown / Lizard Island Sector.

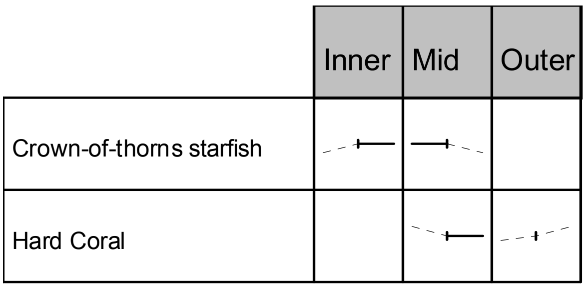


Figure 4.4 (ii) Summary of trends in benthic cover on intensive survey sites in the Cooktown / Lizard Island Sector.

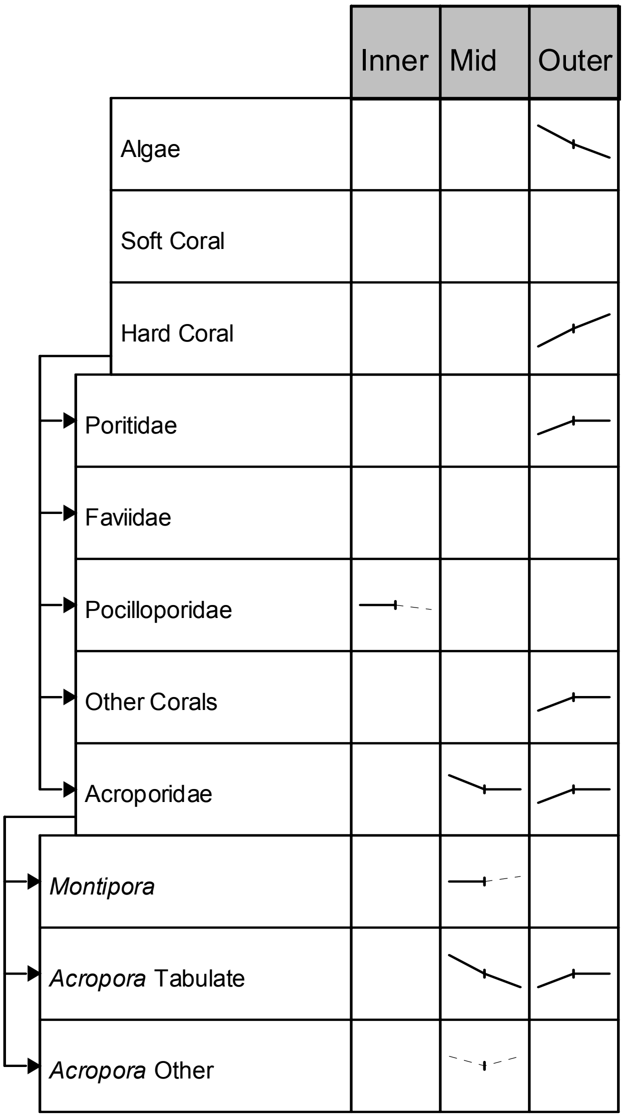


Figure 4.4 (iii) Summary of trends in fish abundance in the Cooktown / Lizard Island Sector.

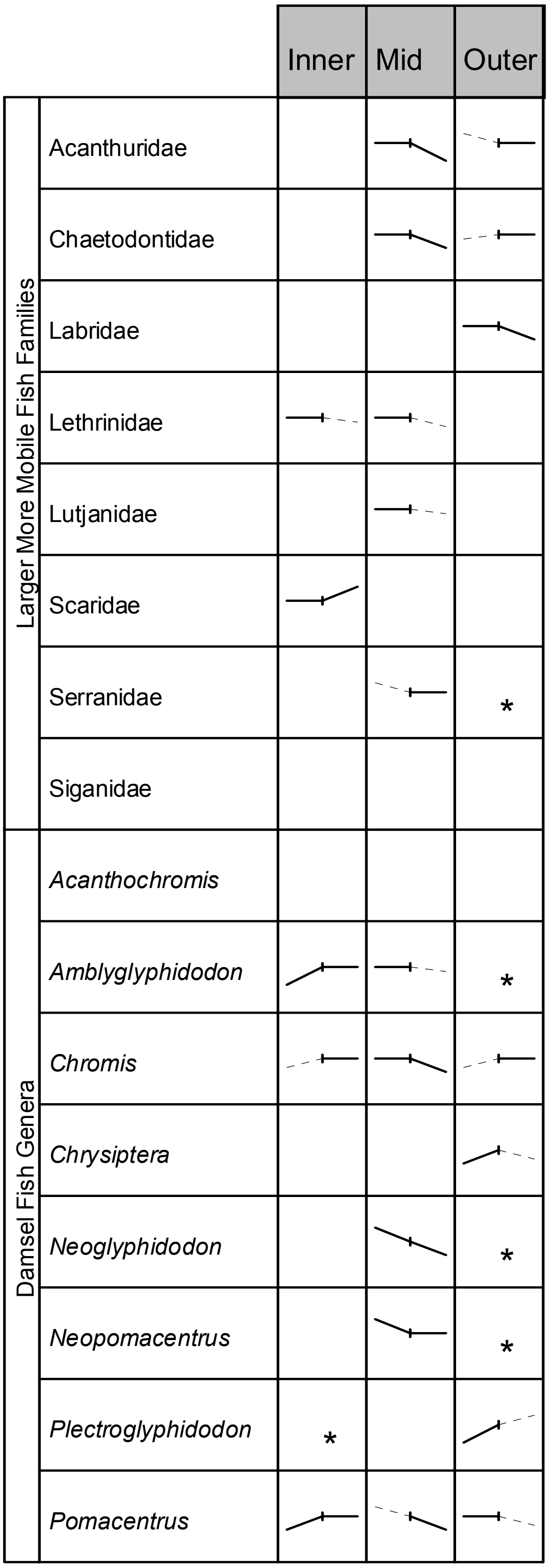
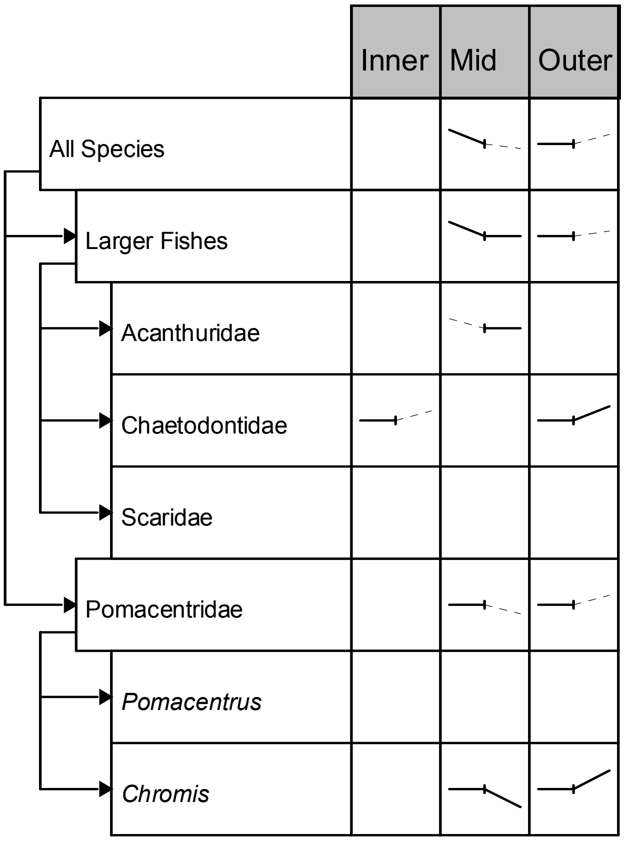


Figure 4.4 (iv) Summary of trends in fish species richness in the Cooktown / Lizard Island Sector.



Cooktown / Lizard Island Sector Inshore Reefs

The numbers of COTS in this region has been increasing over the past five years, but this is no longer the case (Fig. 4.4 (i), 4.5A). Boulder and Egret Reefs have Active Outbreaks while Linnet and Martin Reefs have Incipient Outbreaks. Two Isles Reef is recovering from COTS activity. Manta tow surveys of the perimeters of seven reefs indicate no significant trends in coral cover over the past five years. Reef-wide coral cover is moderate (mean = 23%, Fig. 4.5A)).

Coral cover has also been stable in intensive survey sites, averaging 32% (Fig. 4.4 (ii), Fig. 4.5 B). Cover of algae averages 44% and also has not changed significantly in the past five years. The cover of soft corals was comparatively low (4%) and has also shown no trend. There were no significant changes in the families of hard coral except for the Pocilloporidae, which are currently declining (Fig. 4.4 (ii), Fig. 4.5 C).

The abundance of Scaridae is currently increasing due to one species: *Scarus rivulatus* (Fig. 4.4 (iii), Fig. 4.5 E). The family Lethrinidae declined marginally, although numbers have generally been low (Fig. 4.4 (iii), Fig. 4.5 F). Three damselfish genera, *Amblyglyphidodon*, *Chromis* and *Pomacentrus*, have increased in abundance over the past five years, but show no current trend (Fig. 4.4 (iii), Fig. 4.5 G, H)). These increases have been driven by single species in each genus: *A. curacao*, *C. atripectoralis* and *P. moluccensis* respectively. The number of species of Chaetodontidae (Fig. 4.4 (iv)) is currently increasing regionally.

Figure 4.5(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

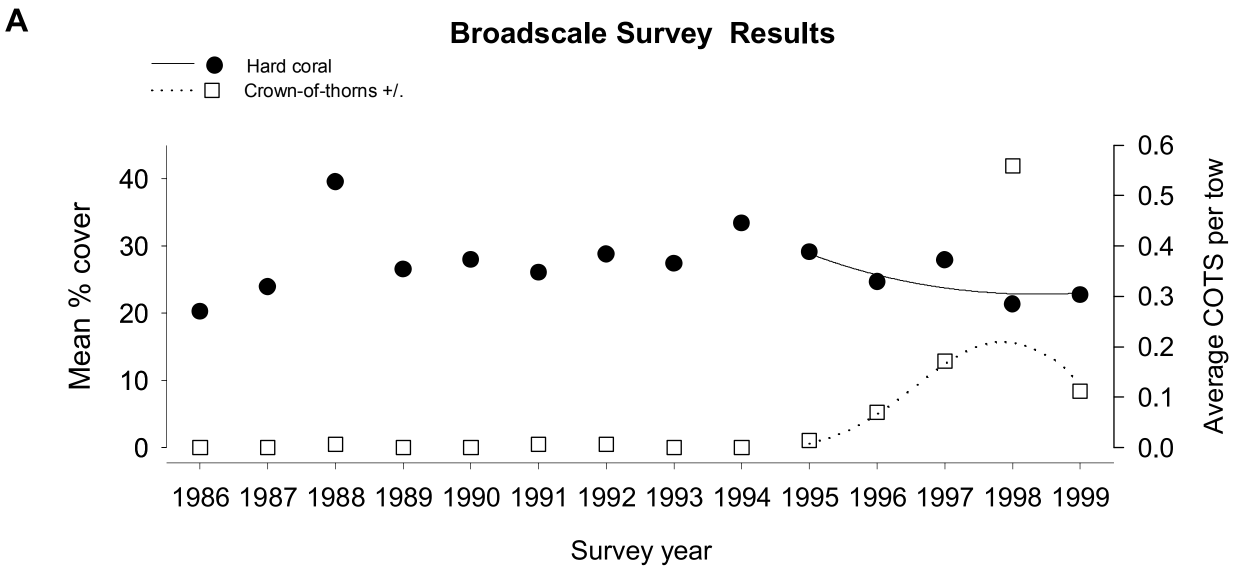
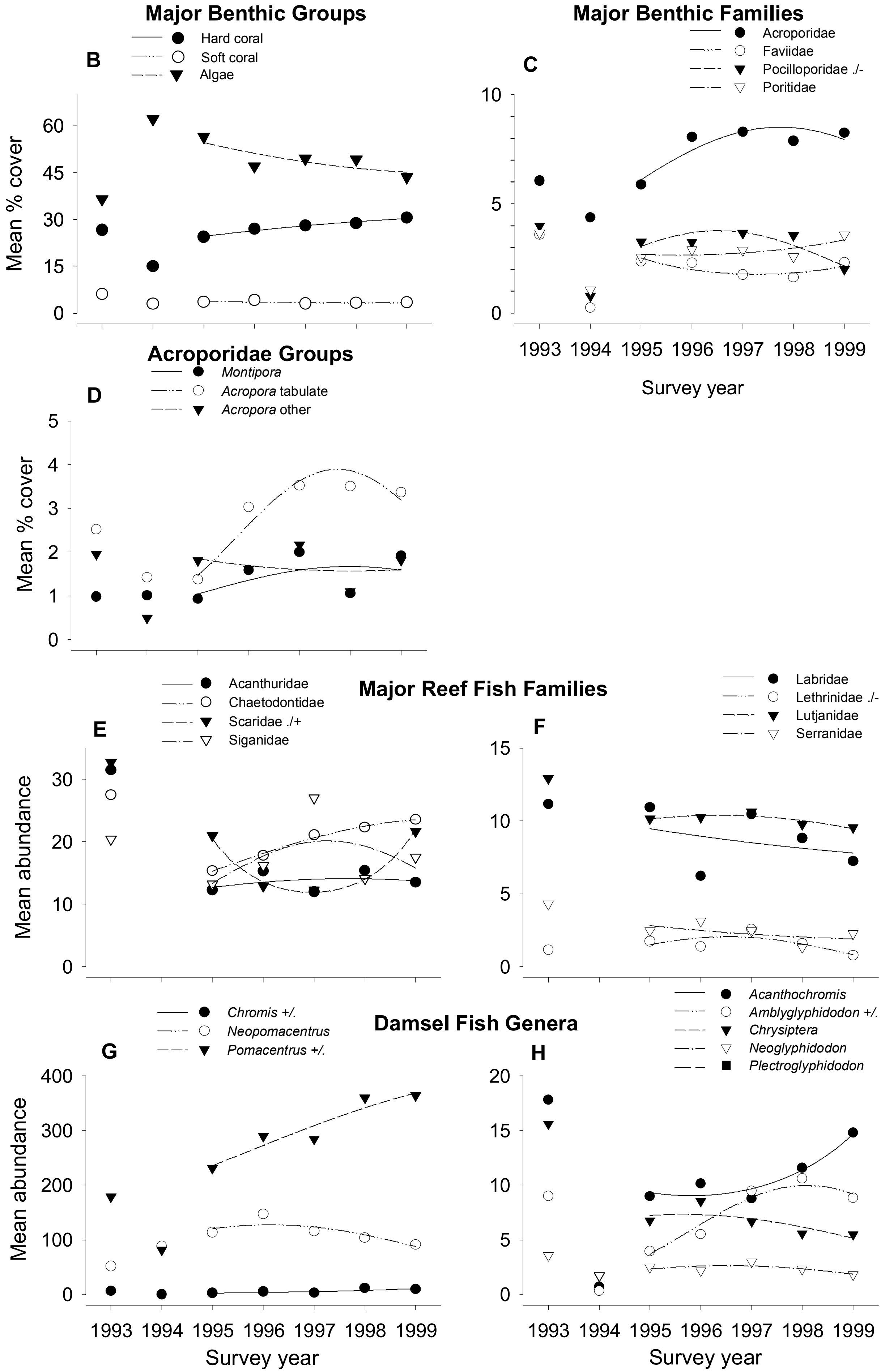


Fig 4.5 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Cooktown / Lizard Island Sector Mid-Shelf Reefs

COTS populations on mid-shelf reefs have reached high levels in the past five years (average 0.36 COTS/tow in 1997) but are currently declining (Fig. 4.4(i), 4.6 A). Of the eight survey reefs, Helsdon Reef has an Active Outbreak while Reef 15-047 and Nymph Is. Reef have Incipient Outbreaks. Lizard Is., MacGillivray and North Direction Is. reefs are recovering from previous COTS activity. Reef-wide coral cover has declined significantly over the past five years but this is not continuing (Fig. 4.4 (i)). Average reef-wide coral cover is moderate (20%, Fig. 4.6 A).

Intensive surveys found that the cover of hard coral, soft coral and algae did not change significantly during the past five years (Fig. 4.4 (ii), Fig. 4.6 B). Algae are the dominant benthic group, covering 56% of the substratum (Fig. 4.6 B). Cover of hard corals and soft corals averages 16% and 8% respectively. The Poritidae continue to be the most abundant family on all reefs in this region (average 7%). The cover of hard corals has remained stable, with the exception of the Acroporidae (Fig 4.4 (ii)). Average cover of this family has decreased from 3% in 1993 to 0.2% in 1999. This is mainly due to a decline in *Acropora* spp. (Fig. 4.6 C, D) and probably reflects COTS activity.

Ten of the 18 reef fish taxa have shown, or currently show, declining trends in abundance over the past five years (Fig. 4.4 (iii)). None has increased. Numbers of Acanthuridae Chaetodontidae, Lethrinidae and Lutjanidae are decreasing (Fig. 4.4 (iii), 4.6 E, F)). These trends are general, being driven by a number of species within each family. The Serranidae, mostly *Plectropomus leopardus*, have declined over the past five years (Fig. 4.4 (iii), 4.6 F). The damselfish genera *Amblyglyphidodon*, *Chromis*, *Neoglyphidodon* and *Pomacentrus* are also decreasing in abundance (Fig. 4.4 (iii), 4.6 G, H)), driven by a number of species within each genus. The general decline in the genus *Neopomacentrus* appears to have slowed (Fig. 4.6 G). It is unclear why such a general decline in fish abundance is occurring. Coral cover on the survey sites has changed little over the last five years, although COTS are present on these reefs. The declines in abundance of families and genera are matched by a general decline in species richness (Fig 4.4 (iv))

Figure 4.6(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

A

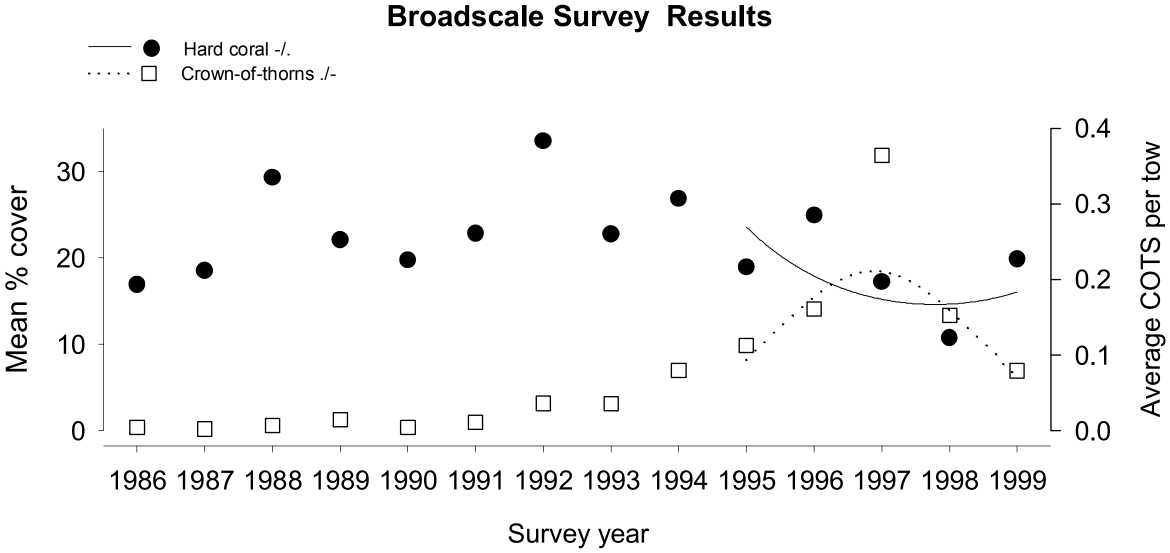
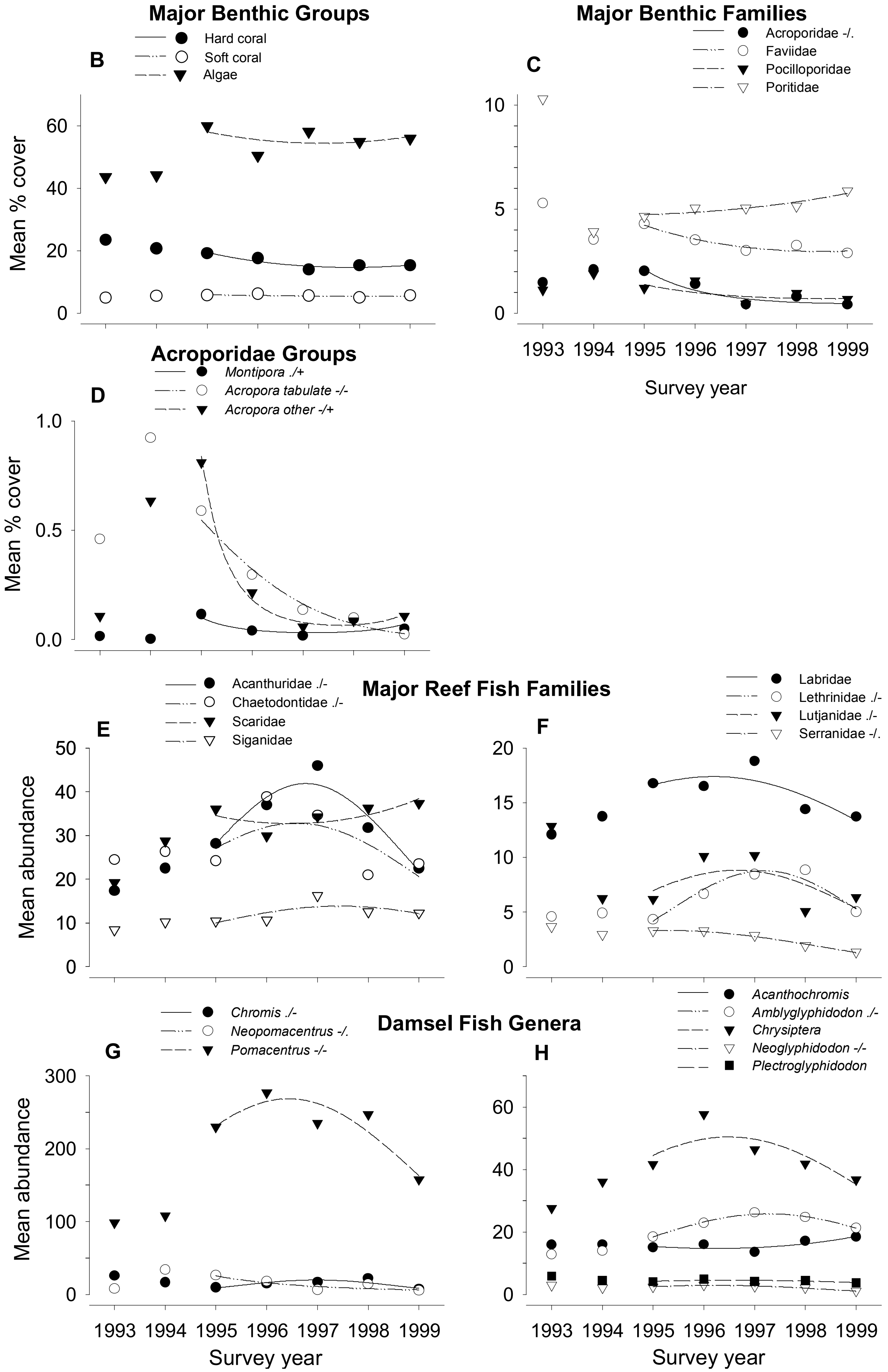


Fig 4.6 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Cooktown / Lizard Island Sector Outer Shelf Reefs

Only a few COTS have been observed in this region since surveys began. Reef-wide coral cover has increased on these reefs over the past five years (Fig. 4.4 (i)). Coral cover is high, with a reef-wide average of 32% (Fig. 4.7 A).

Cover of hard corals on intensive survey sites in the region continues to increase rapidly (Fig. 4.4 (ii)). Average hard coral cover has risen from 12% in 1993 to 61% in 1999 (Fig. 4.7 B). Cover of algae has decreased over the same period. Cover of soft corals has not changed significantly in the last five years (average 6%, Fig. 4.7 B).

Much of the increase in hard corals has been due to rapid growth of tabulate *Acropora* spp. These corals were virtually absent in 1993 and had risen to an average cover of 31% in 1999 (Fig. 4.7 D), accounting for over half of the total increase in hard coral cover. While cover of the family Poritidae and 'Other' corals increased significantly in the last five years, their contribution to overall change is small since both taxa currently average less than 2% of total cover.

Reef fishes in the family Acanthuridae have declined in abundance in the last five years (Fig. 4.4 (iii)). This has coincided with a decline in turf algae (Fig. 4.4 (ii)). A number of Acanthurids feed on algae and much of the decline in total surgeonfish numbers is due to *Ctenochaetus* spp., which feed on detritus trapped in turf algae. Several Labrid species (particularly *Gomphosus varius* and *Hemigymnus fasciatus*) decreased in abundance (Fig. 4.4 (iii), Fig. 4.7 F). The decreases in abundance of the damselfish genera *Chrysiptera* and *Pomacentrus* (Fig. 4.4 (iii), Fig. 4.7 G, H)) are driven by one species in each case: *C. rex* and *P. lepidogenys* respectively. The genus *Chromis* has stabilised in abundance after a general increase (Fig. 4.4 (iii)), while the genus *Plectroglyphidodon* continues to increase in number due to two species: *P. johnstonianus* and *P. dickii*, both of which live among hard corals. Interestingly *P. lacrymatus*, which feeds on algal turf, has not increased in abundance.

There has been an overall increase in species richness, with the family Chaetodontidae and the genus *Chromis* show strong trends (Fig. 4.4 (iv))

Figure 4.7(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

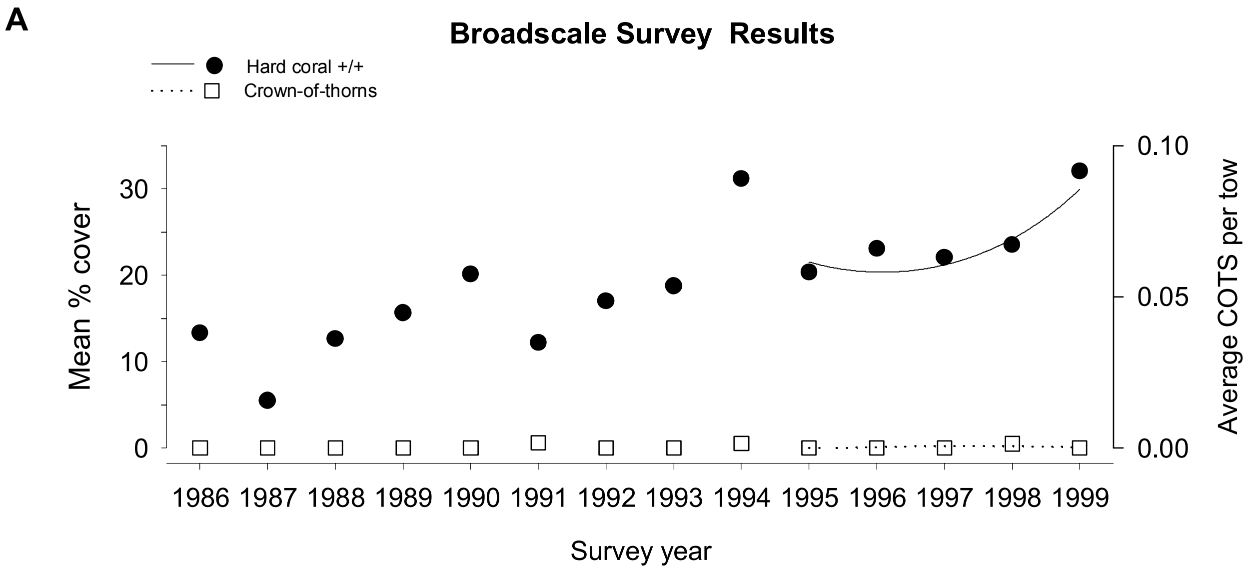
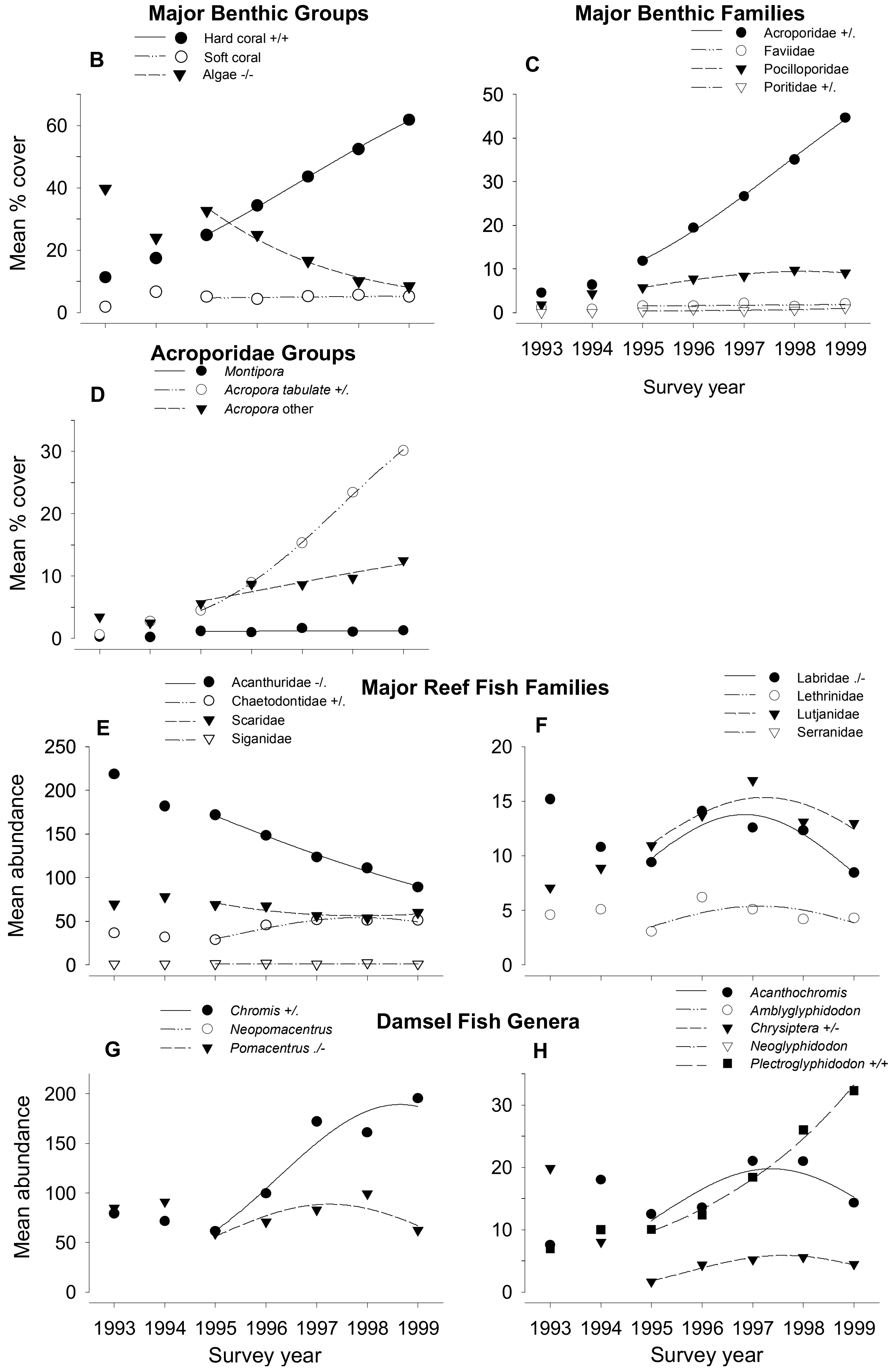


Fig 4.7 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Cairns Sector

This sector was surveyed in February 1999.

Summary

While the total number of reefs in this sector where COTS are present continues to rise, there are few clear trends in the numbers per reef. COTS populations on inshore reefs have changed little and numbers on mid-shelf reefs are no longer increasing significantly. Coral cover has decreased on inshore reefs due to the combined effects of coral bleaching and COTS. No COTS were observed on outer shelf reefs and there is no trend in coral cover on these reefs. Several fish groups are increasing in abundance in all regions, despite the lack of change in coral cover.

Geography

Unlike the Cooktown / Lizard Is. sector to the north, the outer reefs of this sector form less of a barrier, so mid-shelf reefs are likely to be exposed to more wave action and to more oceanic water from the Coral Sea. The coastal hinterland falls within the Wet Tropics and several large rivers drain into this sector.

Bleaching

Reefs in this sector are surveyed in late January/early February, when raised sea water temperatures may be expected to stress some corals. Surveys in 1997 detected no bleaching. In 1998, surveys preceded the mass bleaching event and only scattered bleached colonies were recorded from reef crests of inner and mid-shelf reefs. No bleaching was recorded on outer shelf reefs. Surveys in 1999 found bleaching of <10% of total coral cover on all inshore reefs. On mid-shelf reefs the levels of bleaching varied considerably. Bleaching was patchy on outer shelf reefs and affected <5% overall hard coral cover.

Figure 4.8(i) Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Cairns Sector.

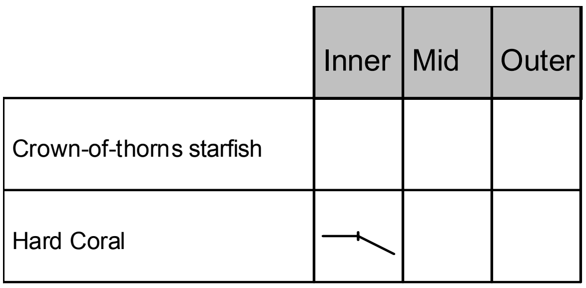


Figure 4.8 (ii) Summary of trends in benthic cover on intensive survey sites in the Cairns Sector.

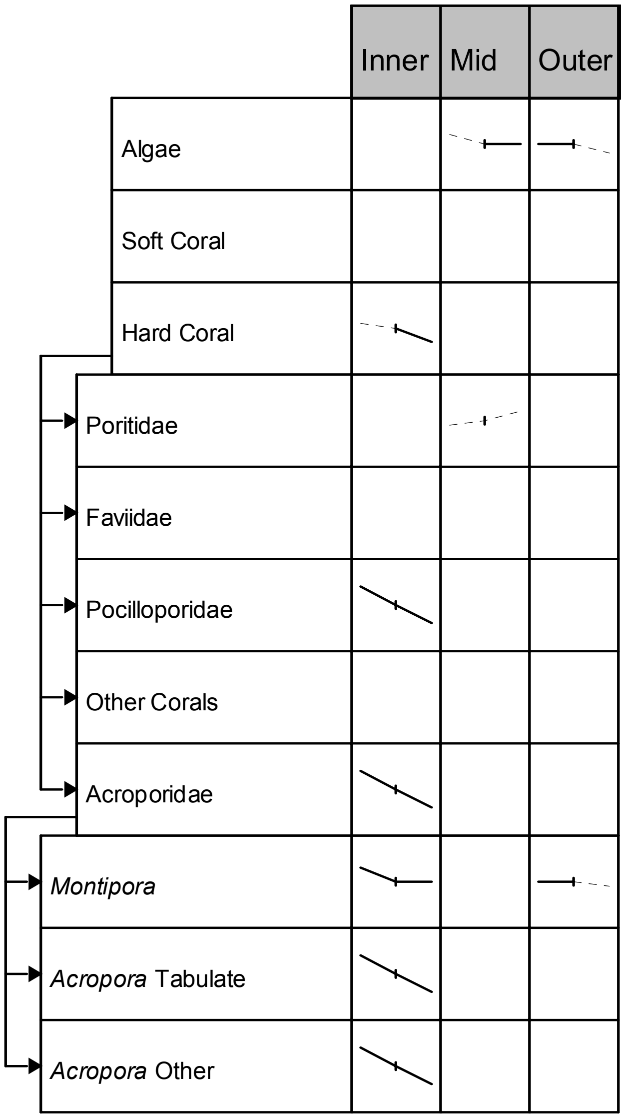


Figure 4.8 (iii) Summary of trends in fish abundance in the Cairns Sector.

