CRC REEF RESEARCH TECHNICAL REPORT

FINE-SCALE SURVEYS OF CROWN-OF-THORNS STARFISH (*ACANTHASTER PLANCI*) IN THE CENTRAL GREAT BARRIER REEF REGION

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

Outbreaks of Crown-of-thorns starfish (COTS) were first observed at Green Island in 1962. People quickly became concerned that this predator had the potential to devastate the Great Barrier Reef. As more outbreaks were reported from other places in the Pacific, it was even suggested that the COTS might drive hard corals to extinction. Questions and controversies arose about almost every aspect of the phenomenon. Were the outbreaks population explosions or aggregations? How many reefs were affects? Were the outbreaks a natural phenomenon or were they caused by human activities?

The most pessimistic predictions did not come true, and the outbreaks of the starfish on the Great Barrier Reef were dissipating by 1977. However, in 1979 the Crown-of-thorns starfish outbreaks returned, once again declining by 1990.

As COTS outbreaks arose and declined over the last thirty years, there was a growing need for detailed studies of the long-term population dynamics of COTS to help us understand the mechanisms underlying the outbreaks. The result of the fine-scale surveys described in this publication go a long way to meeting this goal. Since their initiation in 1994, we have had a far more sensitive tool with which to measure COTS populations than previously. By being able to follow size frequency distributions of COTS with a high level of resolution over space and time, this study has allowed us to predict outbreaks of adult COTS two to three years in advance as counts of juveniles increase.

We still do not know to what extent COTS outbreaks are caused by human activities. However, the detailed understanding of COTS population dynamics that this study gives us may well help scientists develop new hypotheses that will lead to an answer.

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EXECUTIVE SUMMARY

In 1998-99, intensive transect-based surveys of Crown-of-thorns starfish (*Acanthaster planci*) and associated live hard coral cover were conducted on 21 mid-shelf reefs located in the Cairns and Central Sections of the Great Barrier Reef Marine Park.

The following listing is a summary of our key results:

1. We recorded a total of 4,032 *A. planci* on the 21 reefs surveyed. Juvenile starfish (est. age 1) accounted for 2,639 of these with a further 445 individual sub-adults and 948 adult starfish recorded inside the 800 benthic transects sampled. This is the first time in the five-year history of the surveys that juvenile starfish have dominated the sample.

2. *Juvenile starfish (est. age 1):* The average density of juvenile *A. planci* across all reefs surveyed in 1998-99 was estimated at 3.30±0.20 individuals per 250 m^2, which is approximately 13.75 times the previous highest density recorded during the 1995-96 surveys when an average of 0.24±0.02 juveniles was observed across all reefs. Comparable average densities of small crown-of-thorns starfish have, to our knowledge, never before been recorded by any other sampling or monitoring program within the Great Barrier Reef region.

   Highest densities of juvenile *A. planci* were recorded on reefs located in the offshore Port Douglas and Cairns area. Possible Future Spot Outbreaks (FSO) were detected on 9 individual survey reefs (15-070, 15-084, 16-023, 16-024, 16-057, 16-068, 16-071, 17-004 and 17-034). At each of these reefs juvenile densities above the critical threshold of 2.5 individuals per 250 m^2 were found within the exposed front reef zone. At Michaelmas Reef (16-060) both reef zones had juvenile densities above the threshold resulting in its classification as a possible Future reef-wide Outbreak (FO). Future outbreaks are expected to develop on the abovementioned reefs within the next 18-24 months.

   Significant or unsustainably high juvenile densities were found in reef areas both affected and unaffected by recent *A. planci* outbreaks. In areas that had already suffered significant starfish-induced coral mortality over recent years (i.e. remnant live hard coral cover of <10%) we noted an obvious preference of juvenile starfish for feeding on

the smallest most recently recruited hard corals. These observations suggest that this latest starfish cohort has the potential to significantly impact on the onset and progress of the coral recovery phase on previously outbreaking reefs.

3. *Adult starfish (est. age 3 or older)* were significantly more abundant on reefs in the Innisfail to Townsville region compared to adult densities recorded in the more northern regions from offshore Cooktown to offshore Port Douglas and Cairns. Active Spot Outbreaks (ASO) dominated by adult starfish were detected on 9 individual survey reefs (15-024, 15-070, 16-023, 16-071, 17-004, 17-023, 17-034, 17-064 and 18-031). At each of these reefs *A. planci* densities within the protected back reef zone were found to be above the upper limit of a sustainable population. At Eddy Reef (17-047) adult densities exceeded the sustainable threshold in both the back and front reef zones leading to its classification as and Active reef-wide Outbreak (AO).

4. We found significant size-specific patterns of distribution within reefs. Small juvenile starfish were significantly more abundant in exposed front reef zones. Conversely, adult starfish were more common in protected back reef zones. These findings have important implications for future monitoring studies. If the main objective is the early detection of developing outbreaks (*forecasting capability*), then it would appear that considerable effort should go into sampling reef front environments. In contrast, if the main objective is an assessment of past recruitment events on reefs (*hindcasting capability*), then back reef environments may provide a more complete insight into the probable age structure of resident starfish populations.

Our survey results clearly demonstrate the capacity of intensive transect-based surveys to reliably detect the early signs of possible future outbreaks of Crown-of-thorns starfish. The record numbers of small juvenile starfish recorded in 1998-99 provide a strong indication of possible renewed outbreaks likely to develop on many reefs in the Cairns Section of the GBR Marine Park over the next 18 to 24 months. As the identified cohort of small *A. planci* is not only the largest but also the geographically most widespread age class of young starfish recorded on the Great Barrier Reef to date there should be serious concern about their likely future impact on local and regional coral reef communities.

If renewed outbreaks develop within the predicted time frame a second peak in *A. planci* activity would have affected reefs in the central GBR region within the space of only 4 to 5 years. Such a pattern would suggest a possible shift away from the previously observed 15 to 17 year cyclicity of outbreak episodes in this region. A significant shortening of cycle periodicity is likely to be unsustainable in the long term as hard coral communities on affected reefs would have insufficient time for complete recovery and regeneration. Such a scenario could result in an increased number of permanently degraded reef areas unable to recover from an increasingly chronic source of disturbance. As our survey area includes many reefs located directly offshore the Reef tourism centres of Port Douglas and Cairns any such trends could have serious implications for the future operations and sustainability of the regional tourism industry.

Efforts aimed at assessing possible indications of such detrimental trends and conditions should be given a high priority. Intensive fine-scale monitoring of *A. planci* and associated live hard coral cover should not only be continued but extended to maximise the chances of identifying possible signs of further reef degradation and reduced coral recovery rates in the study area in a timely manner.

1. INTRODUCTION

1.1 Background

Twice in the last 35 or so years, major outbreaks of the crown-of-thorns starfish (*Acanthaster planci)* on the Great Barrier Reef (GBR) have apparently originated on reefs in the Cairns Section (14°30'S - 17°52'S) of the Great Barrier Reef Marine Park (GBRMP) (Kenchington 1977, Moran *et al.* 1992). During the two episodes recorded in the 1960's and again in the 1980's, outbreaking populations were first observed on Green Island Reef off Cairns (16°46'S) with a number of surrounding reefs also being affected at about the same time (Moran 1986). However, dedicated surveys of starfish populations were initiated only several years later, when the outbreaks had apparently progressed several hundreds of kilometres from their suggested geographic origin (Dight *et al.* 1990, Moran *et al.* 1992).

Despite a considerable research effort, particularly over the last decade, the ultimate cause(s) of *A. planci* outbreaks on the GBR and elsewhere remain unknown (Engelhardt and Lassig 1997). A lack of data on the dynamics and age structures of *A. planci* populations in particular before, during and after outbreaks has hampered efforts to more fully understand outbreak causality.

Surveys of *A. planci* populations on the GBR and in other parts of the Indo-Pacific region have employed a variety of monitoring techniques, including timed swim searches (Pearson and Endean 1969, Kenchington 1976), spot checks (Pearson 1972), manta tows (Moran *et al.* 1988, Oliver *et. al.* 1995, Sweatman 1997, Sweatman *et. al.* 1998). However, few of these surveys have provided accurate estimates of population densities and age structures (Birkeland and Lucas 1990). Consequently, population field and modelling studies have suffered from the resulting lack of suitable data. Such information is, however, critical for improving our understanding of the possible factors and mechanisms that may be implicated in initiating outbreaks.

Accurately assessing low density populations or populations with substantial numbers of juvenile starfish has posed particular difficulties. Juvenile *A. planci* (<14 cm), because of their cryptic behaviour and nocturnal feeding habits, are not easily sampled and have been rarely seen in the field (Doherty and Davidson 1988, Johnson *et al.* 1991). Consequently, broad-scale survey techniques such as manta towing are considered inadequate to detect the initial stages of an outbreak (Moran and De'ath 1992, Bass and Miller 1995). Ayling and Ayling (1991) showed

that transect-based benthic surveys may be more suitable for accurately censusing low-density populations of the starfish. Benthic belt transects have recently been used on the Great Barrier Reef in an attempt to provide more reliable estimates of population densities and associated age structures (Engelhardt *et. al.* 1997, Mapstone *et. al.* 1998, Mapstone and Ayling 1998). Using an intensive, transect-based methodology the most recent, third recorded outbreak episode, was detected much earlier than previously possible (Engelhardt *et. al.* 1997).

This report presents the results of intensive transect-based surveys of *A. planci* and associated hard coral cover conducted on mid-shelf reefs in the Cairns and Central Sections of the Great Barrier Reef Marine Park (GBRMP) in 1998-99.

1.2 Objectives

Specifically, the surveys' objectives were to:

1. obtain reliable estimates of *A. planci* population densities and associated live hard coral cover on mid-shelf reefs in the survey area;
2. accurately determine size-frequency distributions within *A. planci* populations to facilitate the identification of probable age classes or 'pseudo-cohorts';
3. if present, detect early signs of possible new and emerging outbreaks to provide an early warning of likely future trends; and
4. identify possible differences in the abundance and/or age composition of starfish populations at three different spatial scales - a regional (latitudinal) scale, a between (local) reef scale and a within-reef (zonal) scale.

The implications of our results for future monitoring and research activities are discussed.

2. MATERIALS AND METHODS

2.1 Regional or latitudinal bands

We surveyed 21 mid-shelf reefs across three regional or latitudinal bands with each band covering 1.5 degrees of latitude. The selected latitudinal bands covered the following geographic regions:

Latitudinal band 1	(14°31'-16°00'S)
Latitudinal band 2	(16°01'-17°30'S)
Latitudinal band 3	(17°31'-19°00'S)

2.2 Individual survey reefs

Mid-shelf reefs were selected because modelling of the hydrodynamic characteristics of the central GBR region (latitudes 14°30'-19°30'S) have postulated strong but variable connectivity between mid-shelf reefs (Black and Moran 1991, Bode *et al.* 1992, Burrage *et al.* 1994). In contrast, it has been hypothesised that the inner and outer shelf reefs in this region are hydrodynamically more isolated (Black and Moran 1991, Bode *et al.* 1992), suggesting that they are seldom exposed to competent *A. planci* larvae from upstream sources. Most field data on *A. planci* distribution across the GBR also indicate a propensity of mid-shelf reefs to support larger numbers of starfish than either inner- or outer-shelf reefs (Moran *et al.* 1992, Engelhardt, *unpublished data*).

All mid-shelf reefs surveyed since the inception of the fine-scale surveys in 1994-95 have been selected haphazardly. However, over the past 5 years both logistic and operational considerations have resulted in a number of changes to the original set of 24 survey reefs. Reasons for either having dropped or added individual reefs are as follows:

- Some reefs were dropped due to the local introduction of *A. planci* control programs that potentially modified the natural dynamics and characteristics of the local starfish population;
- Some reefs were dropped to accommodate the staged southward expansion of the survey area. Budget constraints did not allow for the retention of all previously surveyed reefs;
- Some reefs were dropped due to logistic and/or operational difficulties such as highly patchy distribution of suitable continuous reef habitats or exceedingly large size of reef structure with a corresponding need for excessive travel away from the mother ship;
- Some reefs or individual reef zones were not surveyed during certain years due to cyclonic activity in the survey area.

In all instances, the abovementioned program modifications were only implemented following formal discussions with and approval by members of the Crown-of-thorns Starfish Research Committee (COTSREC) - an independent advisory body providing expert advice in relation to the starfish to the Great Barrier Reef Marine Park Authority (GBRMPA). A complete overview of individual reefs surveyed since 1994-95 as part of the GBRMPA/CRC survey program is provided in Appendix A. Relevant details with regards to actual program changes are also provided.

In August 1998, the abolition of two staff positions in the COTS program area at the GBRMPA resulted in a reduction in the total amount of financial support available for the survey program. Furthermore, full responsibility for the operation of the survey program was formally transferred from GBRMPA to the CRC Reef Research Centre prior to the 1998-99 survey season. As a result of these operational changes and financial implications, some reefs had to be dropped from the annual sampling program. However, the one availability of limited carry over funds did allow us to survey two additional reefs (Michaelmas and Moore Reef) located directly offshore Cairns. All reefs surveyed in 1998-99 were located along a mid-shelf trajectory from the Cairns Section in the north to the Central Section of the GBRMP in the south (Figure 1). Individual reefs were surveyed between the months of October 1998 and April 1999.

2.3 Within-reef zones

At each individual survey reef we sampled an equal number of sites and replicate transects within each of two distinct within-reef zones - the protected back reef zone (BR) and the exposed front reef zone (FR). Generally, the exposed front reef zone was defined as reef areas facing more or less directly south-east into the direction of the prevailing winds that affect the Great Barrier Reef region for most of the year. Conversely, the back reef zone comprises those parts of a reef that are largely protected from the south-easterly winds and associated wave action. Both reef zones typically include a more or less continuous and distinct solid reef edge as well as isolated reef outcrops or bommies.

2.4 Sites and replicate transects

At each survey reef, two teams of SCUBA divers were used to independently survey a total of 10 individual sites within each of the two within-reef zones identified. A comprehensive methodological study by Mapstone and Ayling (1998) showed that, for visually assessing the abundance of discrete benthic organisms such as *A. planci*, belt transects measuring 50 x 5 metres often provide the least biased density estimates, particularly within the logistic and

operational constraints of many survey programs. We sampled two replicate 50 x 5 metre (250 m^2) transects at each site. Both site selection and transect placement were haphazard at all times.

Transects were placed at an oblique angle down the available reef substratum from as shallow as possible (typically 1-2 m depth) to a maximum depth of 15 metres. To improve the accuracy of starfish density estimates, observers searched transects intensively as two 2.5 metre wide lanes. Where necessary, the position of marginal individuals relative to the transect was confirmed using a 2.5 metre tape measure placed at right angles to the transect line. Starfish were considered to be within the transect area when a minimum of 50% of their total body surface area was located inside the transect. For each transect the total number and size(s) of all *A. planci* present was recorded. Starfish size was measured as maximum body diameter (central disc plus extended arms) to the nearest centimetre. Accurate size measurements using rulers or tape measures were obtained where starfish were exposed and easily accessible, while sizes were estimated where starfish were partially or totally hidden.

A visual estimate of total live hard coral cover (LHCC) within each transect was recorded. LHCC estimates were recorded as '10%-range estimates', that is coral cover was assigned to a cover category with a 10%-range (i.e. 5-15%, 25-35%, 40-50% etc.) The only exception to this rule was the use of a single 5%-range estimate where LHCC was found to be extremely low and was estimated to be under 5% live cover. For calculating the mean percent cover of live hard coral across individual reef zones and reefs, we used the mid-points of the range estimates obtained (i.e. a value of 10% was used where the range estimate was recorded as 5-15%). The estimation error was set at $\pm$5%. Note that in all cases, the standard error (SE) for calculated visual LHCC estimates was actually less than the 5% margin set here. However, we decided that the more conservative, higher error margin would more accurately reflect the typically spatial variability of most coral reef organisms including hard corals (Mapstone *et. al.* 1998). A complete overview of the survey and sampling design used in 1998-99 is provided in Table 1.

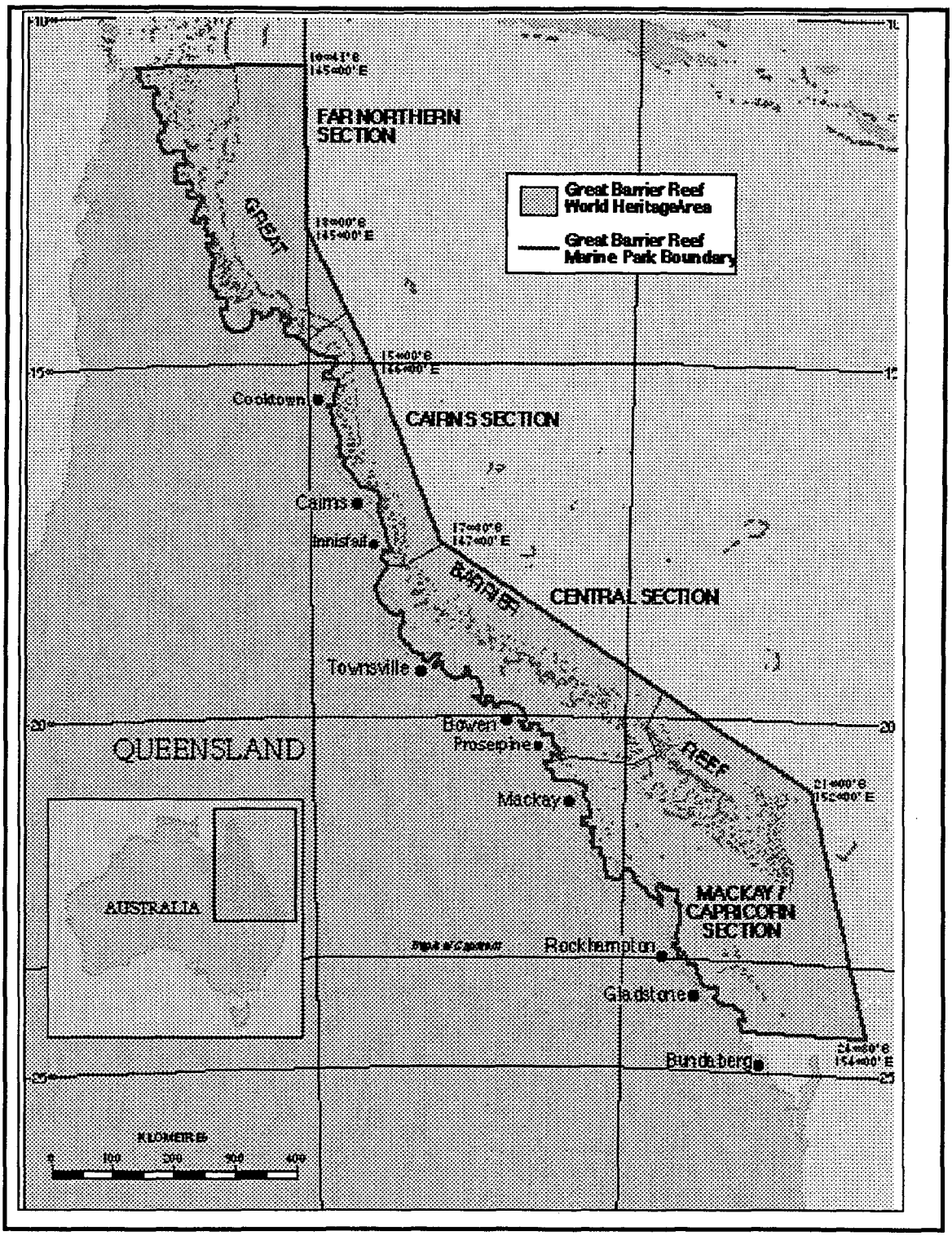


Figure 1: Map of the Great Barrier Reef Marine Park (GBRMP) showing the location of the 1998-99 survey area covering the Cairns Section as well as the northern parts of the Central Section of the Park.

Latitudinal band	Reef ID number [1]	Reef name	Zones per reef	Sites x transects per zone
1 (14°31'-16°00'S)	14-132b	Rocky Islets Reef	BR / FR	10 x 2
	15-109	Long Reef	BR / FR	10 x 2
	15-024	Mackay Reefs	BR / FR	10 x 2
	15-070	Unnamed Reef	BR / FR	10 x 2
	15-084	Irene Reef	BR / FR	10 x 2
	15-095	Evening Reef	BR / FR	10 x 2
2 (16°01'-17°30'S)	16-023	Rudder Reef	BR / FR	10 x 2
	16-024	Unnamed Reef	BR / FR	10 x 2
	16-057	Hastings Reef	BR / FR	10 x 2
	16-060	Michaelmas Reef	BR / FR	10 x 2
	16-068	Thetford Reef	BR / FR	10 x 2
	16-071#	Moore Reef	BR / FR	10 x 2
	17-004	Scott Reef	BR / FR	10 x 2
	17-011*	Coates Reef	BR only*	10 x 2
	17-023*	Cayley Reef	BR only*	10 x 2
3 (17°31'-19°00'S)	17-034	Feather Reef	BR / FR	10 x 2
	17-047	Eddy Reef	BR / FR	10 x 2
	17-064	Taylor Reef	BR / FR	10 x 2
	18-031	Little Kelso Reef	BR / FR	10 x 2
	18-075	John Brewer Reef	BR / FR	10 x 2
	18-078	Lodestone Reef	BR / FR	10 x 2
TOTALS:	**19+2* reefs**		**40 zones**	**400 sites / 800 transects**

[1] *Reef ID numbers as per GBRMPA Reef Gazetteer*

Table 1: Overview of the sampling design used for *A. planci* fine-scale surveys in 1998-99. Reefs marked * indicate that, due to severe weather conditions, only the back reef zone was sampled. Note that in order to achieve a fully balanced sampling design, as required for the non-parametric statistical tests used here, reefs marked * and # were excluded from the full analyses. Reef 16-071 (marked #) was excluded from the full analyses following its random selection from the list of reefs surveyed in latitudinal band 2.