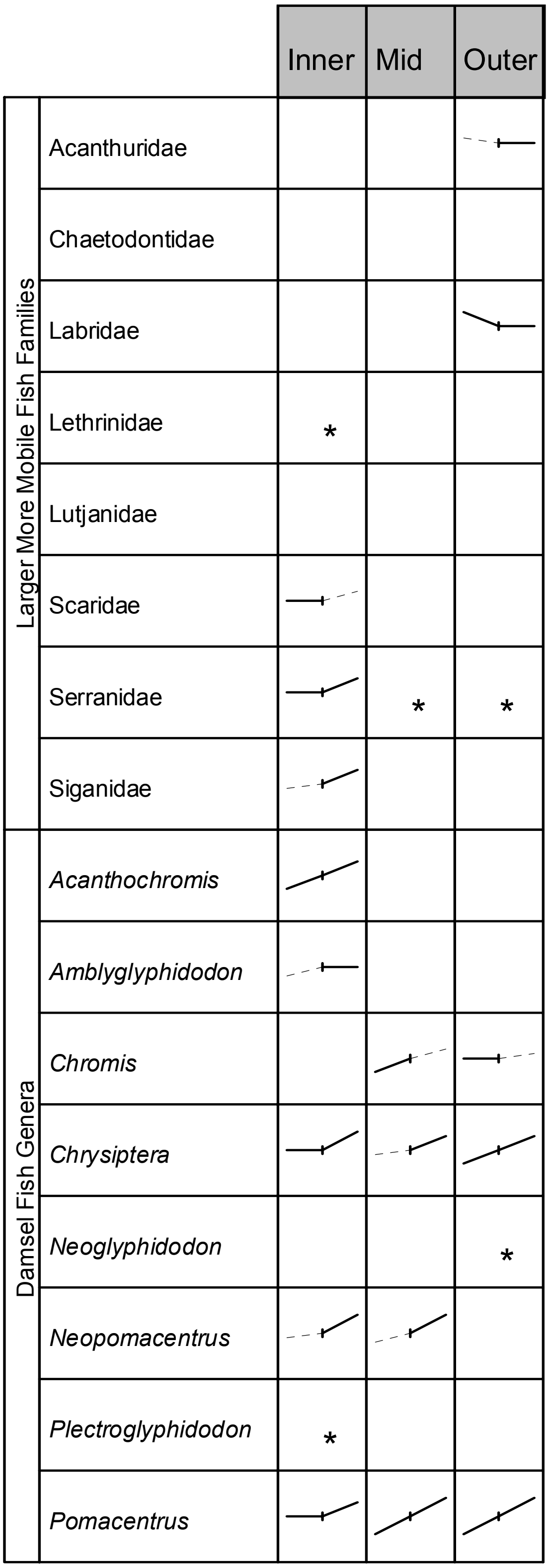
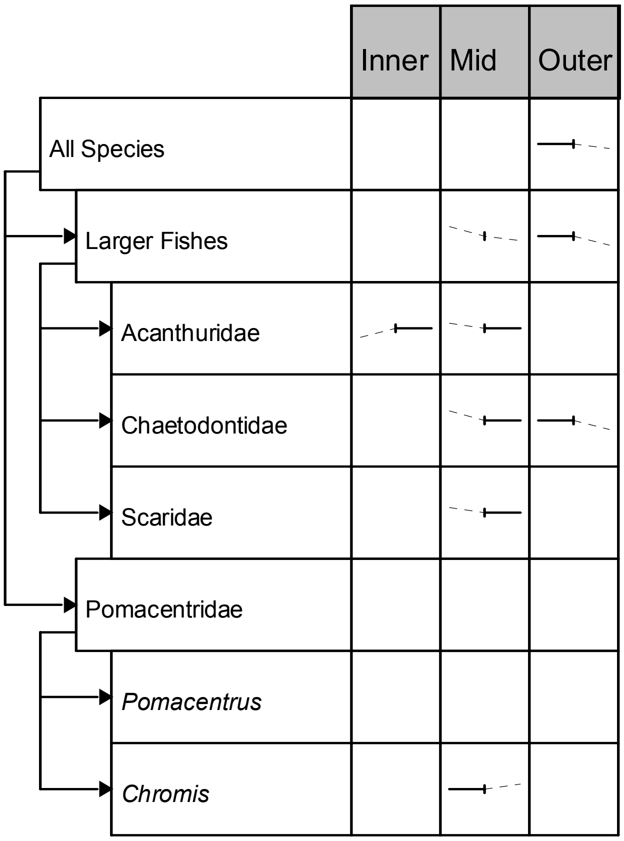


Figure 4.8 (iv) Summary of trends in fish species richness in the Cairns Sector.



Cairns Sector Inshore Reefs

Though COTS numbers have increased since their initial appearance at Green Is. in 1994, they have remained below outbreak levels (Fig. 4.9 A). Surveys in 1999 indicate that reef-wide coral cover has declined sharply, particularly between the past two surveys. This probably represents the combined effects of COTS and coral bleaching. Cyclone Rona affected Low Isles (see Section 6). Small numbers of COTS and low levels of coral bleaching were recorded on Low Isles in 1998. There was extensive bleaching at Fitzroy Is. in 1998 and the most recent survey revealed many standing coral colonies that had been dead for some time, probably since the 1998 bleaching event.

Hard coral cover is decreasing at the intensive survey sites. Significant declines have occurred in the Pocilloporidae and the Acroporidae, both *Montipora* spp. and *Acropora* spp. (Fig. 4.8 (ii), Fig. 4.9 C, D). Average cover of hard coral varies among reefs, ranging from about 30% at Fitzroy Is. to about 5% at Green Is. which had the lowest coral cover of any reef surveyed in 1999. There are few regional trends in hard coral cover because the changes varied among the reefs. The greatest changes occurred in the Acroporidae (Fig 4.9 C), which declined dramatically at Green Is. and Low Isles but remained relatively stable at Fitzroy Is. Cover of soft corals and algae remained stable on all reefs, currently averaging 12% and 51% respectively (Fig. 4.8 (ii), Fig. 4.9 B).

No significant decrease in numbers of any fish taxon was recorded in this region. Numbers of Scaridae have increased recently (Fig. 4.8 (iii)), largely due to *Scarus rivulatus*. Serranidae (essentially coral trout) and Siganidae also increased in number. Several genera of damselfishes increased in number (Fig. 4.8 (iii)). *Acanthochromis polyacanthus* and *Chrysiptera rollandi* were responsible for increases in abundance of their respective genera (Fig. 4.9 H). Both *Neopomacentrus azysron* and *N. bankieri* contributed to increases in *Neopomacentrus* (Fig. 4.9 G). Several *Pomacentrus* spp. have been increasing in abundance (*P. adelus*, *P. amboinensis*, *P. brachialis*, *P. wardi* and particularly *P. moluccensis*). Numbers of fishes within this genus are now at a seven-year high (Fig. 4.9 G), even at Green Is. where hard coral cover averages only 5%.

There is no regional trend in overall species richness of fishes (Fig. 4.8 (iv)). The number of Acanthurid species has increased marginally over the past five years.

Figure 4.9(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

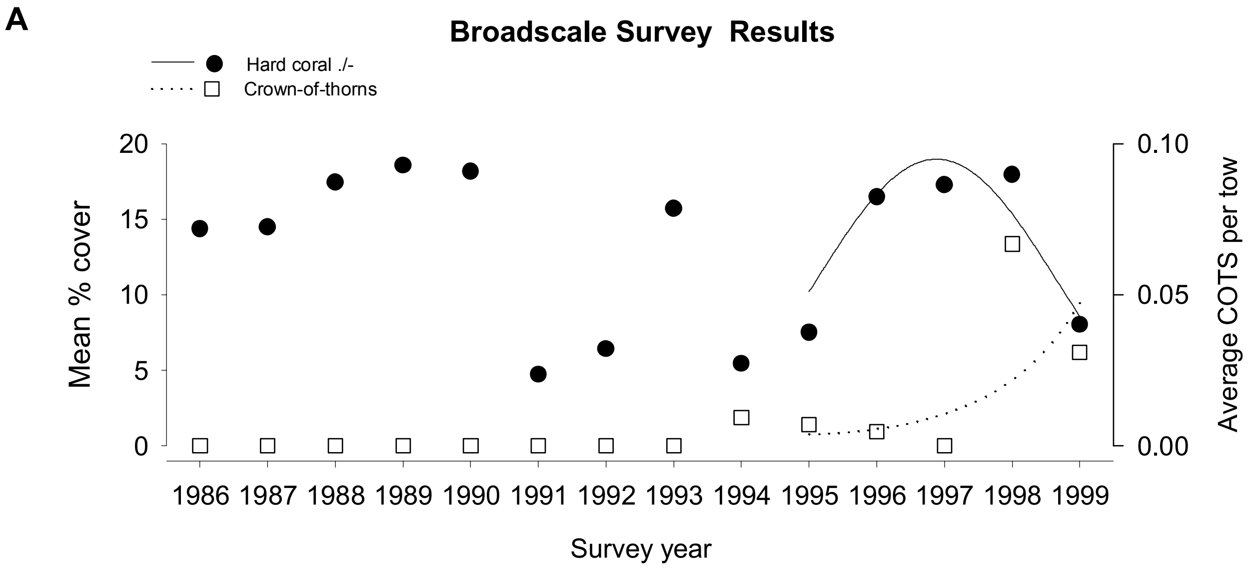
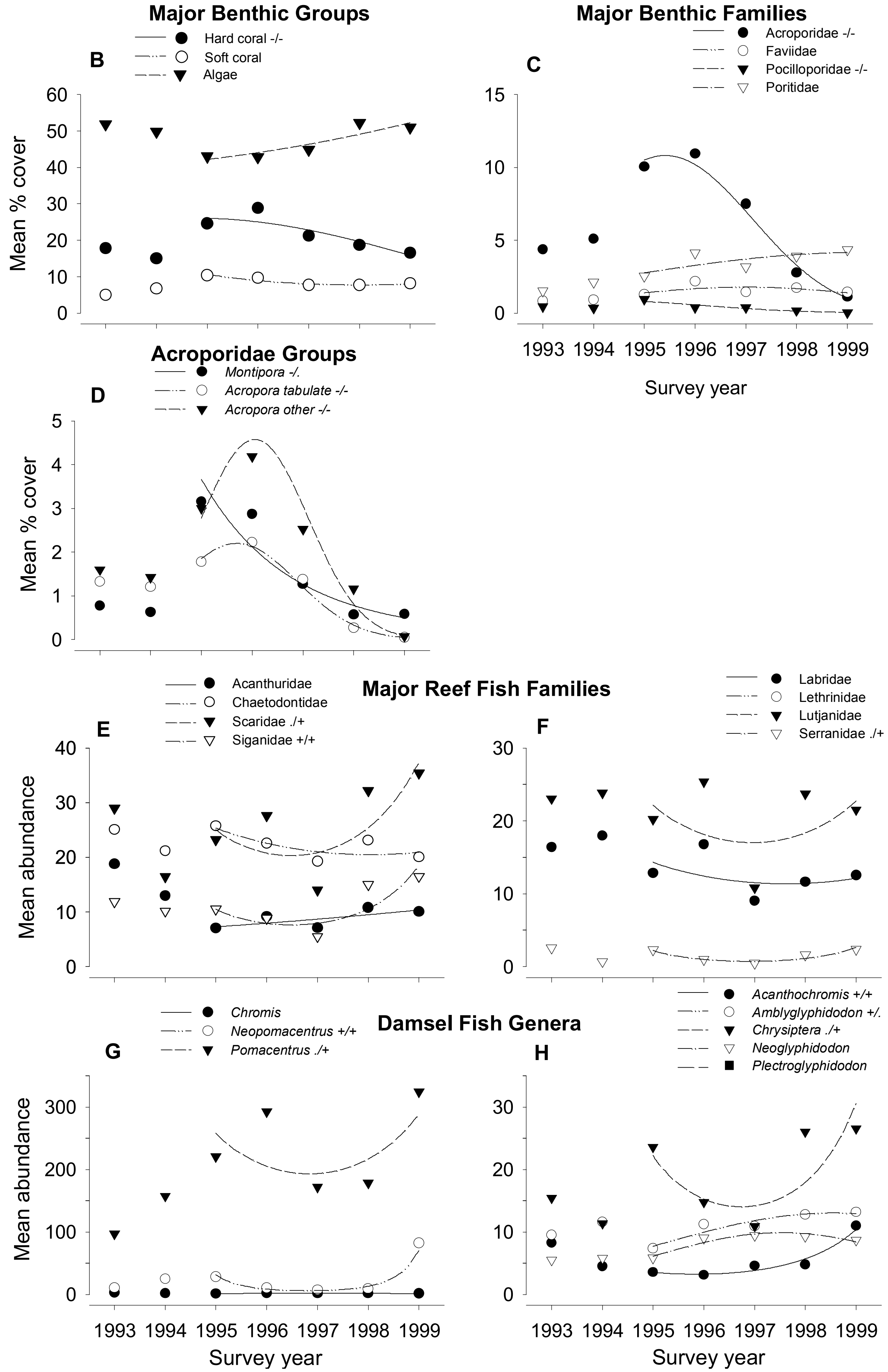


Fig 4.9 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Cairns Sector Mid-Shelf Reefs

A few COTS have been observed in this region in most survey years. In 1999 surveys, COTS were observed on seven of the 10 reefs. Of these, Rudder Reef has an Active Outbreak while two others, Mackay Reef and Oyster Reef, have Incipient Outbreaks. There has been little change in COTS populations recently (Fig. 4.10 A). Average reef-wide COTS densities are too low to cause significant coral mortality. Similarly while reef-wide coral cover has decreased since 1995 (Fig. 4.10 A), there is currently no clear trend (Fig. 4.8 (i)). Coral cover in this region is moderate (average 18%, Fig. 4.10 A).

Cover of hard coral and soft coral at the intensive survey sites have not changed significantly in the last five years (Fig. 4.8 (i), Fig. 4.10 B). The cover of algae has decreased over the last five years, but currently shows no trend. Average cover of hard coral is currently 30% while cover of algae averages 36%. Cover of soft coral is relatively high (particularly at Hastings, Michaelmas and Thetford Reefs) averaging 15% (Fig. 4.10 B).

Though total cover of hard coral has not changed greatly, cover of Poritidae has increased (Fig. 4.8 (ii), Fig. 4.10 C). This family is a minor component of hard coral community, covering 3% of the substrate on average. There were no significant changes in cover of any other families of hard corals in the region (Fig. 4.8 (ii)).

There were no clear trends in numbers of larger mobile fishes but the abundance of several genera of damselfishes increased (Fig. 4.8 (iii), Fig. 4.10 G, H). Abundance of the genus *Chromis* continues to increase marginally, due mainly to *C. atripectoralis* and *C. weberi*. As on inshore reefs, increases in numbers of *Chrysiptera rollandi* and *Neopomacentrus azysron* are driving increases in abundance of their genera (Fig. 4.8 (iii)). The abundance of *Pomacentrus* spp. is increasing (Fig. 4.8 (iii), Fig. 4.10 G), largely due to *P. lepidogenys* and *P. moluccensis*.

There has been an regional decrease in species richness of larger reef fish species overall (Fig. 4.8 (iv)), including all the selected families. Species richness of damselfishes shows no regional trend though there has been a marginal increase in the number of species of the genus *Chromis* (Fig. 4.8 (iv))

Figure 4.10(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

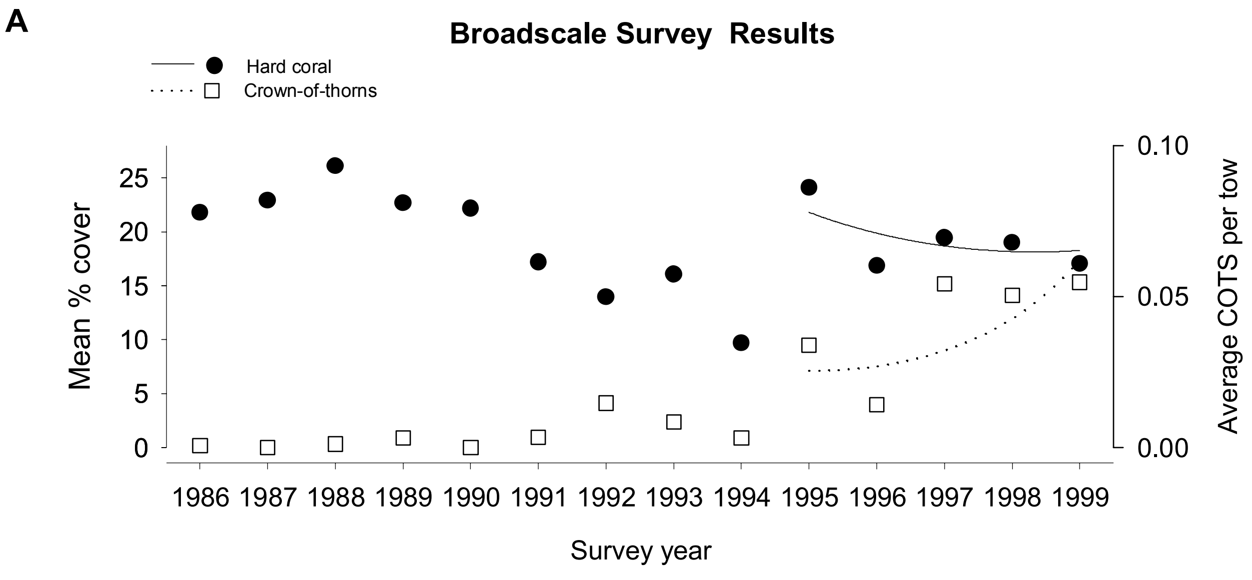
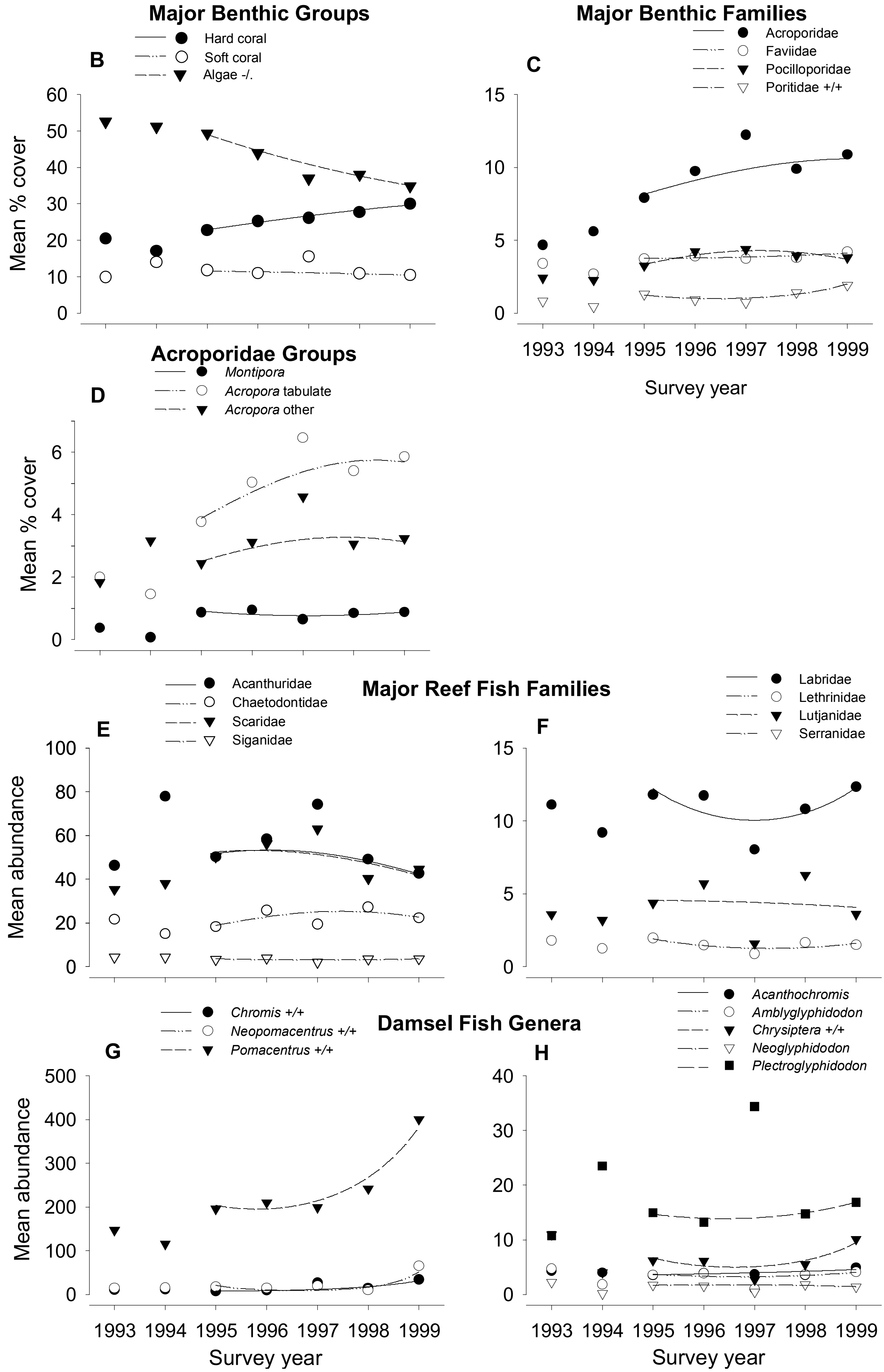


Fig 4.10 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Cairns Sector Outer Shelf Reefs

No COTS were observed on the five outer shelf reefs that were surveyed during 1999. Reef-wide coral cover is a moderate 21% and has changed little since the mid-1980s (Fig. 4.11 A).

No significant changes in cover of hard corals occurred in the intensive study sites over the last five years (Fig. 4.8 (ii)), with cover currently at 28% (Fig. 4.11 B). Cover of soft corals also remained stable, maintaining an average cover of 32%, while cover of algae decreased. No significant change was observed in the cover of any family or genus of hard coral (Fig. 4.8 (ii)). Hard corals are dominated by the family Acroporidae which accounts for 16% of cover. All other families average less than 5% cover (Fig. 4.11C, D).

A general decline in abundance of Acanthuridae and Labridae may be slowing (Fig. 4.11 E, F). Several *Chromis* spp. are increasing in numbers while strong increases have occurred and continue in the genera *Chrysiptera* (due to *C. rex*) and *Pomacentrus* (mainly due to *P. lepidogenys* and *P. bankanensis*) (Fig. 4.11 G, H).

The overall regional species richness has shown no trend over five years, but is currently decreasing (Fig. 4.8 (iv)). This is reflected in the larger species, notably the Chaetodontidae, but there are no significant trends in the number of damselfish species (Fig. 4.8 (iv))

Figure 4.11(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

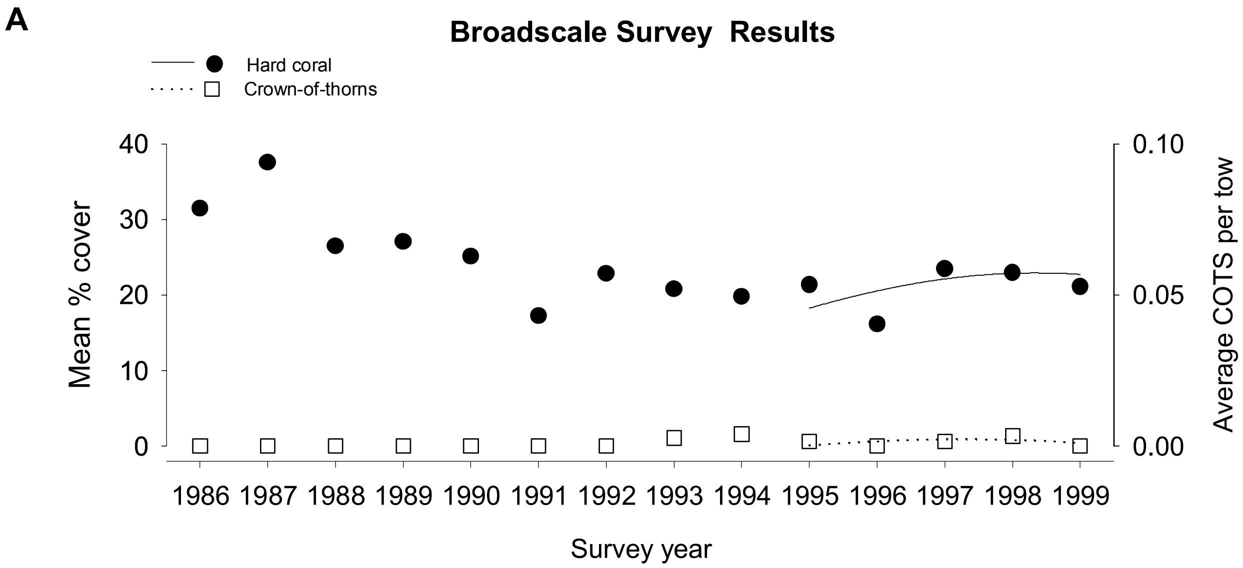
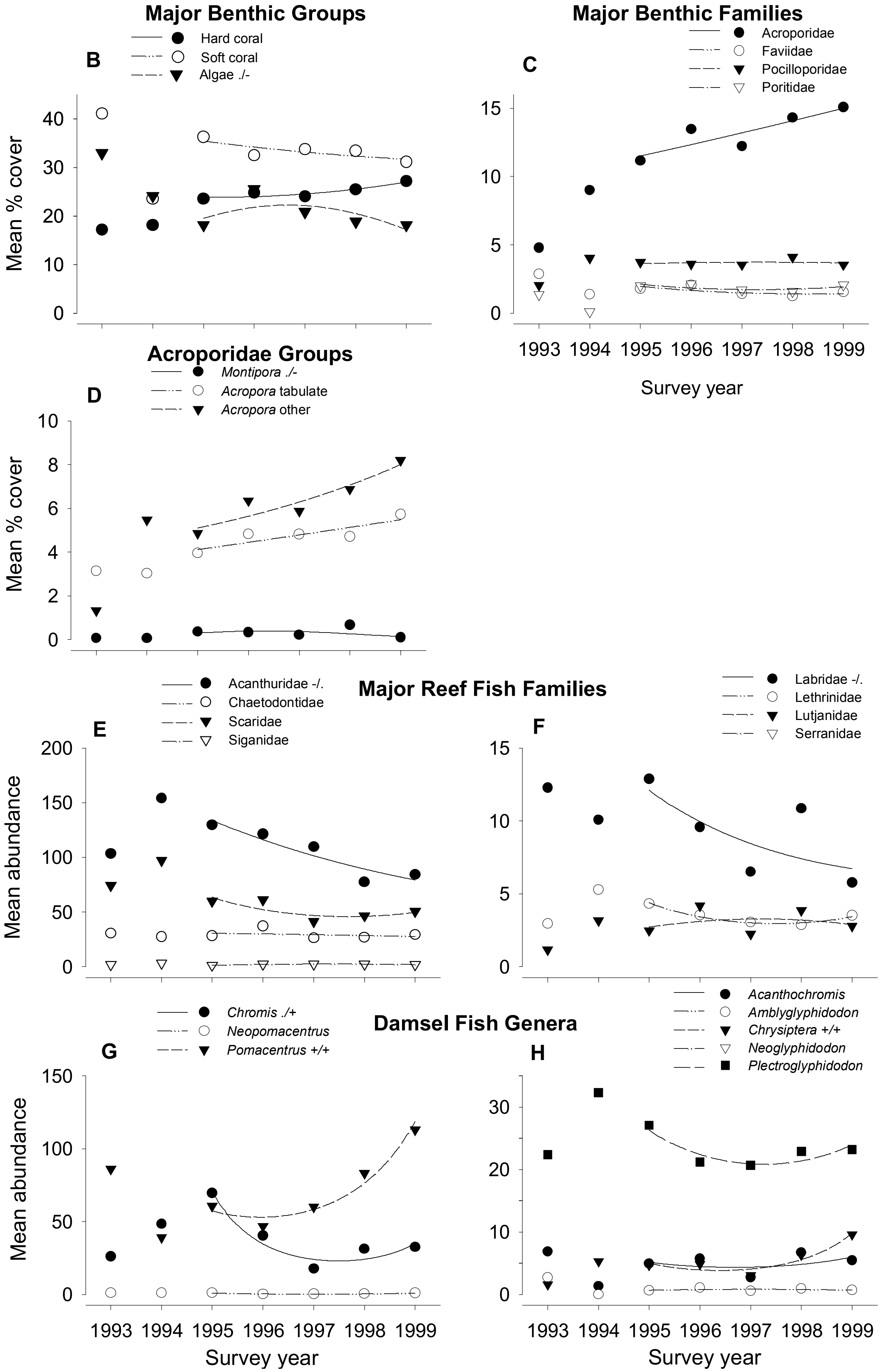


Fig 4.11 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Innisfail Sector

This sector was surveyed in February 1999.

Summary

Too few reefs were surveyed to provide a sound estimate of regional trends in COTS and coral cover in this sector. At least one reef has an active COTS outbreak. Reef-wide coral cover has declined on reefs with recent COTS activity.

Geography

This sector resembles the Cairns sector in that the outer-shelf reefs do not form an impermeable barrier to oceanic influences and the adjacent coast receives a lot of rainfall.

Bleaching

In February 1999 there were low levels of coral bleaching (<10% of total hard coral cover with isolated colonies affected) on all reefs surveyed in this sector and bleaching generally increased with distance offshore.

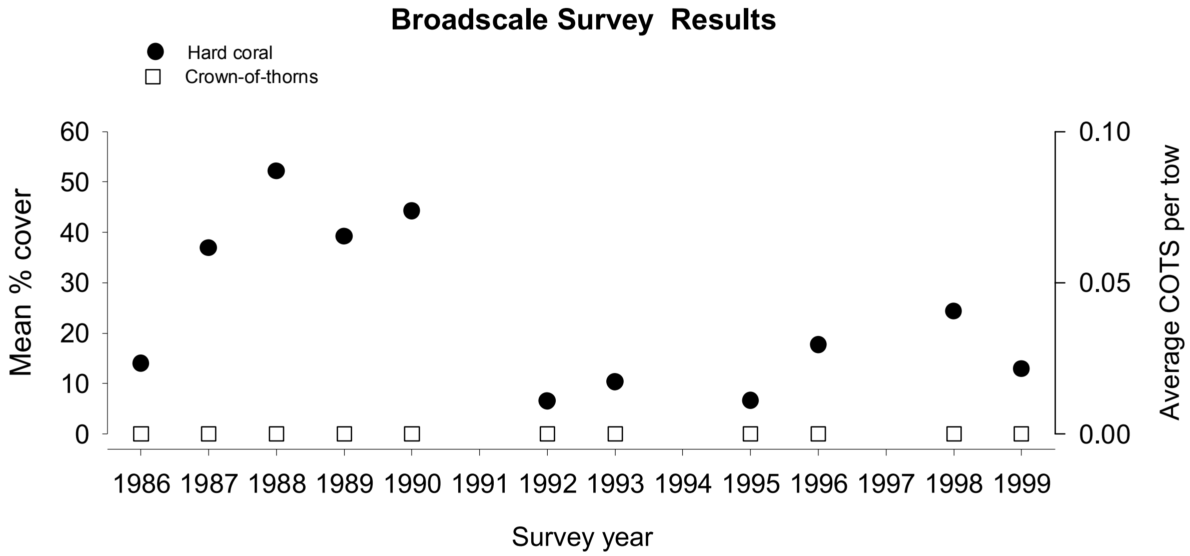
Figure 4.12 Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Innisfail Sector.

	Mid	Outer
Crown-of-thorns starfish	*	*
Hard Coral	*	*

Innisfail Sector Inshore Reefs

Only Normanby Is. Reef was surveyed in this region in 1999; no COTS were recorded. Too few inshore reefs have been sampled recently to estimate regional trends reliably.

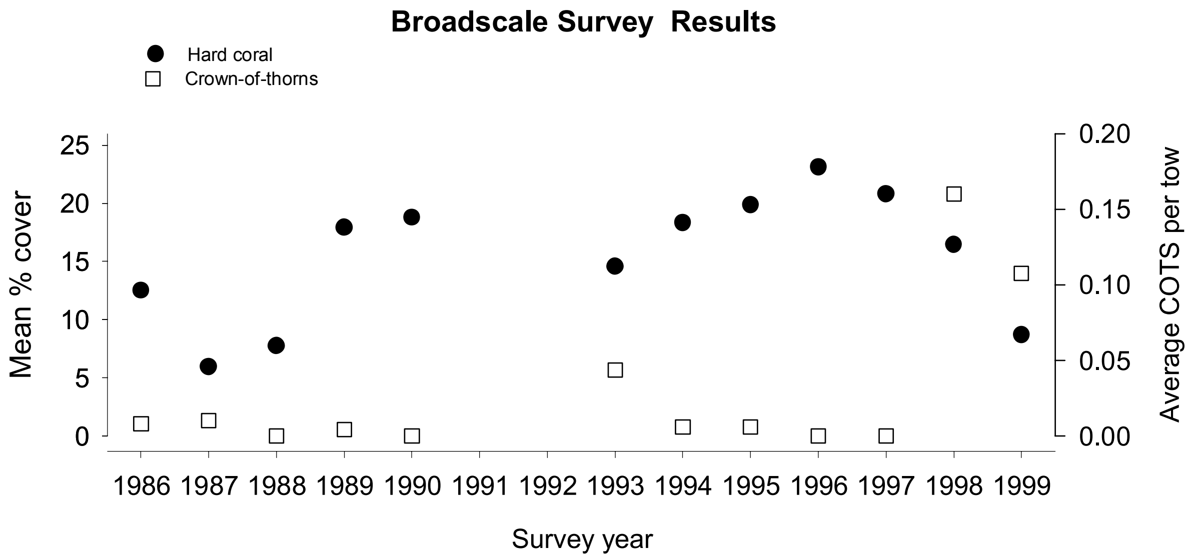
Figure 4.13 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Innisfail Sector Mid-Shelf Reefs

Only two reefs were surveyed in 1999. No COTS were observed on Feather Reef and there was no appreciable change in coral cover from previous years. Flora Reef has an Active Outbreak and reef-wide cover of live coral has decreased dramatically to 1-5% from 20-30% in 1996. Some of this decline may be due to bleaching which was extensive in this sector in 1998 (Berkelmans & Oliver 1999). No bleaching was observed on Flora Reef in February 1998, but coral may have bleached subsequently.

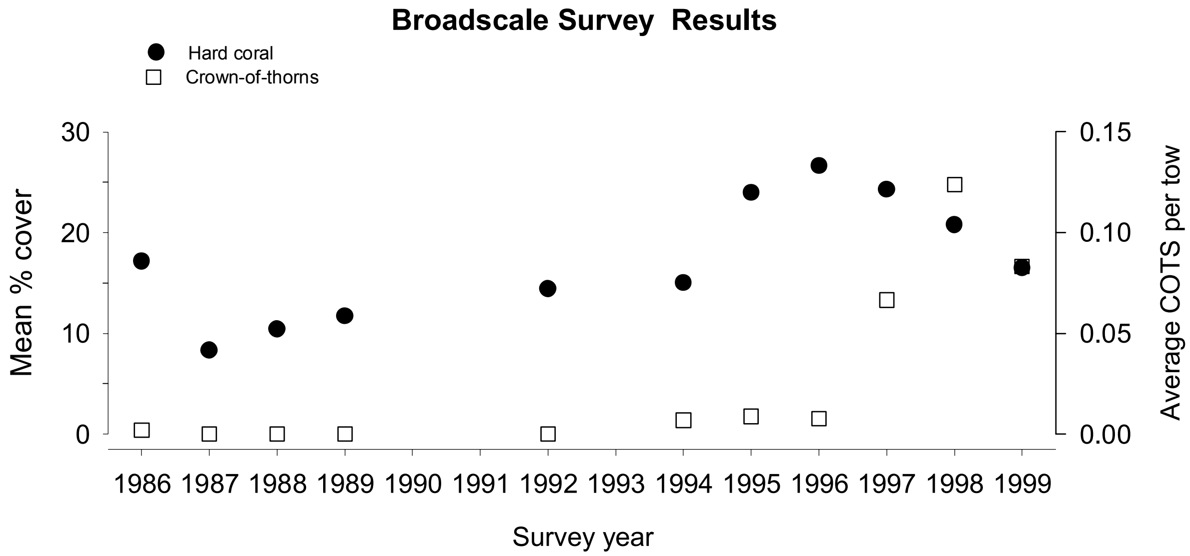
Figure 4.14 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Innisfail Sector Outer Shelf Reefs

Two reefs, Gilbey and Wardle, were surveyed in 1999 which precludes the estimation of trends. COTS were observed on both reefs, though not at outbreak densities. Coral cover on Gilbey Reef has not changed significantly; it is currently classified as recovering. Wardle Reef was classified as an incipient outbreak in 1998 but is now classified as recovering. Reef-wide coral cover has been declining since 1997 and is currently 5-10% (Fig. 4.15).

Figure 4.15 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Townsville Sector

This sector was surveyed in June 1999.

Summary

Coral communities on Havannah Is and Pandora Reefs have been badly affected by bleaching. The COTS population at Rib Reef is expected to cause loss of hard coral, but this is not evident yet. Poor visibility meant that no data on fishes were collected on inshore reefs where benthos has changed. There have been few changes in benthic animals or fishes in mid-shelf and outer shelf regions.

Geography

The outer-shelf reefs in this sector do not exclude oceanic influences, but the GBR lagoon is wider near Townsville than it is further north. The Herbert River drains into the northern part of this sector, and the mouth of the Burdekin is just to the south. River plumes tend to be transported northwards by the prevailing winds.

Bleaching

No bleaching was observed on the one inshore reef surveyed in 1999. Low levels of bleaching (<10% of the total hard coral cover) were recorded from both mid and outer shelf reefs. Bleached corals were mainly *Montipora* spp.

Figure 4.16(i) Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Townsville Sector.

	Mid	Outer
Crown-of-thorns starfish		
Hard Coral		

Figure 4.16 (ii) Summary of trends in benthic cover on intensive survey sites in the Townsville Sector.

	Inner	Mid	Outer
Algae			
Soft Coral			
Hard Coral			
Poritidae			
Faviidae			
Pocilloporidae			
Other Corals			
Acroporidae			
Montipora			
Acropora Tabulate			
Acropora Other			

Figure 4.16 (iii) Summary of trends in fish abundance in the Townsville Sector.

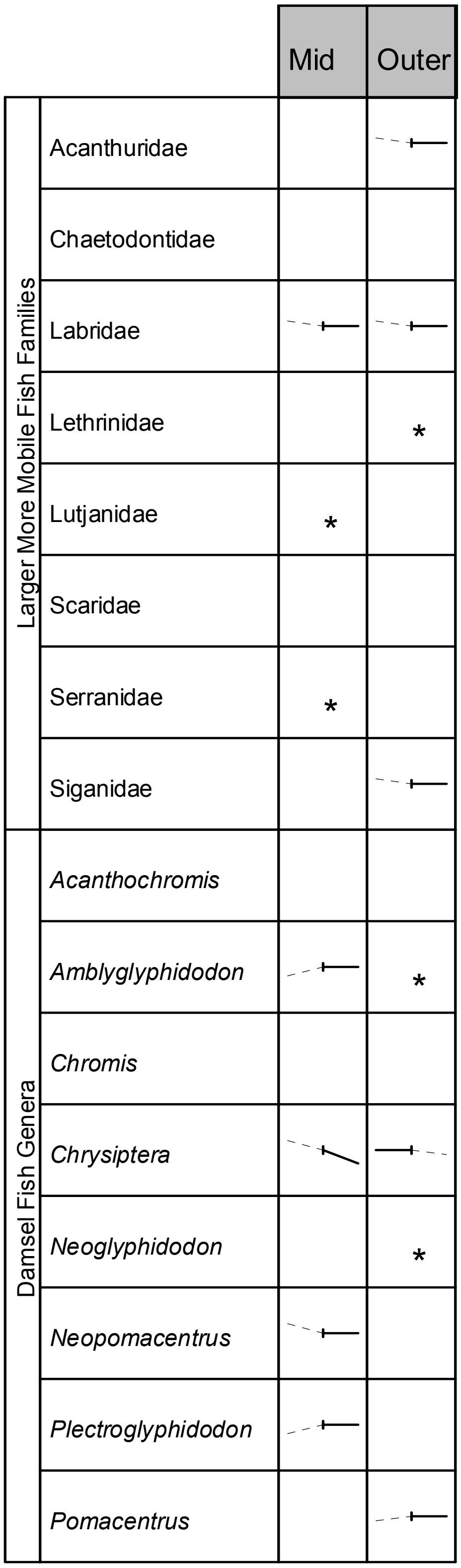
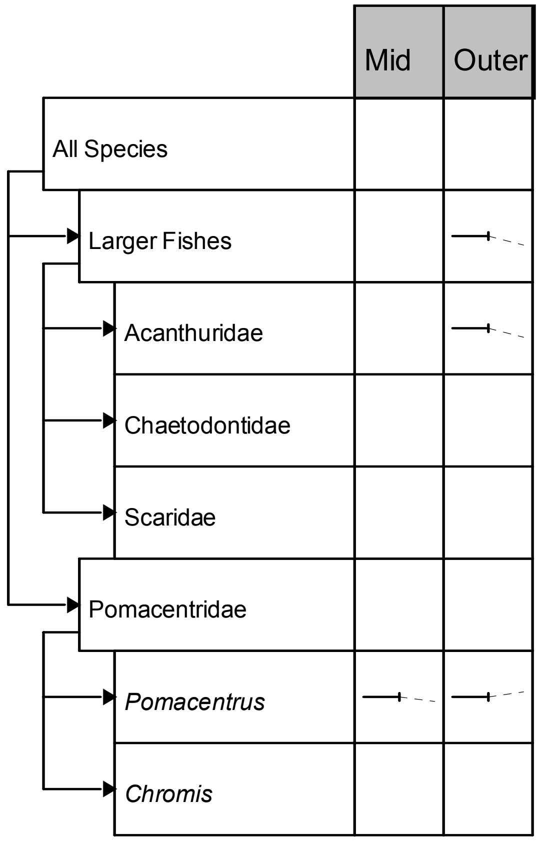


Figure 4.16 (iv) Summary of trends in fish species richness in the Townsville Sector.



Townsville Sector Inshore Reefs

Only two reefs in this region, Havannah Is and Fantome, were surveyed by manta tow in 1999. Havannah Is reef suffered severe bleaching in February 1998. This contributed to a regional decline in reef-wide coral cover (Fig. 4.17 A). Coral cover has continued to decline on this reef over the past 12 months to a current 5-10%. No COTS were observed. Too few inshore reefs have been sampled over recent years to estimate regional trends.

Intensive surveys in this region also show that hard coral cover has decreased in the past year (Fig. 4.16 (ii), Fig. 4.17 B). Average cover of hard coral is currently 39%. Declines in cover of hard coral are most pronounced at Havannah Is. The declines in cover of hard coral have been matched by an increase in algal cover (Fig. 4.16 (ii), Fig. 4.17 B). Cover of soft corals has remained about 14% (Fig. 4.17B).

Among hard corals, *Montipora* spp. declined from 5% cover in 1997 to 4% in 1998 (Fig. 4.17 D). Large declines in branching and bottle-brush *Acropora* spp. (*Acropora* other) were observed at Havannah Is. Reef, where cover was reduced from 22% in 1997 to 13% in 1998. Cover of Poritidae (13%) and Faviidae (3%) did not change over this survey period (Fig. 4.16 (ii), 4.17C). These taxa constitute large parts of the hard coral community at both Middle and Pandora Reefs.

The poor visibility on these inshore reefs has meant that larger fishes often cannot be counted effectively and no trends can be estimated. Damselfish have been surveyed in most years on Middle and Pandora Reefs but Havannah Reef has only been surveyed in the past three years. Trends estimated from these data would be unreliable.

Figure 4.17(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

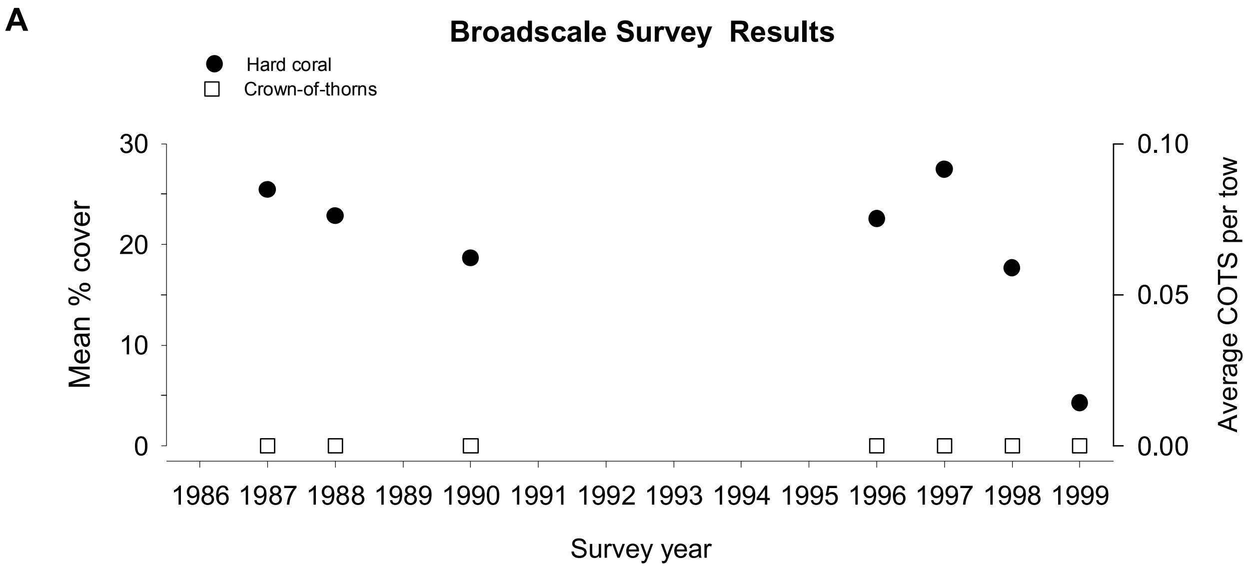
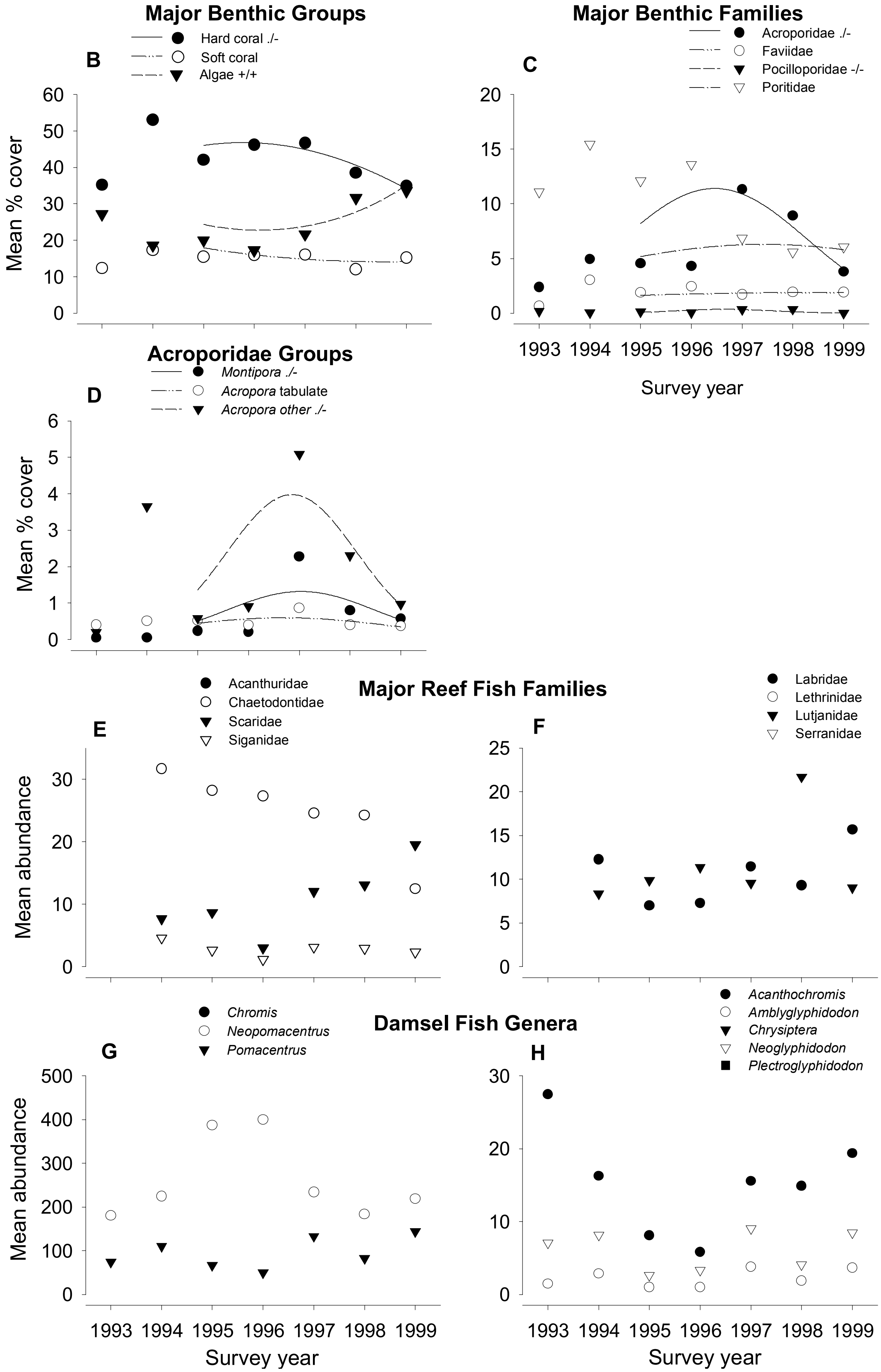


Fig 4.17 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Townsville Sector Mid-Shelf Reefs

COTS were recorded on two of the six survey reefs, though only Rib Reef had an Active Outbreak. The high numbers on Rib Reef have boosted regional COTS numbers since last year (Fig 4.18 A). Reef-wide coral cover on mid-shelf reefs has not changed significantly (Fig. 4.16 (i)). Coral cover on Davies, Helix, Little Broadhurst and Rib reefs is moderate to high (20 to 40%). Davies, Helix and Little Broadhurst Reefs are classified as recovering from COTS activity. Reef-wide coral cover declined on Wheeler and John Brewer. The cause of decline is uncertain: no COTS were seen on these reefs though some feeding scars were recorded at John Brewer Reef.

Cover of hard corals on the intensive survey sites shows no net trends over the last five years (Fig. 4.16 (ii), Fig 4.18 B). Cover of soft coral has been declining and now averages less than 3%. Among the hard corals, *Porites* spp. (mainly encrusting forms) have increased but still account for less that 3% of the cover (Fig. 4.16 (ii), Fig. 4.18 C).

Among the larger fishes, the family Labridae were decreasing in numbers but this has slowed (Fig 4.16 (iii)). The overall increases in abundance of the genera *Amblyglyphidodon* (largely *A. curacao*) and *Plectroglyphidodon* (largely *P. lacrymatus*) appear to have halted. Marginal general decreases in abundance of *Neopomacentrus* (solely *N. azysron*) have stabilised while the genus *Chrysiptera* continues to decrease, involving both *C. rollandi* and *C. talboti* (Fig. 4.18 G, H).

The only significant regional trend in species richness was a marginal decrease in species in the genus *Pomacentrus* (Fig. 4.16 (iv))

Figure 4.18(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

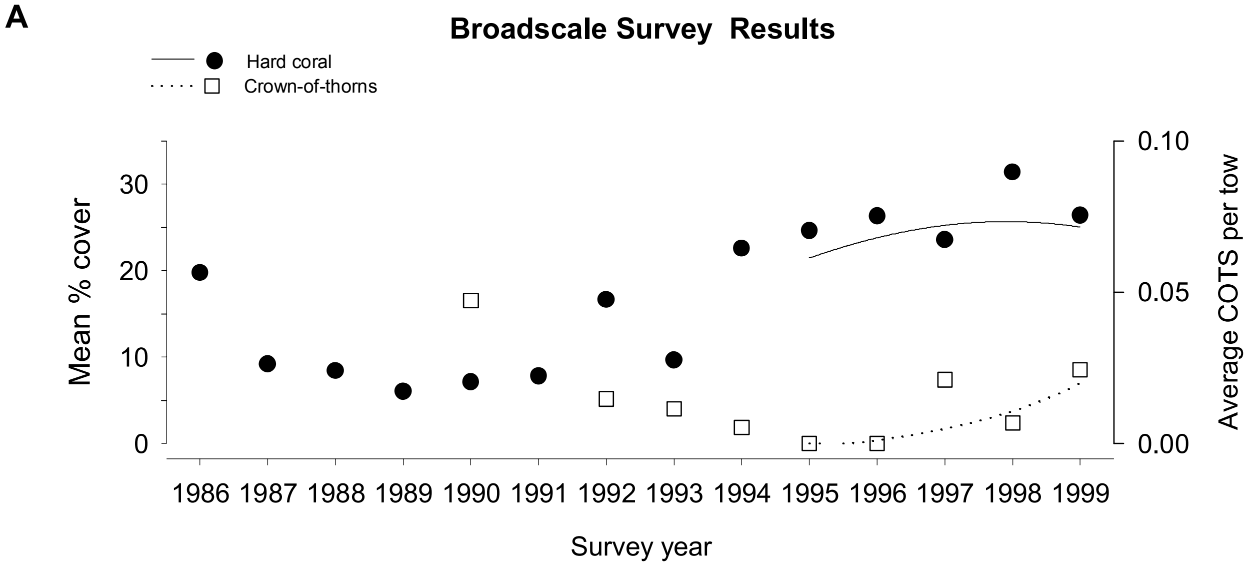
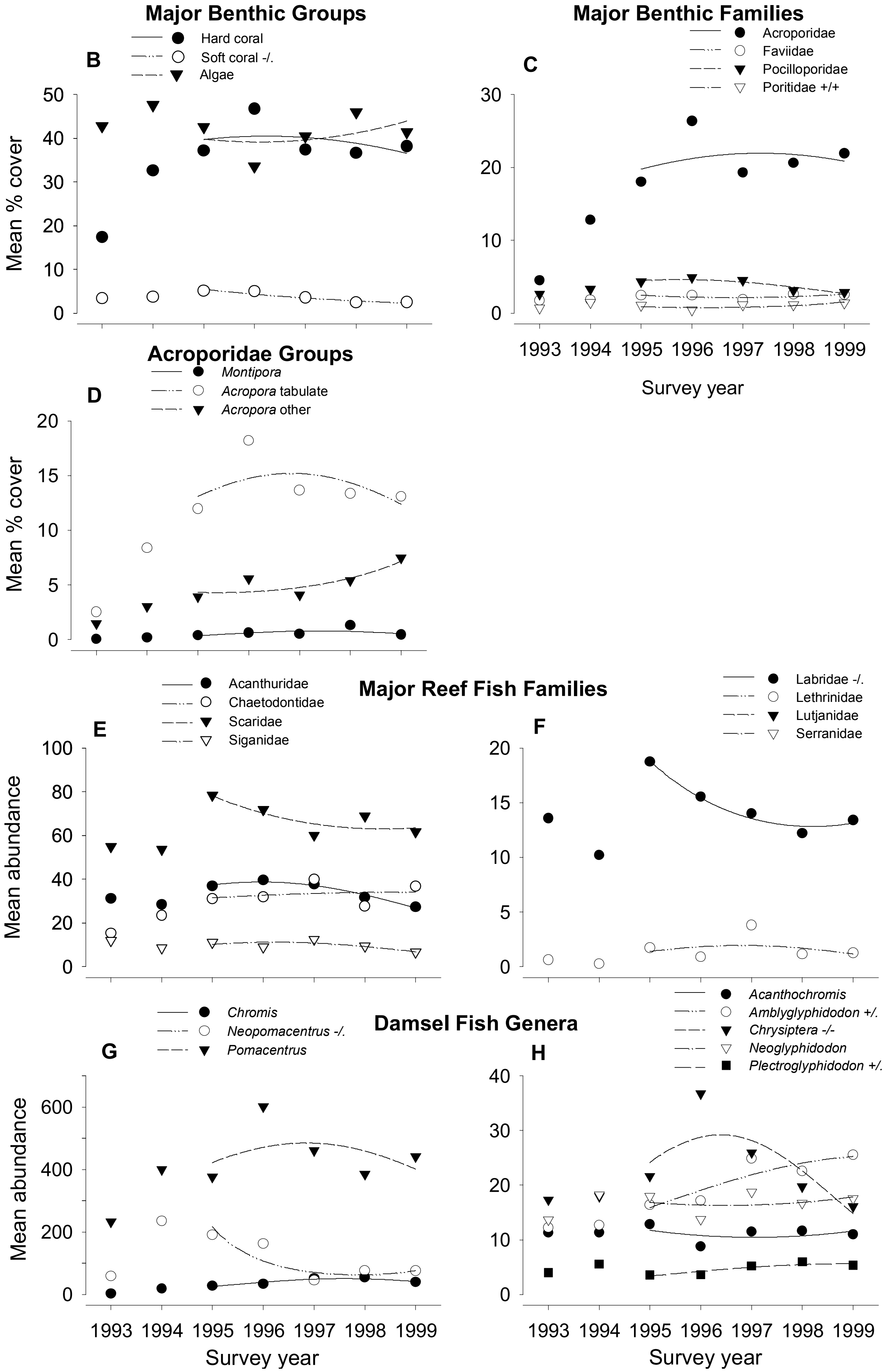


Fig 4.18 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Townsville Sector Outer Shelf Reefs

No COTS were recorded on any of the three reefs surveyed by manta tow in 1999. Reef-wide coral cover in this sector is moderate (24%) and has changed little over the last five years (Fig. 4.16 (i), Fig 4.19 A).

Intensive surveys show that hard coral has not changed significantly in recent years and averages 37% (Fig 4.19 B). Cover of algae has declined in the previous five years to 23% in 1999. Cover of soft corals has been consistent and is currently 16%.

Little significant change in numbers has occurred in either the larger, mobile fish families or the damselfishes (Fig. 4.16 (iii)). Acanthuridae, Labridae and Siganidae have shown marginal decreases over time (Fig. 4.19 E, F)) but declines have slowed in each case. There is currently a marginal decline in the genus *Chrysiptera*, mainly due to *C. rex*. Pomacentrids have increased in abundance in the past five years, mainly due to *P. lepidogenys*.

The species richness of larger reef fishes has declined regionally, due in part to a decrease in the number of surgeonfish species recorded (Fig. 4.16 (iv)). In contrast to the mid-shelf region, there has been a marginal increase in the numbers of species in the genus *Pomacentrus*.

Figure 4.19(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

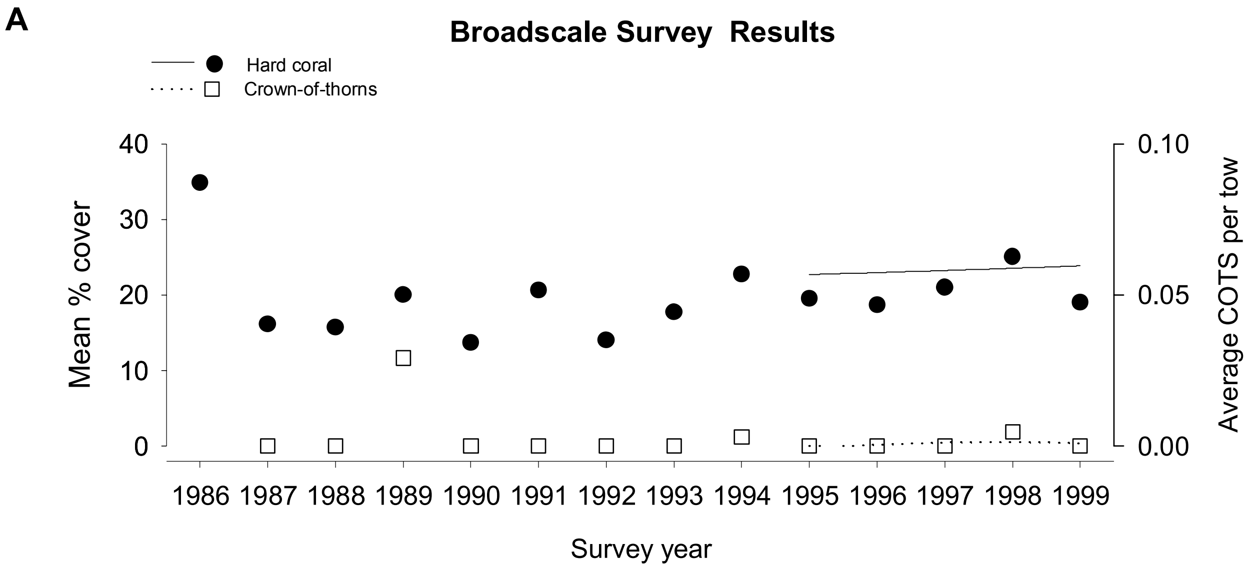
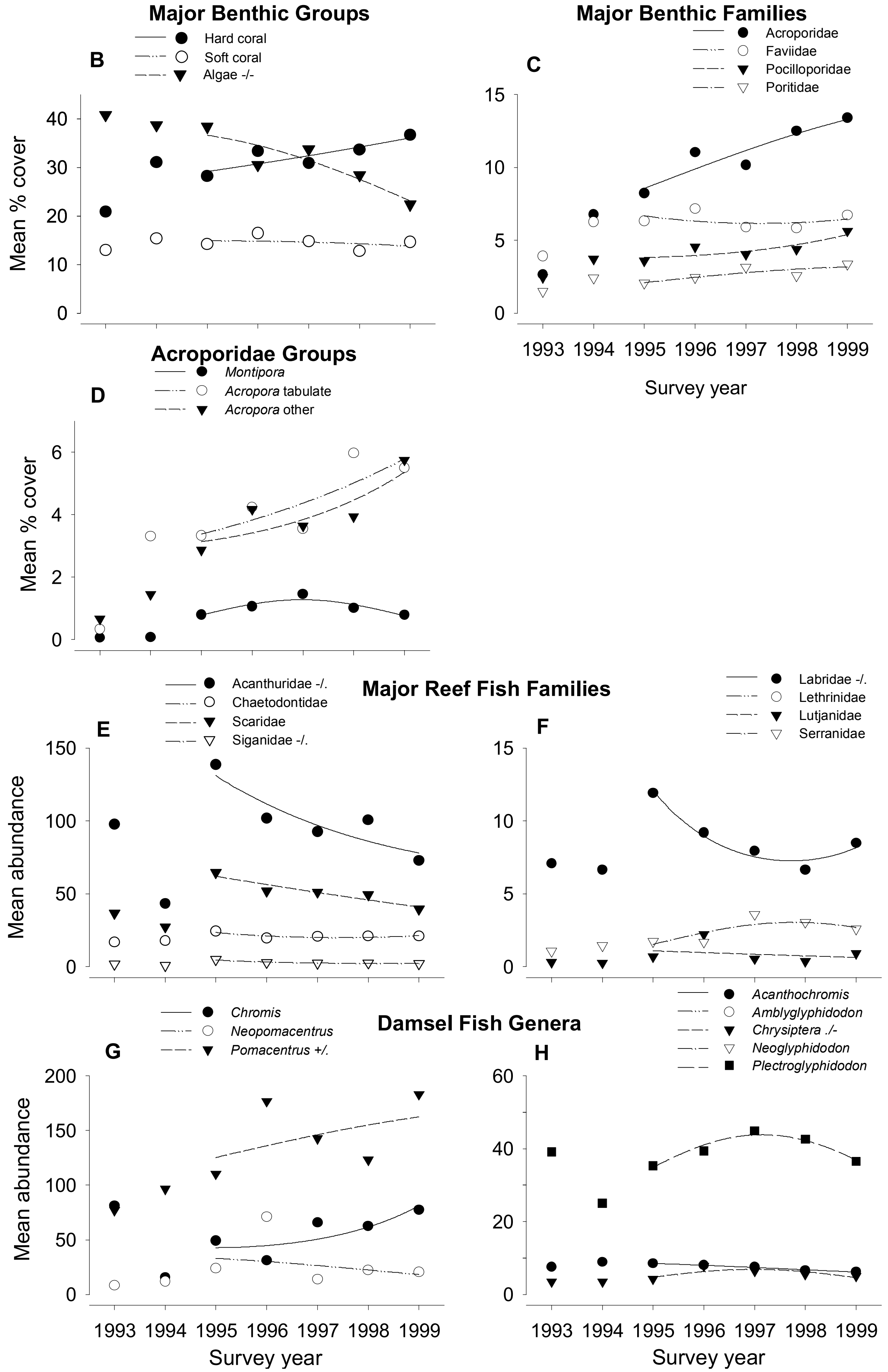


Fig 4.19 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Cape Upstart Sector

This sector was surveyed in June 1999.

Summary

No active COTS outbreaks were recorded on any of the survey reefs. Reef-wide cover of live coral increased slightly on mid-shelf reefs. The reefs in this sector are surveyed by manta tow only, often at intervals of more than a year. Only one inshore reef is surveyed, so trends have not been estimated for this region.

Geography

The reefs in the Cape Upstart sector do not form a significant barrier to oceanic influences and the tidal range is higher than in the sectors to the north.

Bleaching

Reefs in this sector are surveyed in April or May each year. No inner-shelf reefs were surveyed in 1999. There were low levels of bleaching on mid-shelf reefs but none was recorded from outer shelf reefs.

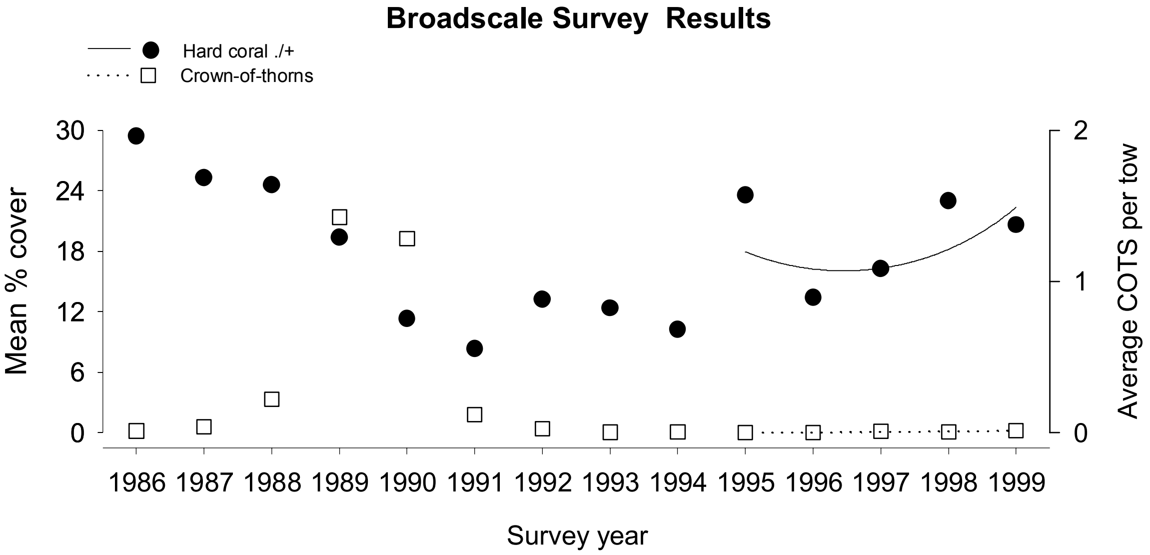
Figure 4.20 Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Cape Upstart Sector.

	Mid
Crown-of-thorns starfish	
Hard Coral	

Cape Upstart Sector Mid-Shelf Reefs

COTS were observed in very low numbers on three of the five reefs surveyed in 1999. Overall COTS activity remains well below levels that would cause significant coral mortality. Reef-wide cover of hard coral has remained at a moderate level (22%) over the last five years and is now increasing (Fig. 4.20, Fig. 4.21)

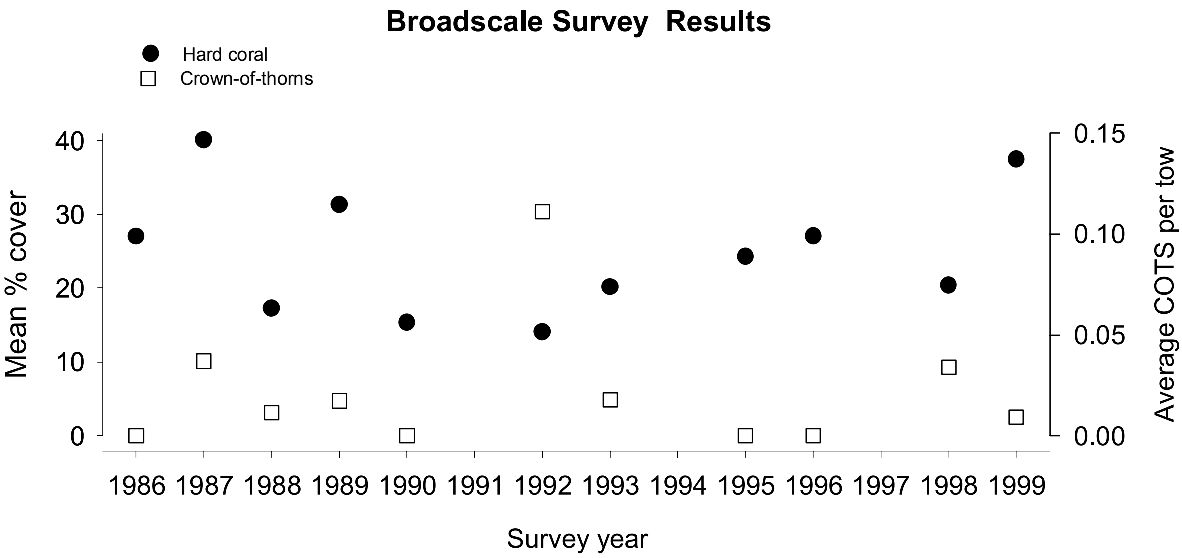
Figure 4.21 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Cape Upstart Sector Outer Shelf Reefs

Only two reefs were surveyed which precludes estimation of trends. Changes in coral cover have differed between reefs, resulting in no clear regional pattern. Small numbers of COTS have been recorded on these reefs at every survey, but populations have remained well below outbreak levels.