2.5 Estimation of probable age classes of *A. planci*

In the absence of reliable ageing techniques for *A. planci*, probable ages of individual starfish were estimated by fitting size measurements or estimates to a previously constructed probable 'size-at-age' curve for *A. planci* in the central Great Barrier Reef (Figure 2). This curve had been constructed using detailed size-frequency information from more than 3,500 individual starfish recorded and measured during previous surveys (Engelhardt, unpublished data). In line with accepted convention, distinct peaks (modes) apparent in the size-frequency distribution of the target organism, in this case *A. planci,* were deemed to be indicative of probable age classes or 'pseudo-cohorts'. The identified 'pseudo-cohorts' were used again here to assign individual *A. planci* observed in 1998-99 to one of three probable age classes - juvenile starfish (estimated age 1, ≤13 cm), sub-adult starfish (estimated age 2, 14-25 cm) and adult starfish (estimated age 3 or older, ≥26 cm). The broad size/age classes used here correspond well with other published information on probable size and age relationships in *A. planci*. These include natural, *in situ* (Zann *et al.* 1987, 1990, Zann and Vuki 1992) as well as laboratory-based estimates of 'size-at-age' (Yamaguchi 1974, Lucas 1984). Whilst available estimates of juvenile and sub-adult growth show some variability, for example 12-month old starfish may range from approximately 4.5-11.5 cm across, with 24-month old starfish most commonly in the range of 15-24 cm, they do provide a useful tool for assessing recent recruitment history across the area under investigation.

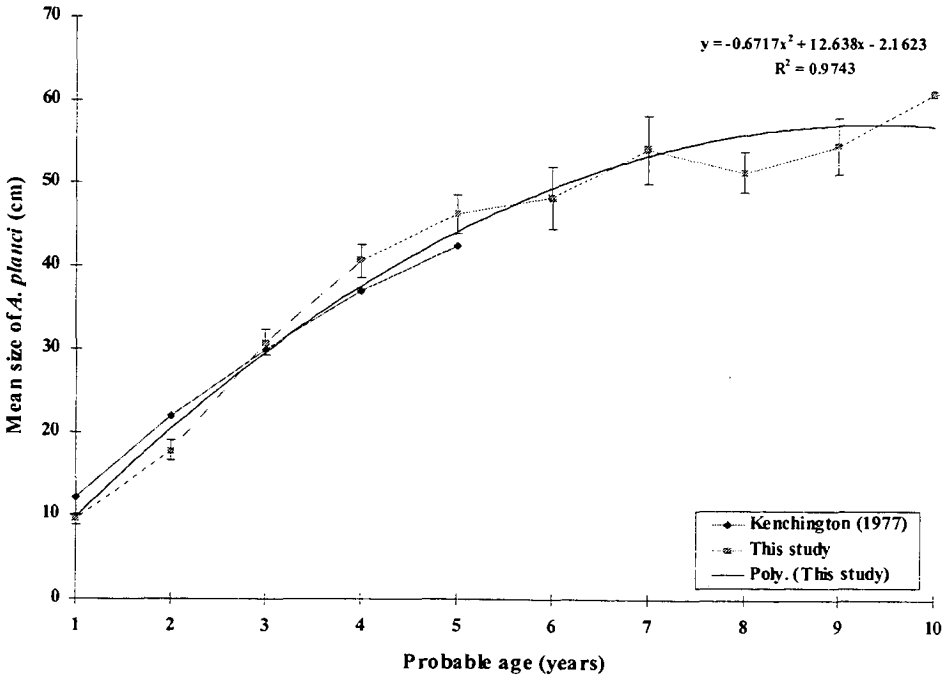


Figure 2: Estimated size-at-age plot for *A. planci* in the central Great Barrier Reef region. Error bars show standard errors (±1 SE.). Note that the term 'Poly.' as shown in the legend refers to the 2nd-order polynomial function used to fit the curve for this study's data set.

2.6 Determination of reef status

Reefs were classified as sustaining actively outbreaking populations of *A. planci* if the mean density (minus 1 standard error SE) of adult starfish was ≥0.75 individuals per 250 m^2 transect. This upper threshold level for a sustainable population density of *A. planci* is based on *in situ* observations and subsequent calculations of *A. planci* feeding rates. Keesing (1990) and Keesing and Lucas (1992) suggested that a density of between 10 and 15 adult *A. planci* per 10,000 m^2 could be sustained in areas with 20-50 % live coral cover (equals a mean adult density of between 0.25 and 0.375 per 250 m^2). The higher threshold of 0.75 individuals per 250 m^2 used in this study is more conservative and takes some additional variables, such as possibly higher coral cover and seasonally reduced feeding rates into account. Determination of individual reef classifications followed a hierarchical principle as summarised in Table 2. Selected data sub-sets were analysed in the exact order shown in Table 2, that is the ADULT sub-set first, the SUB-ADULT AND ADULT set second with the JUVENILE set last.

Data sub-set	**Classification criteria**	**Reef Status Category**
ADULT *A. planci* counts only (≥26 cm max. diameter), back reef **OR** front reef transects only.	**IF** mean density of **ADULT** *A. planci* (minus 1 standard error) **IS** ≥ 0.75 individuals per 250 m^2 in **EITHER** back **OR** front reef zone	**THEN** Active Spot **O**utbreak **ASO (BR) / ASO (FR)** (current outbreak)
ADULT *A. planci* counts only (≥26 cm max. diameter).	**IF** mean density of **ADULT** *A. planci* (minus 1 standard error) **IS** ≥ 0.75 individuals per 250 m^2 in **BOTH** back **AND** front reef zone	**THEN** Active **O**utbreak **AO** (current outbreak)
SUB-ADULT AND ADULT *A. planci* counts combined (≥14 cm max. diameter), back reef **OR** front reef transects only.	**IF** mean density of **SUB-ADULT AND ADULT** *A. planci* combined (minus 1 standard error) **IS** ≥ 0.75 individuals per 250 m^2 in **EITHER** back **OR** front reef zone	**THEN** Incipient Spot **O**utbreak **ISO (BR)** or **ISO (FR)** (within 12-18 months)
SUB-ADULT AND ADULT *A. planci* counts combined (≥14 cm max. diameter).	**IF** mean density of **SUB-ADULT AND ADULT** *A. planci* combined (minus 1 standard error) **IS** ≥ 0.75 individuals per 250 m^2 in **BOTH** back **AND** front reef zone	**THEN** Incipient **O**utbreak **IO** (within 12-18 months)

JUVENILE *A. planci* only (≤13 cm max. diameter), back reef **OR** front reef transects only.	**IF** mean density of **JUVENILE** *A. planci* (minus 1 standard error) **IS** ≥ 2.5 individuals per 250 m^2 in **EITHER** back **OR** front reef zone	**THEN** Future Spot Outbreak **FSO (BR) / FSO (FR)** (within 18-24 months)
JUVENILE *A. planci* only (≤13 cm max. diameter).	**IF** mean density of **JUVENILE** *A. planci* (minus 1 standard error) **IS** ≥ 2.5 individuals per 250 m^2 in **BOTH** back **AND** front reef zone	**THEN** Future Outbreak **FO** (within 18-24 months)
	IF NONE of the above classifications apply to any of the data sub-sets **BUT** the reef has recently (within the last 5 years) been classified as actively outbreaking (**AO / ASO** category assigned)	**THEN** Post Outbreak **PO / PSO(BR/FR)** respectively
	IF NONE of the above classifications apply to any of the above data sub-sets **AND** the reef has **NOT** recently (within the last 5 years) been classified as actively outbreaking	**THEN** Non-Outbreaking **NO**

Table 2: Reef status classification scheme - overview of data sub-sets and criteria used to determine the status of individual within reef zones and reefs surveyed in 1998-99.

The threshold value of 2.5 (mean-1 SE.) individual juvenile *A. planci* per 250 m^2 used to define possible Future spot and reef-wide outbreaks (FSO/FO respectively) is based on relevant observations made over recent survey seasons. In a number of instances, average juvenile densities of approximately 1.25 individuals per transect have provided a reliable early indication of new and emerging outbreaks (Engelhardt, *unpublished data*). However, we decided to use a more conservative average figure of 2.5 juveniles per transect before assigning the Future Outbreak classification to any of the reefs surveyed in 1998-99. Throughout the report we refer to juvenile densities of between 1.25 and 2.5 (mean-1 SE) individual juvenile *A. planci* per 250 m^2 as *'significant'* densities, with estimates above the critical threshold of 2.5 (mean-1 SE) individual juvenile *A. planci* being referred to as *'unsustainably high'* densities.

2.7 Statistical analyses

Data for individual reefs and within-reef zones were first analysed using simple descriptive statistics. Results of these analyses are shown graphically in Figure 3.

Non-parametric Kruskal-Wallis tests (Kruskal and Wallis 1952) were used to investigate possible differences in the abundance of individual 'pseudo-cohorts' of *A. planci* across the three selected spatial scales. Non-parametric tests were required because starfish count data were mostly non-normally distributed. As a result of substantial numbers of individual 'zero' counts, commonly advocated data transformations did not achieve acceptable levels of 'normality' to allow for the use of standard parametric ANOVA techniques. Instead we used Kruskal-Wallis analyses of variance by rank procedures to test for significant differences between sample medians. The Kruskal-Wallis test tests the null hypothesis that the medians of the selected variable within each of the selected levels are the same. The data from all the levels is first combined and ranked from smallest to largest. The average rank is then computed for the data at each individual level. Where the P-value is less than 0.05, there is a statistically significant difference amongst the medians at the 95.0% confidence level. Box-and-Whisker plots shown throughout this report are to be interpreted as follows. The rectangular part of the plot extends from the lower quartile to the upper quartile, covering the centre half of each sample. The centre lines within each box show the location of the sample medians. The plus (+) signs indicate the location of the sample means. The whiskers extend from the box to the minimum and maximum values in the sample. Also shown on the plots are notches covering a distance above and below each median. To determine which medians are significantly different from which others, we used the position of these median notches. If the two notches for any pair of medians do not overlap, there is a statistically significant difference between the medians at the 95% confidence level.

3. RESULTS

3.1 The distribution and abundance of estimated age classes of *A. planci* in 1998-99

Overview of results

We recorded a total of 4,032 *A. planci* on the 21 reefs surveyed. Juvenile starfish (est. age 1) accounted for 2,639 of these with a further 445 individual sub-adults and 948 adult starfish recorded inside the 800 benthic transects sampled in 1998-99.

Adult *A. planci* (est. age 3 and older): Densities of adult starfish on individual survey reefs ranged from 0.00±0.00 (reef mean ± 1 SE.) individuals per 250 m^2 at Coates Reef (17-011) to 6.75±1.86 individuals at Eddy Reef (17-047) - approximately 9 times what is considered to be a sustainable density. The average density of adult *A. planci* across all reefs surveyed in 1998-99 was estimated at 1.19±0.12 individuals per 250 m^2.

Active Spot Outbreaks (ASO) were detected on 9 individual survey reefs (15-024, 15-070, 16-023, 16-071, 17-004, 17-023, 17-034, 17-064 and 18-031). At each of these reefs *A. planci* densities within the protected back reef zone were found to be above the upper limit of a sustainable population. At Eddy Reef (17-047) adult densities exceeded the sustainable threshold of 0.75 individuals per 250 m^2 in both reef zones leading to its classification as an Active reef-wide Outbreak (AO). Details of adult starfish densities for individual reefs and zones within reefs are presented in Tables 3.1 to 3.21.

Sub-adult *A. planci* (est. age 2): Densities of sub-adult starfish on individual survey reefs ranged from 0.00±0.00 (reef mean ± 1 SE.) individuals per 250 m^2 at Coates Reef (17-011) to 1.30±0.32 individuals at Eddy Reef (17-047). The average density of sub-adult *A. planci* across all reefs surveyed in 1998-99 was estimated at 0.56±0.04 individuals per 250 m^2. An Incipient Spot Outbreak (ISO) was detected at the exposed front reef zone at Long Reef (15-019). This zone is expected to develop into an active spot outbreak within the next 12 to 18 months. Details of sub-adult starfish densities for individual reefs and zones within reefs are presented in Tables 3.1 to 3.21.

Juvenile *A. planci* (est. age 1): Densities of juvenile starfish on individual survey reefs ranged from 0.45±0.21 (reef mean ± 1 SE.) individuals per 250 m^2 at Long Reef (15-019) to 9.13±1.48 individuals at Michaelmas Reef (16-060). The average density of juvenile *A. planci* across all

reefs surveyed in 1998-99 was estimated at 3.30±0.20 individuals per 250 m^2, which is approximately 13.75 times the previous highest density recorded during the 1995-96 surveys when an average of 0.24±0.02 juveniles was observed across all reefs.

Possible Future Spot Outbreaks (FSO) were detected on 9 individual survey reefs (15-070, 15-084, 16-023, 16-024, 16-057, 16-068, 16-071, 17-004 and 17-034). At each of these reefs juvenile densities above the critical threshold of 2.5 individuals per 250 m^2 were found within the exposed front reef zone. At Michaelmas Reef (16-060) both reef zones had juvenile densities above the threshold resulting in its classification as a possible Future reef-wide Outbreak (FO). Identified possible spot and/or reef-wide outbreaks may develop on the abovementioned reefs within the next 18-24 months. Details of juvenile starfish densities for individual reefs and zones within reefs are presented in Tables 3.1 to 3.21.

3.2 Summaries of survey results for individual reefs

The following section (Figure 3) provides a detailed summary of the results of the 1998-99 fine-scale surveys for individual reefs. In addition to size-frequency information, we provide estimates of average densities for estimated age classes of *A. planci* both across reefs and within individual reef zones. To assist in the interpretation of recent trends in both adult starfish densities and associated live hard coral cover we show relevant time series data collected since the initiation of the survey program in 1994-95. Where reefs or zones within reefs had not been surveyed in a particular year the initials 'NS' (Not Surveyed) are shown.

Note that visual estimates of Live Hard Coral Cover (LHCC) have only been recorded since the 1995-96 survey season. Mean LHCC estimates for 1995-96 were derived from 20%-range estimates (i.e. mid-point ± 10% set error margin). However, since 1996-97 all LHCC estimates have been recorded using higher resolution 10%-range estimates as outlined in this report's methodology section.

Aerial photographs of individual survey reefs show the locations of all sites sampled in 1998-99. Photographs are shown with permission of the GBRMPA and are covered by a formal use agreement. All reef images are oriented along a North-South axis with the top margin pointing due north. Due to the fact that the available imagery came from a variety of photographic scans of unknown magnification we were unable to provide accurate scale bars for inclusion on individual reef images.

Figure 3: Summary of results for individual mid-shelf reefs surveyed in 1998-99

Figure 3.1: Rocky Islets Reef (b) (14-132b)

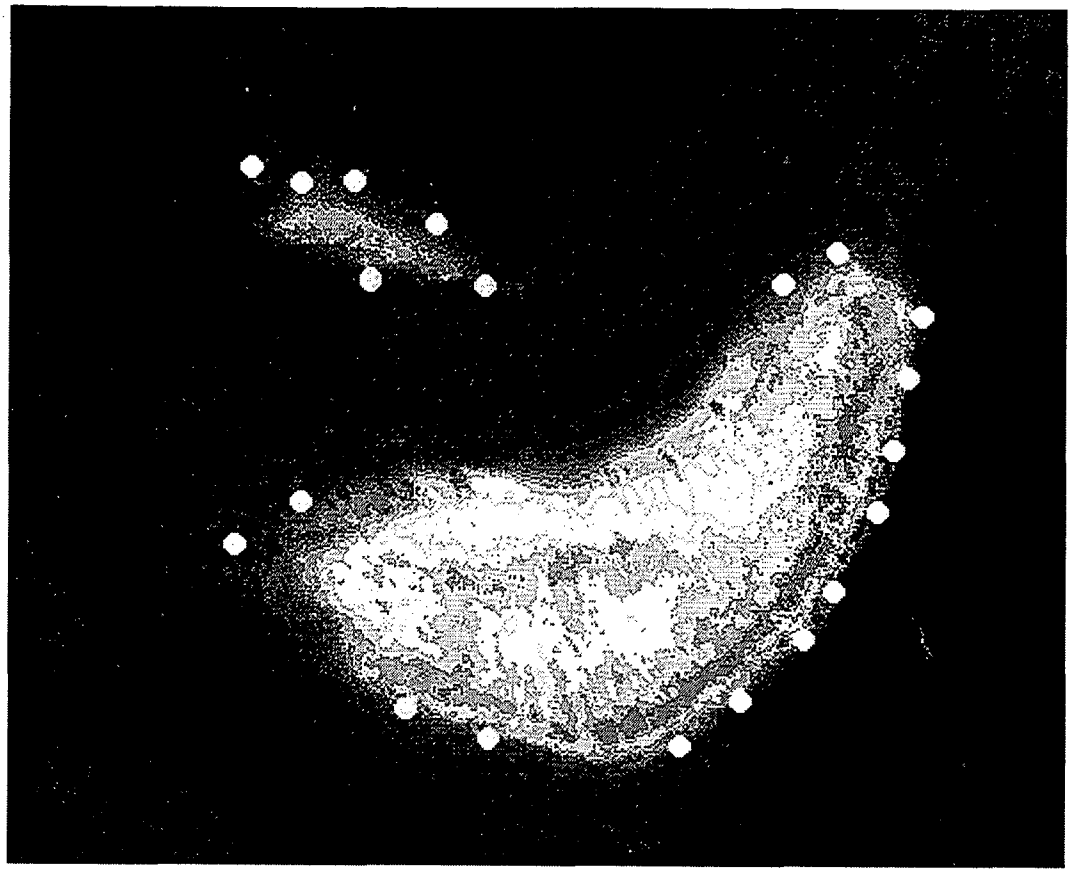


Figure 3.1.1: Aerial photograph of Rocky Islets Reef (b) (14-132b) with white dots indicating the approximate locations of the 20 sites surveyed in October 1998.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	IO	AO	AO	AO
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.25±0.10 (5)	0.30±0.15 (6)	0.00±0.00 (0)	PO
Front Reef (FR)	2.55±1.00 (51)	0.45±0.14 (9)	0.05±0.05 (1)	PO
Entire Reef (R = BR & FR)	1.40±0.53 (56)	0.38±0.10 (15)	0.03±0.03 (1)	PO

Table 3.1 (A-B): Summary of reef status classifications for Reef 14-132b since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

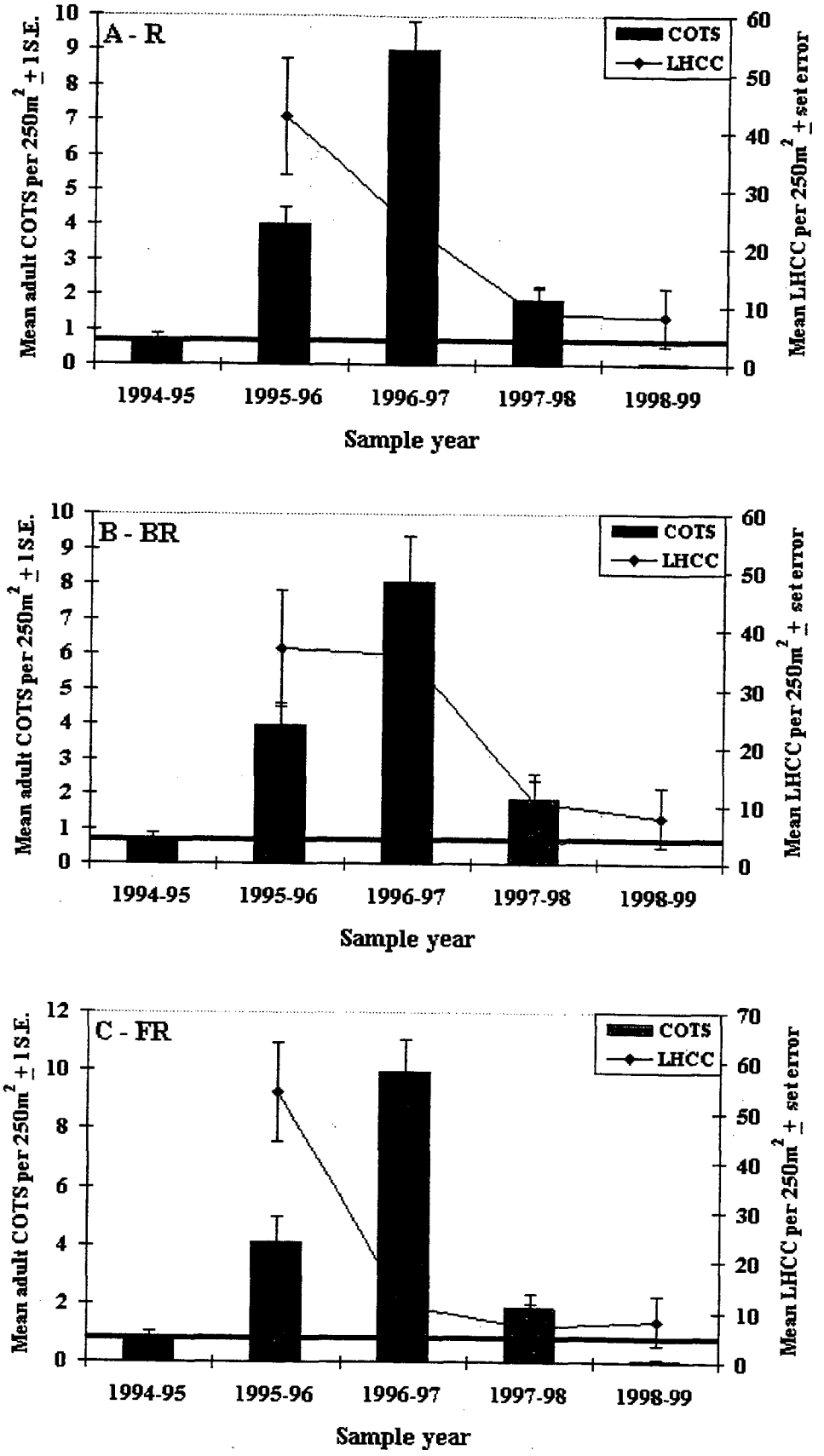


Figure 3.1.2 (A-C): Reef 14-132b - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

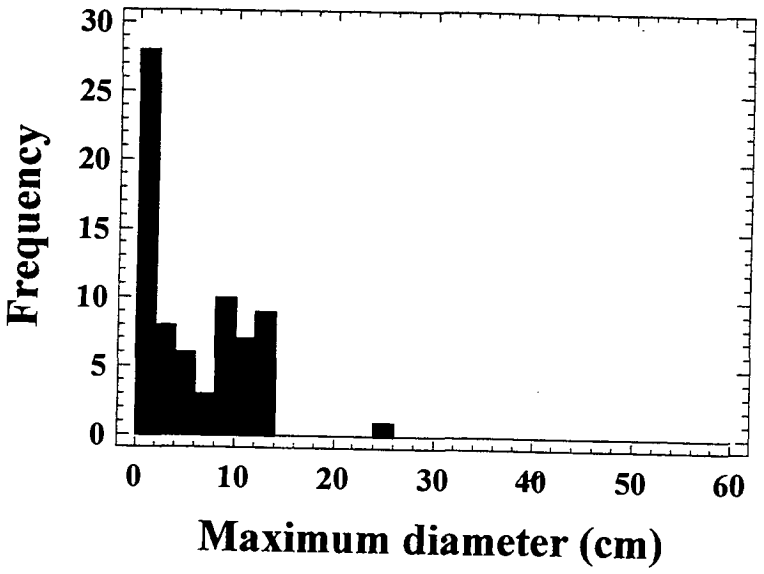


Figure 3.1.3: Size-frequency plot of *A. planci* observed at Reef 14-132b in October 1998.

Summary

Rocky Islets Reef (14-132b) was classified as an Incipient Outbreak (IO) when first surveyed in 1994-95. As predicted, an Active Outbreak (AO) developed on this reef within 12 months following the initial survey. Starfish populations remained at outbreaking densities for the following three years during which live hard coral cover (LHCC) declined from an average of around 40% cover to the current level of less than 10% live cover. Following the severe reduction in LHCC, adult starfish populations had collapsed by 1998-99. However, significant densities of juvenile *A. planci* were recorded in 1998-99 suggesting a possible renewed increase in starfish numbers in the near future. Juveniles observed this season were found feeding on remnant as well as recently recruited hard corals suggesting the possibility of a further reduction in hard coral cover.

Figure 3.2: Long Reef (15-019)

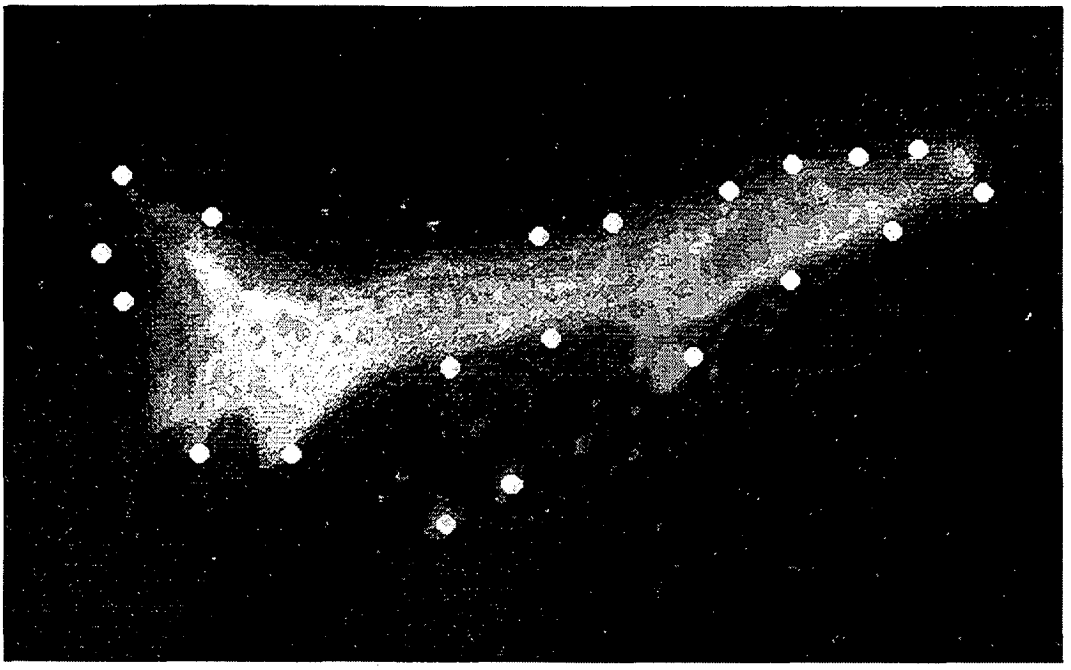
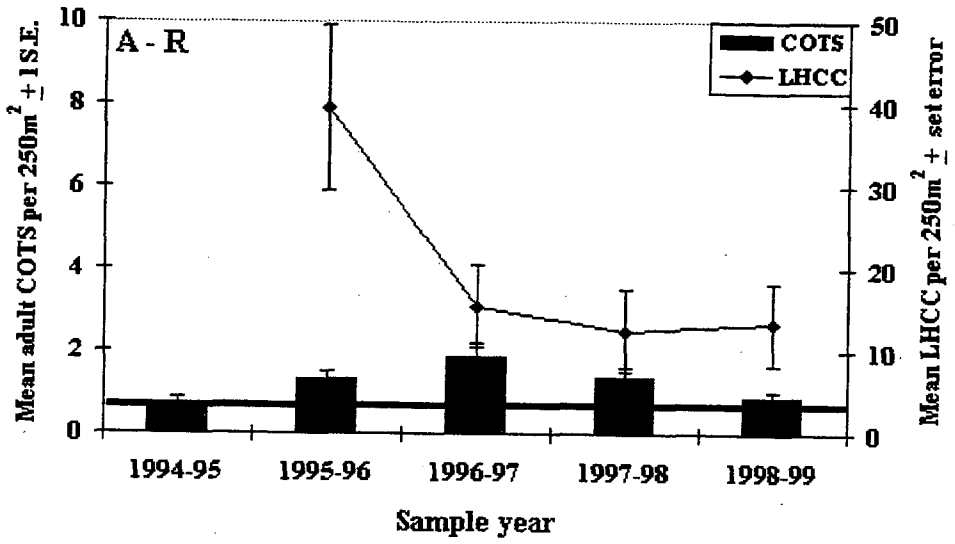
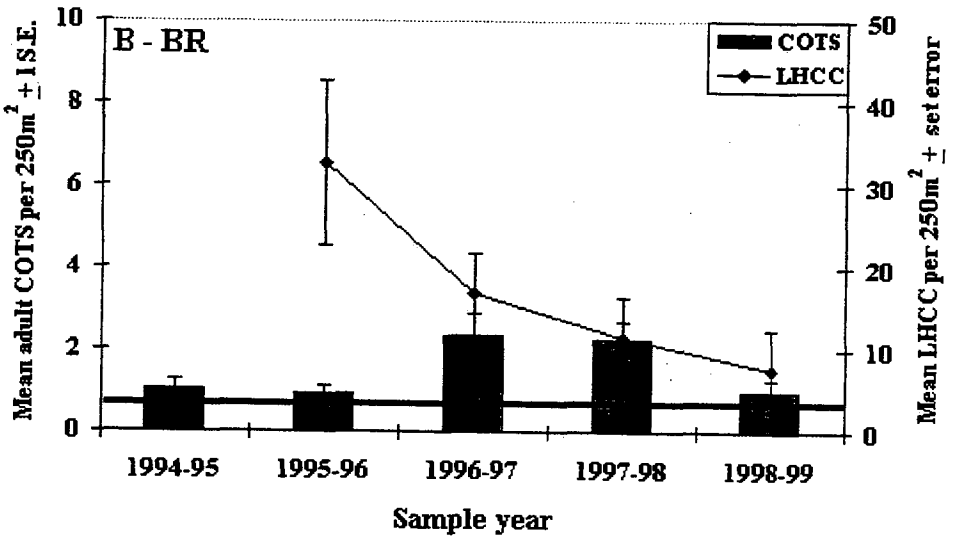


Figure 3.2.1: Aerial photograph of Long Reef (15-019) with white dots indicating the approximate locations of the 20 sites surveyed in October 1998.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	ASO(BR)	AO	AO	ASO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.25±0.14 (5)	0.25±0.10 (5)	1.00±0.28 (20)	PO
Front Reef (FR)	0.65±0.40 (13)	1.50±0.51 (30)	0.75±0.18 (15)	ISO
Entire Reef (R = BR & FR)	0.45±0.21 (18)	0.88±0.27 (35)	0.88±0.16 (35)	PO(BR) ISO(FR)

Table 3.2 (A-B): Summary of reef status classifications for Reef 15-019 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





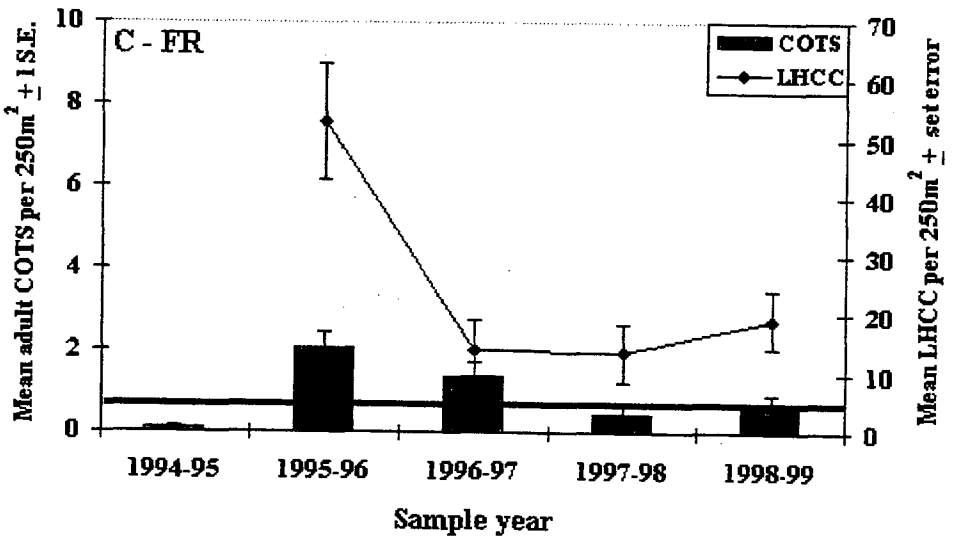


Figure 3.2.2 (A-C): Reef 15-019 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

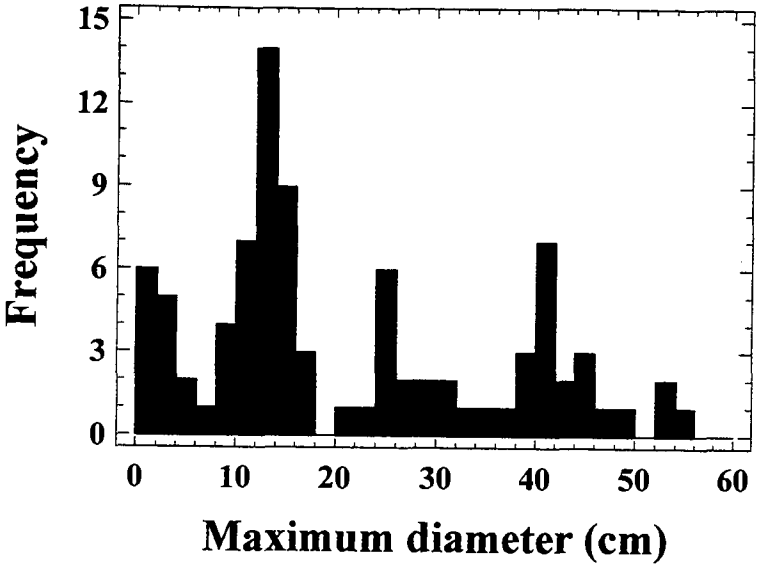


Figure 3.2.3: Size-frequency plot of *A. planci* observed at Reef 15-019 in October 1998.

Summary

An Active Spot Outbreak (ASO) was discovered in the back reef zone at Long Reef (15-019) when first surveyed in 1994-95. By 1995-96 an Active reef-wide Outbreak (AO) had developed. Starfish populations remained at outbreaking densities for the following three years during which live hard coral cover (LHCC) declined from an average of around 40% cover to the current level of between 10 and 15% live cover. Following the significant reduction in LHCC, adult starfish populations had substantially declined by 1998-99. However, both sub-adult and juvenile *A. planci* were recorded in 1998-99 suggesting a possible renewed increase in starfish numbers in the near future. Our surveys indicate that the front reef zone is likely to develop a renewed spot outbreak within the near future. Sub-adult and juvenile starfish observed this season were found feeding on remnant as well as recently recruited hard corals suggesting the possibility of a further reduction in hard coral cover.

Figure 3.3: Mackay Reefs (15-024)

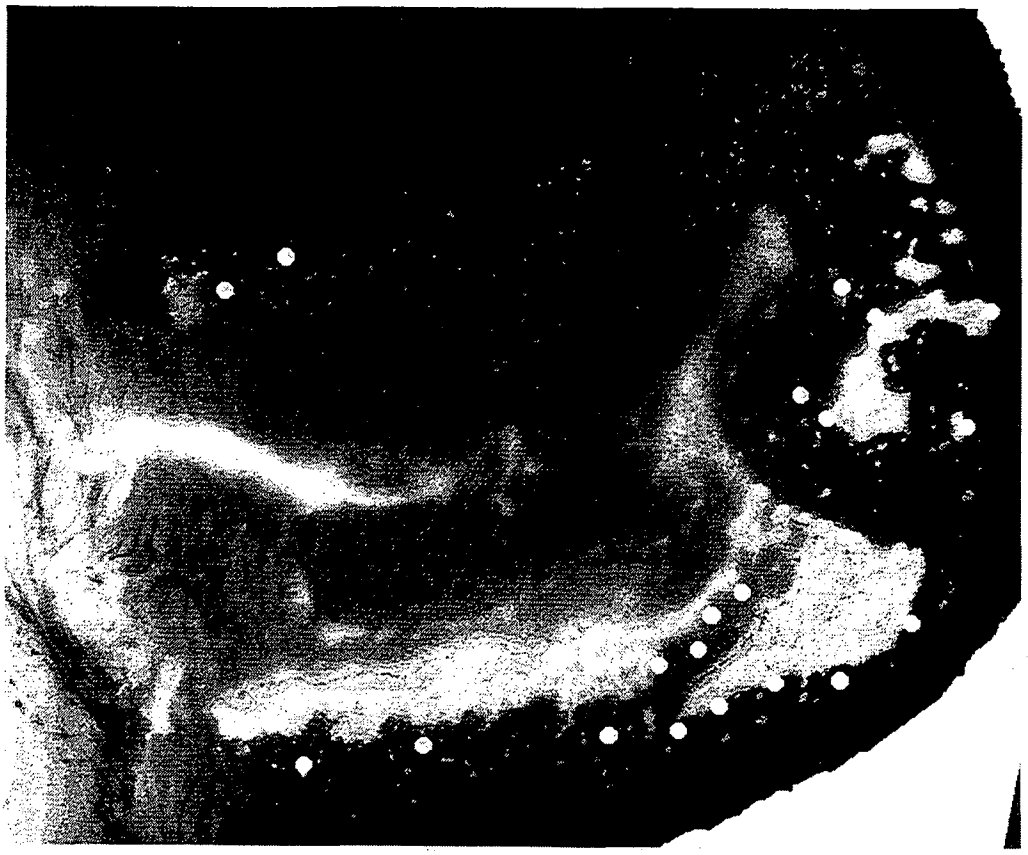


Figure 3.3.1: Aerial photograph of Mackay Reefs (15-024) with white dots indicating the approximate locations of the 20 sites surveyed in October 1998.

A - Sample year	**1994-95**	**1995-96**	**1996-97**	**1997-98**
Reef status	ASO(BR)	AO	AO	AO
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.60±0.27 (12)	0.75±0.36 (15)	1.15±0.29 (23)	ASO
Front Reef (FR)	1.10±0.35 (22)	0.35±0.11 (7)	0.40±0.17 (8)	PO
Entire Reef (R = BR & FR)	0.85±0.22 (34)	0.55±0.19 (22)	0.78±0.18 (31)	ASO(BR) PO(FR)

Table 3.3 (A-B): Summary of reef status classifications for Reef 15-024 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

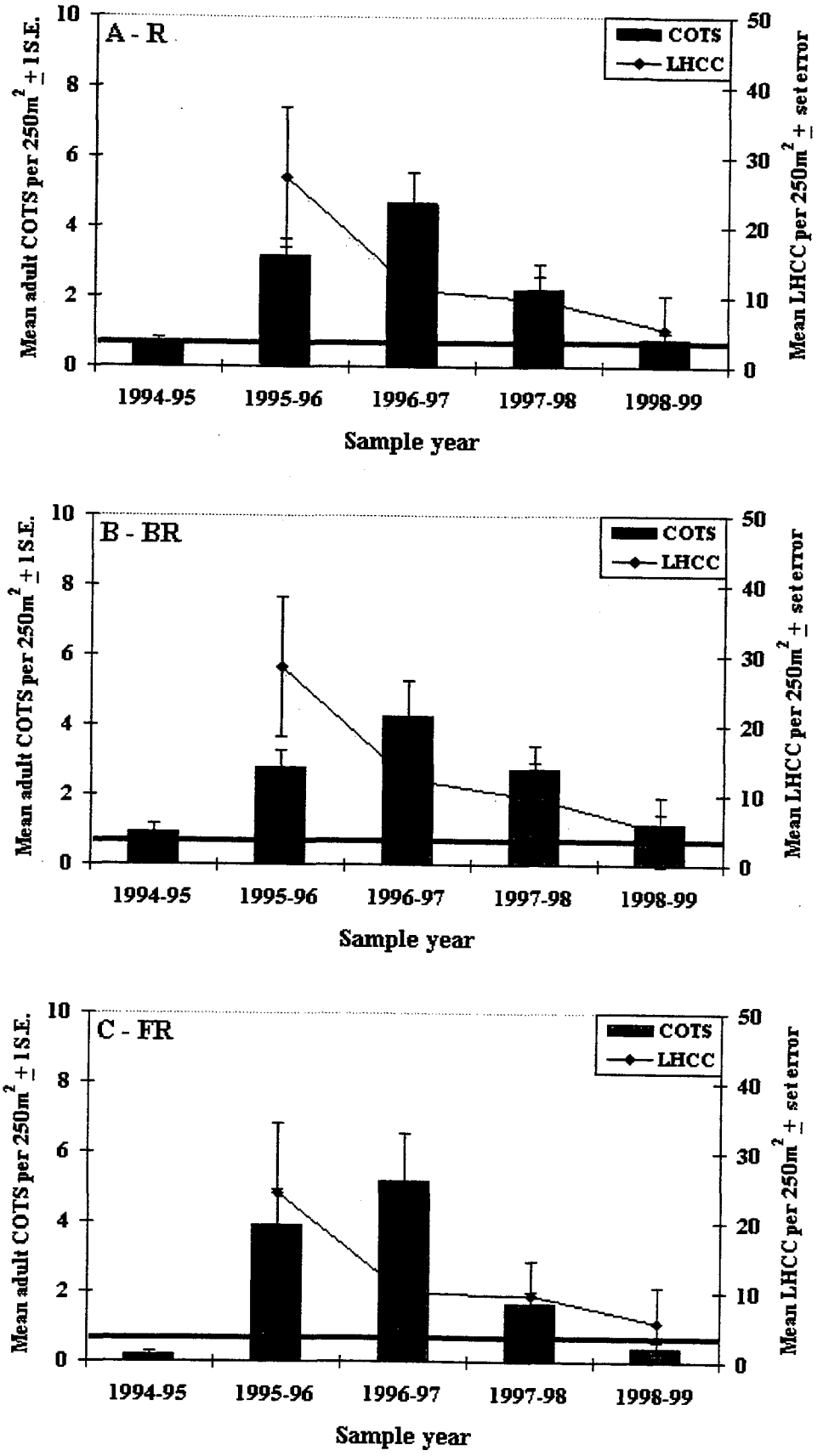


Figure 3.3.2 (A-C): Reef 15-024 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

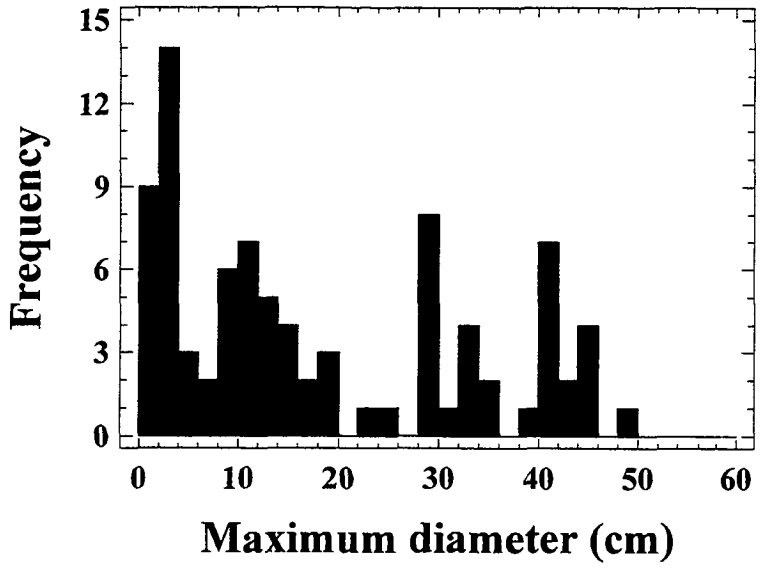


Figure 3.3.3: Size-frequency plot of *A. planci* observed at Reef 15-024 in October 1998.