Figure 4.22 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Whitsunday Sector Inshore Reefs

Only two reefs were surveyed in 1999. Poor visibility has meant that inshore reefs have not been surveyed often enough to estimate broad-scale trends reliably.

Cover of hard coral, algae and soft corals at the intensive study sites has changed little in recent years, averaging about 30%, 29% and 22% respectively (Fig 4.23 (ii), Fig. 4.24 B). The benthic communities in this region vary: Border Is. Reef has high cover of Poritidae (mainly *Goniopora* spp.), while Hayman Is. Reef has a higher cover of branching and bottlebrush *Acropora* spp. None of the taxa of hard coral show any trends in cover over the last five years (Fig 4.23 (ii), Fig. 4.24 B, C, D).

Among larger fishes, several species of Labridae have shown general declines in abundance over the last five years, but most have increased in the last survey (Fig. 4.24 F). Other families of large mobile fishes have shown no consistent trends in abundance. Among damselfishes, the decline in the genus *Chromis* has stabilised (Fig. 4.24 G), though this genus occurs in relatively low numbers on inshore reefs. The increase in abundance of *Chrysiptera* is caused by *C. rollandi*. There have been large annual fluctuations in numbers of *Pomacentrus* spp. (Fig. 4.24 G), due mainly to *P. moluccensis* and *P. brachialis*) but no clear temporal trends have emerged.

The only regional trend in species richness was an increase in the number of species of Chaetodontidae (Fig. 4.23 (iv))

Figure 4.24(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

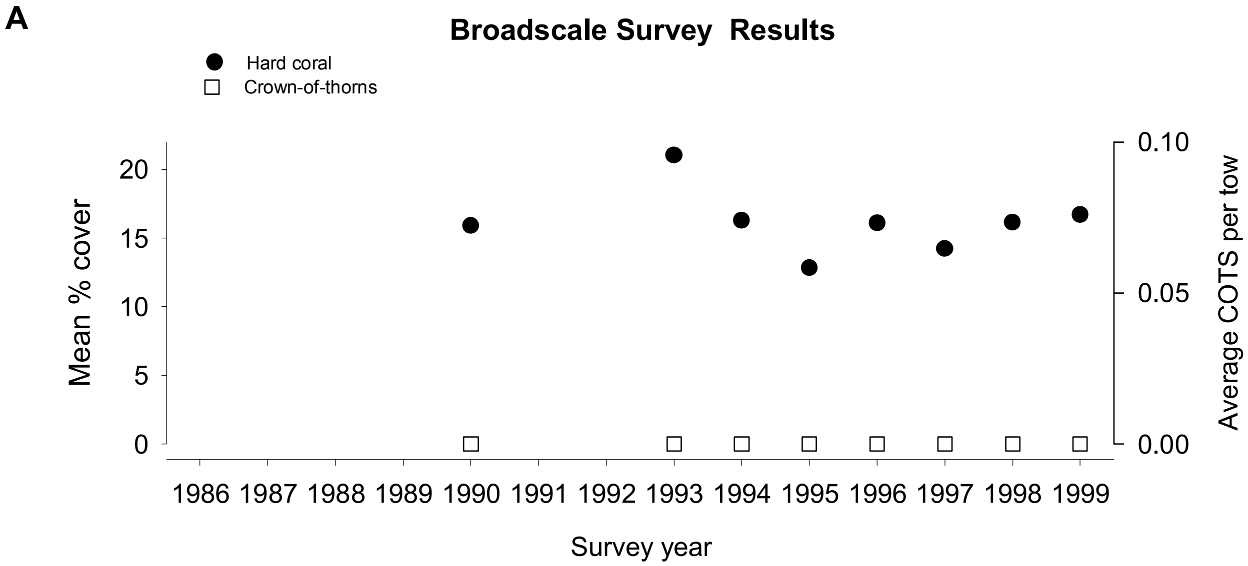
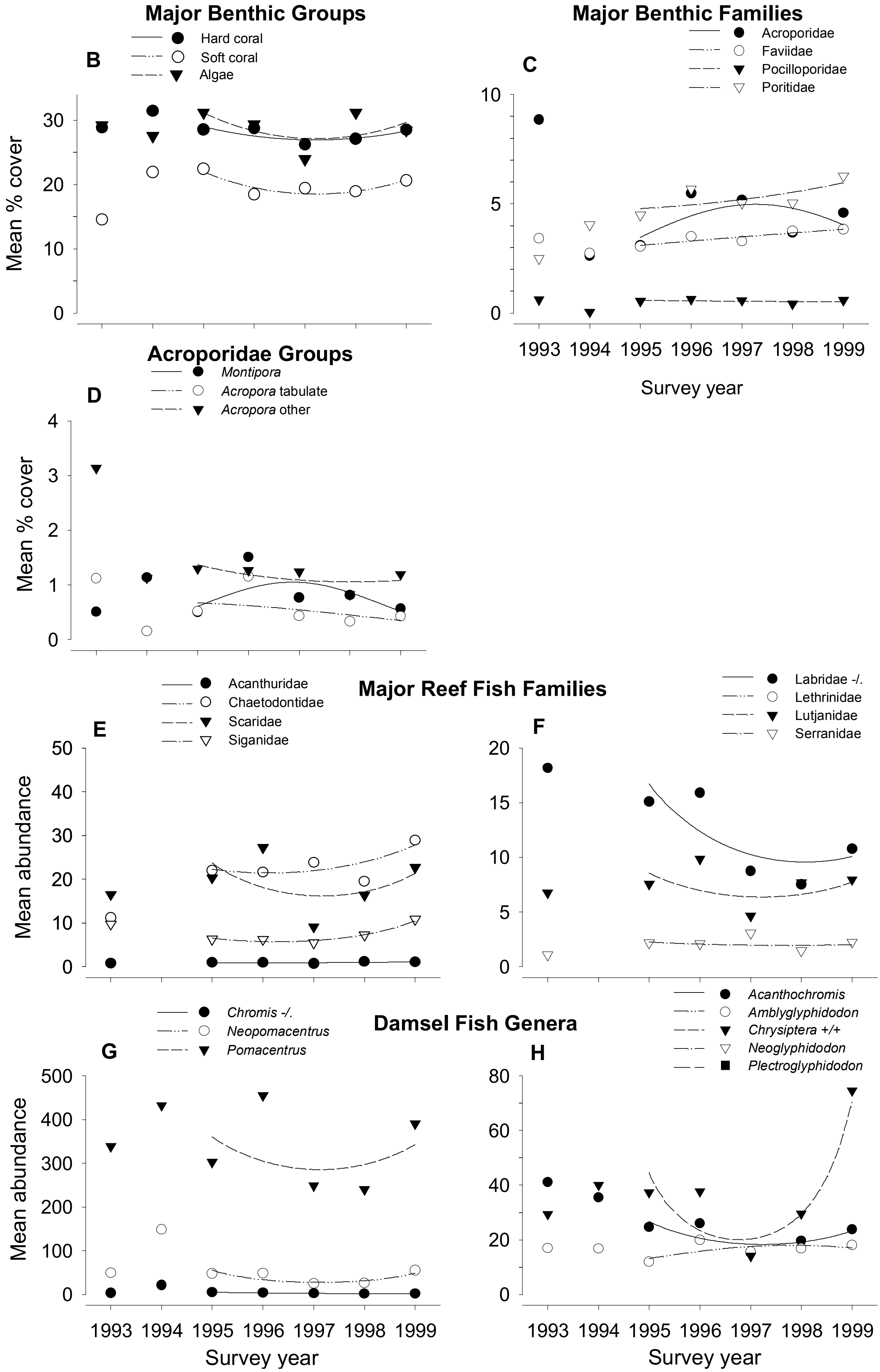


Fig 4.24 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Whitsunday Sector Mid-Shelf Reefs

Few COTS have been observed in this sector over the last five years and no COTS were observed on the four reefs surveyed in 1999. Reef-wide coral cover declined sharply due to Cyclone Justin in March 1997 giving an average decrease over five years. There is currently no trend (Fig. 4.23 (i). Reef-wide cover of hard coral is moderate (17% Fig. 4.25 A).

Cover of hard coral in the intensive survey sites showed a similar pattern, reaching 40% in 1996 then decreasing sharply with Cyclone Justin in 1997. Hard coral cover has recovered little and is currently 27% (Fig 4.25 B). Cover of algae has shown complementary increases. Cover of soft coral has remained less than 2%. Cover of most groups of hard corals show declines associated with Cyclone Justin (Fig. 4.25 C & D). This was significant in the Acroporidae, due to large decreases in cover of tabulate *Acropora* spp. (Fig. 4.23 (ii), 4.25 D).

The general increase in abundance of the family Acanthuridae (mainly *Naso unicornus* and *N. tuberosus* , but also *Ctenochaetus* spp. and *Acanthurus dussumieri*) in 1998 has been followed by a marginal decline, driven by the same species (Fig. 4.25 E). The current significant decline in numbers of fishes in the family Chaetodontidae (Fig. 4.25 E) is largely due to *C. rainfordi*, *C. aureofasciatus* and to a lesser extent *C. baronessa*. This decline started at the same time as the reduction of hard coral cover from around 40% to just above 20% at the time of Cyclone Justin. Since then, hard coral cover has increased marginally, while the Chaetodontidae have continued to decline in numbers Fig. 4.23 (iii). The abundance of Lethrinidae is currently declining, while Scaridae and Siganidae have stabilised after a long-term increase in abundance (Fig. 4.23 (iii), 4.25 F). Among damselfishes *Acanthochromis polyacanthus* is currently increasing in numbers while the genus *Amblyglyphidodon* (principally *A. curacao*) is currently declining (Fig. 4.23 (iii)). The genus *Chromis* has continued to decline, driven largely by *C. nitida* and *C. atripectoralis*, and is now present in very low numbers (Fig. 4.25 G). Increases in *Chrysiptera rollandi* and *C. talboti* have driven the significant increases in abundance of that genus (Fig. 4.25 H). Numbers of *Neopomacentrus azysron* have fluctuated widely and have increased recently (Fig. 4.25 G). There have been large annual fluctuations in numbers of *Pomacentrus* spp. (Fig. 4.25 G), mainly *P. moluccensis* and *P. lepidogenys*) but no clear temporal trends have emerged.

The species richness of the fish assemblages has increased in this region, due in part to increases in the number of species of Acanthurids and Scarids that were observed (Fig. 4.23 (iv))

Figure 4.25(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

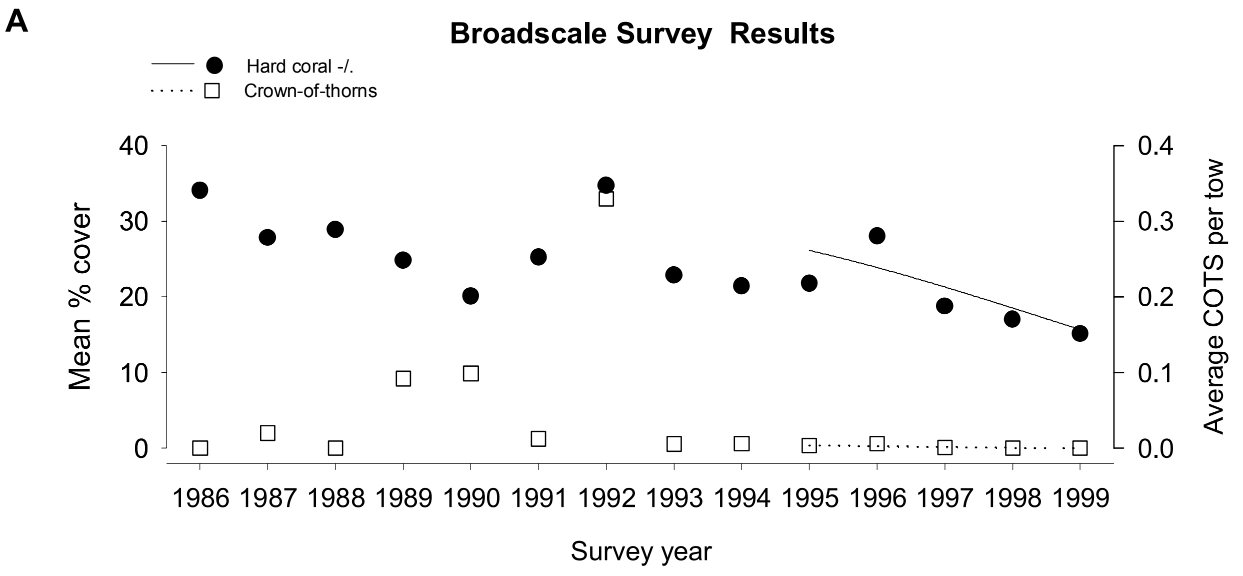
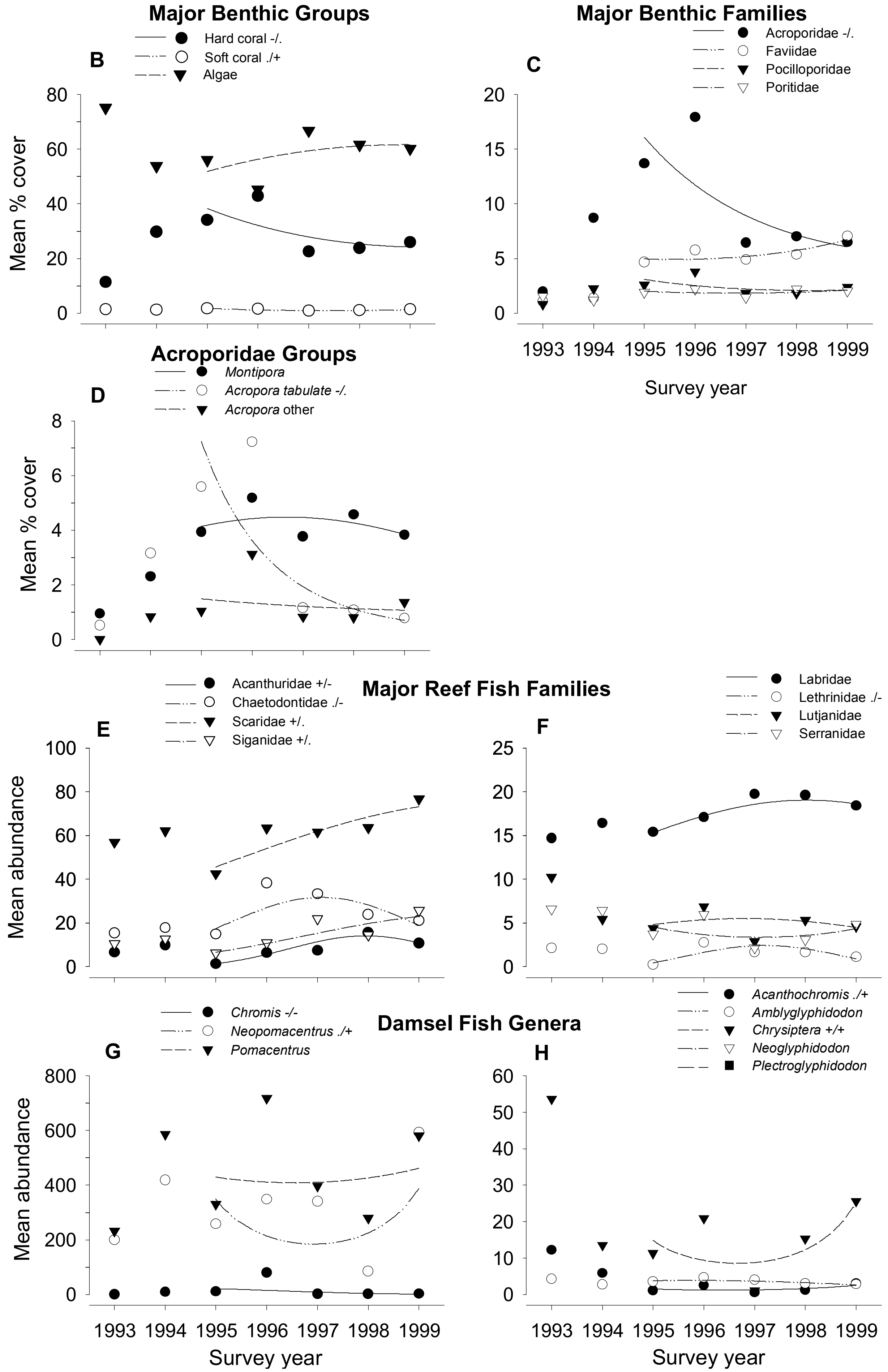


Fig 4.25 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Whitsunday Sector Outer Shelf Reefs

Very few COTS have ever been recorded on reefs in this region and only one COTS was observed in surveys of the three outer shelf reefs in 1999. Reef-wide coral cover remains moderate (27%, Fig. 4.26 A) and has not changed significantly over the last five years.

Cover of hard coral in the intensive study sites averages 28% and has shown no trend over the last five years (Fig. 4.23 (ii), 4.26 B). Cover of algae has been declining but shows no trend, averaging 16%. Soft corals are an important component of these communities (35% cover). These regional averages obscure differences among reefs: Hyde and Rebe Reefs are both dominated by soft corals whereas Reef 19-159 has higher cover of hard coral, particularly *Acropora* spp.

The proportions of different families of hard coral in benthic assemblages also differ among the reefs. Reef 19-159 supports a variety of life-forms in the genus *Acropora* while no particular family of hard coral dominates cover on the other two reefs (Fig. 4.26 C, D).

Among larger fishes, the families Acanthuridae (mainly *A. nigrofuscus*) and Lutjanidae (*L. bohar* and *L. carponotatus*) have declined in abundance recently (Fig. 4.23 (iii), 4.26 E, F). Among damselfishes, the genus *Amblyglyphidodon* continues to increase in abundance because of *A. curacao* (Fig. 4.23 (iii), 4.26 H). Several species in the genus *Chrysiptera* are declining in abundance. The genus *Neoglyphidodon* continues to decline because of *N. melas*. The significant increase in the genus *Pomacentrus* (Fig. 4.26 G) is mainly due to a very large increase (> 200%) in abundance of *P. lepidogenys* since 1998. This reverses the previous trend of decreasing abundance (Sweatman et al. 1998).

The number of species of Pomacentridae is increasing in this region, due in part to an increase in the number of *Chromis* species (Fig.4.23 (iv))

Figure 4.26(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

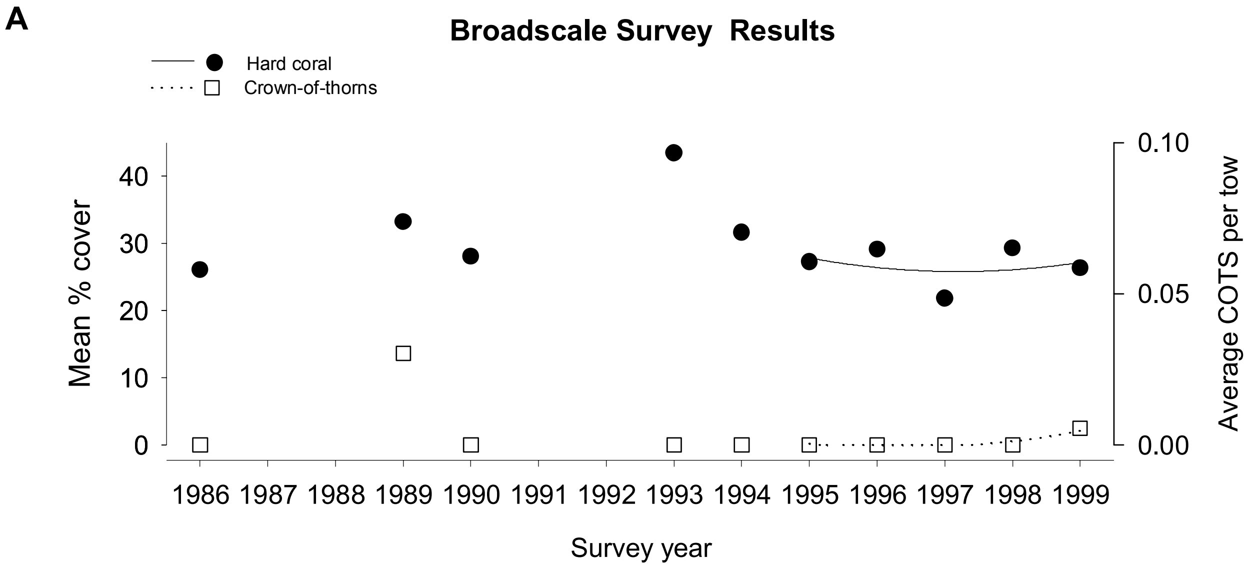
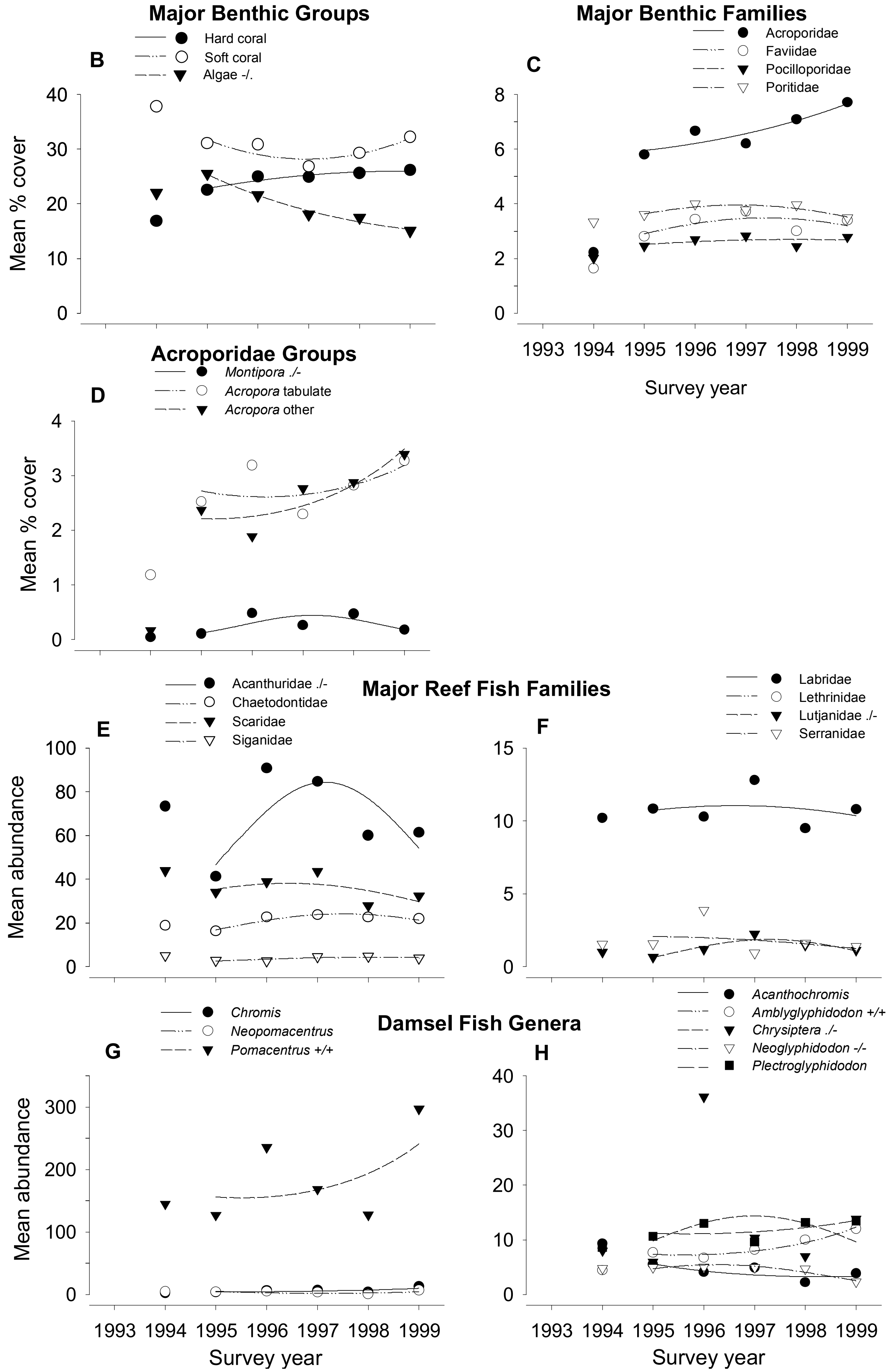


Fig 4.26 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Pompey Sector

This sector was surveyed in March 1999.

Summary

No COTS were observed in this sector and no reefs are classified as recovering from COTS activity. Overall there has been little change in reef-wide coral cover.

Geography

The reefs in this sector are sheltered from oceanic swells by the Hard Line reefs that form a wall. The tidal range in this sector is large.

Bleaching

Surveys in this sector are generally conducted in March - April. In 1998 patchy, low level bleaching was observed on three out of five mid-shelf reefs, while no bleaching was observed on the single outer shelf reef that was surveyed. Bleaching was recorded on all mid- and outer shelf reefs surveyed in 1999, though at low levels (<5% total hard coral cover). Encrusting *Montipora* spp. were the most commonly affected corals.

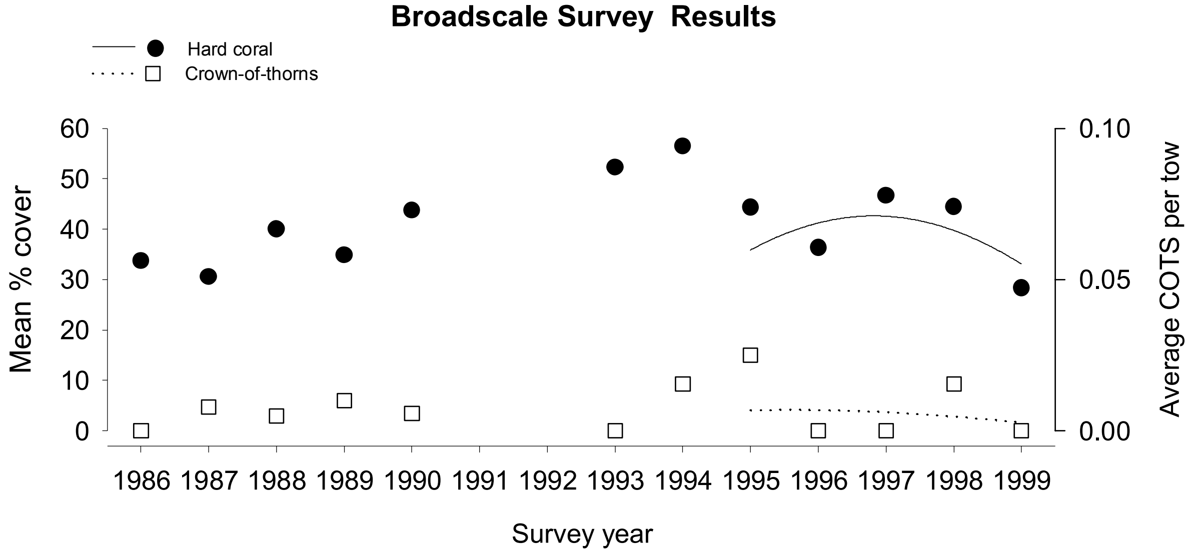
Figure 4.27 Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Pompey Sector.

	Mid	Outer
Crown-of-thorns starfish		
Hard Coral		

Pompey Sector Mid-Shelf Reefs

No COTS were observed on any of the five reefs that were surveyed in 1999. There have been no significant regional trends in reef-wide coral cover in the last five years (Fig.4.27 (i), 4.28 A). Coral cover is generally high (33%) in this region.

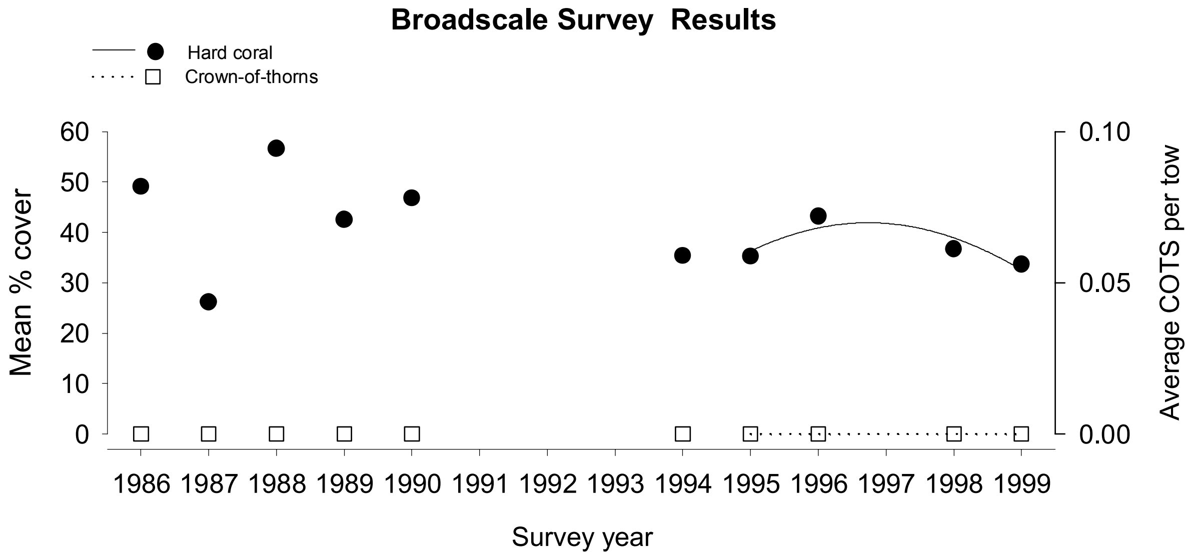
Figure 4.28 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Pompey Sector Outer Shelf Reefs

Only one reef in this region was surveyed in 1999. Too few reefs in this region have been surveyed in recent years to estimate trends reliably.

Figure 4.29 Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.



Swain Sector

This sector was surveyed in December 1998.

Summary

COTS are active in this sector with three of the seven survey reefs supporting Active Outbreaks. Divergent trends on reefs with and without high COTS numbers has produced no overall regional trend in benthic cover. Several fish taxa have shown declining trends on mid-shelf reefs though this cannot be explained simply in terms of changes to benthic communities.

Geography

Reefs in the Swain sector differ from other regions in that they are remote from the coast, so that inner Swains reefs are removed from coastal influence. Because of the prevailing SE wind direction, the inner Swain reefs are subject to more wave action than the mid-shelf reefs. This is also an area of large tides and strong currents.

Bleaching

Reefs in this sector are usually surveyed in November - December. No coral bleaching has been recorded during surveys on any of the reefs in this region over the past three years.

Figure 4.30(i) Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Swain Sector.

	Mid	Outer
Crown-of-thorns starfish		
Hard Coral		

Figure 4.30 (ii) Summary of trends in benthic cover on intensive survey sites in the Swain Sector.

	Mid	Outer
Algae		
Soft Coral		
Hard Coral		
Poritidae		
Faviidae		
Pocilloporidae		
Other Corals		
Acroporidae		
Montipora		
Acropora Tabulate		
Acropora Other		

Figure 4.30 (iii) Summary of trends in fish abundance in the Swain Sector.

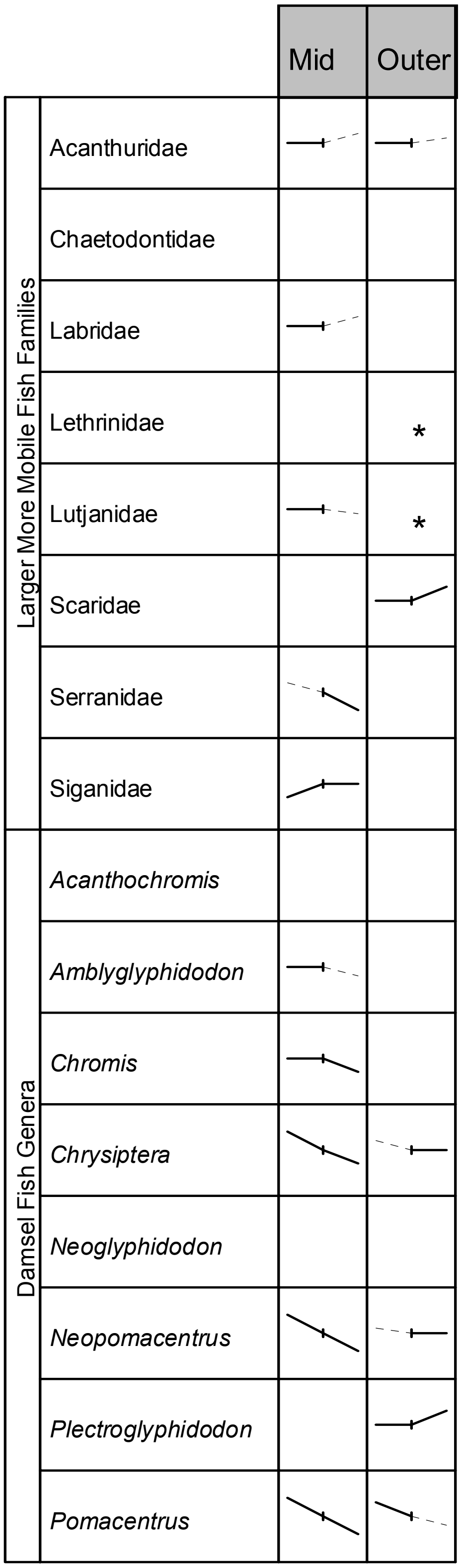
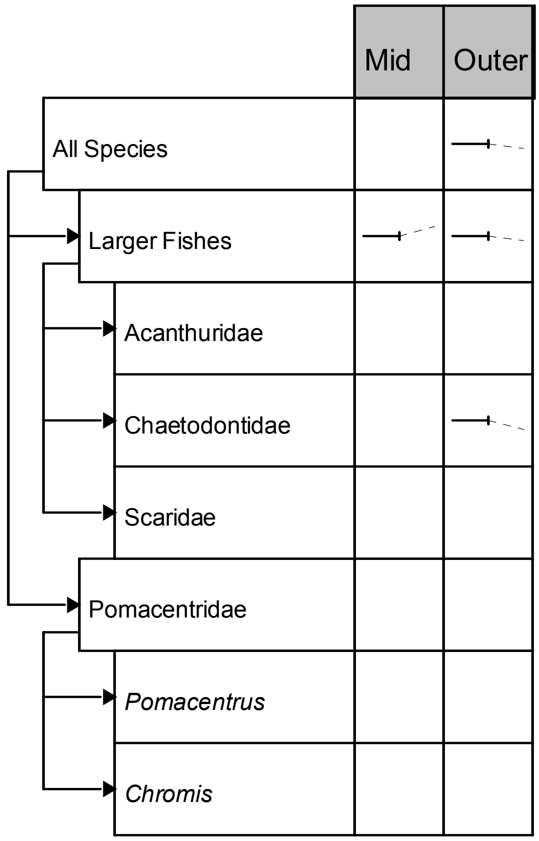


Figure 4.30 (iv) Summary of trends in fish species richness in the Swain Sector.



Swain Sector Mid-Shelf Reefs

Five reefs were surveyed in 1999. Three reefs, Gannet Cay, Horseshoe and Chinaman, currently support active outbreaks. Reef 22-088 is classified as recovering. While COTS are active in this region there has been no regional trend in reef-wide hard coral cover (Fig. 4.30 (i)). This is because declines on reefs affected by COTS have been balanced by increases on unaffected reefs, resulting in little overall change.