Summary

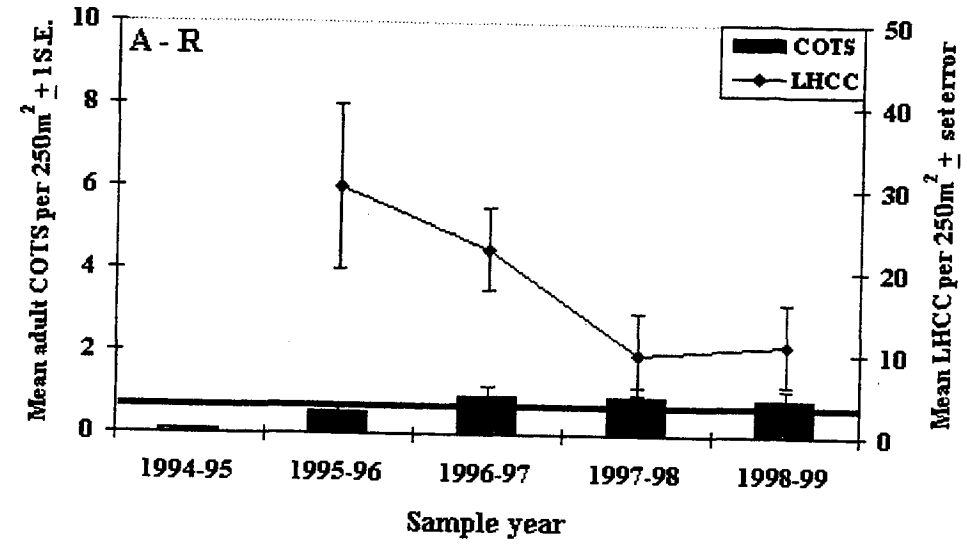
The back reef zone at Mackay Reefs (15-024) was classified as an Incipient Spot Outbreak (ISO) when first surveyed in 1994-95. A reef-wide Active Outbreak (AO) developed on this reef within 12 months following the initial survey. Starfish populations remained at outbreaking densities for the following three years during which live hard coral cover (LHCC) declined from an average of 25-30% cover to the current level of around 5% live cover. Following the severe reduction in LHCC, adult starfish populations had somewhat declined by 1998-99. However, the back reef zone continues to support an above sustainable population of starfish. This remnant population, in combination with juvenile *A. planci* also recorded in 1998-99, suggests the possibility of a further reduction in hard coral cover in the near future.

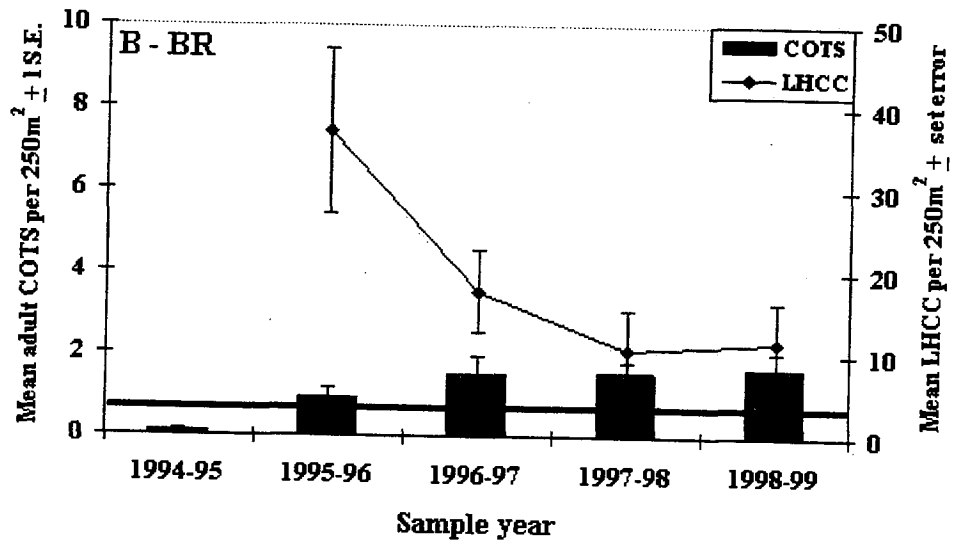
Figure 3.4: Unnamed Reef (15-070)

Figure 3.4.1: Aerial photograph of Unnamed Reef (15-070) with white dots indicating the approximate locations of the 20 sites surveyed in November 1998.

A - Sample year	**1994-95**	**1995-96**	**1996-97**	**1997-98**
Reef status	NO	ASO(BR) ISO(FR)	ASO(BR)	ASO(BR)
B - 1998-99 **Sample area**	**Juveniles** **(est. age 1)**	**Sub-adults** **(est. age 2)**	**Adults (est.** **age 3 or older)**	**Reef status** **1998-99**
Back Reef **(BR)**	0.50±0.20 (10)	0.85±0.35 (17)	1.65±0.39 (33)	ASO
Front Reef **(FR)**	3.65±0.99 (73)	0.60±0.20 (12)	0.10±0.07 (2)	FSO
Entire Reef **(R = BR & FR)**	2.08±0.56 (83)	0.73±0.20 (29)	0.88±0.23 (35)	ASO(BR) FSO(FR)

Table 3.4 (A-B): Summary of reef status classifications for Reef 15-070 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





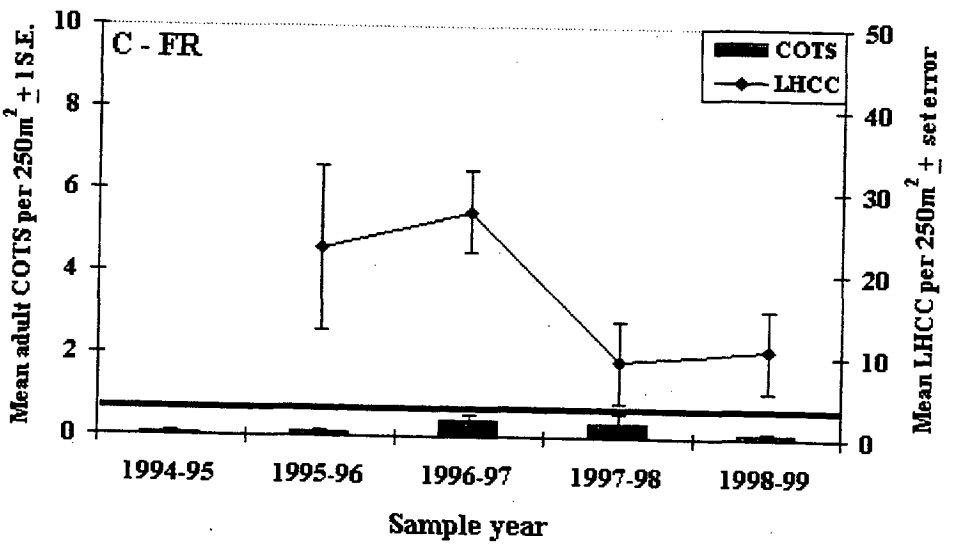


Figure 3.4.2 (A-C): Reef 15-070 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

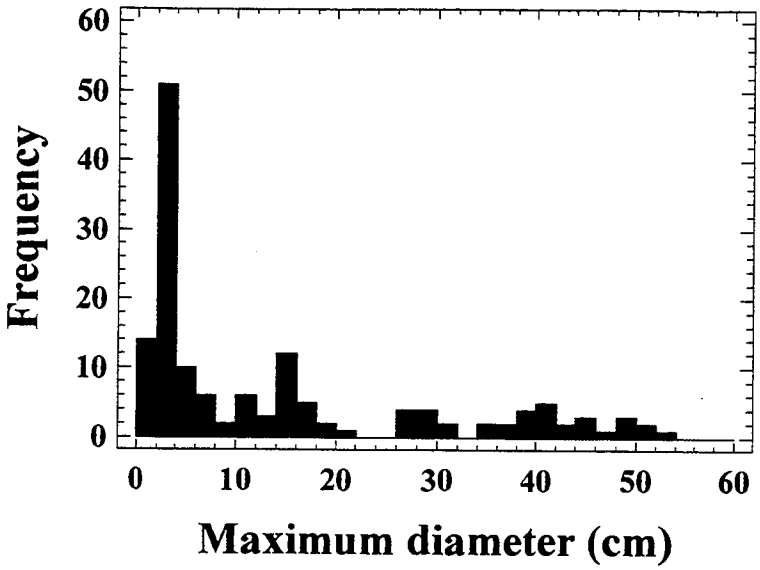


Figure 3.4.3: Size-frequency plot of *A. planci* observed at Reef 15-070 in November 1998.

Summary

The first Active Spot Outbreak (ASO) at Unnamed Reef (15-070) was detected in the reef's back reef zone in 1995-96. Starfish populations in this zone have remained at outbreaking densities since that time. Consequently, live hard coral cover (LHCC) in the back reef zone has declined from an average of around 35% cover to the current level of between 10-15% live cover. Unsustainably high densities of juvenile *A. planci* recorded in 1998-99 suggest the possibility of renewed increases in starfish numbers in the near future, with the exposed front reef zone being the area most likely to be affected by this latest cohort. However, a further reduction in live hard coral cover is also likely in the back reef zone where numbers of adult starfish continue to remain above sustainable levels.

Figure 3.5: Irene Reef (15-084)

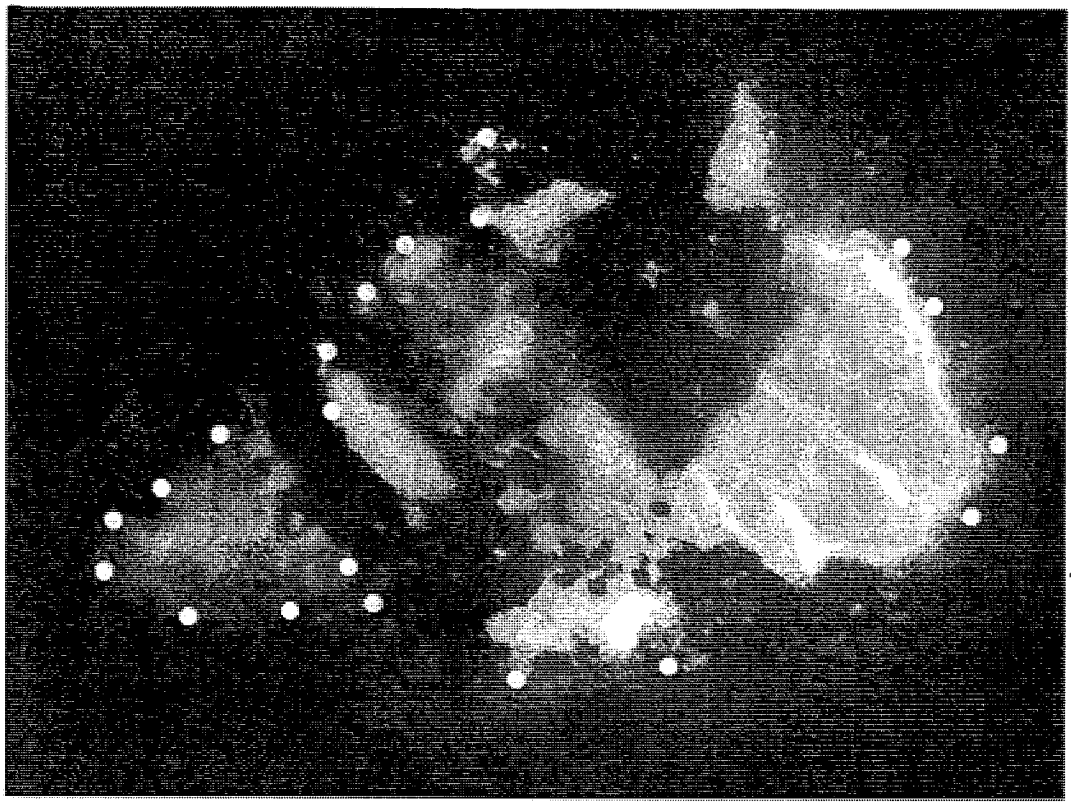


Figure 3.5.1: Aerial photograph of Irene Reef (15-084) with white dots indicating the approximate locations of the 20 sites surveyed in November 1998.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	ASO(BR)	ASO(BR) ISO(FR)	ASO(BR)	ASO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	1.35±0.63 (27)	1.00±0.35 (20)	0.95±0.23 (19)	PO
Front Reef (FR)	3.70±1.13 (74)	0.55±0.11 (11)	0.40±0.17 (8)	FSO
Entire Reef (R = BR & FR)	2.53±0.67 (101)	0.78±0.18 (31)	0.68±0.15 (27)	PO(BR) FSO(FR)

Table 3.5 (A-B): Summary of reef status classifications for Reef 15-084 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

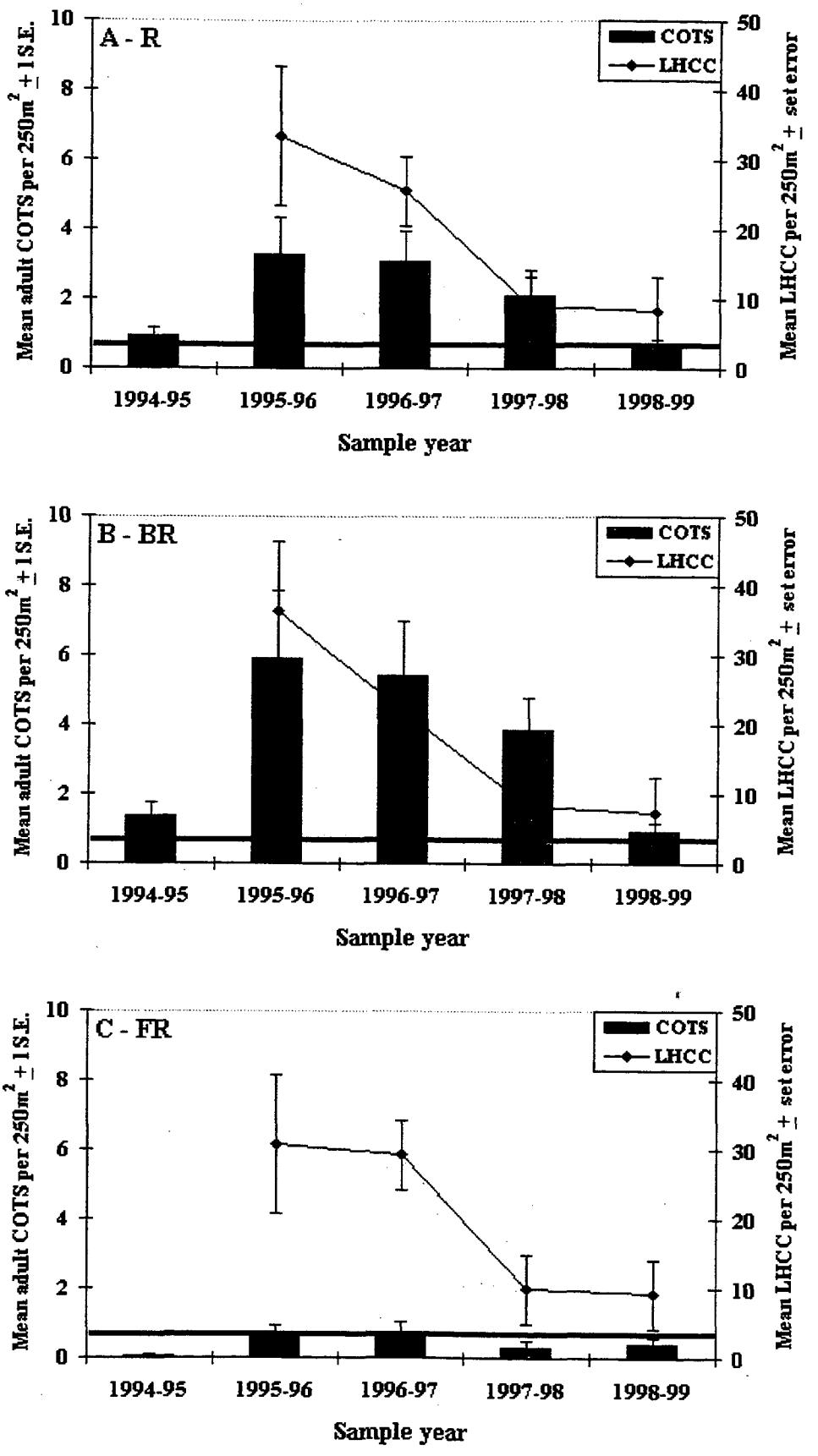


Figure 3.5.2 (A-C): Reef 15-084 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

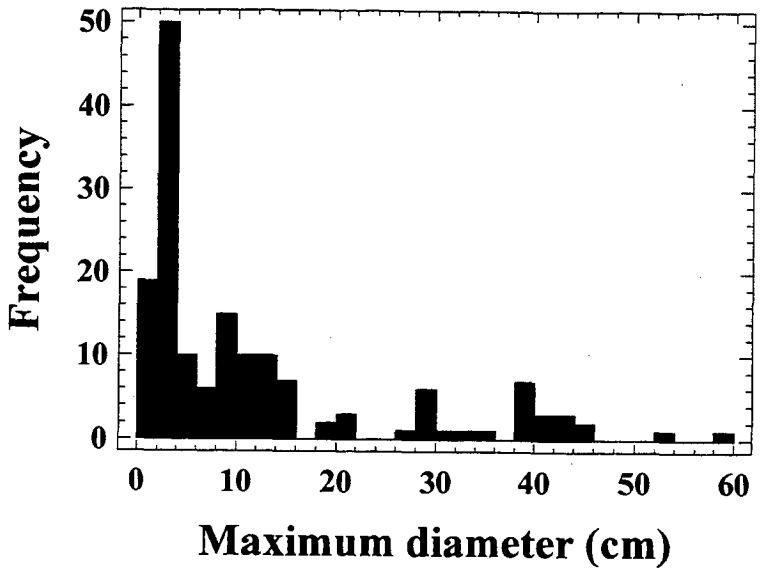


Figure 3.5.3: Size-frequency plot of *A. planci* observed at Reef 15-084 in November 1998.

Summary

The Active Spot Outbreak (ASO) first discovered in the back reef zone at Irene Reef (15-084) in 1994-95 remained at outbreaking densities for four consecutive years. As a result, live hard coral cover (LHCC) in the back reef zone has declined from an average of 35-40% cover to the current level of less than 10% live cover. By 1998-99, the adult starfish population on this reef had also declined markedly. However, the existence of this remnant population combined with unsustainably high densities of juvenile *A. planci* recorded in 1998-99 suggests the possibility of renewed increases in starfish numbers in the near future, with the exposed front reef zone being the area most likely to be affected by this latest cohort. A further reduction in live hard coral cover is also likely in the back reef zone where numbers of adult starfish still remain close to unsustainably high levels.

Figure 3.6: Evening Reef (15-095)

Figure 3.6.1: Aerial photograph of Evening Reef (15-095) with white dots indicating the approximate locations of the 20 sites surveyed in November 1998.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	ASO(BR)	ASO(BR) ISO(FR)	ASO(BR)	PO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.20±0.12 (4)	0.20±0.09 (4)	0.45±0.20 (9)	PO
Front Reef (FR)	1.50±0.34 (30)	0.65±0.22 (13)	0.00±0.00 (0)	NO
Entire Reef (R = BR & FR)	0.85±0.20 (34)	0.43±0.12 (17)	0.23±0.10 (9)	PO(BR) NO(FR)

Table 3.6 (A-B): Summary of reef status classifications for Reef 15-095 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

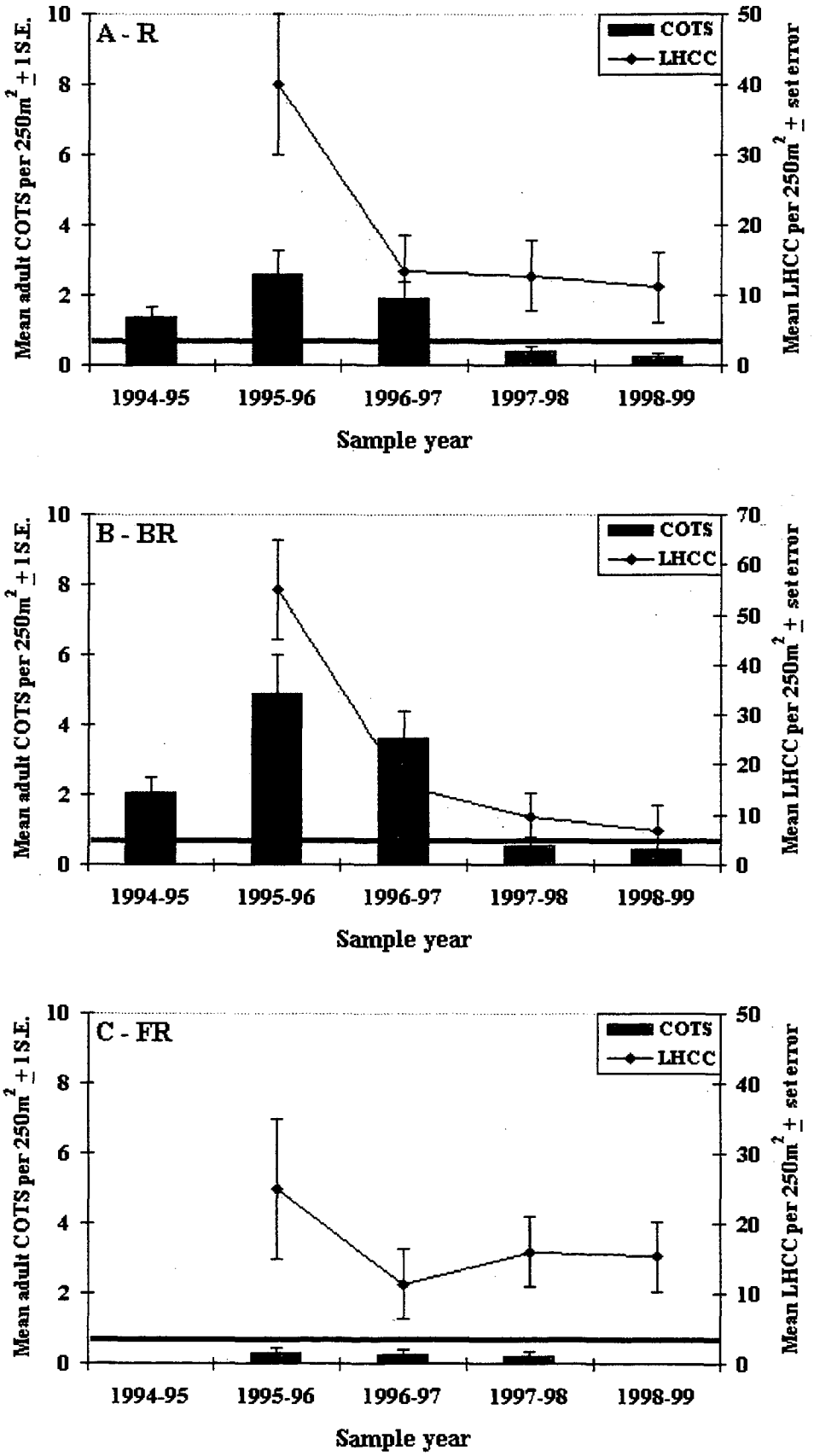


Figure 3.6.2 (A-C): Reef 15-095 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

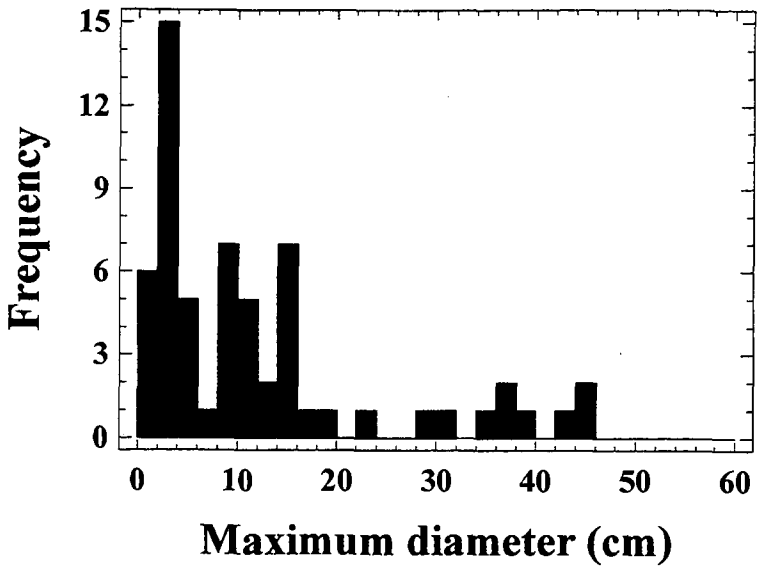


Figure 3.6.3: Size-frequency plot of *A. planci* observed at Reef 15-095 in November 1998.

Summary

The Active Spot Outbreak (ASO) first discovered in the back reef zone at Evening Reef (15-095) in 1994-95 remained at outbreaking densities for three consecutive years. As a result, live hard coral cover (LHCC) in the back reef zone declined from an average of 50-60% cover to the current level of less than 10% live cover. As a consequence of the major reduction in LHCC the adult starfish population on this reef declined markedly in 1997-98. Hard coral cover has since remained low and is showing little if any signs of recovery. The existence of juvenile populations of *A. planci* recorded in 1998-99 suggests the possibility of renewed increases in starfish numbers in the near future, with the exposed front reef zone being the area most likely to be affected by this latest cohort.

Figure 3.7: Rudder Reef (16-023)

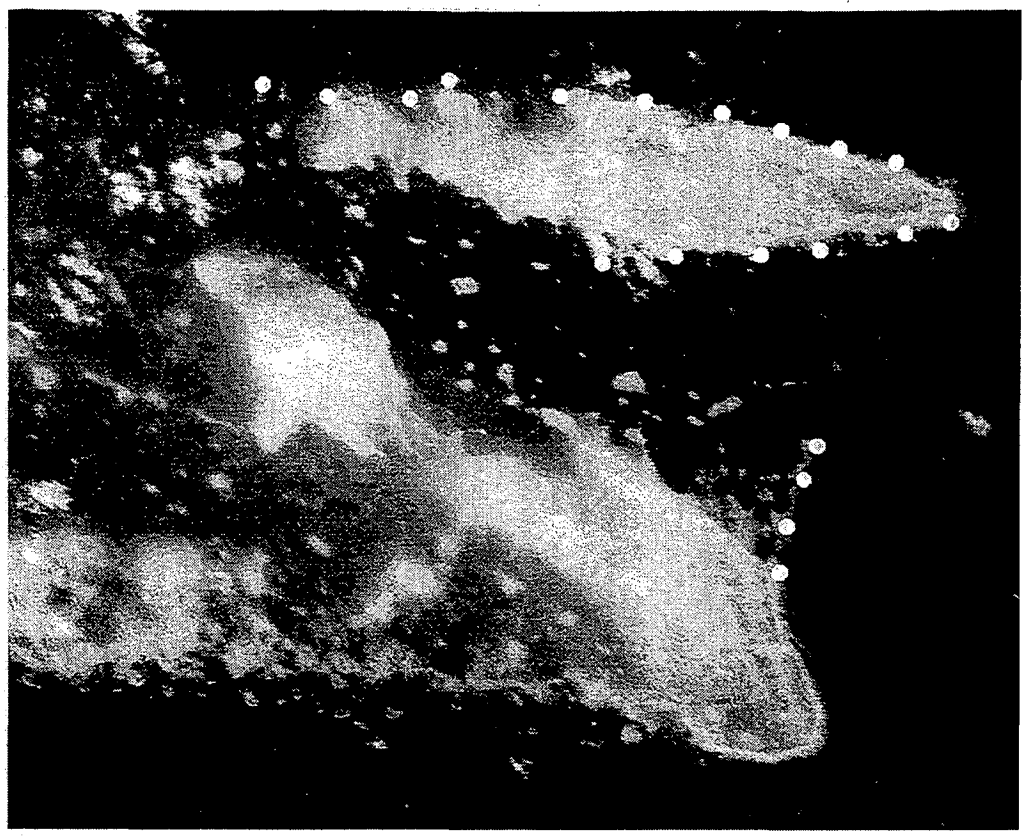


Figure 3.7.1: Aerial photograph of Rudder Reef (east) (16-023) with white dots indicating the approximate locations of the 20 sites surveyed in December 1998 / January 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NO	IO	AO	ASO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	2.65±0.87 (53)	0.15±0.08 (3)	1.85±0.83 (37)	ASO
Front Reef (FR)	13.20±2.03 (264)	1.00±0.33 (20)	0.00±0.00 (0)	FSO
Entire Reef (R = BR & FR)	7.93±1.38 (317)	0.58±0.18 (23)	0.93±0.44 (37)	ASO(BR) FSO(FR)

Table 3.7 (A-B): Summary of reef status classifications for Reef 16-023 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

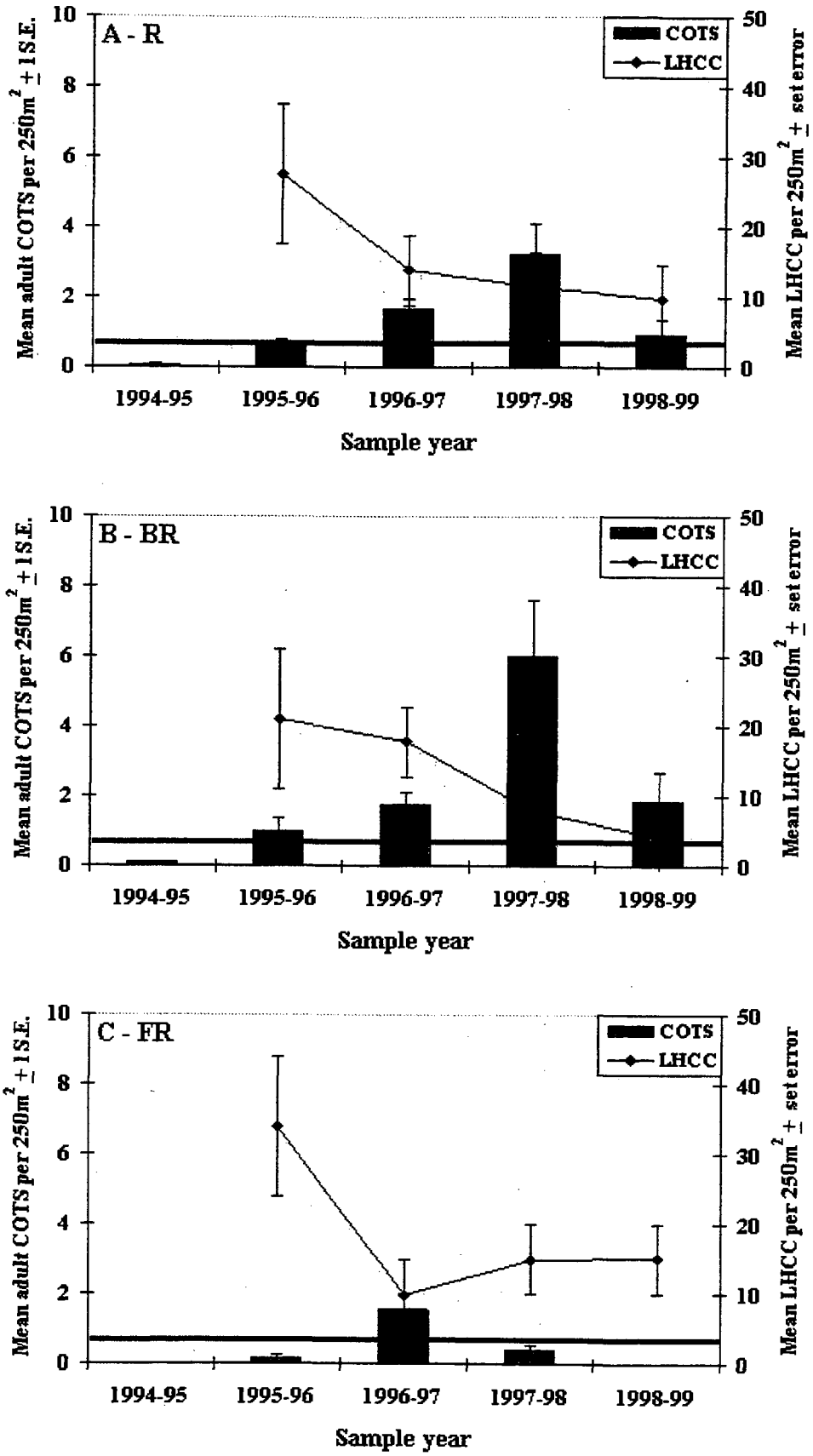


Figure 3.7.2 (A-C): Reef 16-023 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

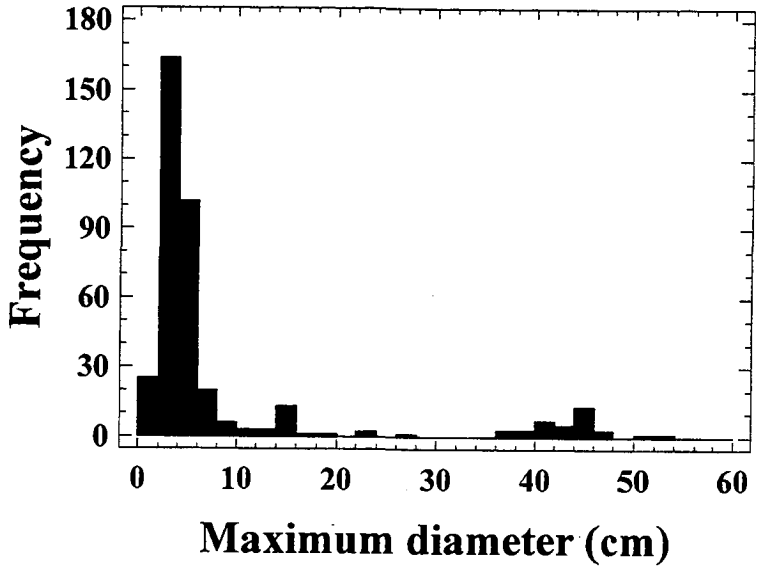


Figure 3.7.3: Size-frequency plot of *A. planci* observed at Reef 16-023 in December 1998 / January 1999.

Summary

Rudder Reef (16-023) was classified as an Incipient Outbreak (IO) in 1995-96. As predicted, an Active Outbreak (AO) developed over the following 12 months. Since that time, starfish populations in the back reef zone have remained at outbreaking densities. Over this now three period, live hard coral cover (LHCC) in the back reef zone has declined from an average of around 20-25% cover to the current level of only 5% live cover. Unsustainably high densities of juvenile *A. planci* recorded in the front reef zone in 1998-99 now suggest the possibility of renewed increases in starfish numbers in the near future, with the exposed front reef zone being the area most likely to be affected by this latest cohort. However, a further reduction in live hard coral cover is also likely in the back reef zone where numbers of adult starfish continue to remain above sustainable levels.

Figure 3.8: Unnamed Reef (16-024)

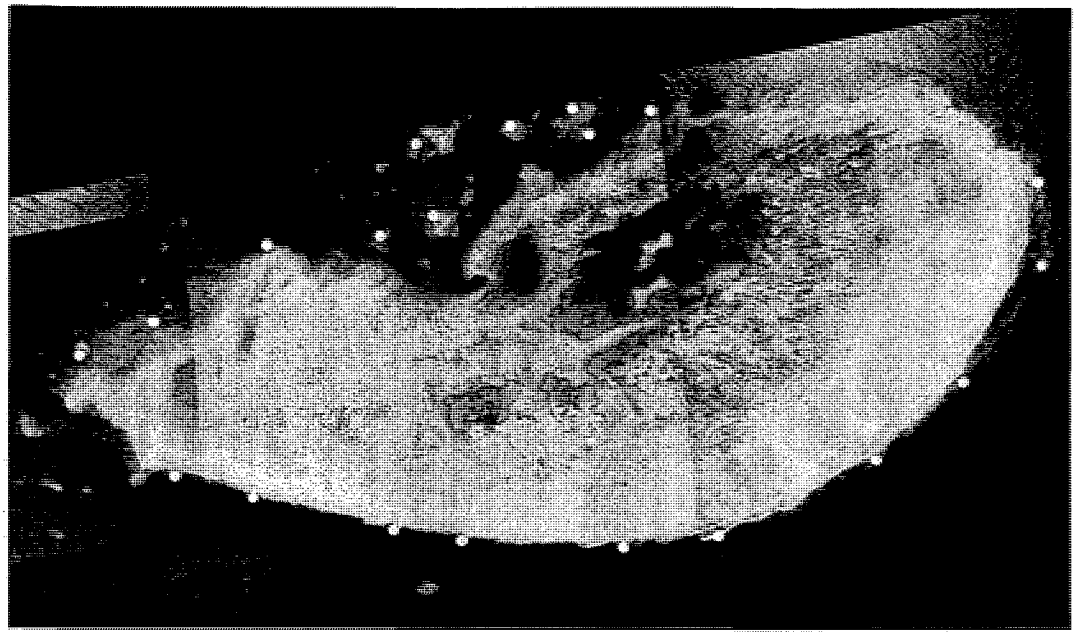
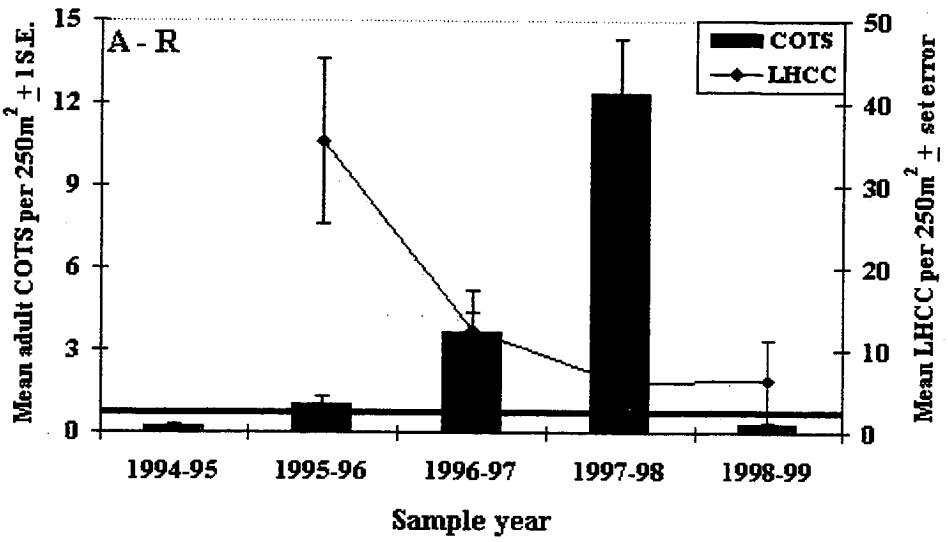
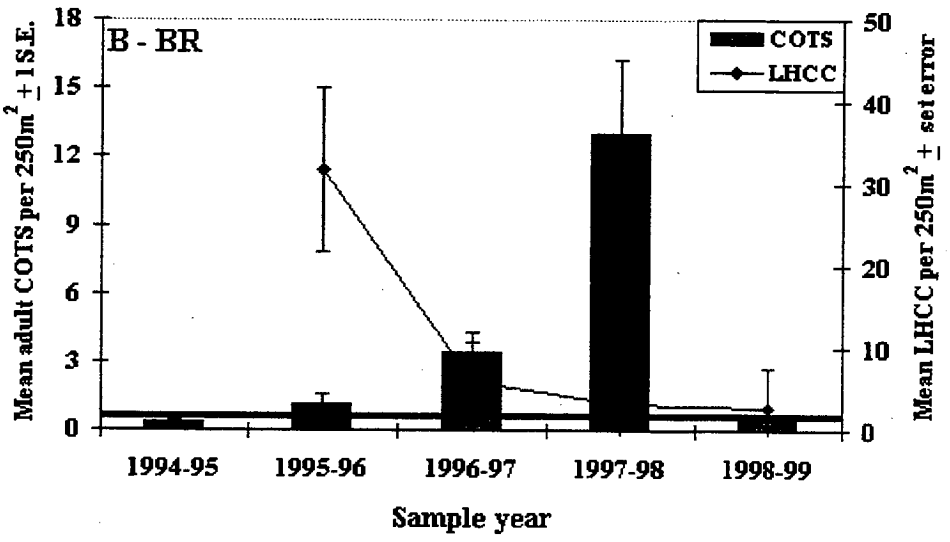


Figure 3.8.1: Aerial photograph of Unnamed Reef (16-024) with white dots indicating the approximate locations of the 20 sites surveyed in December 1998 / January 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NO	IO	AO	AO
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.15±0.08 (3)	0.10±0.07 (2)	0.40±0.17 (8)	PO
Front Reef (FR)	5.20±0.89 (104)	0.00±0.00 (0)	0.20±0.12 (4)	PO/FSO
Entire Reef (R = BR & FR)	2.68±0.60 (107)	0.05±0.03 (2)	0.30±0.10 (12)	PO FSO(FR)

Table 3.8 (A-B): Summary of reef status classifications for Reef 16-024 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





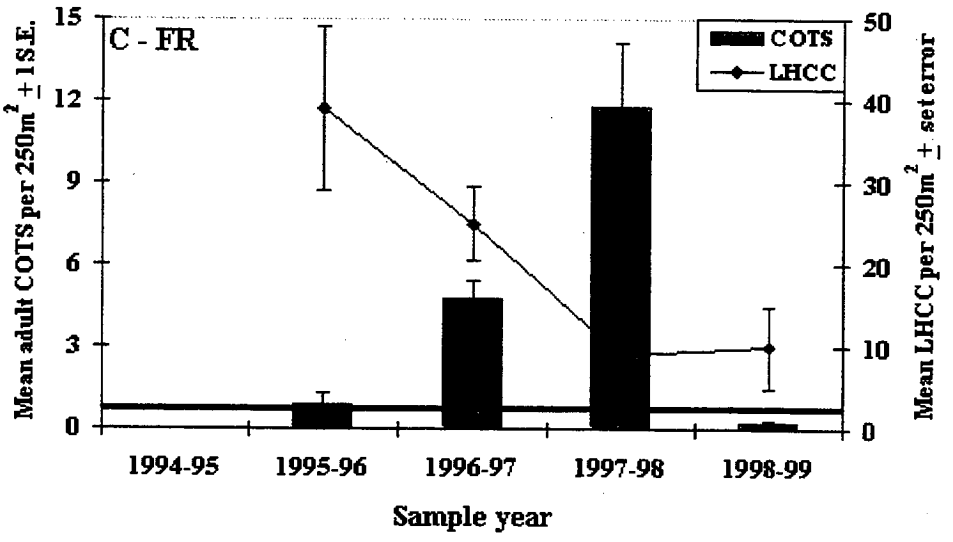


Figure 3.8.2 (A-C): Reef 16-024 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

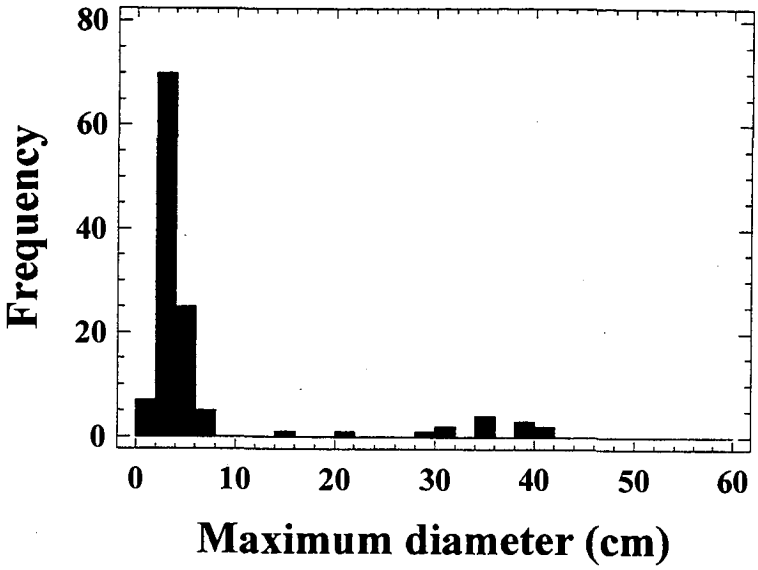


Figure 3.8.3: Size-frequency plot of *A. planci* observed at Reef 16-024 in December 1998 / January 1999.