During the past year intensive surveys have found an increasing trend in cover of algae on mid-shelf reefs (Fig. 4.30 (ii), 4.31B), caused by increases at Gannet Cay and Horseshoe Reef. Cover of hard coral in intensive survey sites follows reef-wide coral cover in showing no overall regional trend, though individual reefs show divergent patterns. Regional hard coral cover averages 34% (Fig. 4.30 (ii), 4.31B), but averages for individual reefs vary from 20 - 50%. Among hard coral taxa, the cover of Poritidae has increased over the last five years (Fig. 4.30 (ii), 4.31C), due largely to Reef 22-088, but is no longer increasing significantly (Fig. 4.30 (ii)). Cover of soft corals has not changed significantly on reefs within this region and averages 8%.

Marginal increases in abundance were recorded in the families Acanthuridae and Labridae (Fig. 4.30 (iii), 4.31E, F). The marginally significant increase in the Labridae is largely due to their particularly low abundance in 1997 rather than a real change compared to other years. The very significant current decline in the family Serranidae (Fig.4.30 (iii)) is being driven by *Plectropomus leopardus*, with numbers now being the lowest recorded during the past seven years (Fig. 4.31F). The family Siganidae has increased in abundance over the last five years (due to unusually large schools of *Siganus doliatus* at two reefs) but this trend has now stabilised. Among damselfishes, the genus *Amblyglyphidodon* (essentially *A. curacao*) is currently declining marginally in abundance (Fig. 4.30 (iii), 4.31H). Currently, numbers of the genus *Chromis* (driven by *C. nitida* and *C. atripectoralis*) are also declining. More general declines are occurring in the genera *Chrysiptera* (*C. rollandi*), *Neopomacentrus* (*N. azysron*) and *Pomacentrus* (Fig. 4.30 (iii), 4.31G, H). The strong decline in the genus *Pomacentrus* is being driven by the two most numerically abundant species, *P. moluccensis* and *P. lepidogenys*, as well as *P. wardi* and *P. brachialis*. Given the lack of consistent changes in hard coral cover, it is unclear why such wide spread decreases in damselfish numbers are occurring in this region.

The only regional trend in species richness is an increasing current trend in species of larger fishes (Fig. 4.30 (iv))

Figure 4.31(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

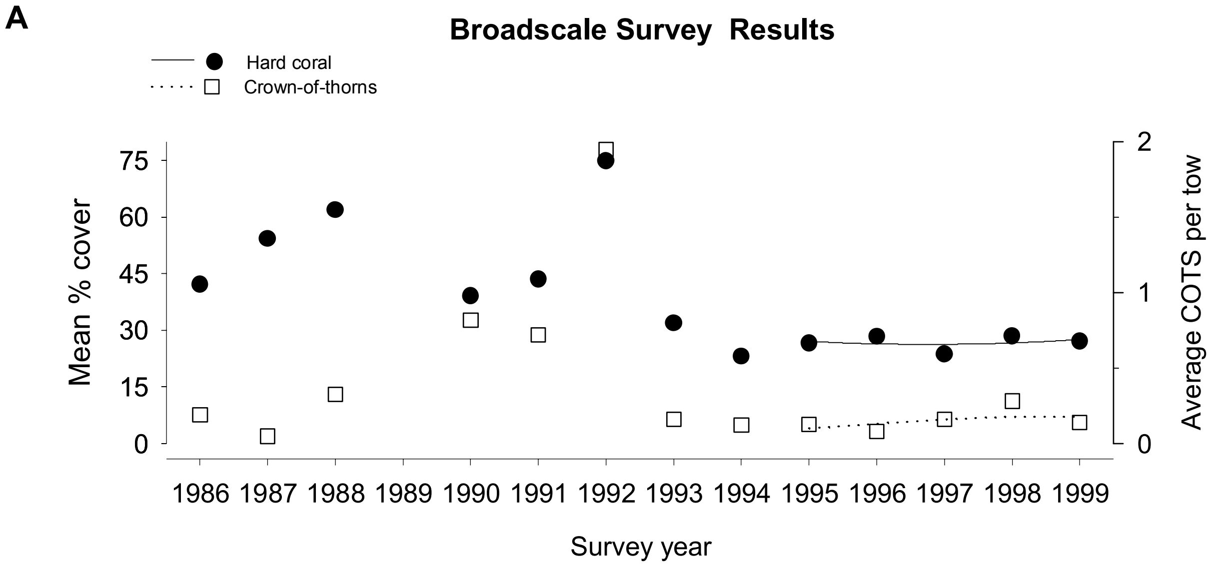
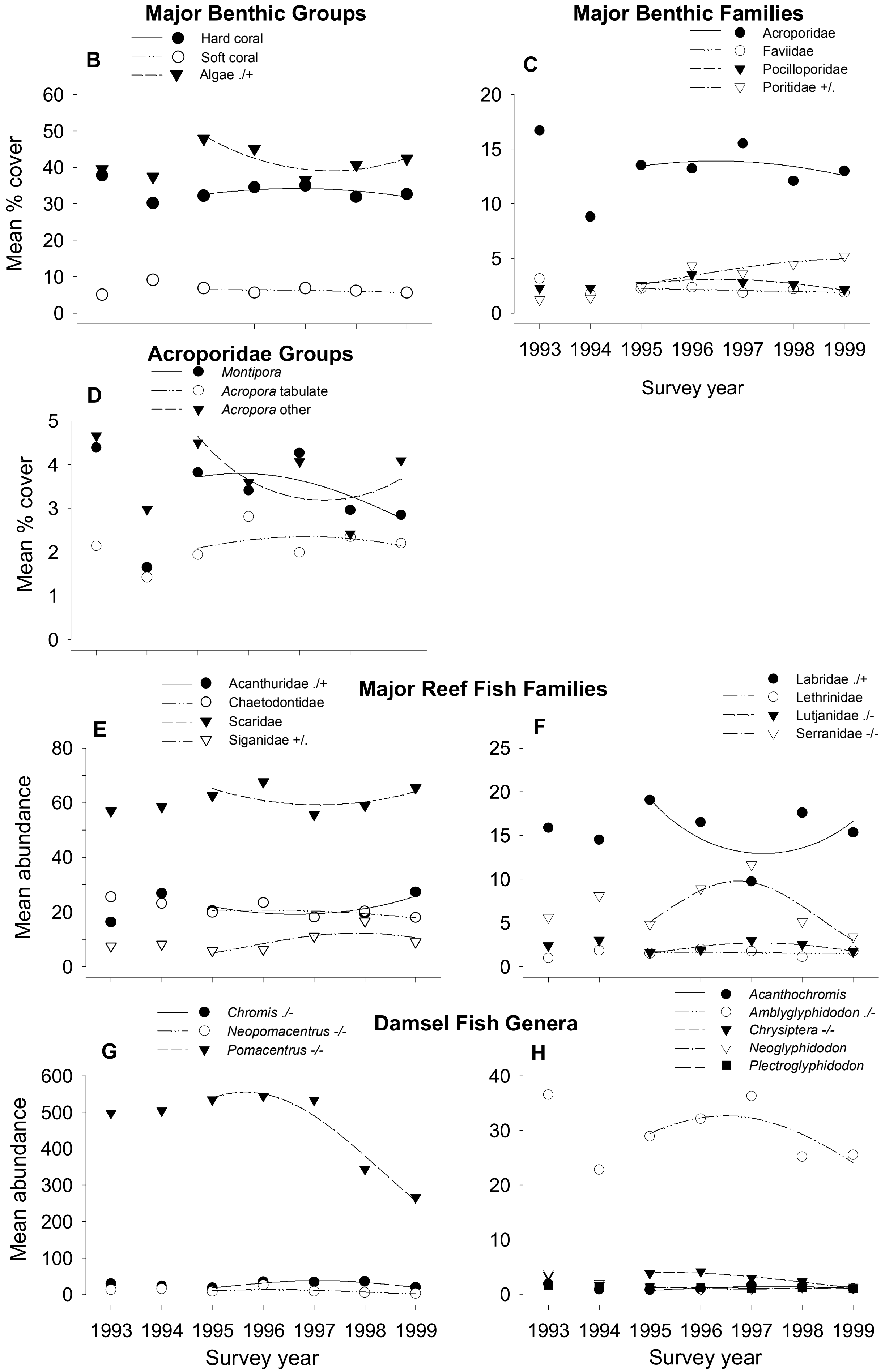


Fig 4.31 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Swain Sector Outer Shelf Reefs

One COTS was recorded on the two survey reefs in this region. There has been little COTS activity in the region over the past five years. Reef-wide coral cover is 32%.

Cover of hard coral on the intensive survey sites averages about 28% and has changed little in the last five years (Fig. 4.30 (ii), 4.32B). Likewise cover of algae (average 27%) and soft corals (average 29%) did not change significantly. None of the families of hard coral displayed a significant increase in cover in the last five years (Fig. 4.30 (ii)).

The families Acanthuridae and Scaridae have not changed significantly over the last five years but their abundance is currently increasing (Fig. 4.30 (iii)). This is due mainly to *Ctenochaetus* spp. and the presence of a large mixed school of *Scarus psittacus*, *S. globiceps* and *S. sordidus* on one reef in 1999. The genera *Chrysiptera* and *Neopomacentrus* decreased in abundance over the past five years although they show no current trend (Fig. 4.30 (iii), 4.32G, H). The genus *Plectroglyphidodon* is presently increasing in abundance (Fig. 4.30 (iii), 4.32H) due to one species, *P. lacrymatus*. The genus *Pomacentrus* continues to decline in abundance (Fig. 4.30 (iii), 4.32G). This is caused by a number of species, but principally *P. lepidogenys*.

The fish assemblages show a regional decline in species richness (Fig. 4.30 (iv)), due partly to larger reef fishes, particularly Chaetodontidae.

Figure 4.32(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

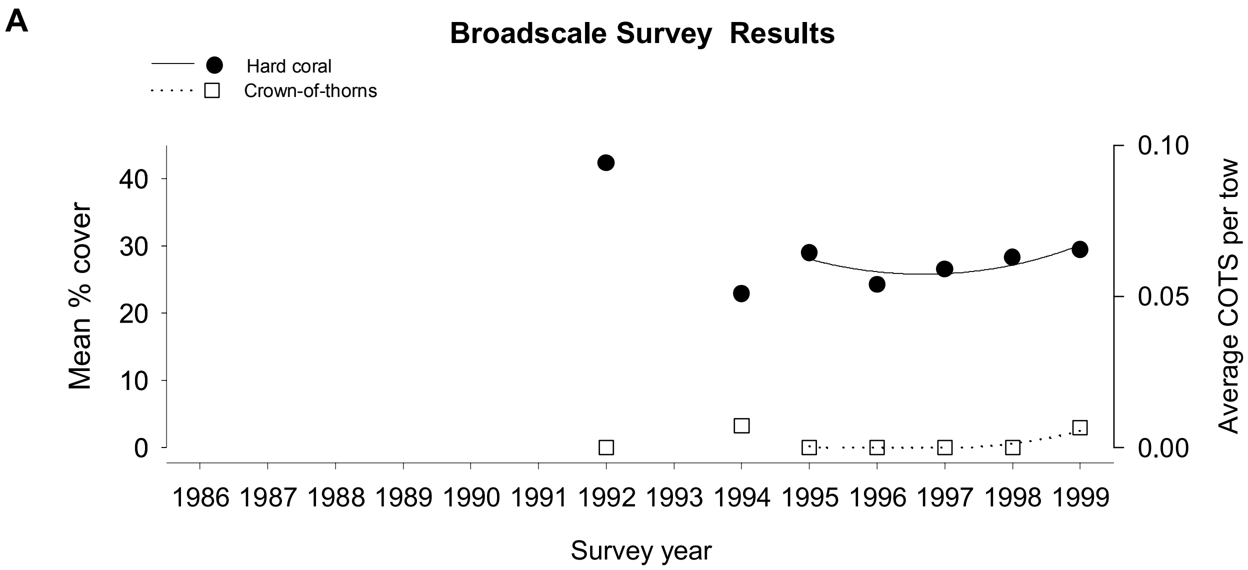
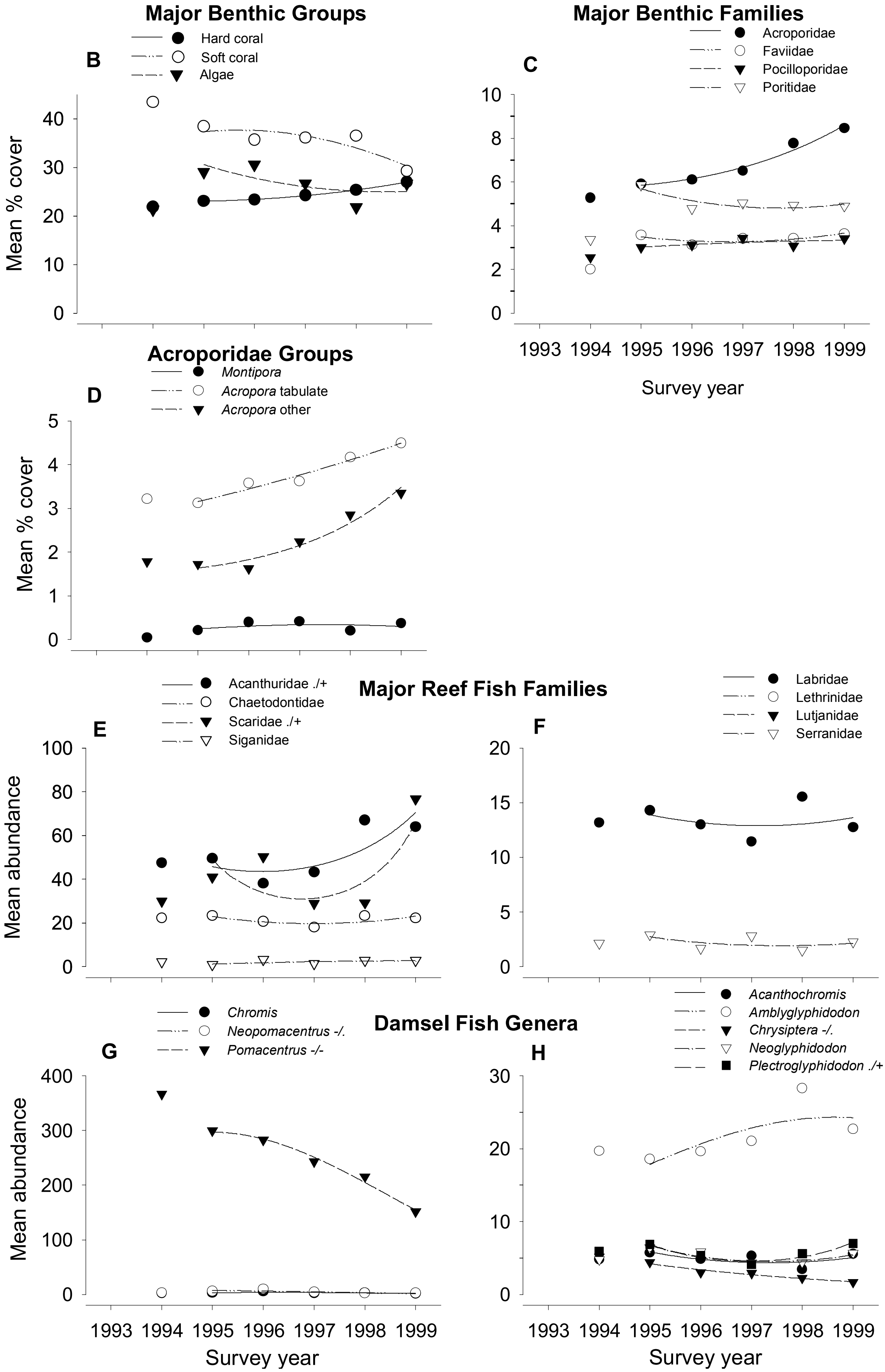


Fig 4.32 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Capricorn Bunker Sector

This sector was surveyed in December 1998.

Summary

No COTS were observed in this sector. In the absence of COTS activity and other major disturbances, hard coral cover on reefs in this sector continues to increase. Much of this cover is made up of tabulate *Acropora* spp. Several groups of reef fishes are increasing in abundance as the coral recovers.

Geography

The survey reefs in the Capricorn-Bunker sector are outer-shelf reefs that are exposed to the influence of the Coral Sea. The low density of reefs means that there is little gradient in exposure. The reefs receive little terrestrial influence in the form of runoff.

Bleaching

Reefs in this sector are usually surveyed in November or December. A few bleached colonies have been recorded on at least one reef in each of the past three years during broadscale surveys.

Figure 4.33(i) Summary of trends in reef-wide hard coral cover and crown-of-thorns starfish abundance from manta tow surveys in the Capricorn Bunker Sector.

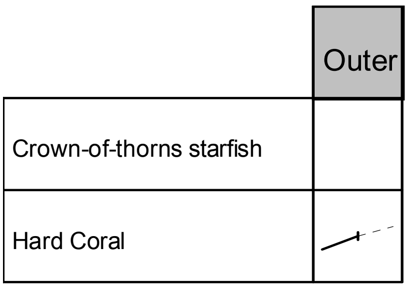


Figure 4.33 (ii) Summary of trends in benthic cover on intensive survey sites in the Capricorn Bunker Sector.

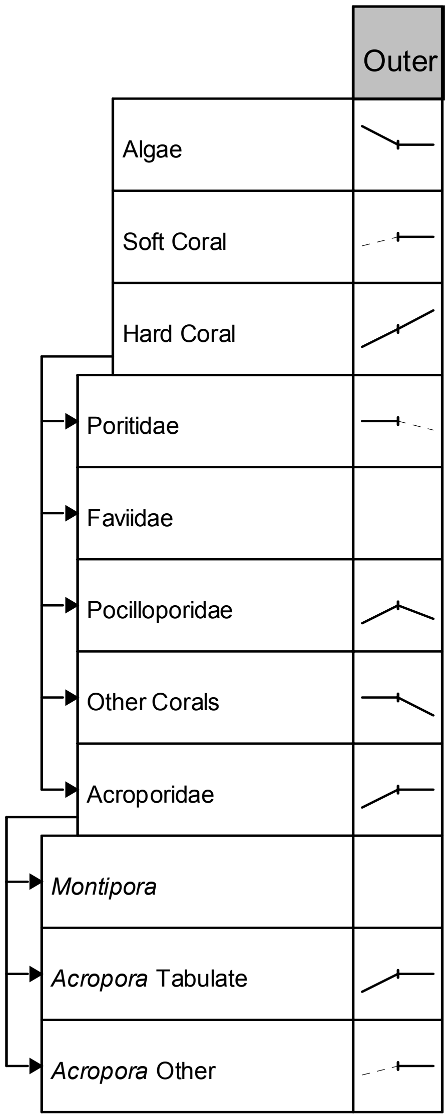


Figure 4.33 (iii) Summary of trends in fish abundance in the Capricorn Bunker Sector.

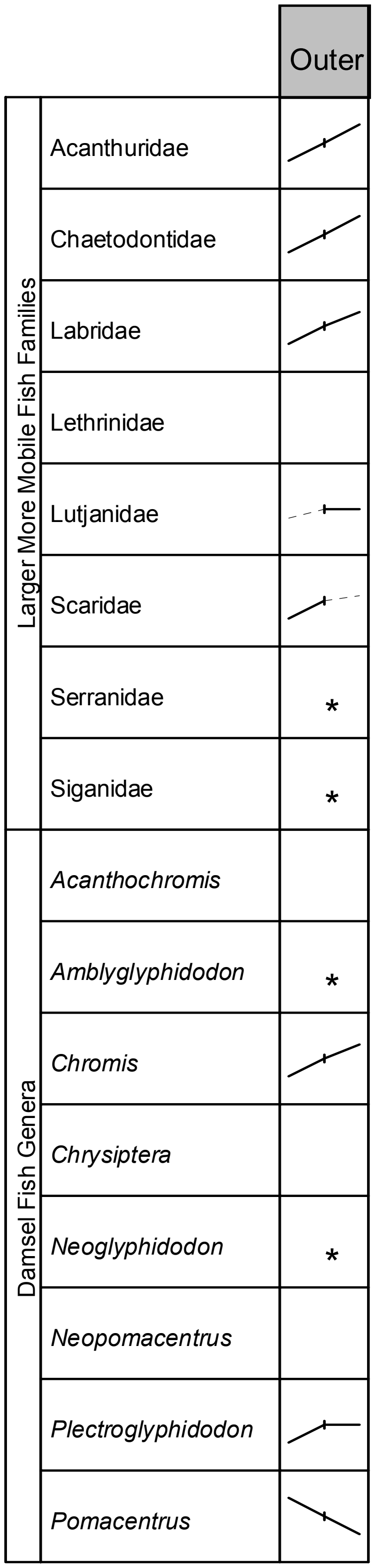
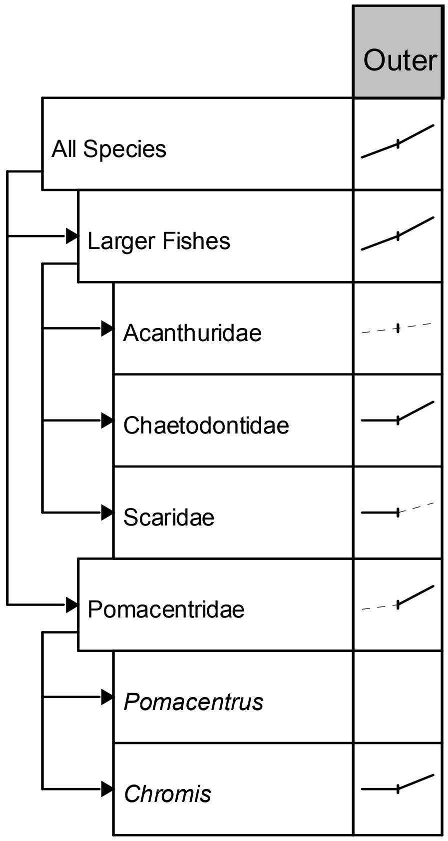


Figure 4.33 (iv) Summary of trends in fish species richness in the Capricorn Bunker Sector.



Capricorn Bunker Sector Outer Shelf Reefs

COTS have been observed intermittently in this sector. Surveys in 1999 suggest that there is no increase in COTS activity and populations are too low to cause significant coral mortality. Reef-wide coral cover is currently high (32%) and increasing (Fig. 4.33 (i)).

Cover of hard corals has been increasing since intensive surveys began, from an average of about 8% in 1993 to 60% in 1999 (Fig 4.34B). There has been a corresponding decrease in cover of algae from 75% in 1993 to 22% in 1999. Cover of soft corals has not changed significantly in the last five years and is currently about 3%.

The increase in cover of hard corals is largely due to increases in tabulate *Acropora* spp., which have increased from 0% in 1993 to cover 45% of the sites in 1999. While there have been statistically significant changes in other families (Fig. 4.34C), their relative contribution to total coral cover is comparatively low as each contributes less than 3%.

The majority of larger, mobile reef fish families have increased in abundance over the last five years and four families (Acanthuridae, Chaetodontidae, Labridae and Scaridae) continue to do so (Fig. 4.33 (iv), 4.34E, H). In all cases, increases in abundance of families have been general, involving a majority of the species. Among damselfishes, the genera *Chromis* and *Plectroglyphidodon* have shown considerable increases in abundance (Fig. 4.34G, H). The decline in abundance of *Pomacentrus* spp. (Fig. 4.33G) is due to one species, *P. coelestis*, which settled in huge numbers in 1994, but has since declined presumably as that cohort died out without substantial replenishment. A number of less abundant *Pomacentrus* spp. have increased in abundance over the last five years (Fig. 4.33 (iii)). A large number of taxa have increased in abundance with the recovery of hard coral cover (Fig. 4.33 (iii), 4.34E-H). The species richness of most taxa is also increasing (Fig. 4.34 (iv)).

Figure 4.34(A) Plots showing distribution of regional means and the fitted trend lines for reef-wide hard coral cover and crown-of-thorns starfish abundance.

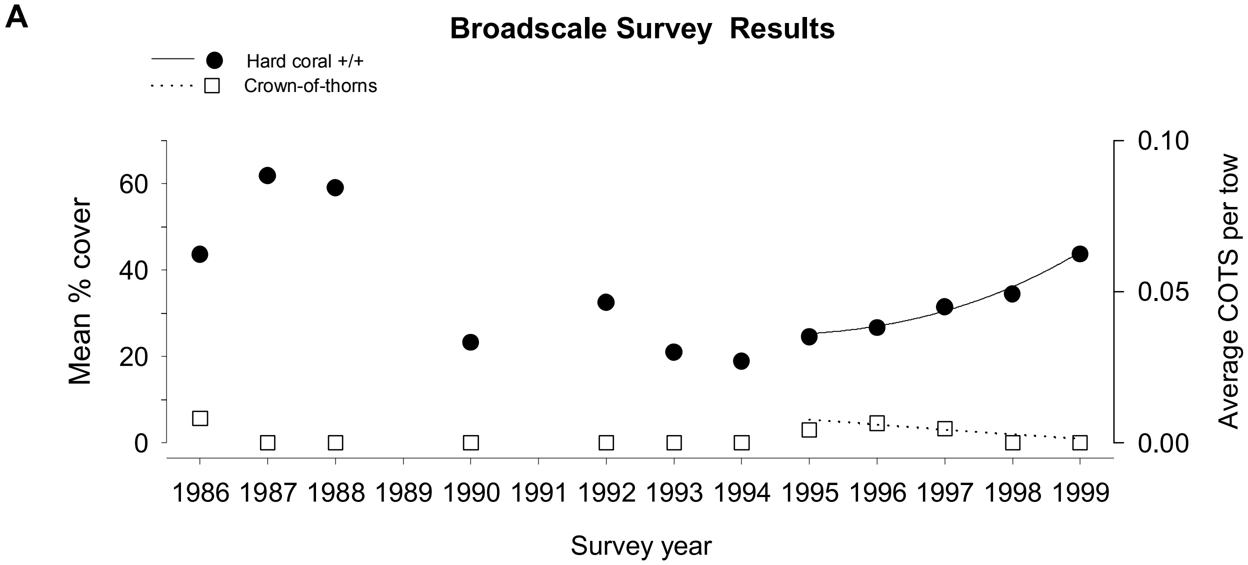
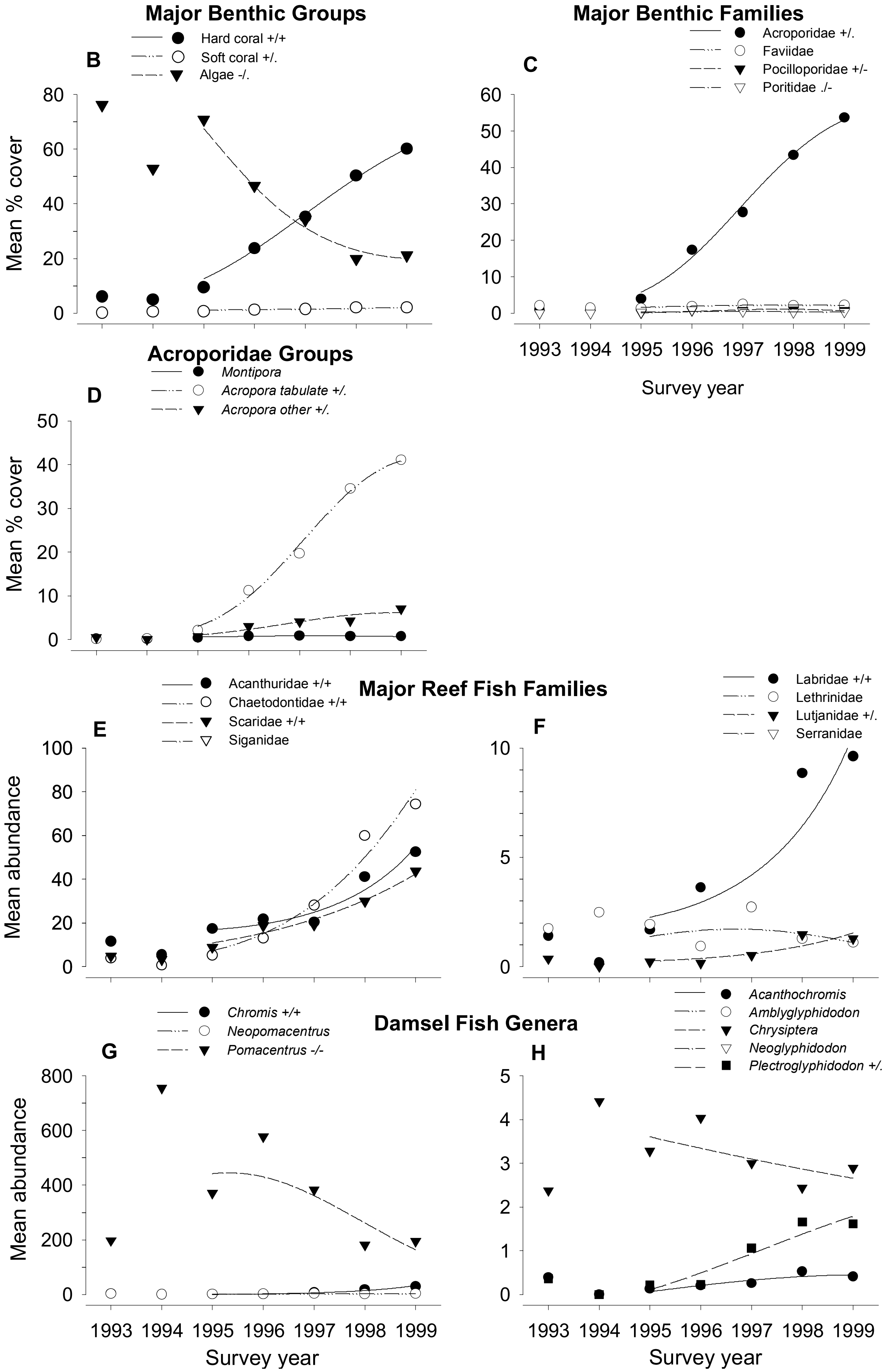


Fig 4.34 cont. Plots showing distribution of regional means and the fitted trend lines for: (B, C, D) percent cover of benthic groups on fixed sites, (E, F, G, H) fish abundance on fixed sites.



Special Topic:
The Effect of Extensive Bleaching in 1998 on Coral Reefs of the Great Barrier Reef

Coral bleaching occurs when zooxanthellae, the symbiotic algae that live within the coral tissues, lose their pigments or leave the tissues of the coral entirely. The coral tissue remains alive and in place but is transparent, so that the pale skeleton shows through. A coral's zooxanthellae supply the coral with a large proportion of their energetic requirements and in their absence the coral may die or recover, depending on the severity and duration of bleaching. Instances of coral bleaching have been recorded over at least the past 20 years (Brown 1987), but occurrences appear to have increased in frequency and geographic scale in recent years (Hoegh-Guldberg, 1999). The incidence of "Mass bleaching events" also appears to be increasing. These involve the bleaching of a large proportion of corals over very large geographic areas. The most extensive of these so far occurred in 1997-98. Between mid-1997 and late 1998, bleached corals were recorded in most tropical regions including the Red Sea, the Arabian Gulf, the Indian Ocean, South East Asia, the Caribbean, the Atlantic Ocean and both the eastern and western Pacific (Wilkinson, 1998).

Records of bleaching on the GBR have followed the global pattern in the past . Bleaching had been reported before 1998, but records suggest that a very small proportion of corals on a small number of reefs was affected in each case (Harriott, 1985; Jones et al., 1997; Fisk and Done, 1985). In late February 1998 extensive bleaching and some mortality of hard corals, soft corals and giant clams was reported from reefs within the central GBR (Baird and Marshall, 1998; Berkelmans and Oliver, 1999; Fabricius, 1999; Page, 1999). In general, bleaching appeared to be most severe on inner-shelf reefs, least severe on outer-shelf reefs and most pronounced in shallow parts of affected reefs (Baird and Marshall, 1998; Berkelmans and Oliver, 1999; Page, 1999). Mortality showed a similar depth distribution, being highest within shallow reef zones and declining with depth (Baird and Marshall, 1998; Page, 1999). Bleaching of corals was most severe in the Townsville and Cairns sectors of the GBR, both in terms of the number of reefs and the proportion of corals affected (Berkelmans and Oliver, 1999). In these sectors high mortality was reported from some inner-shelf reefs while corals on more offshore reefs experienced lower levels of mortality (Berkelmans and Oliver, 1999; Page, 1999). Minimal bleaching and little initial bleaching-related mortality was reported in any other sector of the GBR (Wilkinson, 1998; Berkelmans and Oliver, 1999). The LTMP is in a position to assess the broader effects of the 1998 bleaching event on the GBR and the longer term implications of this disturbance as data on the status of a large number of reefs spanning the Great Barrier Reef has been collected annually since 1992.

The Long-term Monitoring Program surveys span a period between October and May each year. Extensive bleaching was first recorded late in January 1998 and the full extent of bleaching and mortality developed over a period of months, meaning that the 1998 surveys could not give a full picture of this bleaching event. As a simple measure of the broadscale effects of the 1998 bleaching event, the total living hard coral present in the intensive study sites at the 1997 surveys (well before bleaching) was compared with equivalent data from the 1999 surveys (well after bleaching). In this context, it is important to note that the study sites are generally at 6-9 m depth. Intensive surveys of cover of benthic organisms were made in both years at 47 reefs. Figure 6.1 shows the average per cent cover values on sites at each survey reef, arranged by latitude and position across the GBR lagoon (inshore to offshore). For each reef, the filled bar represents the mean hard coral cover at the 1997 survey (made before June 1997). The unfilled bar gives the same information for the 1999 surveys (made after October 1998).

Taking an arbitrary figure of 5% change from pre-existing coral cover as the criterion for substantial change:

- Survey sites on eight of the 47 reefs that were surveyed lost more than 5% of the initial average coral cover over the two years.
- Survey sites on 32 reefs gained more than 5% of the initial coral cover in that period.
- Sites on seven reefs showed little average change (-4.9% to 4.9% of initial cover) over the two years.

The reefs that showed a substantial net loss of hard coral were inshore reefs within the Cairns sector, inshore and mid-shelf reefs within the Townsville sector and some reefs in the Swains sector. Three of these reefs, Rib Reef (Townsville mid-shelf) and Gannet Cay and Horseshoe Reef in the Swains sector are known to have had large populations of the crown-of-thorns starfish (COTS), a predator of corals. Aerial surveys in March 1998 did not detect any bleaching in the Swains sector (Berkelmans and Oliver, 1999) suggesting that the decline in coral cover on the Swains sector reefs was not a result of bleaching.

Seven reefs from four sectors showed little net change in coral cover, perhaps indicating that the 1998 bleaching disturbance retarded the expected pattern of increasing coral cover. However, three of these, Hyde Reef and Reef 19-131 in the Whitsundays sector and Turner Cay in the Swains sector, are in areas where aerial surveys in March 1998 did not detect any bleaching. Martin Reef and MacGillivray Reef in the Cooktown/Lizards Is sector have had COTS populations. Many reefs in the Cairns sector did experience bleaching, but starfish have also been increasing in numbers at Michaelmas Reef.

This simple analysis implies that, among the survey reefs, only sites on inner reefs in the Cairns and Townsville sectors were severely affected by the bleaching event in 1998. Survey sites on the majority of reefs have shown a clear net increase in total coral cover over the period between 1997 and 1999 surveys when any mortality due to bleaching would have been expected. While many reefs of the GBR were not badly affected, reefs in other regions of the world were extensively bleached to more than 20 m depth and there has been extensive loss of coral.