Summary

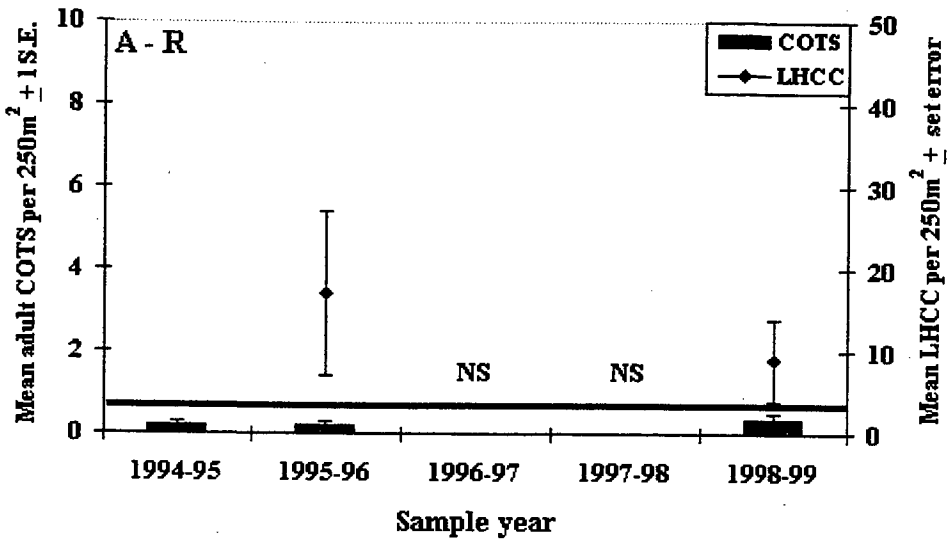
Unnamed Reef (16-024) was classified as an Incipient Outbreak (IO) in 1995-96. As predicted, an Active Outbreak (AO) developed over the following 12 months. Starfish populations in both the back and front reef zone remained at outbreaking densities for the following two years. During this period, live hard coral cover (LHCC) declined from an average of around 35% cover across the reef to the current level of 5-10% live cover. Unsustainably high densities of juvenile *A. planci* recorded in the front reef zone in 1998-99 now suggest the possibility of renewed increases in starfish numbers in the near future, with the exposed front reef zone being the area most likely to be affected by this latest cohort. Live hard coral cover in the back reef zone is less than 5 % with no signs of any significant coral recovery observed in 1998-99.

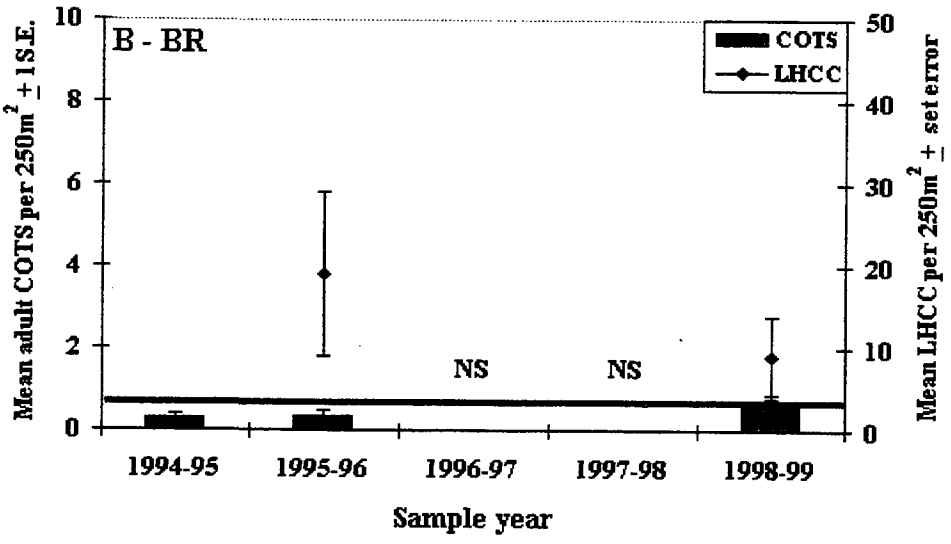
Figure 3.9: Hastings Reef (16-057)

Figure 3.9.1: Aerial photograph of Hastings Reef (16-057) with white dots indicating the approximate locations of the 20 sites surveyed in January / February 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NO	NO	NS	NS
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	1.60±0.82 (32)	0.10±0.10 (2)	0.60±0.26 (12)	NO
Front Reef (FR)	5.15±1.21 (103)	0.40±0.13 (8)	0.10±0.07 (2)	FSO
Entire Reef (R = BR & FR)	3.38±0.78 (135)	0.25±0.09 (10)	0.35±0.14 (14)	FSO(FR)

Table 3.9 (A-B): Summary of reef status classifications for Reef 16-057 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





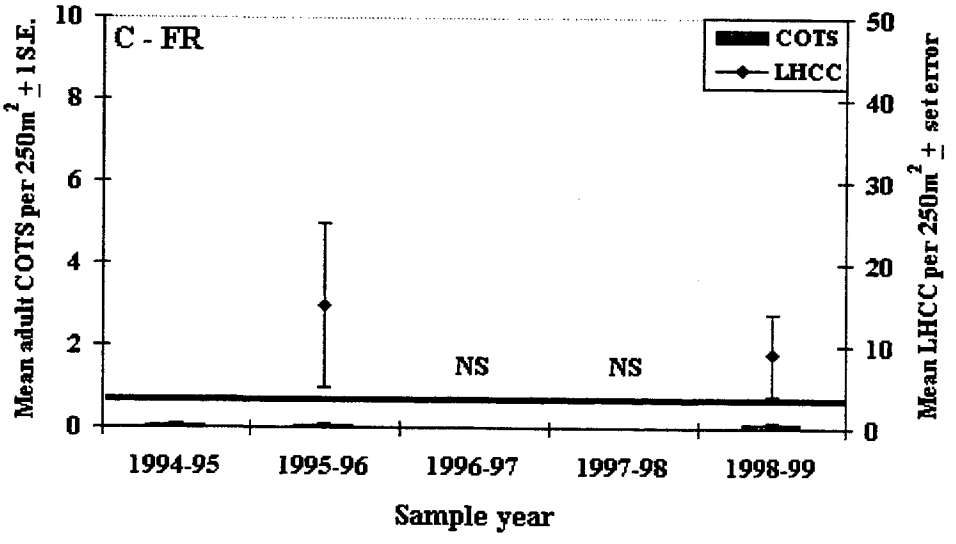


Figure 3.9.2 (A-C): Reef 16-057 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

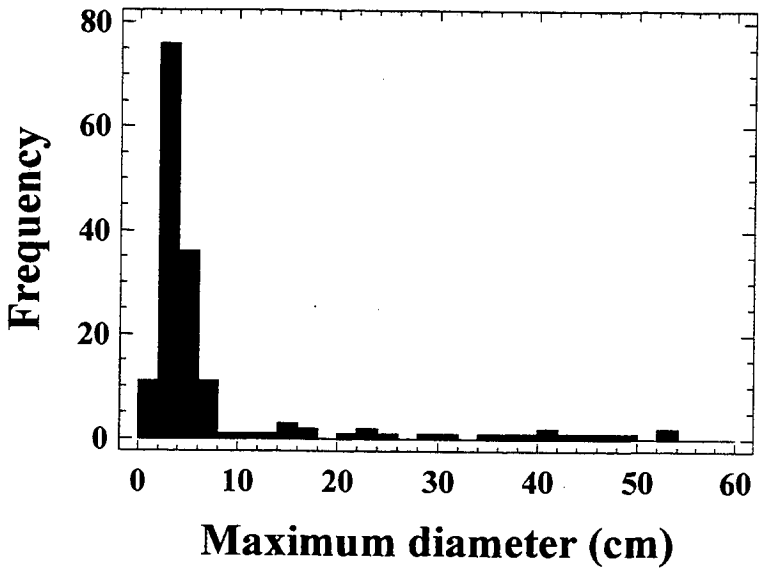


Figure 3.9.3: Size-frequency plot of *A. planci* observed at Reef 16-057 in January / February 1999.

Summary

To date, Hastings Reef (16-057) has only been surveyed three times (1994-95, 1995-96 and 1998-99) with no active outbreaks being recorded at any of these times. However, since our last survey in 1995-96, live hard coral cover (LHCC) has apparently declined from an average of 15-20% cover across the reef to the current level of around 10% live cover. Unsustainably high densities of juvenile *A. planci* recorded in the front reef zone in 1998-99 now suggest the possibility of significant increases in starfish numbers in the near future, with the exposed front reef zone being the area most likely to be affected by this latest cohort.

Figure 3.10: Michaelmas Reef (16-060)

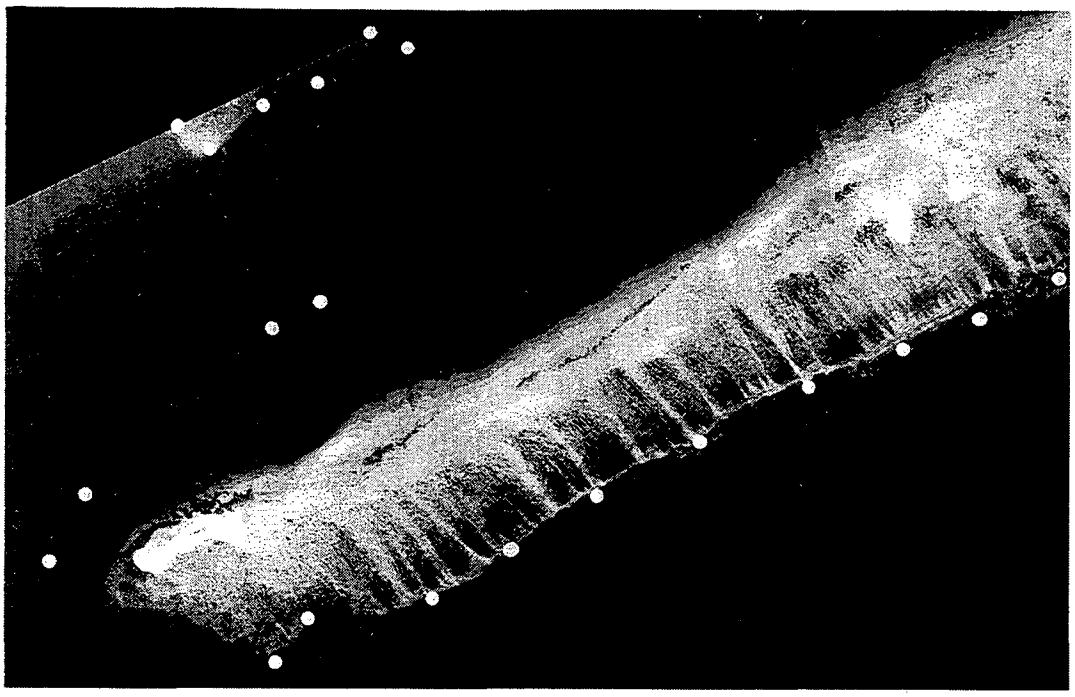
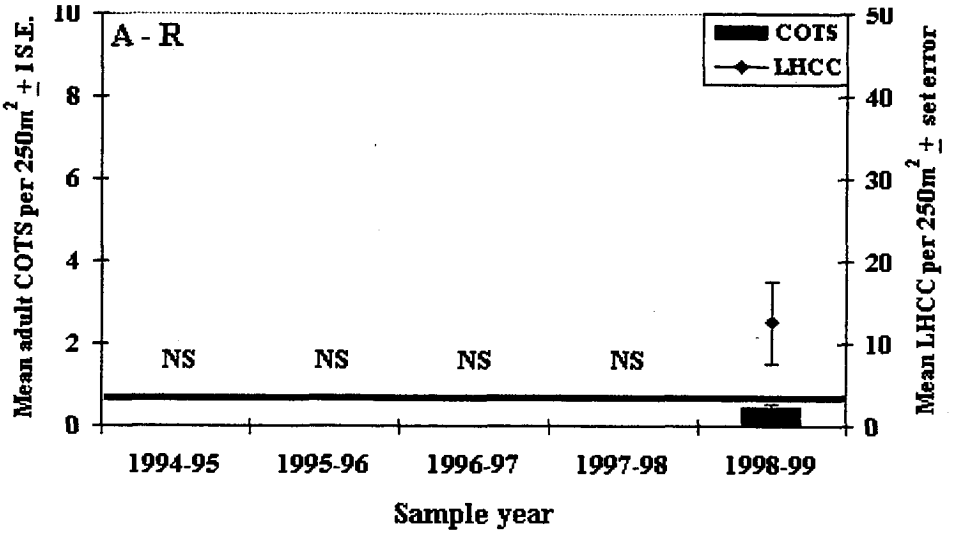
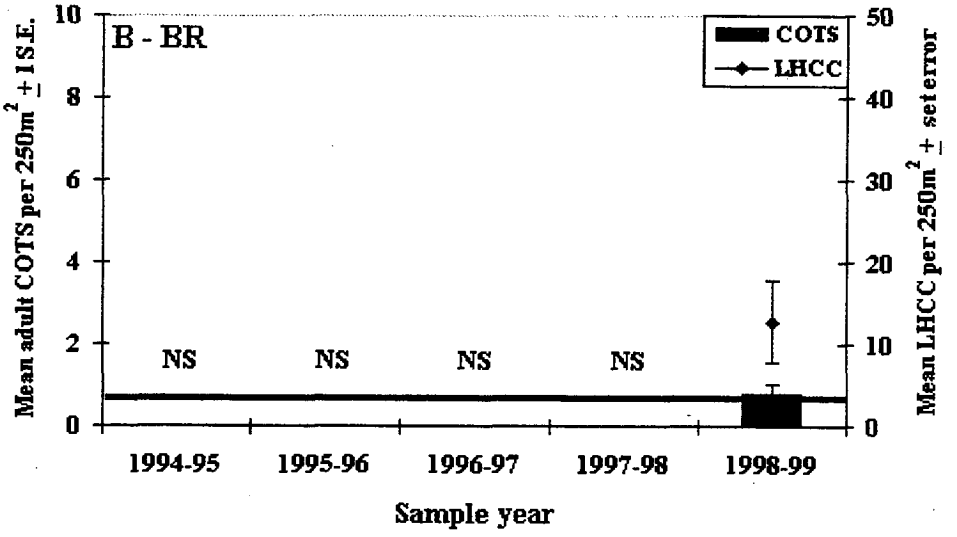


Figure 3.10.1: Aerial photograph of Michaelmas Reef (16-060) with white dots indicating the approximate locations of the 20 sites surveyed in January / February 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	NS	NS
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	3.90±0.70 (78)	0.20±0.09 (4)	0.80±0.22 (16)	FSO
Front Reef (FR)	14.35±2.36 (287)	0.70±0.13 (14)	0.05±0.05 (1)	FSO
Entire Reef (R = BR & FR)	9.13±1.48 (365)	0.45±0.09 (18)	0.43±0.13 (17)	FO

Table 3.10 (A-B): Summary of reef status classifications for Reef 16-060 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





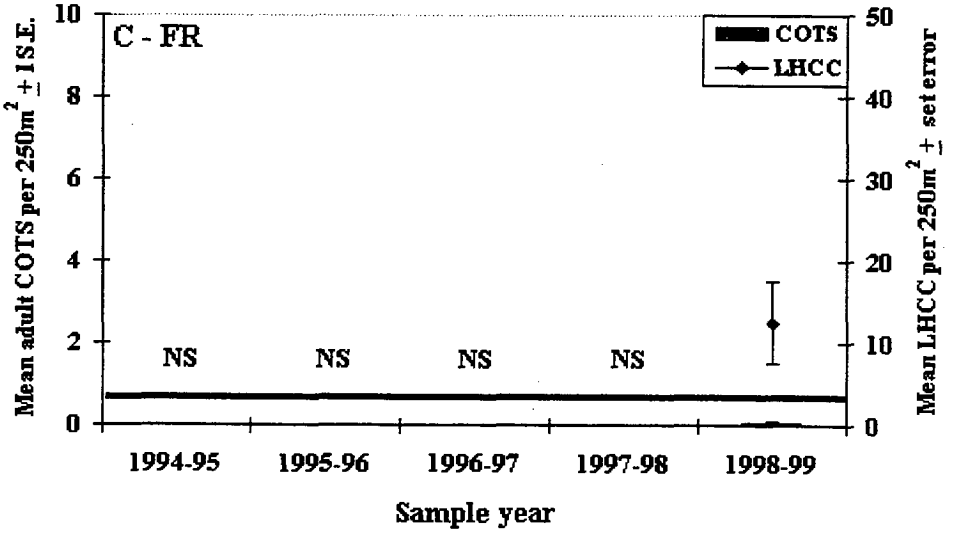


Figure 3.10.2 (A-C): Reef 16-060 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

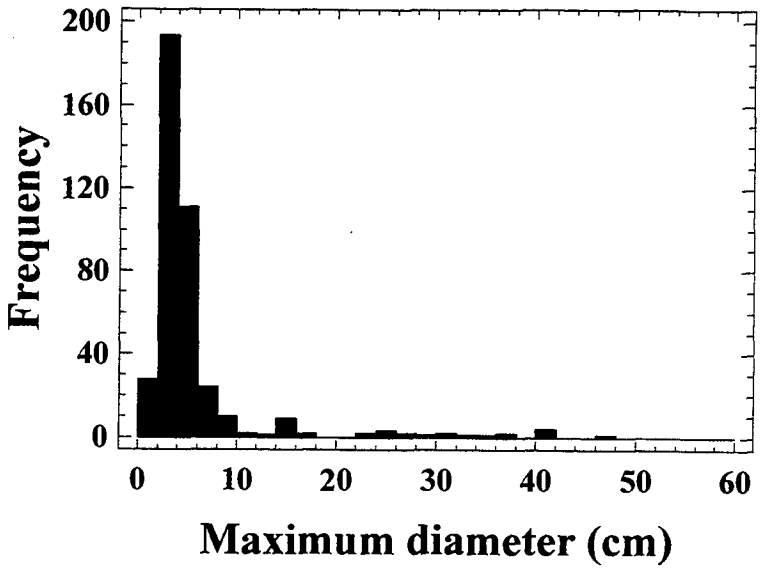


Figure 3.10.3: Size-frequency plot of *A. planci* observed at Reef 16-060 in January / February 1999.

Summary

Michaelmas Reef (16-060) was first surveyed in 1998-99. Unsustainably high densities of juvenile *A. planci* were found in the back and front reef zone respectively. We classified this reef as a possible Future reef-wide Outbreak (FO) indicating a high probability of a new outbreak developing on this reef within the next 18-24 months.

There are confirmed records of a recent outbreaking population of adult starfish in the back reef zone of Michaelmas Reef. Reef-user reports show that the outbreak first started in mid-1993 and lasted until early 1998 (COTSWATCH, unpublished data). If the predicted new outbreak develops on this reef a renewed peak in starfish activity would occur within the space of only a few years.

Figure 3.11: Thetford Reef (16-068)

Figure 3.11.1: Aerial photograph of Thetford Reef (16-068) with white dots indicating the approximate locations of the 20 sites surveyed in December 1998 / January 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NO	NO	ASO(BR)	PO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	2.30±0.81 (46)	0.30±0.18 (6)	0.25±0.12 (5)	PSO
Front Reef (FR)	6.30±1.57 (126)	0.10±0.07 (2)	0.00±0.00 (0)	FSO
Entire Reef (R = BR & FR)	4.30±0.93 (172)	0.20±0.10 (8)	0.13±0.06 (5)	PSO(BR) FSO(FR)

Table 3.11 (A-B): Summary of reef status classifications for Reef 16-068 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

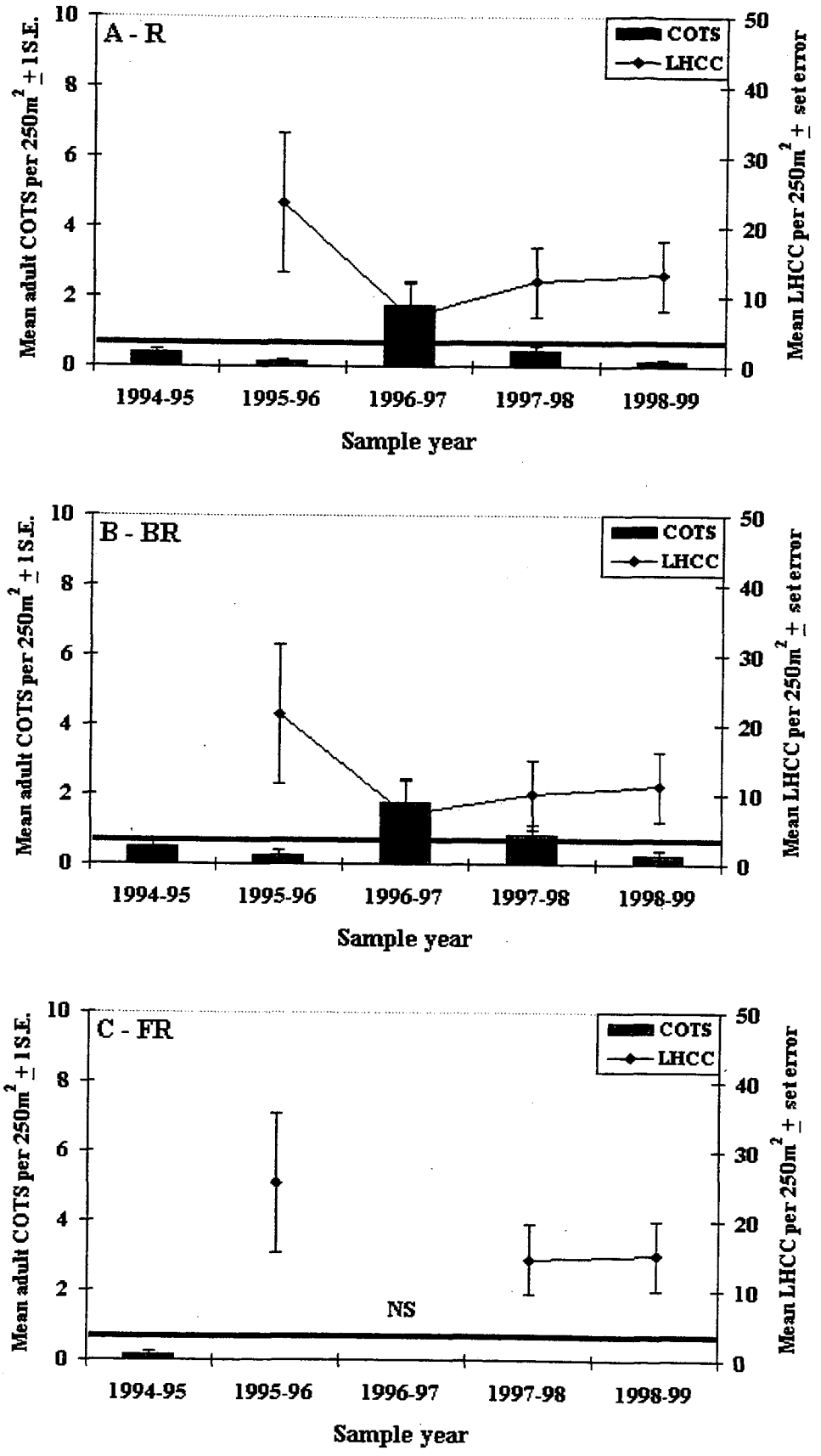


Figure 3.11.2 (A-C): Reef 16-068 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

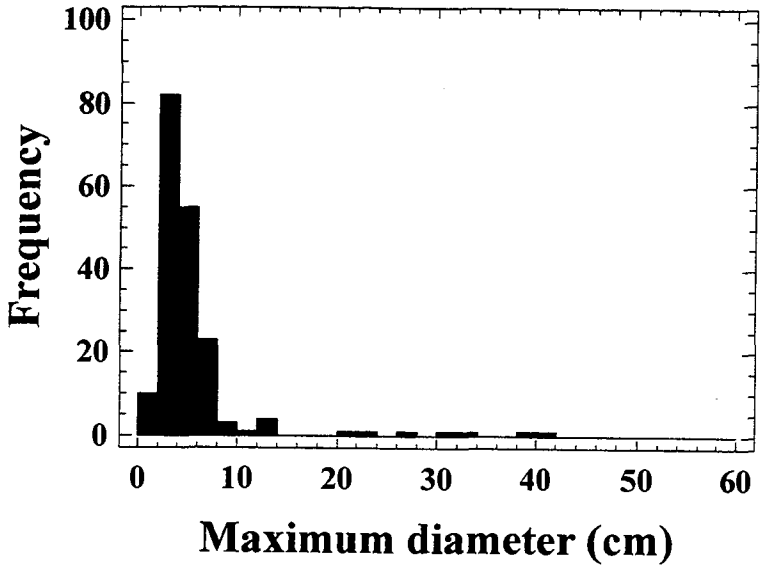


Figure 3.11.3: Size-frequency plot of *A. planci* observed at Reef 16-068 in December 1998 / January 1999.

Summary

The first signs of locally unsustainable *A. planci* densities at Thetford Reef (16-068) were first detected in 1996-97. However, the Active Spot Outbreak (ASO) identified in the back reef zone that year did not remain at unsustainable levels for long. By 1997-98 starfish densities in both reef zones surveyed had declined to just below outbreaking levels. The 1998-99 surveys recorded significant and unsustainably high densities of juvenile *A. planci* in the back and front reef zone respectively. The front reef zone is now classified as a possible Future Spot Outbreak (FSO) indicating a high probability of a new outbreak developing on this reef within the next 18-24 months.

Currently average live hard coral cover (LHCC) across Thetford reef is around 10-20%. However, a further decline in LHCC is expected in the near future as the 1997-98 cohort of *A. planci* approaches maturity.

Figure 3.12: Moore Reef (16-071)

Figure 3.12.1: Aerial photograph of Moore Reef (16-071) with white dots indicating the approximate locations of the 20 sites surveyed in January / February 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	NS	NS
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	6.00±1.69 (120)	1.65±0.48 (33)	2.15±0.73 (43)	ASO
Front Reef (FR)	3.50±0.99 (70)	0.70±0.29 (14)	0.35±0.17 (7)	FSO
Entire Reef (R = BR & FR)	4.75±0.99 (190)	1.18±0.29 (47)	1.25±0.40 (50)	ASO(BR) FSO(FR)

Table 3.12 (A-B): Summary of reef status classifications for Reef 16-071 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

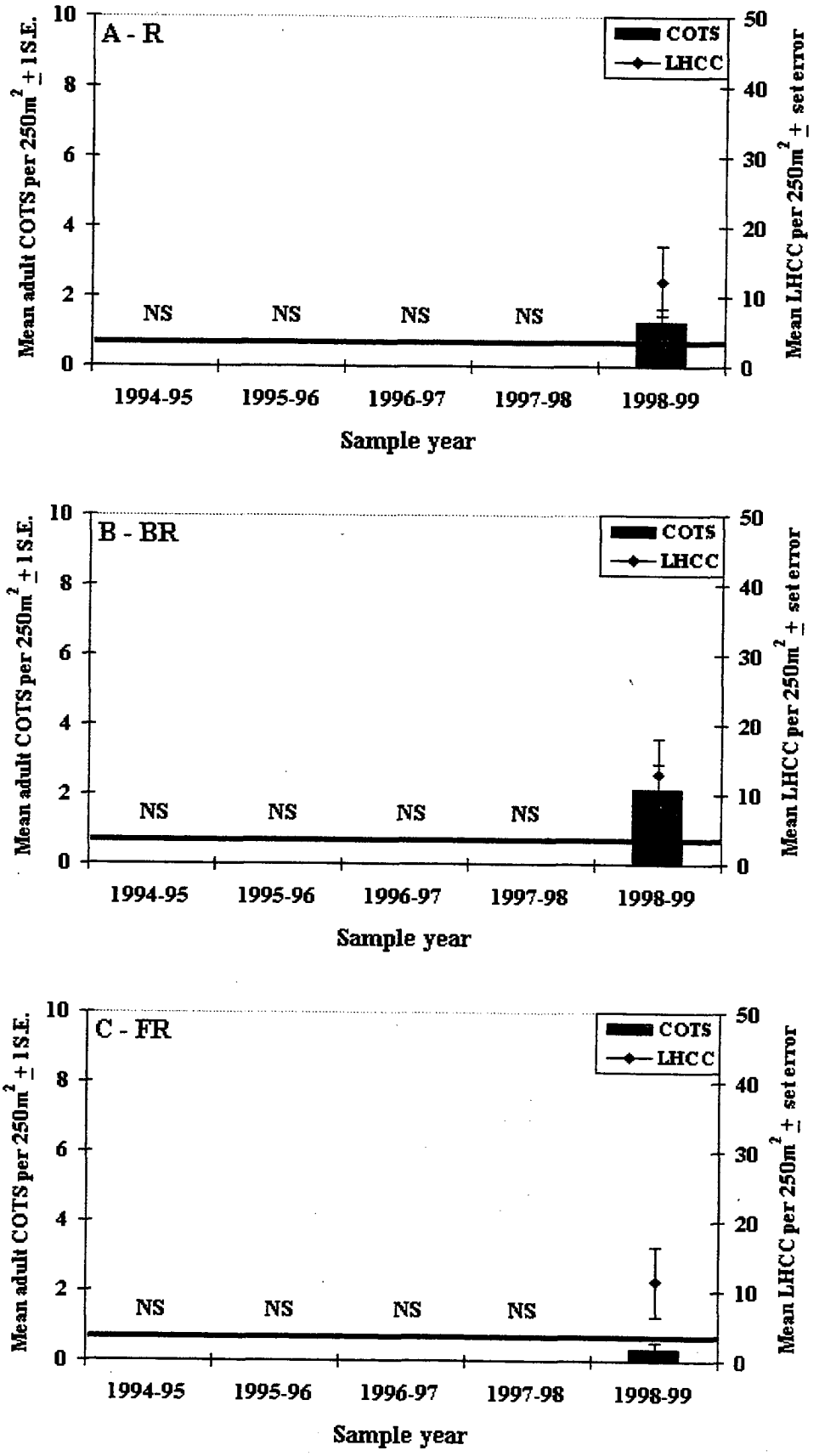


Figure 3.12.2 (A-C): Reef 16-071 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

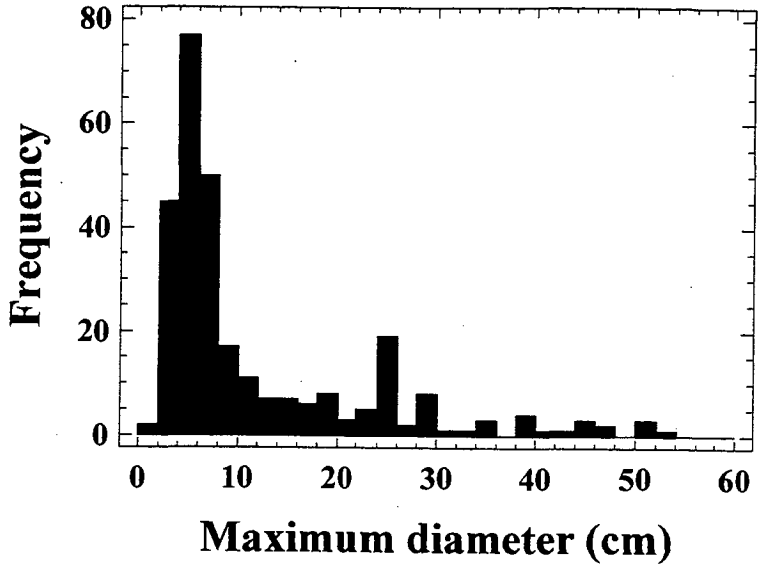


Figure 3.12.3: Size-frequency plot of *A. planci* observed at Reef 16-071 in January / February 1999.

Summary

Moore Reef (16-071) was first surveyed in 1998-99. The Active Spot Outbreak (ASO) detected at this reef is currently restricted to the back reef zone. However, unsustainably high densities of juvenile *A. planci* were found in both the back and front reef zone. Current juvenile densities recorded at the front reef zone warrant its classification as a possible Future Spot Outbreak (FSO) indicating a high probability of the outbreak spreading to include the front reef zone sometime within the next 18-24 months. The current active outbreak in the back reef zone is likely to continue and possibly worsen as the 1997-98 year class of *A. planci* approaches maturity. The current percent cover of live hard coral (LHCC), estimated at around 15%, is thus likely to experience a further significant reduction.

There are confirmed records by Reef-users indicating that the current active outbreak of adult starfish in the back reef zone of Moore Reef first started in late-1996 (COTSWATCH, unpublished data). If the predicted new outbreak develops on this reef a renewed peak in starfish activity would occur within the space of only a few years.

Figure 3.13: Scott Reef (17-004)

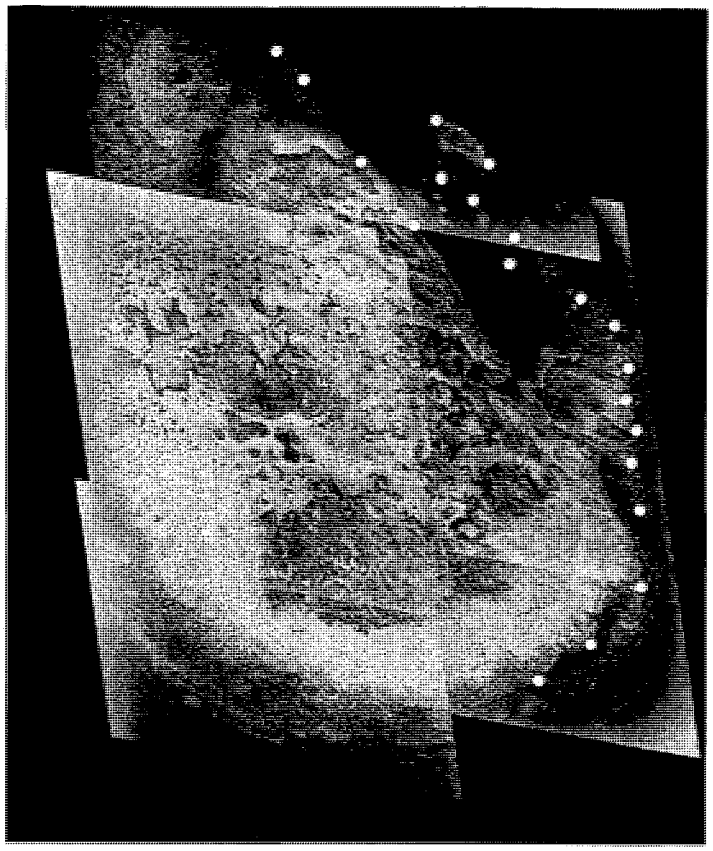
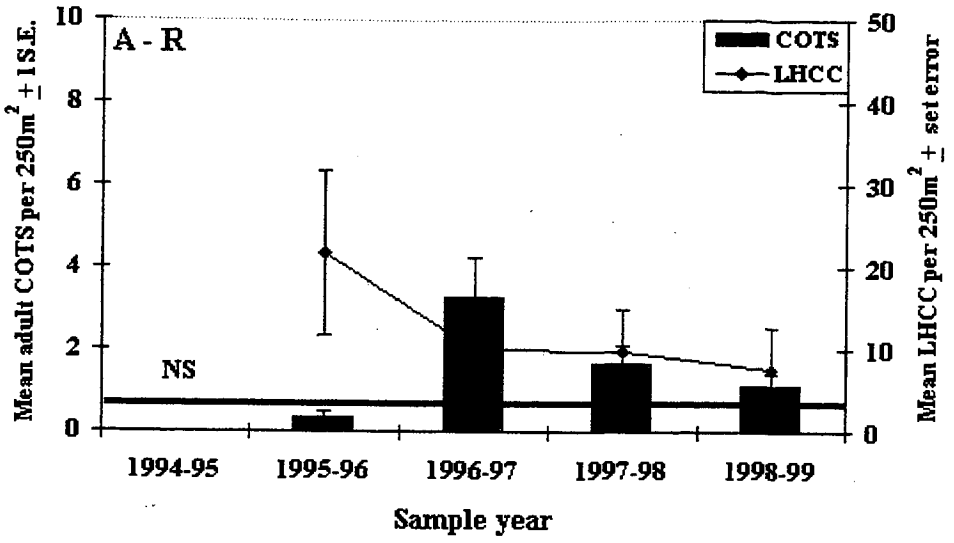
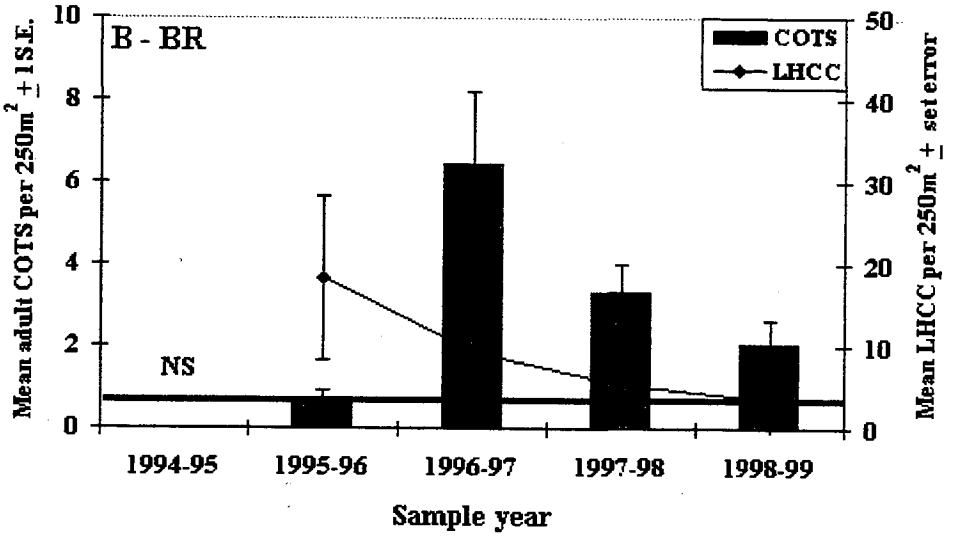


Figure 3.13.1: Aerial photograph of Scott Reef (17-004) with white dots indicating the approximate locations of the 20 sites surveyed in December 1998 / February 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	ISO(BR)	ASO(BR)	ASO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.25±0.12 (5)	0.35±0.13 (7)	2.05±0.57 (41)	ASO
Front Reef (FR)	8.80±2.01 (176)	0.30±0.11 (6)	0.15±0.11 (3)	FSO
Entire Reef (R = BR & FR)	4.53±1.21 (181)	0.33±0.08 (13)	1.10±0.32 (44)	ASO(BR) FSO(FR)

Table 3.13 (A-B): Summary of reef status classifications for Reef 17-004 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





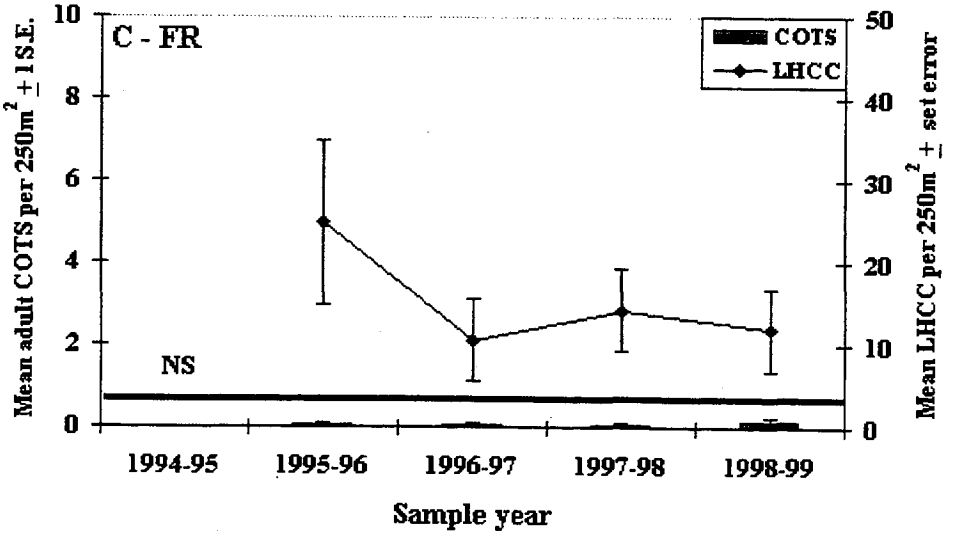


Figure 3.13.2 (A-C): Reef 17-004 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

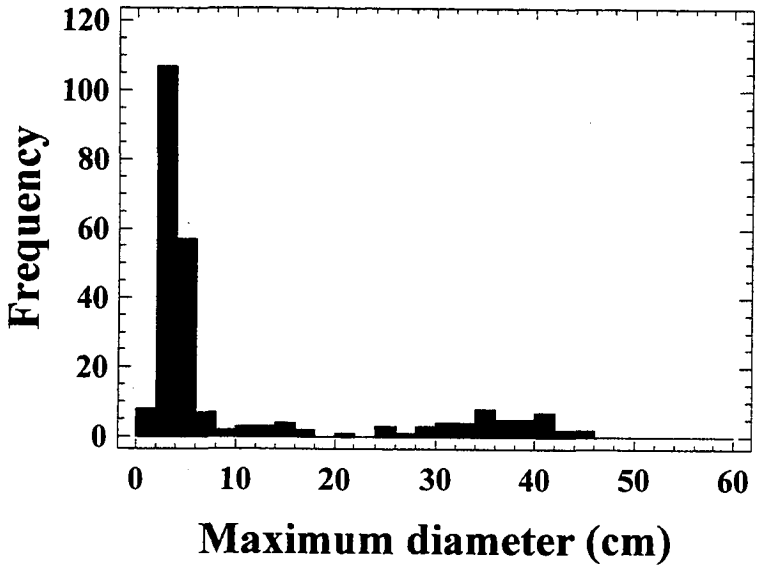


Figure 3.13.3: Size-frequency plot of *A. planci* observed at Reef 17-004 in December 1998 / February 1999.

Summary

The first signs of increasing *A. planci* activity at Scott Reef (17-004) were detected in 1995-96 when an Incipient Spot Outbreak (ISO) was identified in the back reef zone. As predicted, an Active Spot Outbreak (ASO) did develop in this zone within a 12-months period. The unsustainably high density of adult starfish in that zone has persisted since that time. However, as live hard coral cover (LHCC) has declined from an average level of around 20% recorded in 1995-96 to below 5% LHCC in 1998-99, the local *A. planci* population is also declining rapidly.

However, the 1998-99 detected unsustainably high densities of juvenile starfish in the front reef zone of Scott Reef, leading to its classification of a possible Future Spot Outbreak (FSO). As the cover of live hard coral at the front reef zone currently remains at a reasonable level of around 15%, there is a high probability of this latest starfish cohort maturing over the next 18 to 24 months. Consequently, a reduction in LHCC within the front reef zone can be expected.