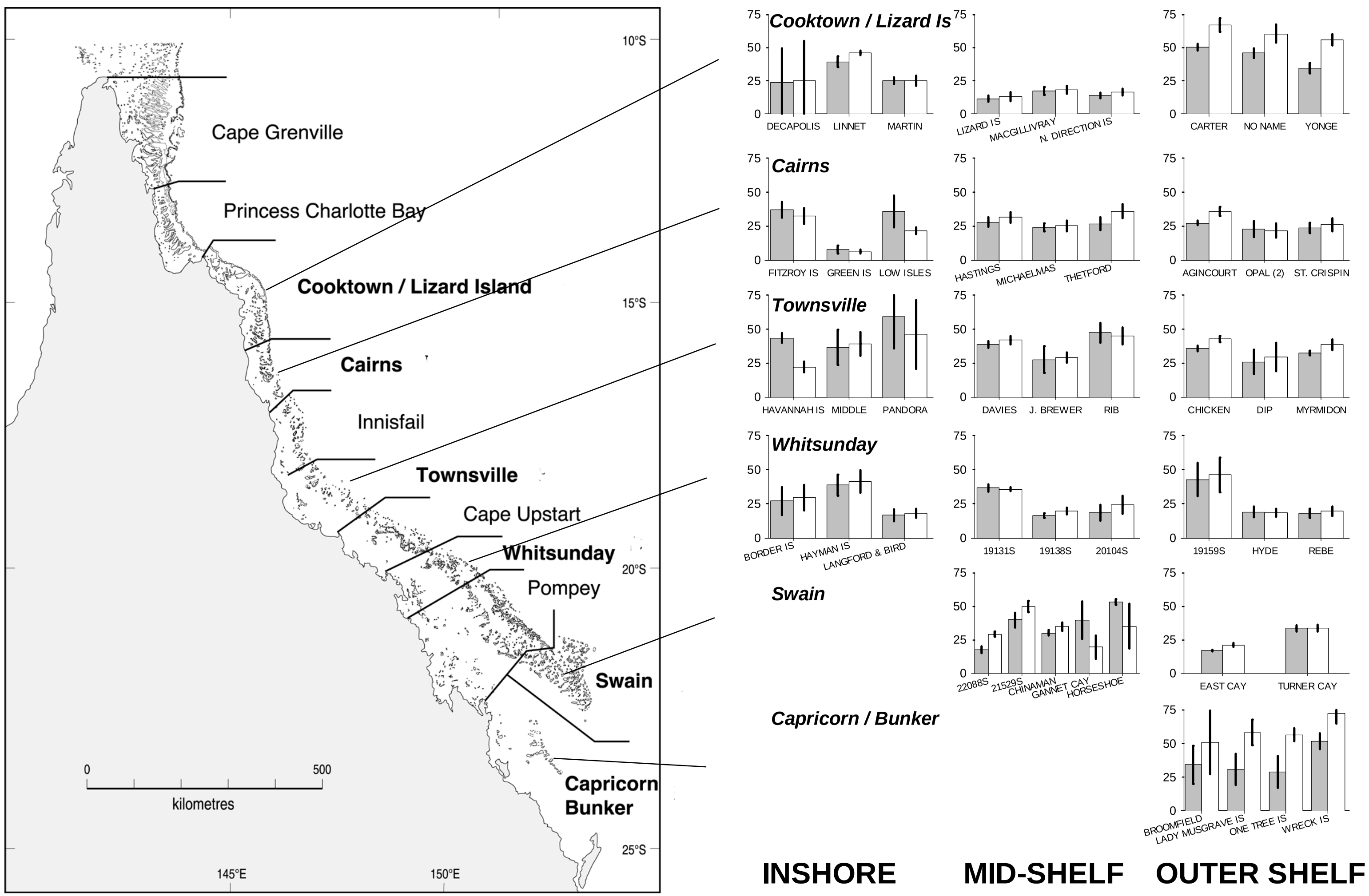


Figure 5.1: Mean cover of hard coral on intensive study sites on survey reefs well before (1997) and well after (1999) the mass coral bleaching in early 1998. Shaded bar = mean % cover at 1997 surveys, open bar = mean % cover at 1999 surveys. Error bars are Standard Errors.

Special Topic: Effects of Tropical Cyclone Rona on Hard Coral and Fish Assemblages of Reefs Near Cairns

Introduction

Tropical cyclones are common in northern Australia between December and April. Coral reef communities on the Great Barrier Reef (GBR) are frequently exposed to the strong winds, large waves and high rainfall associated with these weather systems. Between 1969 and 1997, almost all reefs within the GBR were affected by cyclones at least once (Puotinen et al. 1997), so cyclones are major agents of disturbance in reef assemblages and are likely to cause many changes that monitoring programs will detect. Studies of the impact of cyclones on coral reefs have shown great variation in the magnitude and spatial extent of damage, ranging from considerable disturbance of the reef matrix (Done et.al. 1986) to cases of minimal disturbance (Fenner 1991, Glynn et al. 1998). Damage to reefs is not closely correlated with the wind-strength Categories 1 – 5, by which cyclones are classified. Doubtless this involves many factors, including the duration of the storm, distance of the reef from the storm path, reef topography, the shape, size and biological attributes of reef organisms, their location and depth on the reef, and the time since the previous disturbance (reviewed by Harmelin-Vivien 1994).

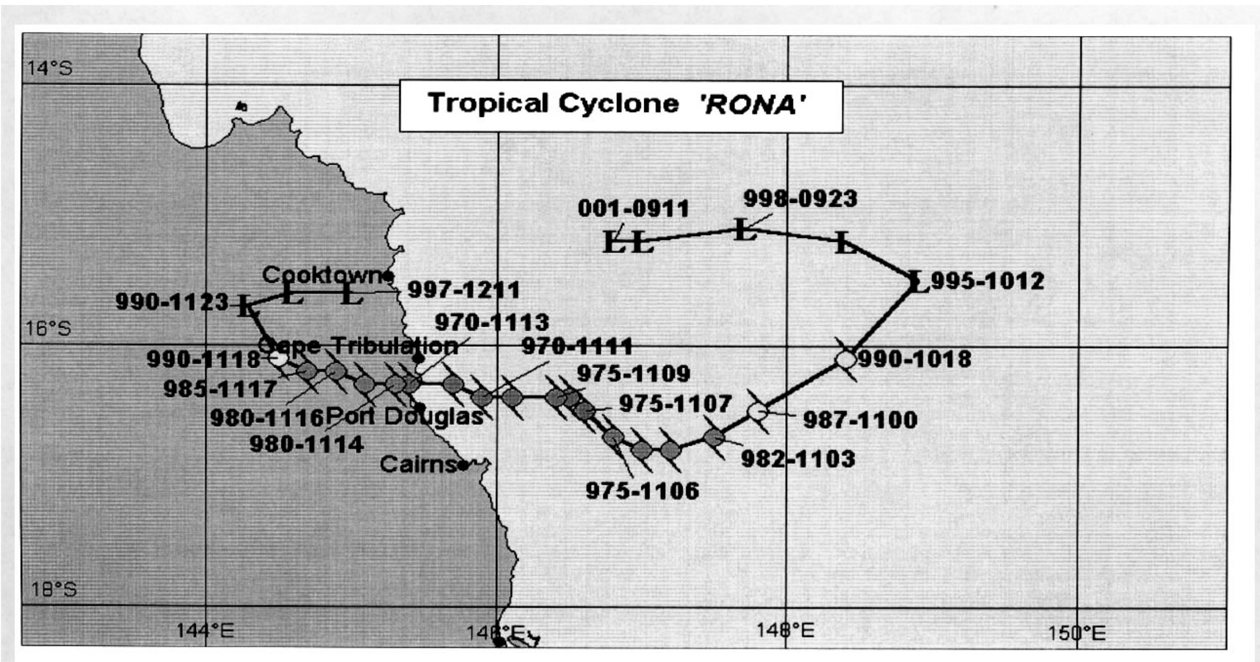


Figure 6.1. Track of tropical Cyclone Rona. Numerical groups (in the form ppp-ddhh) give central pressure (ppp in hPa) on date (dd – day of February) at time (hh - hour UTC). Figure provided by Jeff Callaghan, Bureau of Meteorology, Australia.

On 11 February 1999 Tropical Cyclone Rona (Category 3, maximum wind speeds of 170-224 km/h) passed over a section of the Great Barrier Reef shelf north of Cairns, crossing the coast in the vicinity of the Daintree River (Fig. 6.1). A number of reefs lying close to the path of Cyclone Rona had been surveyed about six weeks before in annual surveys of the Cairns sector. This provided the opportunity to assess the impact of Cyclone Rona on those coral reef assemblages.

Methods

Ten reefs were surveyed for reef-wide coral cover using manta tows. Intensive surveys of benthic and fish assemblages were made at permanent sites on the north east flanks of four of these reefs (Fig. 6.2.) Reefs were surveyed before the cyclone 23 January - 11 February and again 22 March - 1 April 1999. The standard survey methods were used, see Section 2 of this report. The study reefs lay both to the north and south of the cyclone's track at distances of 0 - 26 km (Fig. 6.2).

Mean reef-wide per cent cover of living and of dead hard coral was calculated from manta tow surveys by substituting each cover category by the mid-point of its range.

Mean percentage cover of each coral life form was calculated from video transects of the intensive study sites on NE aspects of four reefs.

The abundances of fish taxa were estimated on intensive study sites on the four reefs. The average of the sums of the fishes counted at each site was calculated for each reef. Species richness is the number of species (from the prescribed list [Appendix C]) recorded in each survey.

Results

Reef-wide coral cover:

There were few changes in mean reef-wide hard coral cover after the passage of the cyclone (Fig. 6.2). One exception was Low Isles, where coral cover dropped from 24 to 7%. However, the data point representing the reef front zone at Low Isles (Fig. 6.3A) was a marked outlier. Coral cover had been reduced more on the reef front (45% to 7%, Fig. 6.3B) than in other zones. The mean reef-wide hard coral cover after the passage of Cyclone Rona (7%) at Low Isles is the lowest recorded in 15 years (Fig. 6.3C), even though two large cyclones(Joy in 1990, category 4, and Justin in 1997, category 2), had passed in the vicinity (Fig. 6.3C).

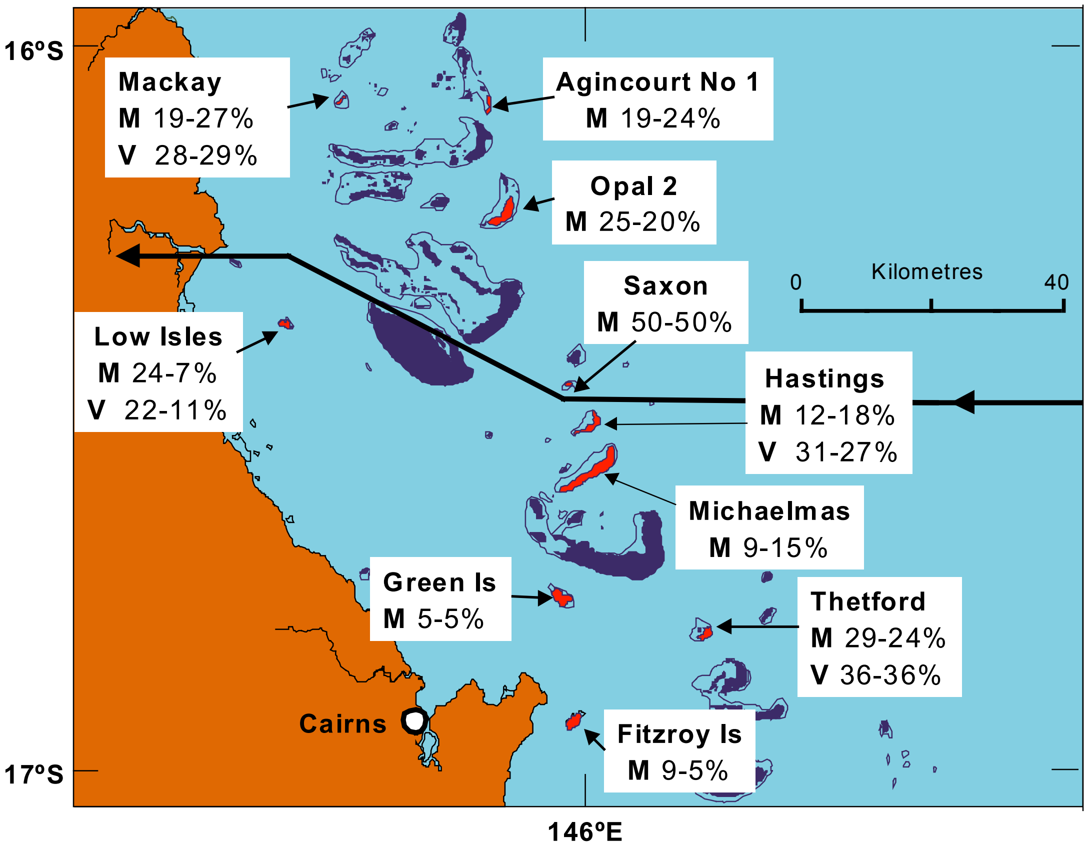


Figure 6.2. Changes in mean hard coral cover (x-y%) on reefs before (x) and after (y) Tropical Cyclone Rona. Data are from two sources: from manta tows of the entire perimeter of the study reefs (**M**) and from video surveys at fixed sites on the north-east flanks of reefs (**V**). The cyclone's path is shown by the arrow.

Benthic video surveys:

The results of detailed video analyses on the north-east flanks of four study reefs mirrored the reef-wide pattern shown by manta tows, with hard coral cover only changing markedly at Low Isles (from 22% to 11%) with the passage of Cyclone Rona (Fig. 6.2). Cover at Hastings Reef decreased by 4% but this is close to the limit of resolution of under-water video. A variety of hard coral life-forms were affected by Cyclone Rona at Low Isles: sub-massive (mainly *Porites rus*, *P. anae*), branching (*P. cylindrica*), massive (*Porites* spp.) and foliaceous (*Echinopora* spp., *Pachyseris rugosa* and *Pavona cactus*) forms. Similar coral assemblages at the nearby Mackay Reef remained unaffected (Fig. 6.4).

Coral reef fishes:

Larger mobile fishes could not be surveyed effectively at Low Isles after Cyclone Rona because of poor visibility. Total abundance of larger mobile fishes and damselfishes (even at Low Isles where hard coral cover was reduced by 50%) did not change significantly (paired t-tests, $p>0.05$) as a result of Cyclone Rona at any of the four study reefs (Table 6.1). Total species richness also changed little with the exception of Thetford Reef where numbers declined from 52 to 43 species. The previous lowest species richness recorded at Thetford Reef since 1994 was 44.

Table 6.1. Changes in mean abundance (± 1 SE) and total reef species richness of fishes, pre and post Cyclone Rona, on the north-east flank of the four study reefs. Asterisk (*) indicates no sample due to poor visibility.

	Hastings Reef		Thetford Reef		Low Isles		Mackay Reef	
Abundance	Pre	Post	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Large mobile species (pooled)	184.3 ± 25.4	149.3 ± 3.3	**212.7** ± 63.3	**190.7** ± 39.7	*	*	**110.3** ± 19.9	**117.3** ± 18.5
Pomacentrid species (pooled)	691.0 ± 68.4	768.0 ± 59.0	**729.7** ± 122.1	**617.0** ± 47.9	**518.0** ± 74.6	**700.0** ± 64.7	**568.6** ± 82.3	**687.0** ± 94.7
Species Richness								
Large mobile species	44	48	**52**	**43**	*	*	**41**	**44**
Pomacentrid species	**22**	**22**	**24**	**24**	**18**	**20**	**23**	**20**

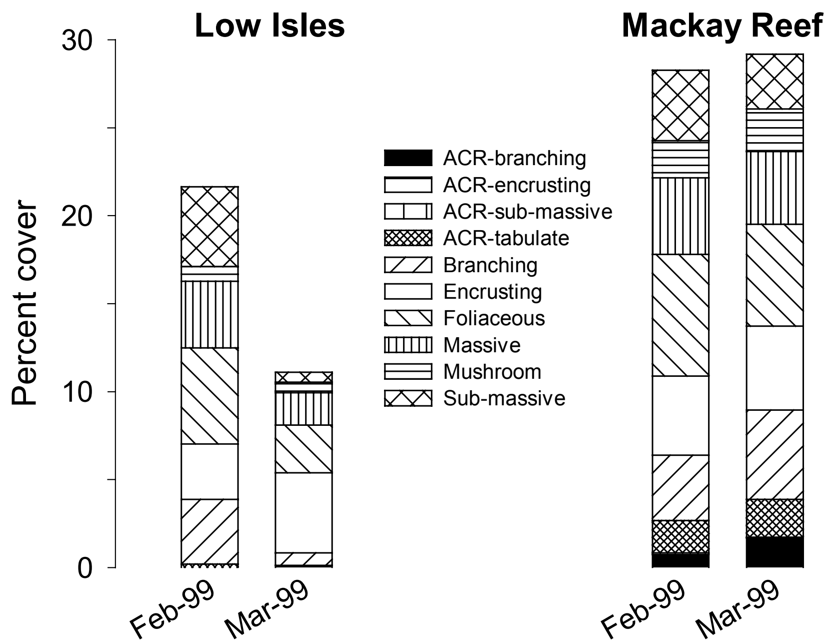


Figure 6.4. Percentage cover of hard coral by life-forms on two inner shelf reefs, Low Isles and Mackay Reef, before and after Cyclone Rona. Life-forms are differentiated into those belonging to the genus *Acropora* (ACR in legend) and those that do not.

Discussion

Cyclone Rona was a powerful cyclone but cyclonic damage to corals was limited to only one study reef, Low Isles. There were no noticeable changes in coral and fish assemblages on the mid- and outer shelf reefs, even though Saxon and Hastings Reef lie very close to the cyclone's path. Cyclone Rona may have had a limited effect because the system developed rapidly and was unusually short lived, crossing the coast and decaying only 19 hours after formation (Callaghan 1999). A major cause of damage to reefs by cyclones is the pounding action of large swells generated by slower moving, persistent cyclonic systems. In the area north of Cairns the Ribbon Reefs, which form a continuous seaward barrier in the Cooktown/Lizard Is sector, give way to a more open reef structure. Because of this, the coral assemblages on mid- and outer shelf reefs in the Cairns sector are regularly exposed to rough seas and so consist of robust forms, resistant to storm waves. A cyclone such as Rona that forms rapidly and moves quickly may not generate swells that are intense enough to damage such coral assemblages.

Cyclone Rona's path meant that Low Isles, an inshore reef, was exposed to the full force of winds from the south-east. Because of the bathymetry of surrounding water and the long fetch to the south-east (with few shielding reefs) this resulted in unusually large waves.

Winds were recorded up to 85 knots at the Low Isles weather station, and wave heights (up to 6.3m) were exceptionally high for this inshore area (Callaghan 1999). Coral assemblages on Low Isles reef usually only experience moderate wave conditions and so include fragile branching and foliaceous forms, growing on a largely unconsolidated reef base as is typical of such inshore reefs. An additional factor was the presence of massive coral boulders (*Porites* spp) 0.5 - 1m in diameter. Large numbers of these boulders were lying on their sides on the reef front, often clustered in depressions in the reef and sometimes with gouges of coral and rubble marking their passage across the reef. Done and Potts (1992) noted that *Porites* boulders of this size often moved during storm events. Similar coral communities on nearby Mackay Reef experienced no damage. This reef is shielded on three sides by other reefs (Fig. 6.2) and has steeper sides. It was also located north of the cyclone's path and so experienced winds blowing from the west over a short stretch of water.

Assemblages of coral reef fishes were not affected by the passage of Cyclone Rona with measures of total abundance and species richness generally changing little. The reduction in fish species richness at Thetford Reef from 52 to 43 species occurred because several rare species were not recorded in the post-cyclone counts. This is not unusual in the counts over the past seven years and probably represents background variation in counts rather than a specific effect of the cyclone. The fact that fish assemblages were little changed after a 50% reduction in hard coral habitat is not necessarily unusual. Several reports indicate that reef fishes can survive the strong currents, pounding waves and removal of portions of habitat experienced during cyclones (Walsh 1983, Fenner 1991). However, many of these studies only considered adult fishes, which are likely to be more powerful swimmers than smaller individuals. Lassig (1983) found that adults were unaffected by a cyclone at Lizard Island on the GBR, while sub-adult individuals were redistributed and juveniles suffered high mortality. We also only recorded numbers of adult fish in this study. The recruitment season was in progress when Cyclone Rona occurred; it remains to be seen whether there is evidence of reduced numbers of recruits entering the adult population in the following season.

In a historical context, the fact that hard coral cover at Low Isles is now at a 15 year low is of concern. It may be argued that coral cover was already low because of COTS activity before the storm and the fact that Cyclone Rona has reduced cover to lower levels again is a natural event. There are records of cyclones damaging the corals at Low Isles extending back to the 1930's (Moorhouse 1936, Stephenson et.al. 1958). However, in the current era of climatic change and suspected increasing anthropogenic stresses, inshore reefs such as Low Isles may not have the same capacity for recovery as in past years. The recovery of the Low Isles reef will be monitored carefully.

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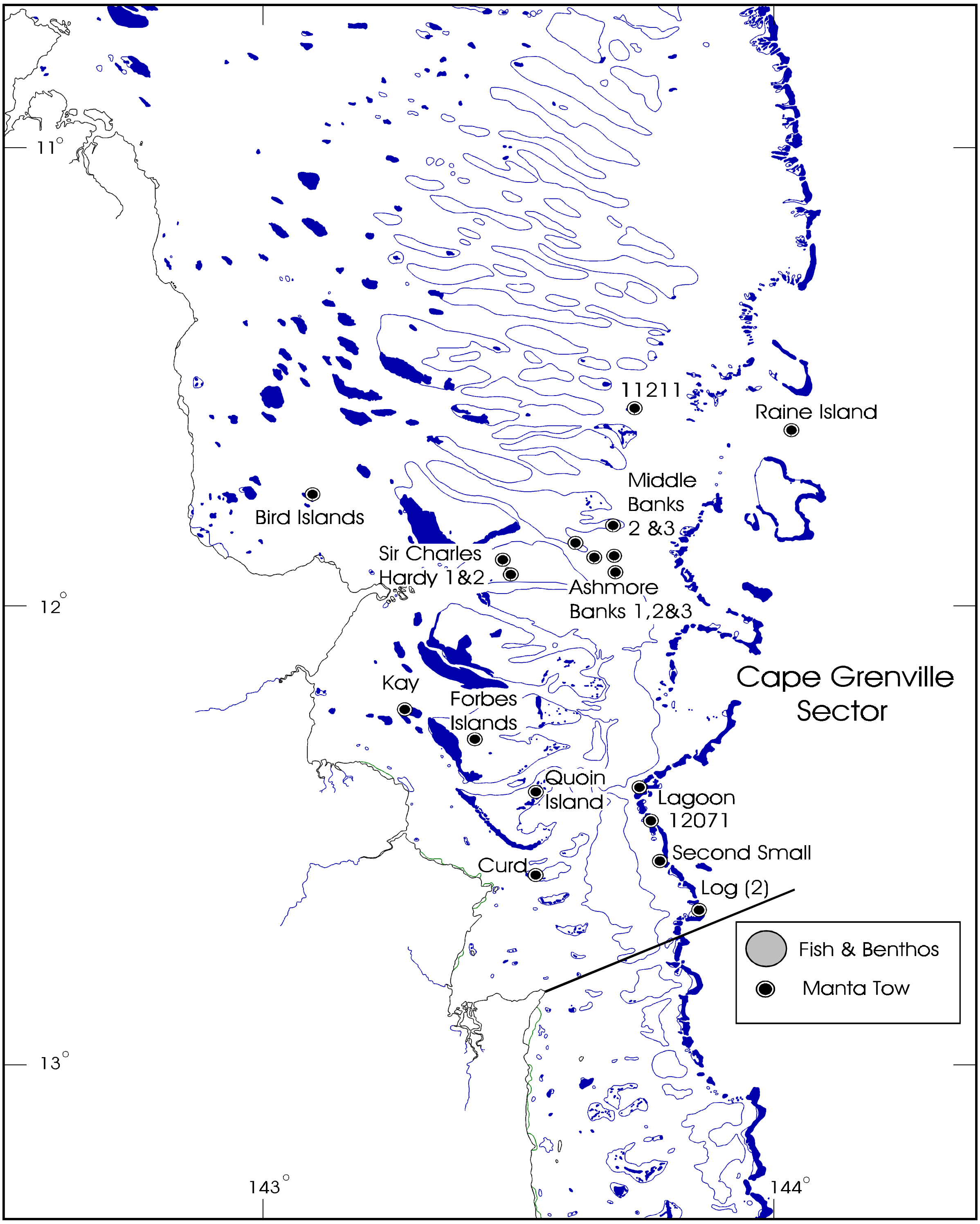
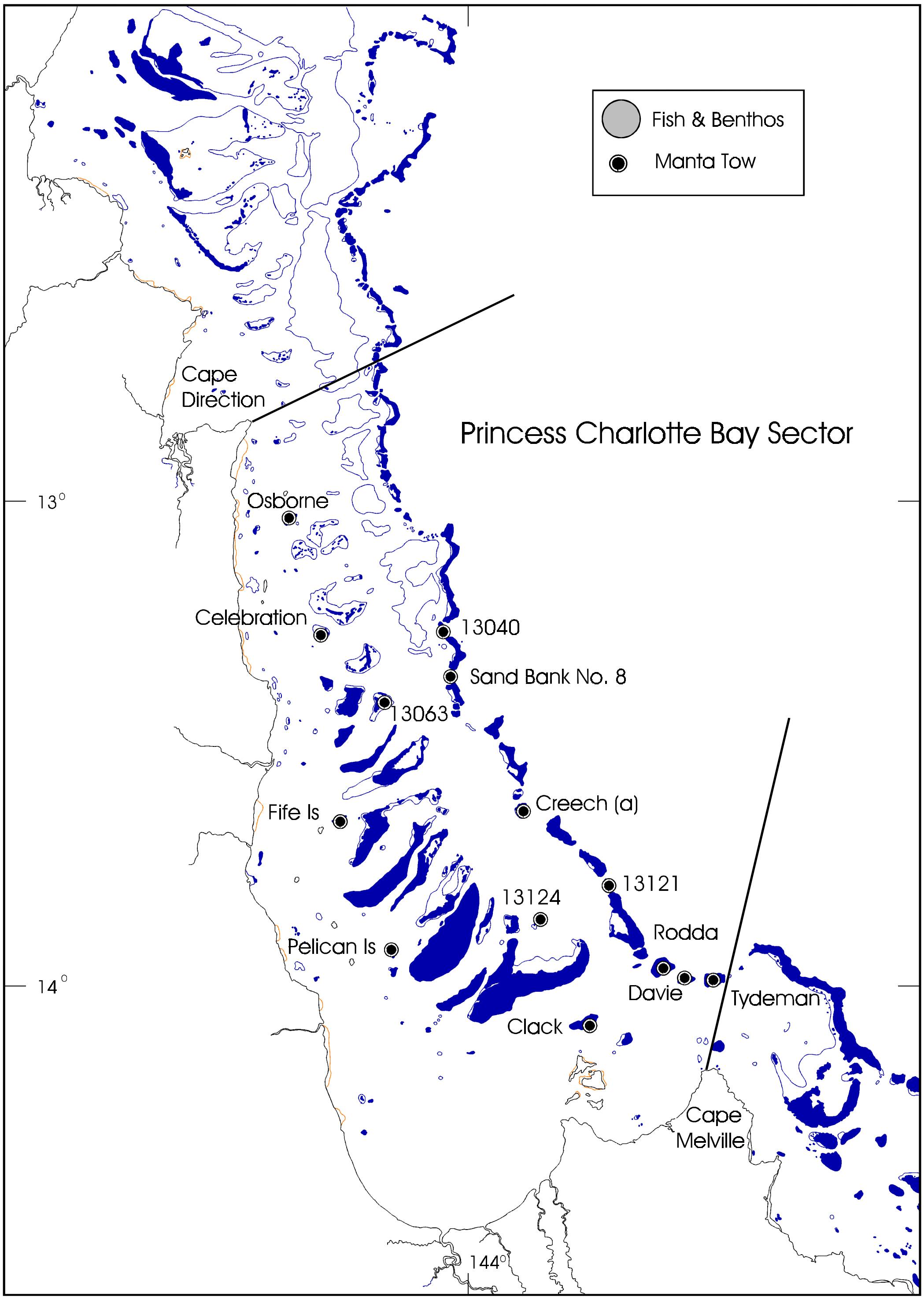
7. Appendices

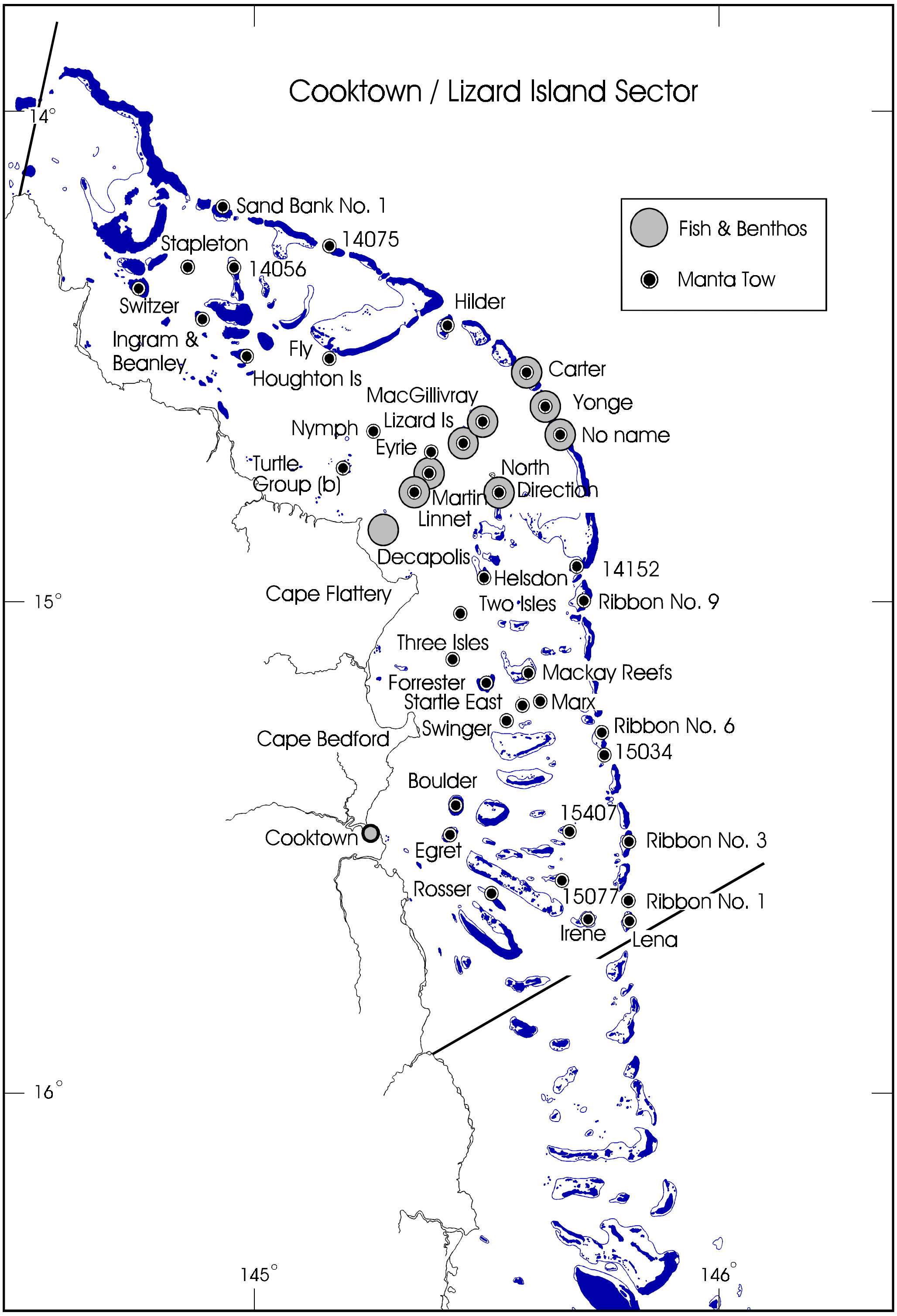
Appendix A

Locations of survey reefs and the types of samples taken.





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


Cooktown / Lizard Island Sector
Fish & Benthos
Manta Tow
14°
15°
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145°
146°
Sand Bank No. 1
Stapleton
14075
14056
Switzer
Ingram &
Beanley
Fly
Houghton Is
Hilder
Carter
Yonge
No name
MacGillivray
Lizard Is
Nymph
Eyrie
Turtle
Group (b)
North
Direction
Martin
Linnet
Decapolis
Helsdon
14152
Cape Flattery
Two Isles
Ribbon No. 9
Three Isles
Mackay Reefs
Forrester
Startle East
Marx
Swinger
Ribbon No. 6
Cape Bedford
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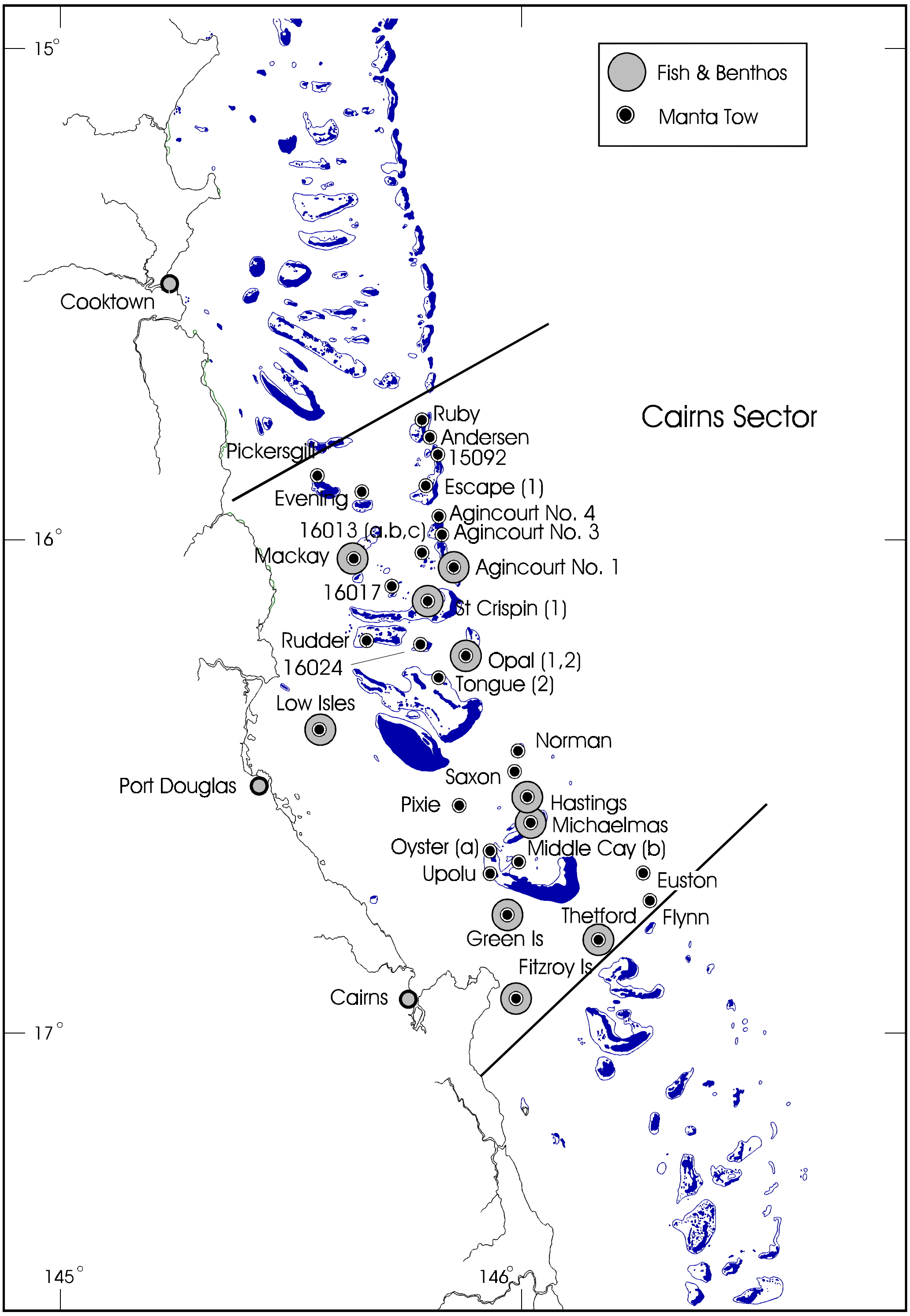
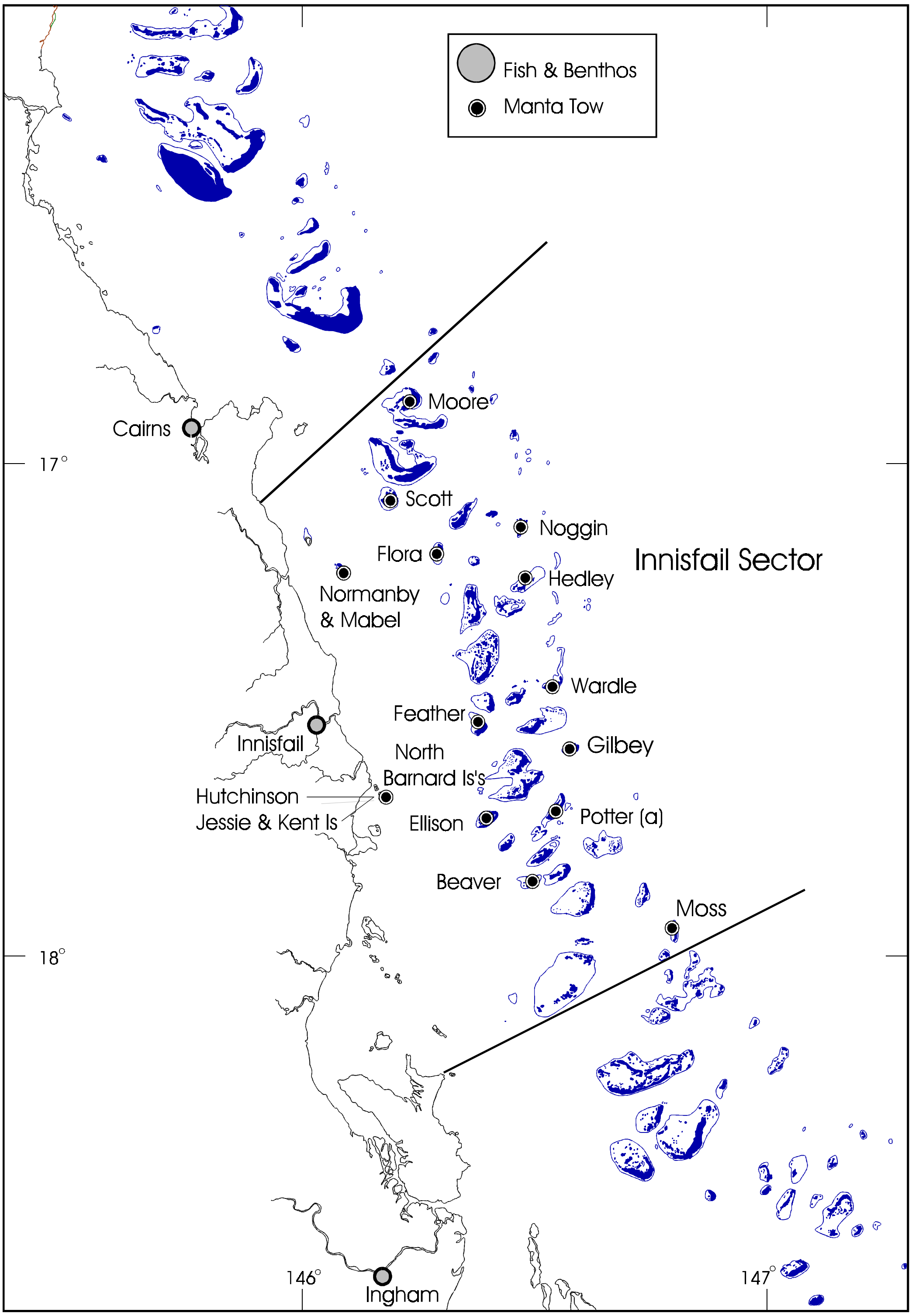
Boulder
15407
Cooktown
Egret
Ribbon No. 3
Rosser
15077
Ribbon No. 1
Irene
Lena


Fish & Benthos
Manta Tow
Cairns Sector
15°
16°
17°
145°
146°
Cooktown
Pickersgill
Evening
16013 (a,b,c)
Mackay
16017
Rudder
16024
Low Isles
Port Douglas
Cairns
Ruby
Andersen
15092
Escape (1)
Agincourt No. 4
Agincourt No. 3
Agincourt No. 1
St Crispin (1)
Opal (1,2)
Tongue (2)
Norman
Saxon
Pixie
Hastings
Michaelmas
Oyster (a)
Middle Cay (b)
Upolu
Euston
Flynn
Thetford
Green Is
Fitzroy Is


Fish & Benthos
Manta Tow
Cairns
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Moore
Scott
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& Mabel
Wardle
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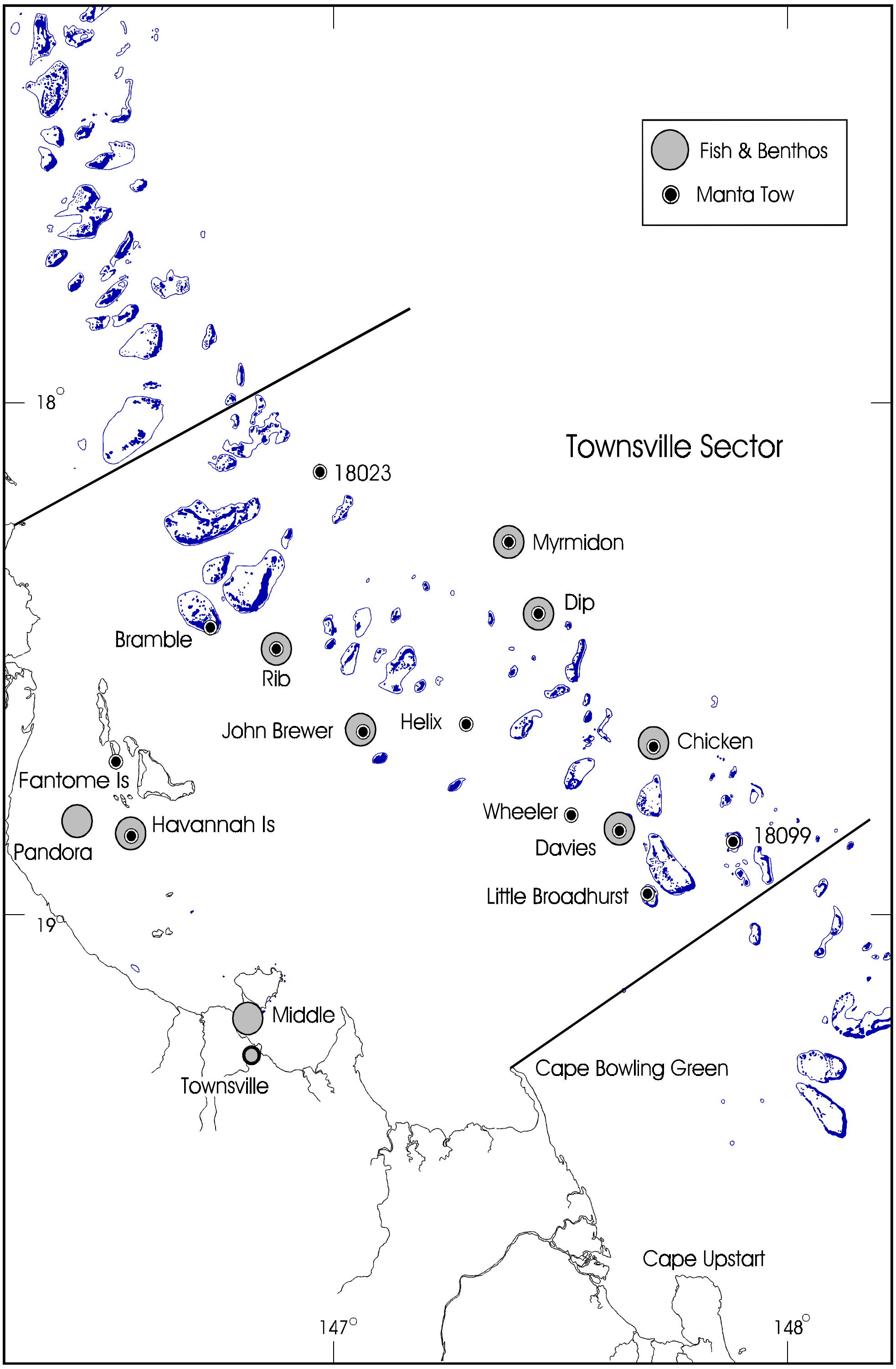
Hutchinson
Jessie & Kent Is
Ellison
Potter (a)
Beaver
Moss
Ingham



Fish & Benthos
Manta Tow
Townsville Sector
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Myrmidon
Dip
Bramble
Rib
John Brewer
Helix
Chicken
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Wheeler
Davies
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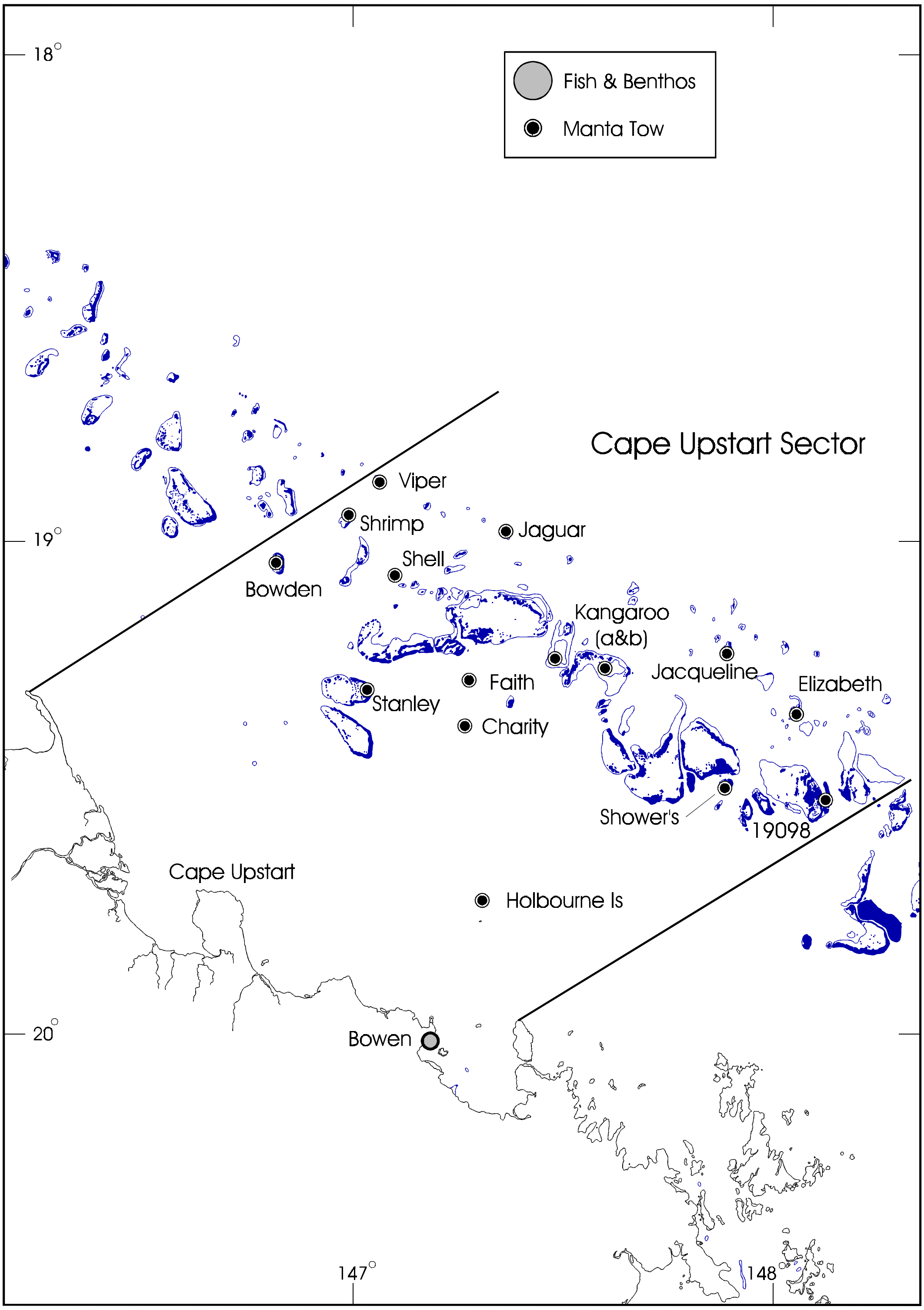
Little Broadhurst
Middle
Townsville
Cape Bowling Green
Cape Upstart



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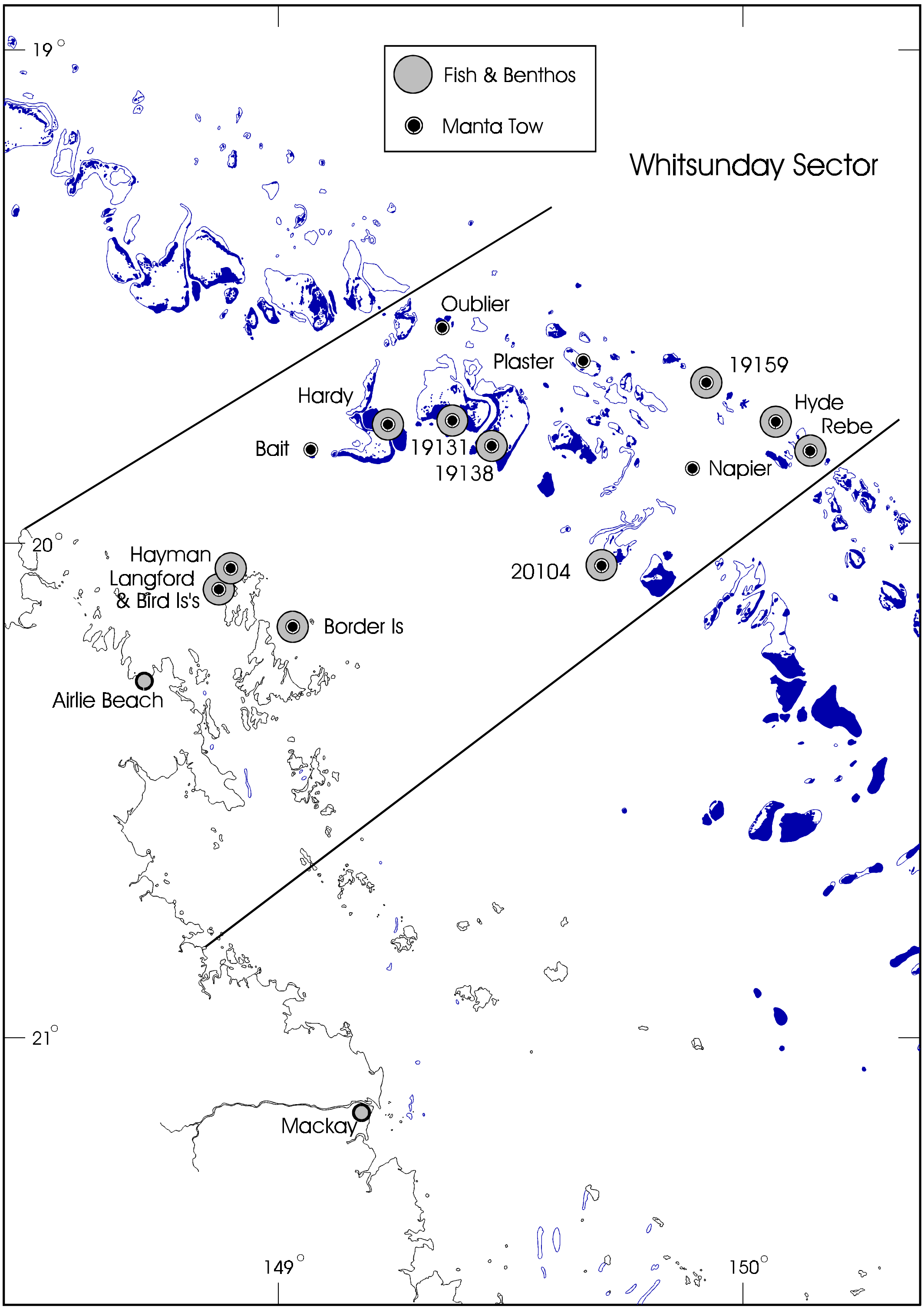
148°
Fish & Benthos
Manta Tow
Cape Upstart Sector
Viper
Shrimp
Jaguar
Shell
Bowden
Kangaroo
(a&b)
Faith
Jacqueline
Elizabeth
Stanley
Charity
Shower's
19098
Cape Upstart
Holbourne Is
Bowen



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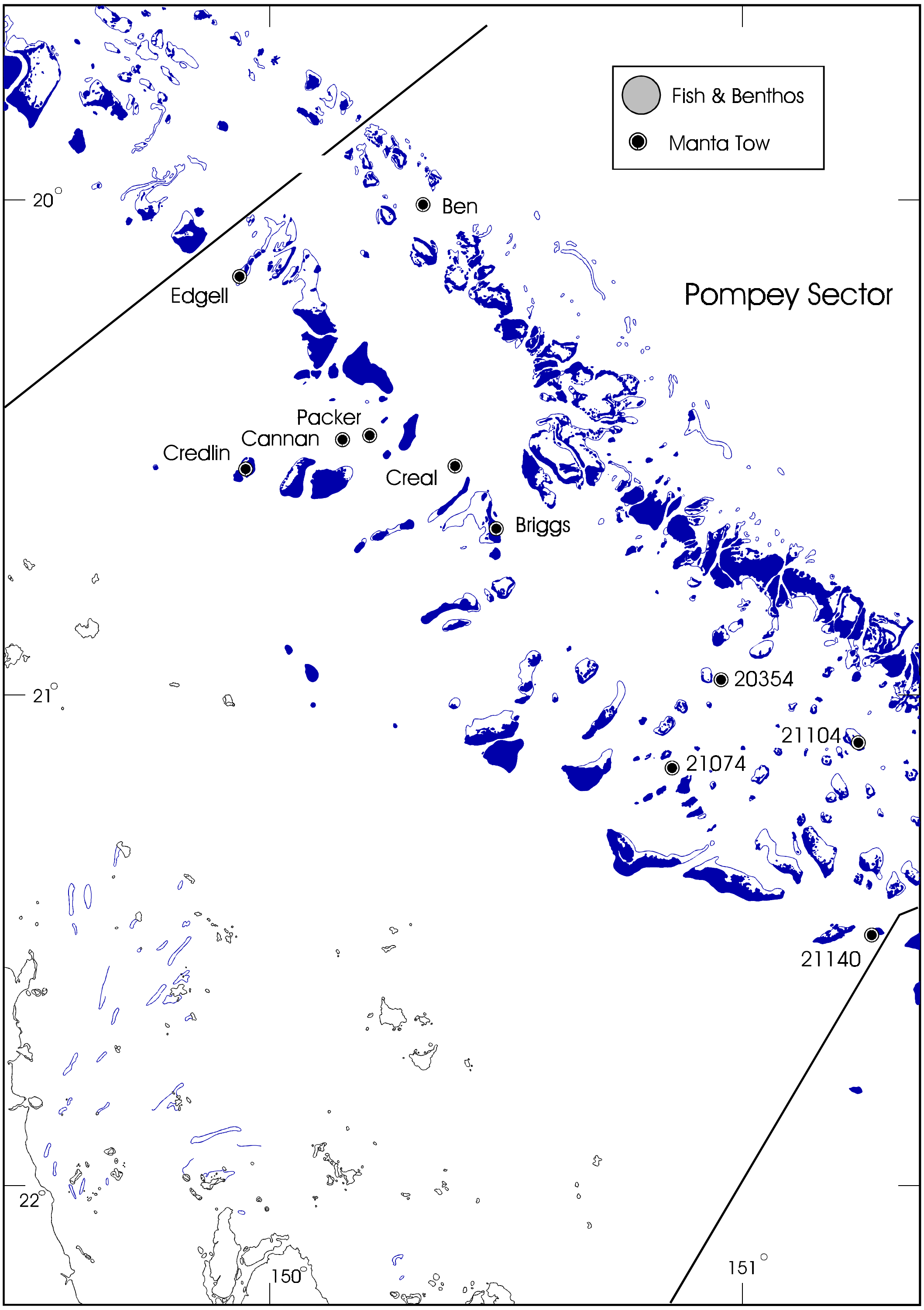
Napier
20104
Hayman
Langford
& Bird Is's
Border Is
Airlie Beach
Mackay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Pompey Sector
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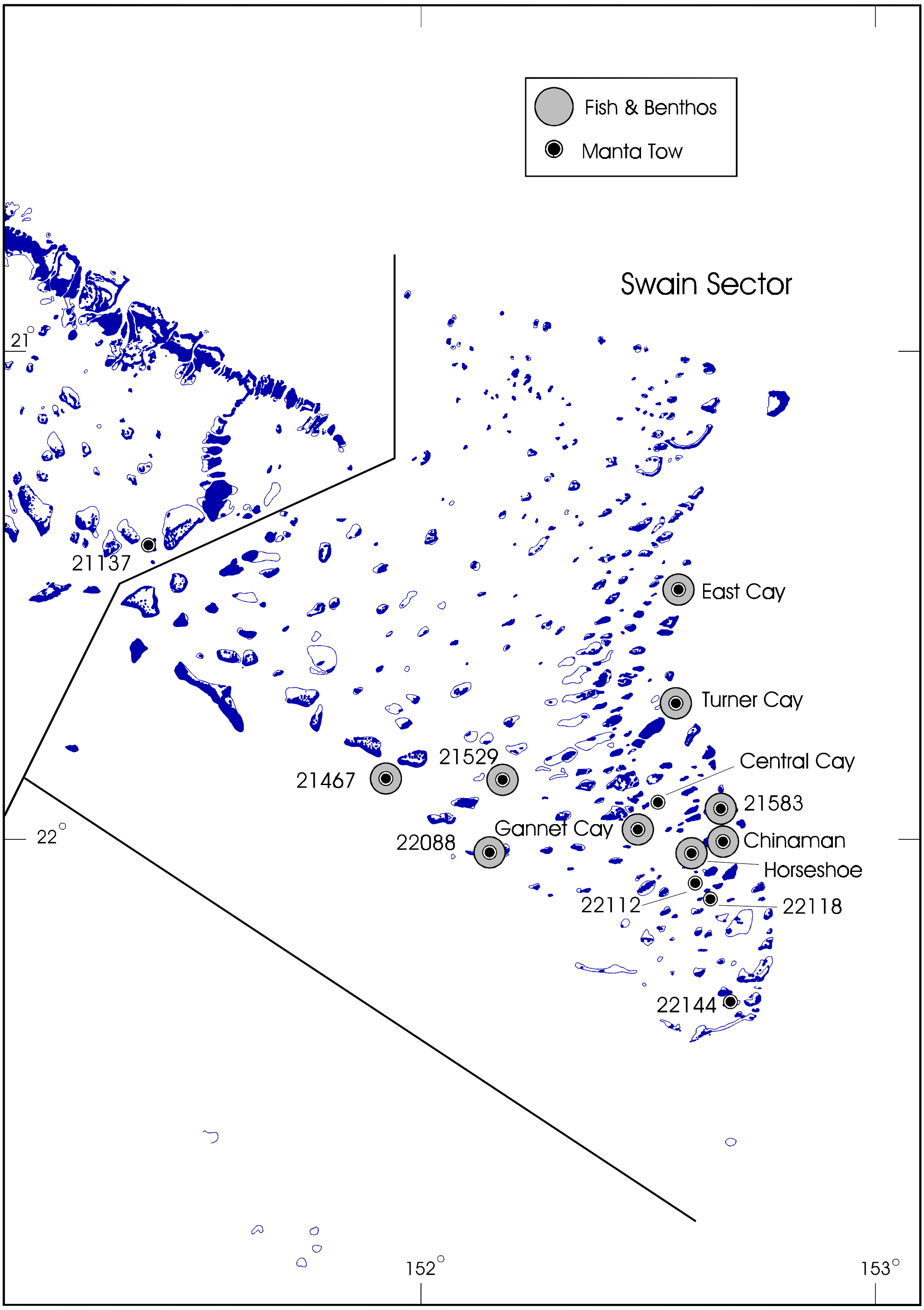

Fish & Benthos
Manta Tow
Swain Sector
21°
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21137
East Cay
Turner Cay
Central Cay
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Gannet Cay
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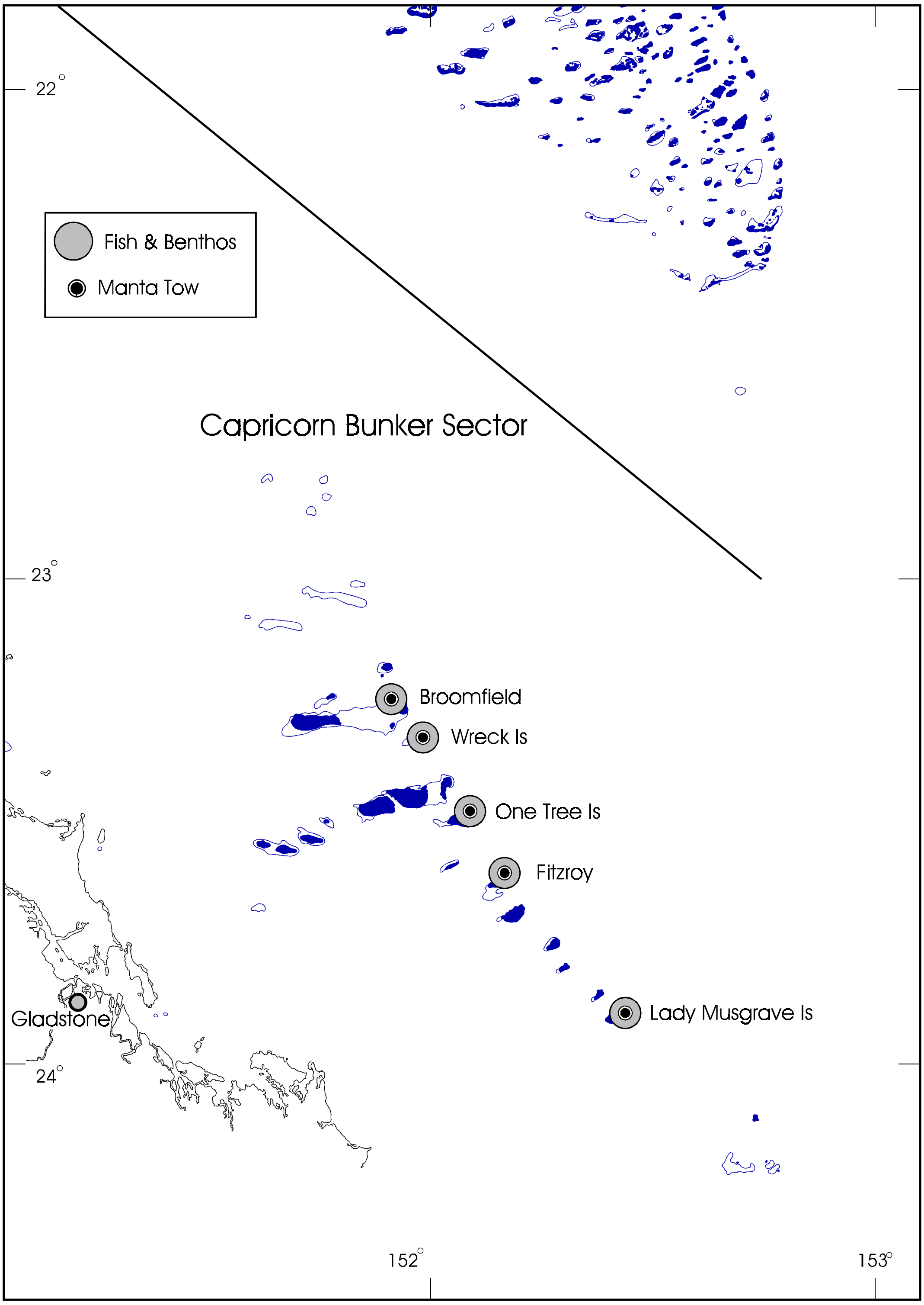
Horseshoe
22112
22118
22144



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

Appendix B

Summary of reefs surveyed in the last 3 years of the LTMP. Reef ID refers to the GBRMPA Gazetteer. Sampling codes:
B = benthos, F = reef fishes, f = small fish species only, M = manta tow.

Sector	Shelf Position	Reef ID	Reef Name	Year Surveyed
				1998/99
Princess Charlotte Bay	Mid-Shelf	13063	13063	M
		13124	13124	M
Princess Charlotte Bay	Outer-Shelf	13056	Sandbank No.8	M
		13127	Rodda	M
		13133	Tydeman	M
Cooktown / Lizard Is	Inshore	14094	Houghton Is	M
		14120	Turtle B	M
		14123	Martin	MBF
		14126	Linnet	MBF
		14131	Decapolis	BF
		15002	Two Isles	M
		15012	Boulder	M
		15013	Egret	M
Cooktown / Lizard Is	Mid-Shelf	14056	14056	M
		14114	Macgillivray	MBF
		14115	Nymph Is	M
		14116	Lizard Is	MBF
		14135	Helsdon	M
		14143	North Direction Is	MBF
		15047	15047	M
		15081	Rosser	M
Cooktown / Lizard Is	Outer-Shelf	14045	Sandbank No.1	M
		14137	Carter	MBF
		14138	Yonge	MBF
		14139	No Name	MBF
		14154	Ribbon No.9	M
		15034	15034	M

Sector	Shelf Position	Reef ID	Reef Name	Year Surveyed
				1998/99
Cairns	Inshore	16028	Low Islets	MBF
		16049	Green Is	MBF
		16054	Fitzroy Is	MBF
Cairns	Mid-Shelf	15093	Pickersgill	M
		16015	Mackay	MBF
		16023	Rudder	M
		16026	Tongue	M
		16032	Saxon	M
		16040	Pixie	M
		16043	Oyster (A)	M
		16057	Hastings	MBF
		16060	Michaelmas	MBF
		16068	Thetford	MBF
Cairns	Outer-Shelf	15088	Ruby	M
		15096	Agincourt No.4	M
		15099	Agincourt No.1	MBF
		16019	St. Crispin	MBF
		16025	Opal (2)	MBF
Innisfail	Inshore	17012	Normanby And Mabel Is'	M
Innisfail	Mid-Shelf	17010	Flora	M
		17034	Feather	M
Innisfail	Outer-Shelf	17032	Wardle	M
		17057	Gilbey	M
Townsville	Inshore	18051	Pandora	Bf
		18065	Havannah Is	MBF
		19011	Middle	B
Townsville	Mid-Shelf	18032	Rib	MBF
		18075	John Brewer	MBF
		18076	Helix	M
		18095	Wheeler	M
		18096	Davies	MBF
		18106	Little Broadhurst	M
Townsville	Outer-Shelf	18034	Myrmidon	MBF
		18039	Dip	MBF
		18086	Chicken	MBF
Cape Upstart	Mid-Shelf	19019	Bowden	M
		19044	Faith	M
		19045	Stanley	M
		19063	Kangaroo (A)	M
		19063	Kangaroo (B)	M
Cape Upstart	Outer-Shelf	18112	Viper	M
		18120	Jaguar	M

Sector	Shelf Position	Reef ID	Reef Name	Year Surveyed
				1998/99
Whitsunday	Inshore	20014	Hayman Is	MBF
		20019	Langford And Bird Is's	MBF
		20067	Border Is	BF
Whitsunday	Mid-Shelf	19131	19131	MBF
		19135	Hardy	M
		19138	19138	MBF
		20104	20104	MBF
Whitsunday	Outer-Shelf	19159	19159	MBF
		19207	Hyde	MBF
		19209	Rebe	MBF
Pompey	Mid-Shelf	20144	Cannan	M
		20287	Credlin	M
		20348	20348	M
		20354	20354	M
		21104	21104	M
Pompey	Outer-Shelf	20113	Ben	M
Swain	Mid-Shelf	21529	21529	MBF
		21556	Gannet Cay	MBF
		22088	22088	MBF
		22102	Chinaman	MBF
		22104	Horseshoe	MBF
Swain	Outer-Shelf	21305	East Cay	MBF
		21562	Turner Cay	MBF
Capricorn/Bunker	Outer-Shelf	23048	Broomfield	MBF
		23051	Wreck Is	MBF
		23055	One Tree Is	MBF
		23082	Lady Musgrave Is	MBF

APPENDIX C

A. List of large, mobile fish species that would be counted on 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 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 D

General status of crown-of-thorns starfish in each sector on the Great Barrier Reef for survey year 1998-99.

D1. Status of crown-of-thorns starfish (COTS) in each sector in 1996. AO = Active outbreak, IO = Incipient outbreak, RE = Recovering, NO = No outbreak.

Sector	No. of Reefs	No. COTS/ tow	No. COTS	Number (%) of Reefs with COTS	Median (range) coral cover		Mean Coral Cover ± SE	% AO or IO reefs	% RE reefs	% NO reefs
Princess Charlotte Bay	5	0.01	3	1 (20)	2U	(2U to 3L)	28.41 ± 3.09	0	40	60
Cooktown / Lizard Island	21	0.34	309	9 (43)	2L/2U	(1U to 3U)	25.93 ± 2.21	38.1	38.1	23.8
Cairns	18	0.11	106	9 (50)	2L	(1L to 3L)	18.3 ± 2.28	16.67	33.33	50
Innisfail	5	0.33	73	3 (60)	1U	(1L to 2U)	13.1 ± 2.50	20	60	20
Townsville	10	0.49	201	2 (20)	2L/2U	(1L to 3L)	22.16 ± 2.56	10	60	30
Cape Upstart	7	0.01	5	4 (57)	2U	(2L to 3L)	25.67 ± 3.78	0	42.86	57.1
Whitsunday	9	0.002	1	1 (11)	2L	(1U to 2U)	19.67 ± 2.46	0	22.22	77.8
Pompey	6	0	0	0 (0)	2U	(2L to 4L)	31.17 ± 5.98	0	0	100
Swain	7	0.4	143	4 (57)	2U	(2L to 3U)	28.71 ± 3.78	42.86	14.29	42.9
Capricorn Bunker	4	0	0	0 (0)	3U	(3L to 3U)	43.68 ± 2.34	0	0	100

Appendix E

Percentage cover of selected groups of benthic organisms recorded from each region in 1998-99 Survey.
Figures are regional means.
CG = Cape Grenville, PC = Princess Charlotte Bay, CL = Cooktown / Lizard Is, CA = Cairns, TO = Townsville, WH = Whitsundays, SW = Swains, CB = Capricorn / Bunkers. I= Inshore, M = Mid-shelf, O = Outer shelf

Sector	Shelf	Hard Coral	Soft Coral	Algae	Acroporidae	Favidae	Pocilloporidae	Poritidae	Acropora Tabulate	Acropora Other	Montipora
CL	I	32.2	3.7	44.0	10.5	4.3	4.9	5.2	4.7	3.2	2.6
CL	M	15.9	7.6	55.9	1.0	3.1	0.9	6.8	0.2	0.5	0.2
CL	O	61.4	6.0	8.8	44.6	2.3	9.7	1.7	30.7	12.6	1.3
CA	I	20.1	12.3	50.7	4.8	1.8	0.1	6.0	0.4	2.4	2.1
CA	M	30.3	15.2	36.2	13.3	4.4	4.0	2.5	7.6	4.4	1.2
CA	O	27.9	31.7	19.1	16.0	2.0	4.3	2.6	6.6	9.1	0.2
TO	I	35.9	16.9	34.9	8.0	3.1	0.1	13.2	1.0	4.4	2.6
TO	M	38.5	2.6	41.6	23.8	3.3	3.3	2.9	14.5	8.4	0.9
TO	O	37.1	15.8	22.8	14.2	7.7	6.1	3.7	6.7	6.4	1.1
WH	I	29.7	22.1	29.0	8.8	4.5	0.6	9.1	0.5	3.0	5.1
WH	M	26.6	1.5	59.9	6.9	7.9	2.4	2.4	1.0	1.4	4.5
WH	O	28.1	35.2	15.6	12.0	4.0	3.3	4.7	4.6	6.4	0.9
SW	M	33.7	8.3	43.3	15.3	3.0	2.5	6.5	4.0	7.4	4.0
SW	O	27.5	29.4	27.4	9.4	3.8	3.5	5.4	5.3	3.7	0.4
CB	O	59.6	2.8	22.0	53.7	2.6	0.9	0.6	45.2	7.3	1.2

Appendix F

Summary counts of the different fish taxa recorded from each region in 1998-99 Survey.
Figures are regional means for the sums of individuals on 15 transects (3 sites) on each survey reef.

F1. Number of larger more mobile fishes recorded in the regions in the 199899 survey.

CG = Cape Grenville, PC = Princess Charlotte Bay, CL = Cooktown / Lizard Is, CA = Cairns, TO = Townsville, WH = Whitsundays, SW = Swains, CB = Capricorn / Bunkers. I= Inshore, M = Mid-shelf, O = Outer shelf

Sector	Shelf	Acanthuridae	Chaetodontidae	Labridae	Lethrinidae	Lutjanidae	Scaridae	Serranidae	Siganidae	Zanclidae
CL	I	73	85	35	4	36	94	8	72	1
CL	M	80	72	42	17	23	136	6	42	1
CL	O	277	157	27	14	73	186	2	5	12
CA	I	81	61	41	3	103	138	8	63	0
CA	M	162	73	39	6	17	179	5	13	4
CA	O	264	93	22	13	13	165	1	6	5
TO	I	0	38	48	0	29	61	3	7	0
TO	M	89	116	44	5	3	194	3	23	0
TO	O	246	69	26	4	4	132	9	9	2
WH	I	4	91	38	1	30	73	8	35	0
WH	M	43	73	61	5	21	276	17	99	0
WH	O	198	80	35	3	4	130	5	14	8
SW	M	148	67	48	9	8	217	16	34	5
SW	O	194	80	40	5	2	274	9	14	12
CB	O	173	245	36	6	6	140	4	2	6

F2. Number of damselfishes recorded in the regions in the 1999 survey.

CG = Cape Grenville, PC = Princess Charlotte Bay, CL = Cooktown / Lizard Is, CA = Cairns, TO = Townsville, WH = Whitsundays, SW = Swains, CB = Capricorn / Bunkers. I= Inshore, M = Mid-shelf, O = Outer shelf

Sector	Shelf	Acantho-chromis	Amblygly-phidodon	Amphip-rion	Chromis	Chrysip-tera	Dascyllus	Dischist-odus	Neogly-phidodon	Neopoma-centrus	Plectrogly-phidodon	Poma-centrus	Poma-chromis	Premnas	Stegastes
CL	I	152	75	0	108	36	8	0	10	305	0	1355	0	1	1
CL	M	69	67	1	36	112	32	4	6	45	18	505	0	0	1
CL	O	46	1	0	664	17	3	0	0	0	102	198	0	0	1
CA	I	38	42	0	10	117	0	3	38	319	2	989	0	0	0
CA	M	20	34	2	320	45	10	6	17	490	94	1212	0	1	17
CA	O	20	7	1	111	36	1	0	3	6	78	381	0	0	0
TO	I	67	17	0	0	0	0	0	36	958	0	479	0	0	1
TO	M	36	83	8	272	54	4	4	70	304	22	1382	0	0	4
TO	O	20	2	3	307	19	4	1	1	364	117	656	0	0	27
WH	I	92	58	0	15	268	0	1	4	398	0	1241	0	0	0
WH	M	11	11	0	13	104	0	0	3	2789	0	1809	0	0	9
WH	O	14	48	2	213	44	2	0	15	58	48	931	0	0	2
SW	M	4	93	3	540	12	0	0	7	32	7	830	0	0	4
SW	O	19	74	4	38	9	0	0	19	12	26	483	0	0	10
CB	O	2	0	1	137	10	2	0	1	25	8	789	0	0	0

Appendix I

Statistical Analysis of the LTMP Survey Data

Analysis of Individual Reef Trends [see web pages]

Fish abundance data

The model chosen to describe fish counts (y_{ijklm} represents the natural logarithm of (number of fish + 1) of a particular taxon counted on site *l* for the *k*th reef in the *ij*th region at time *m*) was:

$$y_{ijklm} = \beta_{oijk} + \beta_{1ijk} x_{ijklm} + \beta_{2ijk} x_{ijklm}^2 + \varepsilon_{ijklm}$$

where

β_{oijk} represents the response at $x_{ijklm} = 0$ for the *k*th reef in the *ij*th region,
β_{1ijk} represents the instantaneous rate of change of the response at $x_{ijklm} = 0$ for the *k*th reef in the *ij*th region,
β_{2ijk} represents the curvature of the response for the *k*th reef in the *ij*th region,
x_{ijklm} is the coded survey number for the *l*th site, *k*th reef in the *ij*th region at time *m*,
and ε_{ijklm} is the error term

Coding of survey number

The data were analysed twice using the survey number coded as:

$x_{ijklm} = (survey\,number - 5.0)$
and
$x_{ijklm} = (survey\,number - 7.0)$

to allow direct estimation of β_{oijk} and β_{1ijk} at two different times during the survey period. When the survey number is centered around 5, the parameters β_{oijk} and β_{1ijk} represent the average value of the response over the past five years for reef *ijk* and the linear change in the response over the period of the survey for reef *ijk*, respectively. When the survey number is centered around 7, the parameters β_{oijk} and β_{1ijk} represent the estimated average value of the response for reef *ijk* in the last survey year and the instantaneous linear change in the response for reef *ijk* in the last survey year, respectively.

Choosing a covariance structure

The errors were assumed to conform to a multivariate normal distribution with mean 0 and covariance structure Σ. The form of Σ was chosen as follows:

(1) the value of the likelihood was obtained for the model above assuming each of the following covariance structures:
   (a) independence
   (b) compound symmetry
   (c) first order autoregressive
   (d) autoregressive moving average (ARMA(1,1))
   (e) Toeplitz
   In each case the structure was assumed to be homogeneous for all reefs.

(2) the likelihood ratio test was then used to compare nested models and to choose the simplest nested covariance structure which described the model adequately.

Table I1: Average minimum detectable rate of change (MDD) for abundances of different reef fish taxa based on means for sites on reefs. MDD over the last 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to minimum detectable rate of change at the most recent survey. Note that these values are absolute; they apply to both positive and negative rates of change. These values are used in conjunction with Appendix H and Figure I1, see figure caption.

Larger fishes	MDD over last 5 years	MDD (current)	Damselfishes	MDD over last 5 years	MDD (current)
Acanthuridae	0.23	0.82	*Acanthochromis*	0.29	1.04
Chaetodontidae	0.20	0.72	*Amblyglyphidodon*	0.18	0.65
Labridae	0.26	0.91	*Chromis*	0.47	1.65
Lethrinidae	0.36	1.28	*Chrysiptera*	0.30	1.07
Lutjanidae	0.36	1.25	*Neoglyphidodon*	0.25	0.89
Scaridae	0.30	1.07	*Neopomacentrus*	0.59	2.09
Serranidae	0.35	1.23	*Plectroglyphidodon*	0.19	0.67
Siganidae	0.38	1.36	*Pomacentrus*	0.19	0.68

Power

The measure of power that was used for this analysis was the minimal detectable rate of change. This estimates the smallest rate of change significantly different from zero $(\Delta\beta_{1ij})$ that could be detected reliably (90% of the time at the 5% level of significance). This measure was calculated for each taxon at each reef using the following formula:

$$\Delta\beta_{1ijk} = se_{\beta_{1ijk}}(\phi(0.975)+\phi(0.90))$$

where

$se_{\beta_{1ijk}}$ is the standard error of the rate of change for reef *ijk*
$\phi(0.975)$ is the 97.5 percentile of the standard normal distribution which corresponds to a two sided test for and $\alpha = 0.05$
$\phi(0.90)$ is the 90th percentile of the standard normal distribution corresponding to a power of 90% (Zar 1984).

The average minimum detectable rate of change was tabulated on the logarithmic scale and can be converted to a rate of change on the count scale using Figure I1. To do this:

(1) estimate the mean abundance of fish ***per site*** for the reef of interest in the last survey year, see Appendix H (or the mean abundance of fish ***per reef*** for the region of interest, see Appendix F)
(2) find this value on the horizontal axis of Figure I1.
(3) draw a vertical line through this point until it intersects the two isopleths (or the margins of the figure) which bracket the minimal detectable rate of change of the taxa of interest (from Table I1)
(4) draw a horizontal line from each of these points to the left hand vertical axis
(5) the points of intersection on the vertical axis bracket the minimal detectable rate of change in abundance for the reef for interest.

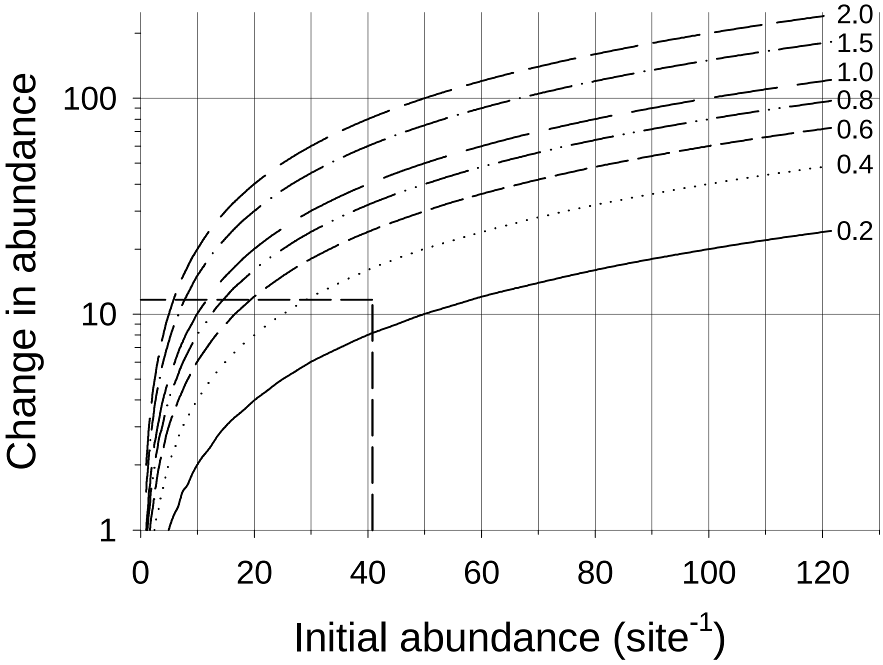


Figure I1: Relationship between mean abundance of fish per site and detectable rate of change in abundance for different values of minimum rate of change (MDD). Note detectable rate of change is given on a log scale. ***Interpretation:*** Drop-line gives an estimate of minimum detectable rate of change for overall trends in abundance of Scaridae at Agincourt No. 1 in the Cairns sector. From Appendix F, mean abundance in 1999 was 123 fish per reef, thus the abundance *per site* was 123/3 = 41 (X axis). From Table I1, average minimum detectable rate of change over five years was 0.30. Using an interpolated MDD curve between those for MDD = 0.2 and MDD =0.4, the estimated minimum detectable rate of change would be a gain or loss of about 13 fish annually (~32%).

Benthic Cover Data

Estimates of coverage for the benthic groups are obtained by point sampling a 50 m transect recorded on videotape. Statistical analysis of these estimates differed from the analysis described for the fish taxa in the following ways:

(1) the response (average percent cover of 5 transects) is transformed using the empirical logit:

$$log\left(\frac{p+cf}{100-p+cf}\right)$$

where p was the average percentage cover for a given benthic group and cf represented the correction factor for zero $\left(cf = \frac{1}{2} * \frac{1}{200} * \frac{1}{15} * 100\right)$ where $\frac{1}{2}$ is the correction factor suggested by McCullagh and Nelder (1989), $\frac{1}{200}$ averages this single point over the number of points sampled for a video transect (200), $\frac{1}{15}$ average this number over the 15 transects and 100 puts this on a percentage scale).

Table I2: Average minimum detectable rate of change (MDD) for percent cover of different taxa of benthic organisms based on means for sites on reefs. MDD over 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to the minimum detectable rate of change at the most recent survey. Note that these values are absolute: they apply to both positive and negative rates of change. These values are used in conjunction with Appendix G and Figure I2, see figure caption.

(1) Taxon	**MDD over 5 years**	**MDD (current)**
(2) Hard Corals	0.18	0.45
Acroporidae	0.32	0.85
Tabulate *Acropora* spp.	0.49	1.28
Other *Acropora* spp.	0.51	1.40
Montipora spp.	0.66	1.86
Faviidae	0.30	0.81
Pocilloporidae	0.40	1.13
Poritidae	0.37	1.14
(3) Soft Corals	0.53	0.73
(4) Algae	0.18	0.53

(2) the statistical model is the same as that used for analysis of trends in abundance of the fish taxa.

(3) for the estimation of power: values of percent cover from Appendix G and MDDs from Table I2 are used in conjunction with Figure I2.

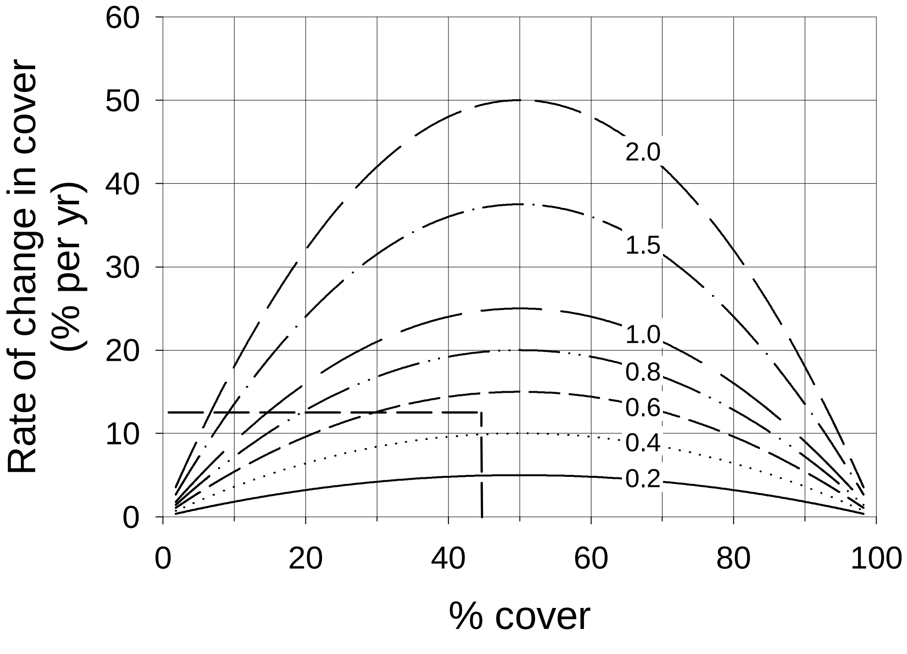


Figure I2: Relationship between cover of benthic taxa per site and detectable rate of change in percent cover for different values of minimum detectable difference (MDD) in rate of change. ***Interpretation:*** Drop-line gives an estimate of minimum detectable rate of change for the current trend in algaes on Hastings Reef (Cairns sector). From Appendix G, mean cover in 1998 was 44.2% (X axis). From Table I2, the average minimum detectable rate of change is 0.53. Using an interpolated MDD curve between those for MDD = 0.4 and MDD = 0.6, the estimated minimum detectable current rate of change would be a gain or loss of about 12% bottom cover annually (27% of the average algal cover).

Table I3: Average minimum detectable rate of change for abundances of different reef fish taxa based on **regional** means for sites on reefs. MDD over 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to the minimum detectable rate of change at the most recent survey. Note that these values are absolute; they apply to both positive and negative rates of change. These values are used in conjunction with Appendix F and Figure K1, see figure caption.

Larger fishes	**MDD over 5 years**	**MDD (current)**	**Damselfishes**	**MDD over 5 years**	**MDD (current)**
Acanthuridae	0.26	0.60	*Acanthochromis*	0.28	0.85
Chaetodontidae	0.20	0.54	*Amblyglyphidodon*	0.22	0.47
Labridae	0.20	0.47	*Chromis*	0.68	1.70
Lethrinidae	0.38	0.98	*Chrysiptera*	0.37	0.95
Lutjanidae	0.33	0.93	*Neoglyphidodon*	0.30	0.66
Scaridae	0.23	0.66	*Neopomacentrus*	0.69	1.85
Serranidae	0.29	0.85	*Plectroglyphidodon*	0.23	0.49
Siganidae	0.30	0.93	*Pomacentrus*	0.18	0.46

Analysis of regional trends [Section 4]

Fish abundance and benthic cover data

The regional analysis for both groups was carried out using the same models from the corresponding reef trend analysis, with the following changes:

(1) reef means were used instead of site means for the benthic cover analysis

(2) reef means of $\ell n(count+1)$ were used instead of $\ell n(count+1)$ for the fish count data covariance structures which were heterogeneous across shelf position were considered.

Table I4: Average minimum detectable rate of change for percent cover of different taxa of benthic organisms based on **regional** means for sites on reefs. MDD over 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to the minimum detectable rate of change at the most recent survey. Note that these values are absolute: they apply to both positive and negative rates of change. These values are used in conjunction with Appendix E and Figure I2, see figure caption.

(5) Taxon	(6) MDD over 5 years	(7) MDD (current)
Hard Corals	0.19	0.41
Acroporidae	0.29	0.62
Tabulate *Acropora* spp.	0.34	0.78
Other *Acropora* spp.	0.37	0.90
Montipora spp.	0.29	0.90
Faviidae	0.16	0.47
Pocilloporidae	0.33	0.79
Poritidae	0.18	0.56
Soft Corals	0.20	0.49
Algae	0.20	0.52

(3) to estimate power: values for benthic cover or fish abundance are obtained from Appendices E or F and MDDs from Tables I3 or I4 are used in conjunction with Figures I1 or I2.

Broad scale survey data

The broad scale data are visual estimates of the average number of COTS per tow and the average hard coral cover per tow. The analysis of these data was based upon the use of summary statistics to obtain the best estimates of the sector trend. The sector trends were obtained in the following fashion:

(1) for each reef the following quadratic model was fit:

$$y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \varepsilon_i$$

where y_i represents the average coral cover or the $\ell n(average\,COTS\,count + 1)$ on a given reef for year *i*, β_o represents the average response at year Z, β_1 represents the rate of change at year Z, β_2 represents the curvature of the trend, x_i = *survey number* - Z, and ε_i represents the error.

(2) for each reef the response for each year (including the years where observations are missing) was estimated using the model presented in (1).

(3) for each region, the estimate of the average response was obtained by averaging the predicted response for each reef for each year.

(4) finally, the average response was back transformed to the original scale where required.

Statistical computing

The SAS system software (SAS Institute Inc., Cary, NC, USA) was used for all analyses. The MIXED procedure was used to fit the statistical models described for the fish abundance and benthic cover data. The REG procedure was used to obtain the estimates described for the broad scale survey data.

Appendix I

Statistical Analysis of the LTMP Survey Data

Analysis of Individual Reef Trends [see web pages]

Fish abundance data

The model chosen to describe fish counts (y_{ijklm} represents the natural logarithm of (number of fish + 1) of a particular taxon counted on site *l* for the k^{th} reef in the ij^{th} region at time *m*) was:

$$y_{ijklm} = \beta_{oijk} + \beta_{1ijk} x_{ijklm} + \beta_{2ijk} x_{ijklm}^2 + \varepsilon_{ijklm}$$

where

β_{oijk} represents the response at $x_{ijklm} = 0$ for the k^{th} reef in the ij^{th} region,
β_{1ijk} represents the instantaneous rate of change of the response at $x_{ijklm} = 0$ for the k^{th} reef in the ij^{th} region,
β_{2ijk} represents the curvature of the response for the k^{th} reef in the ij^{th} region,
x_{ijklm} is the coded survey number for the l^{th} site, k^{th} reef in the ij^{th} region at time *m*,
and ε_{ijklm} is the error term

Coding of survey number

The data were analysed twice using the survey number coded as:

$x_{ijklm} = (survey\,number - 5.0)$
and
$x_{ijklm} = (survey\,number - 7.0)$

to allow direct estimation of β_{oijk} and β_{1ijk} at two different times during the survey period. When the survey number is centered around 5, the parameters β_{oijk} and β_{1ijk} represent the average value of the response over the past five years for reef *ijk* and the linear change in the response over the period of the survey for reef *ijk*, respectively. When the survey number is centered around 7, the parameters β_{oijk} and β_{1ijk} represent the estimated average value of the response for reef *ijk* in the last survey year and the instantaneous linear change in the response for reef *ijk* in the last survey year, respectively.

Choosing a covariance structure

The errors were assumed to conform to a multivariate normal distribution with mean 0 and covariance structure Σ. The form of Σ was chosen as follows:

(1) the value of the likelihood was obtained for the model above assuming each of the following covariance structures:
  (a) independence
  (b) compound symmetry
  (c) first order autoregressive
  (d) autoregressive moving average (ARMA(1,1))
  (e) Toeplitz
  In each case the structure was assumed to be homogeneous for all reefs.

(2) the likelihood ratio test was then used to compare nested models and to choose the simplest nested covariance structure which described the model adequately.

Table I1: Average minimum detectable rate of change (MDD) for abundances of different reef fish taxa based on means for sites on reefs. MDD over the last 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to minimum detectable rate of change at the most recent survey. Note that these values are absolute; they apply to both positive and negative rates of change. These values are used in conjunction with Appendix H and Figure I1, see figure caption.

Larger fishes	MDD over last 5 years	MDD (current)	Damselfishes	MDD over last 5 years	MDD (current)
Acanthuridae	0.23	0.82	*Acanthochromis*	0.29	1.04
Chaetodontidae	0.20	0.72	*Amblyglyphidodon*	0.18	0.65
Labridae	0.26	0.91	*Chromis*	0.47	1.65
Lethrinidae	0.36	1.28	*Chrysiptera*	0.30	1.07
Lutjanidae	0.36	1.25	*Neoglyphidodon*	0.25	0.89
Scaridae	0.30	1.07	*Neopomacentrus*	0.59	2.09
Serranidae	0.35	1.23	*Plectroglyphidodon*	0.19	0.67
Siganidae	0.38	1.36	*Pomacentrus*	0.19	0.68

Power

The measure of power that was used for this analysis was the minimal detectable rate of change. This estimates the smallest rate of change significantly different from zero $(\Delta\beta_{1ij})$ that could be detected reliably (90% of the time at the 5% level of significance). This measure was calculated for each taxon at each reef using the following formula:

$$\Delta\beta_{1ijk} = se_{\beta_{1ijk}}(\phi(0.975)+\phi(0.90))$$

where

$se_{\beta_{1ijk}}$ is the standard error of the rate of change for reef *ijk*
$\phi(0.975)$ is the 97.5 percentile of the standard normal distribution which corresponds to a two sided test for and $\alpha = 0.05$
$\phi(0.90)$ is the 90th percentile of the standard normal distribution corresponding to a power of 90% (Zar 1984).

The average minimum detectable rate of change was tabulated on the logarithmic scale and can be converted to a rate of change on the count scale using Figure I1. To do this:

(1) estimate the mean abundance of fish ***per site*** for the reef of interest in the last survey year, see Appendix H (or the mean abundance of fish ***per reef*** for the region of interest, see Appendix F)
(2) find this value on the horizontal axis of Figure I1.
(3) draw a vertical line through this point until it intersects the two isopleths (or the margins of the figure) which bracket the minimal detectable rate of change of the taxa of interest (from Table I1)
(4) draw a horizontal line from each of these points to the left hand vertical axis
(5) the points of intersection on the vertical axis bracket the minimal detectable rate of change in abundance for the reef for interest.

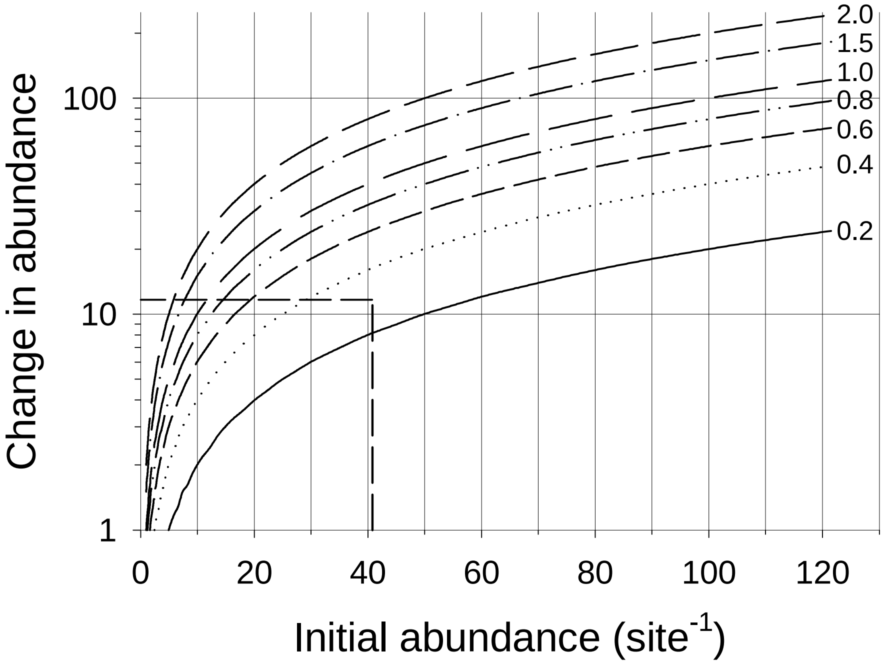


Figure I1: Relationship between mean abundance of fish per site and detectable rate of change in abundance for different values of minimum rate of change (MDD). Note detectable rate of change is given on a log scale. ***Interpretation:*** Drop-line gives an estimate of minimum detectable rate of change for overall trends in abundance of Scaridae at Agincourt No. 1 in the Cairns sector. From Appendix F, mean abundance in 1999 was 123 fish per reef, thus the abundance *per site* was 123/3 = 41 (X axis). From Table I1, average minimum detectable rate of change over five years was 0.30. Using an interpolated MDD curve between those for MDD = 0.2 and MDD =0.4, the estimated minimum detectable rate of change would be a gain or loss of about 13 fish annually (~32%).

Benthic Cover Data

Estimates of coverage for the benthic groups are obtained by point sampling a 50 m transect recorded on videotape. Statistical analysis of these estimates differed from the analysis described for the fish taxa in the following ways:

(1) the response (average percent cover of 5 transects) is transformed using the empirical logit:

$$log\left(\frac{p+cf}{100-p+cf}\right)$$

where p was the average percentage cover for a given benthic group and cf represented the correction factor for zero $\left(cf = \frac{1}{2} * \frac{1}{200} * \frac{1}{15} * 100\right)$ where $\frac{1}{2}$ is the correction factor suggested by McCullagh and Nelder (1989), $\frac{1}{200}$ averages this single point over the number of points sampled for a video transect (200), $\frac{1}{15}$ average this number over the 15 transects and 100 puts this on a percentage scale).

Table I2: Average minimum detectable rate of change (MDD) for percent cover of different taxa of benthic organisms based on means for sites on reefs. MDD over 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to the minimum detectable rate of change at the most recent survey. Note that these values are absolute: they apply to both positive and negative rates of change. These values are used in conjunction with Appendix G and Figure I2, see figure caption.

(1) Taxon	**MDD over 5 years**	**MDD (current)**
(2) Hard Corals	0.18	0.45
Acroporidae	0.32	0.85
Tabulate *Acropora* spp.	0.49	1.28
Other *Acropora* spp.	0.51	1.40
Montipora spp.	0.66	1.86
Faviidae	0.30	0.81
Pocilloporidae	0.40	1.13
Poritidae	0.37	1.14
(3) Soft Corals	0.53	0.73
(4) Algae	0.18	0.53

(2) the statistical model is the same as that used for analysis of trends in abundance of the fish taxa.

(3) for the estimation of power: values of percent cover from Appendix G and MDDs from Table I2 are used in conjunction with Figure I2.

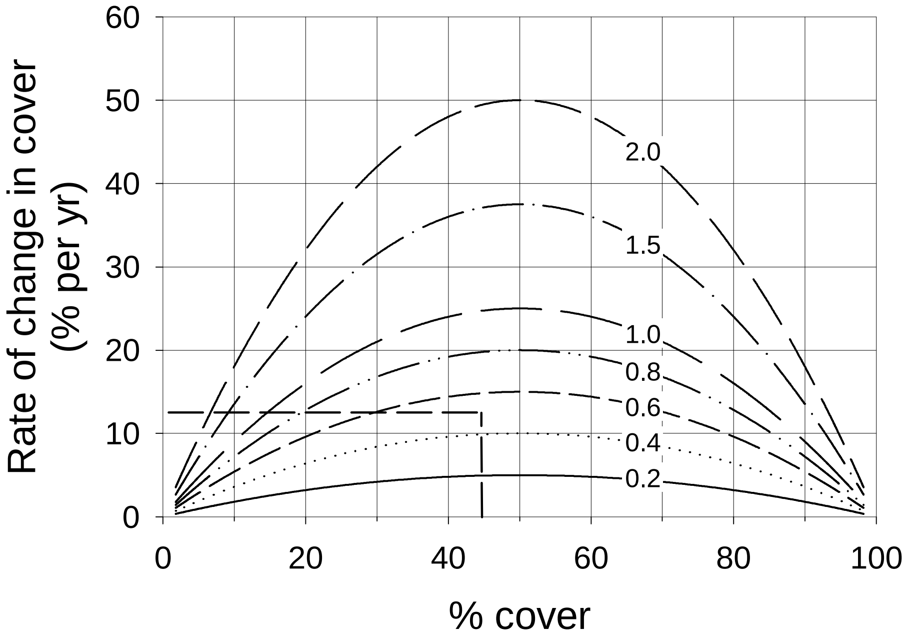


Figure I2: Relationship between cover of benthic taxa per site and detectable rate of change in percent cover for different values of minimum detectable difference (MDD) in rate of change. ***Interpretation:*** Drop-line gives an estimate of minimum detectable rate of change for the current trend in algaes on Hastings Reef (Cairns sector). From Appendix G, mean cover in 1998 was 44.2% (X axis). From Table I2, the average minimum detectable rate of change is 0.53. Using an interpolated MDD curve between those for MDD = 0.4 and MDD = 0.6, the estimated minimum detectable current rate of change would be a gain or loss of about 12% bottom cover annually (27% of the average algal cover).

Table I3: Average minimum detectable rate of change for abundances of different reef fish taxa based on **regional** means for sites on reefs. MDD over 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to the minimum detectable rate of change at the most recent survey. Note that these values are absolute; they apply to both positive and negative rates of change. These values are used in conjunction with Appendix F and Figure K1, see figure caption.

Larger fishes	**MDD over 5 years**	**MDD (current)**	**Damselfishes**	**MDD over 5 years**	**MDD (current)**
Acanthuridae	0.26	0.60	*Acanthochromis*	0.28	0.85
Chaetodontidae	0.20	0.54	*Amblyglyphidodon*	0.22	0.47
Labridae	0.20	0.47	*Chromis*	0.68	1.70
Lethrinidae	0.38	0.98	*Chrysiptera*	0.37	0.95
Lutjanidae	0.33	0.93	*Neoglyphidodon*	0.30	0.66
Scaridae	0.23	0.66	*Neopomacentrus*	0.69	1.85
Serranidae	0.29	0.85	*Plectroglyphidodon*	0.23	0.49
Siganidae	0.30	0.93	*Pomacentrus*	0.18	0.46

Analysis of regional trends [Section 4]

Fish abundance and benthic cover data

The regional analysis for both groups was carried out using the same models from the corresponding reef trend analysis, with the following changes:

(1) reef means were used instead of site means for the benthic cover analysis

(2) reef means of $\ell n(count+1)$ were used instead of $\ell n(count+1)$ for the fish count data covariance structures which were heterogeneous across shelf position were considered.

Table I4: Average minimum detectable rate of change for percent cover of different taxa of benthic organisms based on **regional** means for sites on reefs. MDD over 5 years is the minimum detectable rate of change for the average trend, MDD (current) refers to the minimum detectable rate of change at the most recent survey. Note that these values are absolute: they apply to both positive and negative rates of change. These values are used in conjunction with Appendix E and Figure I2, see figure caption.

(5) Taxon	(6) MDD over 5 years	(7) MDD (current)
Hard Corals	0.19	0.41
Acroporidae	0.29	0.62
Tabulate *Acropora* spp.	0.34	0.78
Other *Acropora* spp.	0.37	0.90
Montipora spp.	0.29	0.90
Faviidae	0.16	0.47
Pocilloporidae	0.33	0.79
Poritidae	0.18	0.56
Soft Corals	0.20	0.49
Algae	0.20	0.52

(3) to estimate power: values for benthic cover or fish abundance are obtained from Appendices E or F and MDDs from Tables I3 or I4 are used in conjunction with Figures I1 or I2.

Broad scale survey data

The broad scale data are visual estimates of the average number of COTS per tow and the average hard coral cover per tow. The analysis of these data was based upon the use of summary statistics to obtain the best estimates of the sector trend. The sector trends were obtained in the following fashion:

(1) for each reef the following quadratic model was fit:

$$y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \varepsilon_i$$

where y_i represents the average coral cover or the $\ell n(average\, COTS\, count + 1)$ on a given reef for year *i*, β_o represents the average response at year Z, β_1 represents the rate of change at year Z, β_2 represents the curvature of the trend, x_i = *survey number* - Z, and ε_i represents the error.

(2) for each reef the response for each year (including the years where observations are missing) was estimated using the model presented in (1).

(3) for each region, the estimate of the average response was obtained by averaging the predicted response for each reef for each year.

(4) finally, the average response was back transformed to the original scale where required.

Statistical computing

The SAS system software (SAS Institute Inc., Cary, NC, USA) was used for all analyses. The MIXED procedure was used to fit the statistical models described for the fish abundance and benthic cover data. The REG procedure was used to obtain the estimates described for the broad scale survey data.