Figure 3.14: Coates Reef (17-011)

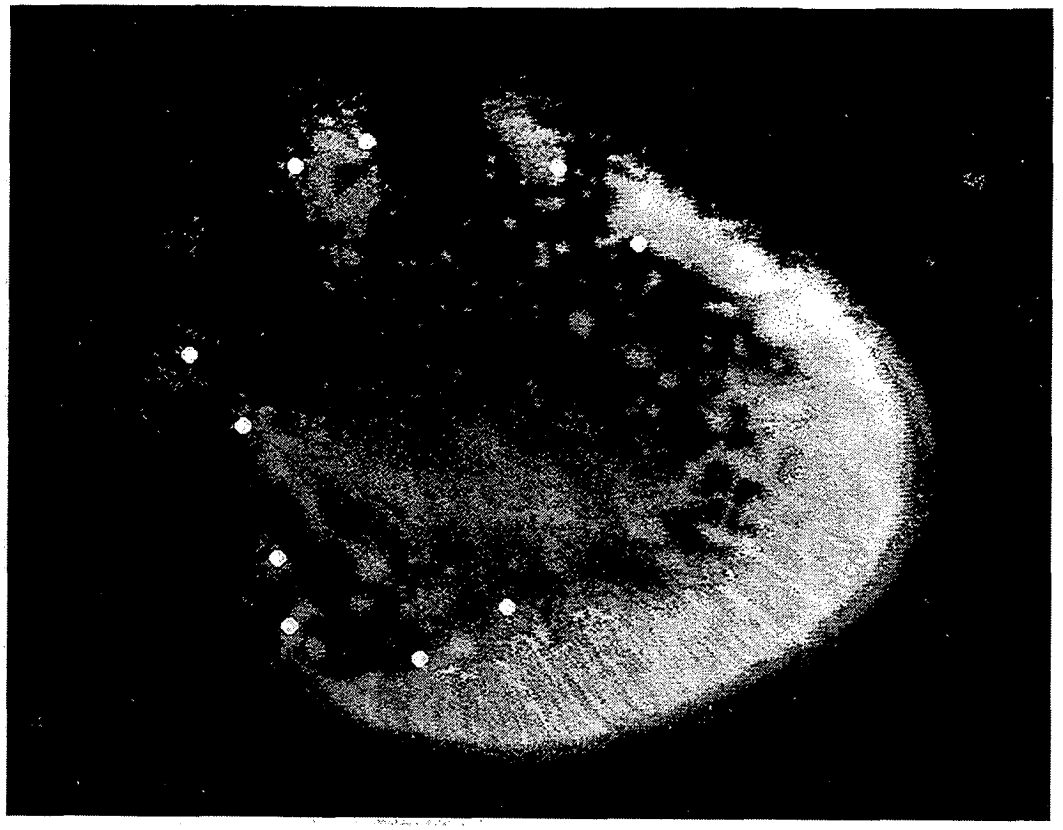
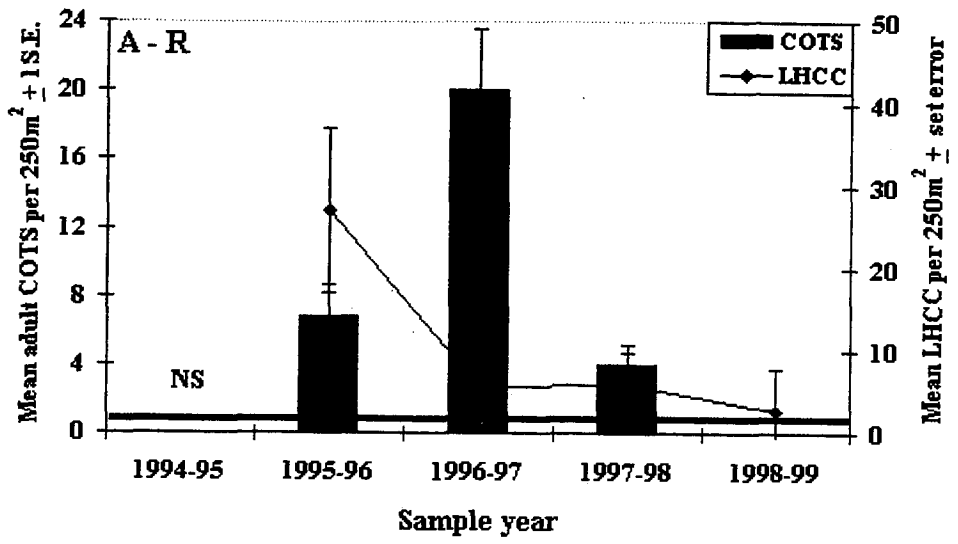
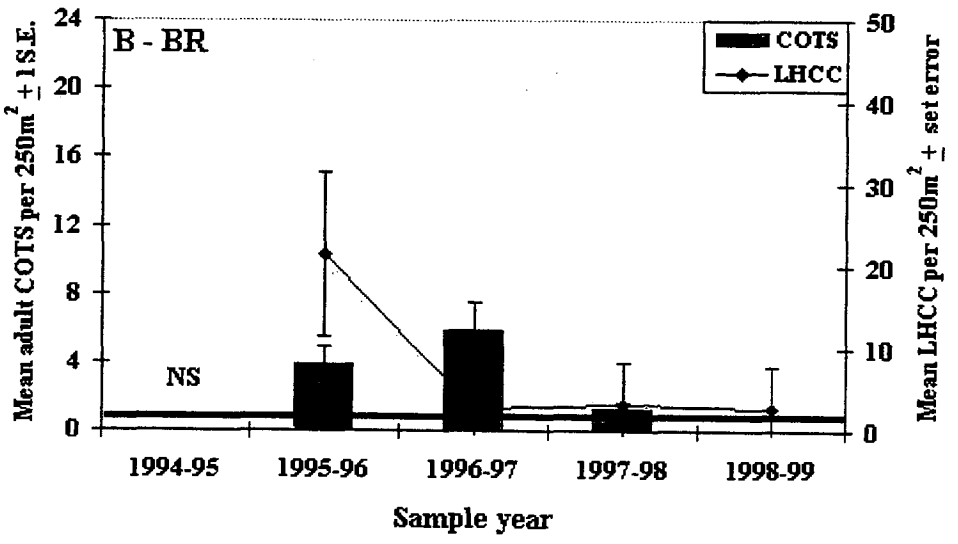


Figure 3.14.1: Aerial photograph of Coates Reef (17-011) with white dots indicating the approximate locations of the 10 sites surveyed in February 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	AO	AO	AO
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	1.20±0.45 (24)	0.00±0.00 (0)	0.00±0.00 (0)	PSO
Front Reef (FR)	NS	NS	NS	NS
Entire Reef (R = BR & FR)	-	-	-	PSO(BR) NS

Table 3.14 (A-B): Summary of reef status classifications for Reef 17-011 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





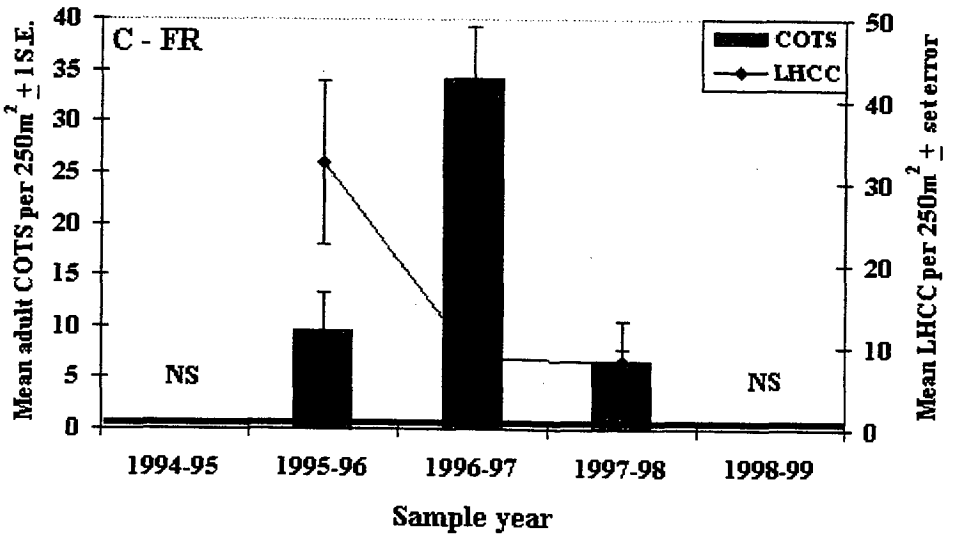


Figure 3.14.2 (A-C): Reef 17-011 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

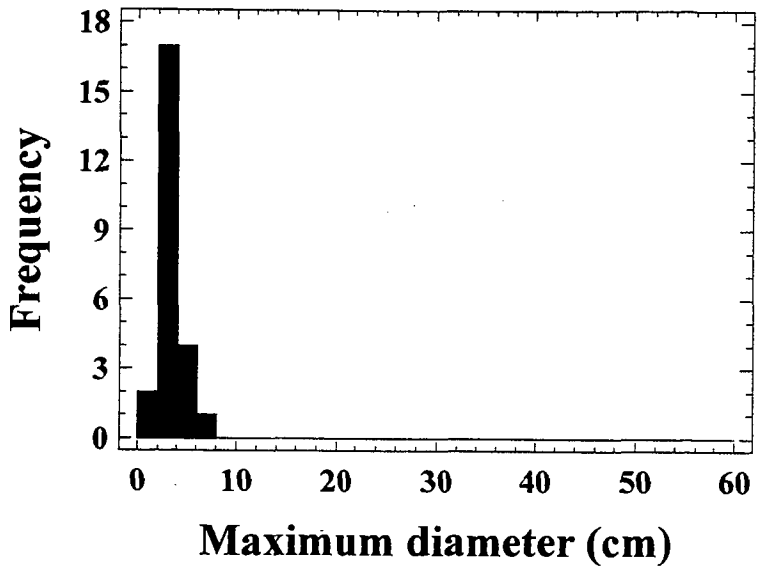


Figure 3.14.3: Size-frequency plot of *A. planci* observed at Reef 17-011 in February 1999.

Summary

When first surveyed in 1995-96, Coates Reef (17-011) already supported an Active reef-wide Outbreak (AO). The outbreak lasted until 1997-98 when adult starfish populations in both the back and front reef zone started to decline rapidly. During this three-year period, live hard coral cover (LHCC) in the back reef zone was reduced from an average of around 20-25% recorded to the current level of below 5% LHCC.

Juvenile *A. planci* recorded in the back reef zone in 1998-99 were observed feeding mainly on recently settled hard coral recruits. Whilst the remaining live hard coral cover (LHCC) is unlikely to be sufficient for the 1997-98 cohort of starfish to grow to maturity, there is a possibility that their feeding activity may significantly impact on the onset and progress of the coral recovery phase.

Figure 3.15: Cayley Reef (17-023)

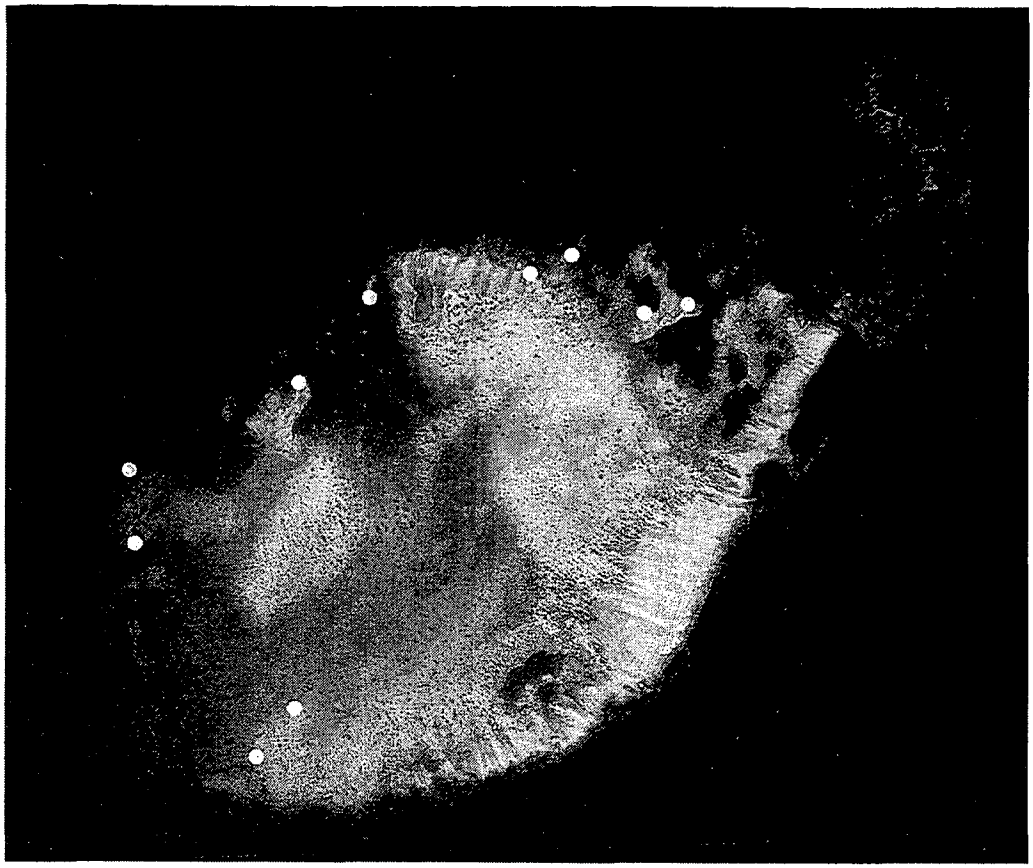
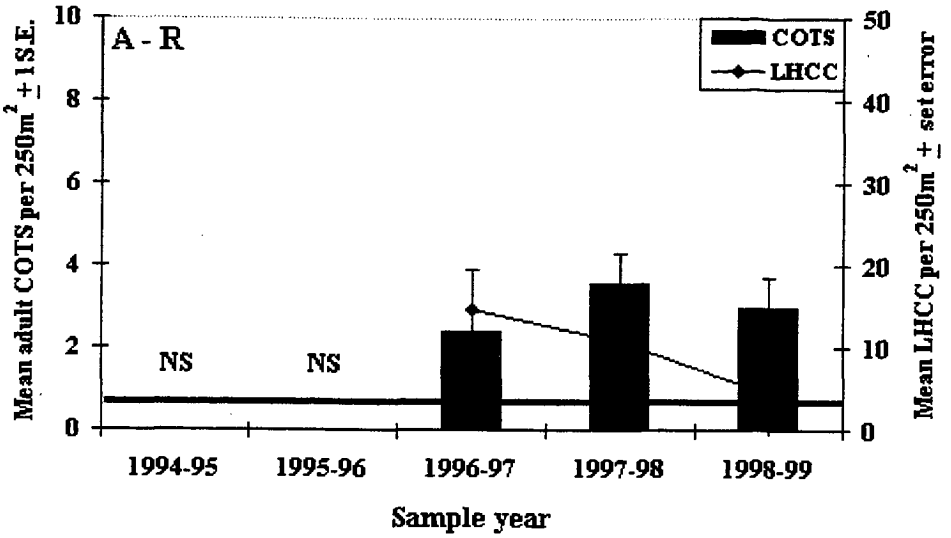
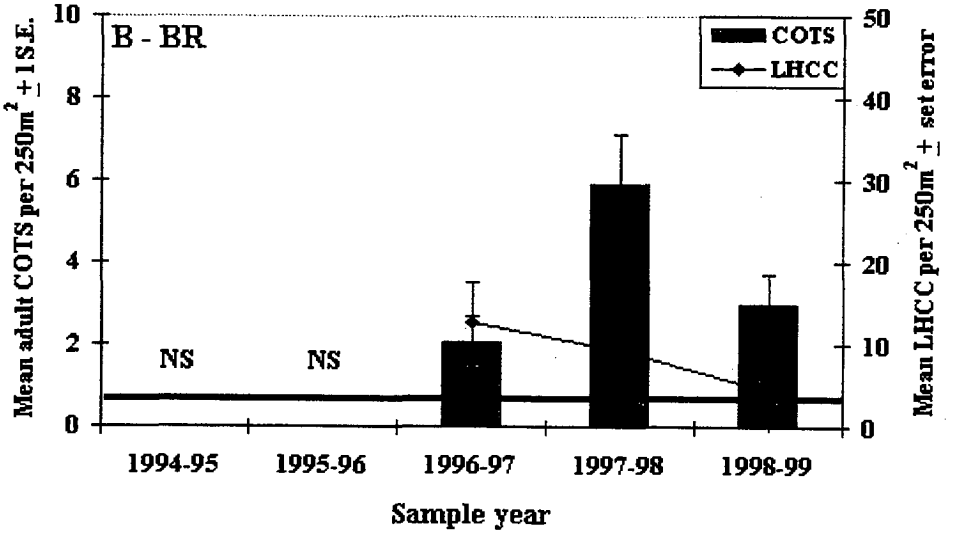


Figure 3.15.1: Aerial photograph of Cayley Reef (17-023) with white dots indicating the approximate locations of the 10 sites surveyed in March 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	AO	ASO(BR) PSO(FR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	1.55+0.69 (31)	0.80+0.22 (16)	3.00+0.72 (60)	ASO
Front Reef (FR)	NS	NS	NS	NS
Entire Reef (R = BR & FR)	-	-	-	ASO(BR) NS

Table 3.15 (A-B): Summary of reef status classifications for Reef 17-023 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





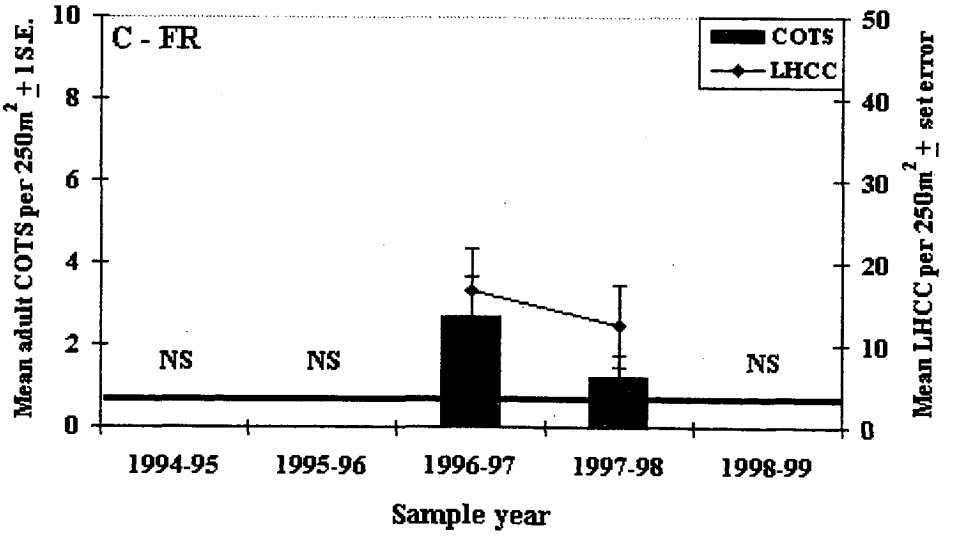


Figure 3.15.2 (A-C): Reef 17-023 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

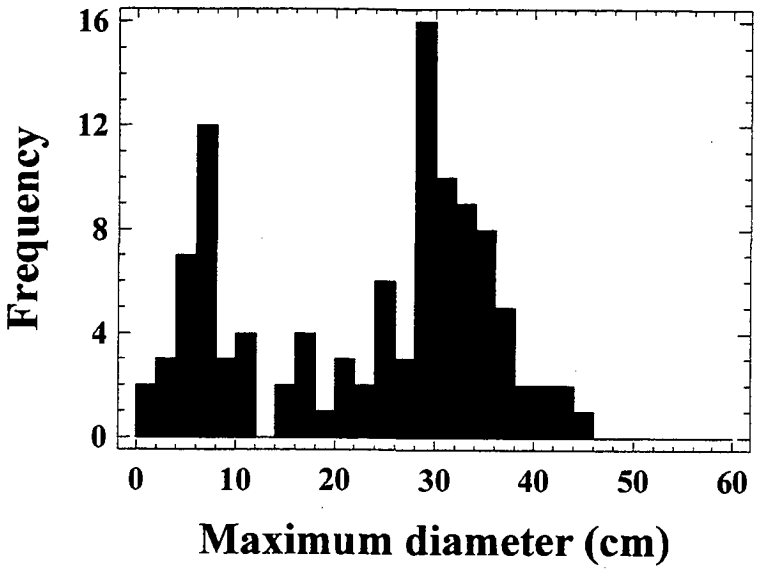


Figure 3.15.3: Size-frequency plot of *A. planci* observed at Reef 17-023 in March 1999.

Summary

When first surveyed in 1996-97, Cayley Reef (17-023) already supported an Active reef-wide Outbreak (AO). Since then, an Active Spot Outbreak (ASO) has persisted in the back reef zone of this reef. During this three-year period, live hard coral cover (LHCC) in the back reef zone has declined from around 10-15% down to the current level of below 5% cover. As a result of this marked reduction in food availability, the current remnant population of adult starfish is likely to decline rapidly over the next 12 or so months.

In addition to the remaining adult population, the 1998-99 surveys also recorded juvenile *A. planci* in the back reef zone. The combined feeding activity of both newly settled juvenile and remnant adult starfish populations has the potential to significantly impact on the onset and progress of the coral recovery phase.

Figure 3.16: Feather Reef (17-034)

Figure 3.16.1: Aerial photograph of Feather Reef (17-034) with white dots indicating the approximate locations of the 20 sites surveyed in March 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NO	NO	ISO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	6.55±1.52 (131)	1.30±0.37 (26)	3.05±0.93 (61)	ASO
Front Reef (FR)	4.35±0.89 (87)	0.50±0.26 (10)	0.70±0.27 (14)	FSO
Entire Reef (R = BR & FR)	5.45±0.89 (218)	0.90±0.23 (36)	1.88±0.51 (75)	ASO(BR) FSO(FR)

Table 3.16 (A-B): Summary of reef status classifications for Reef 17-034 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

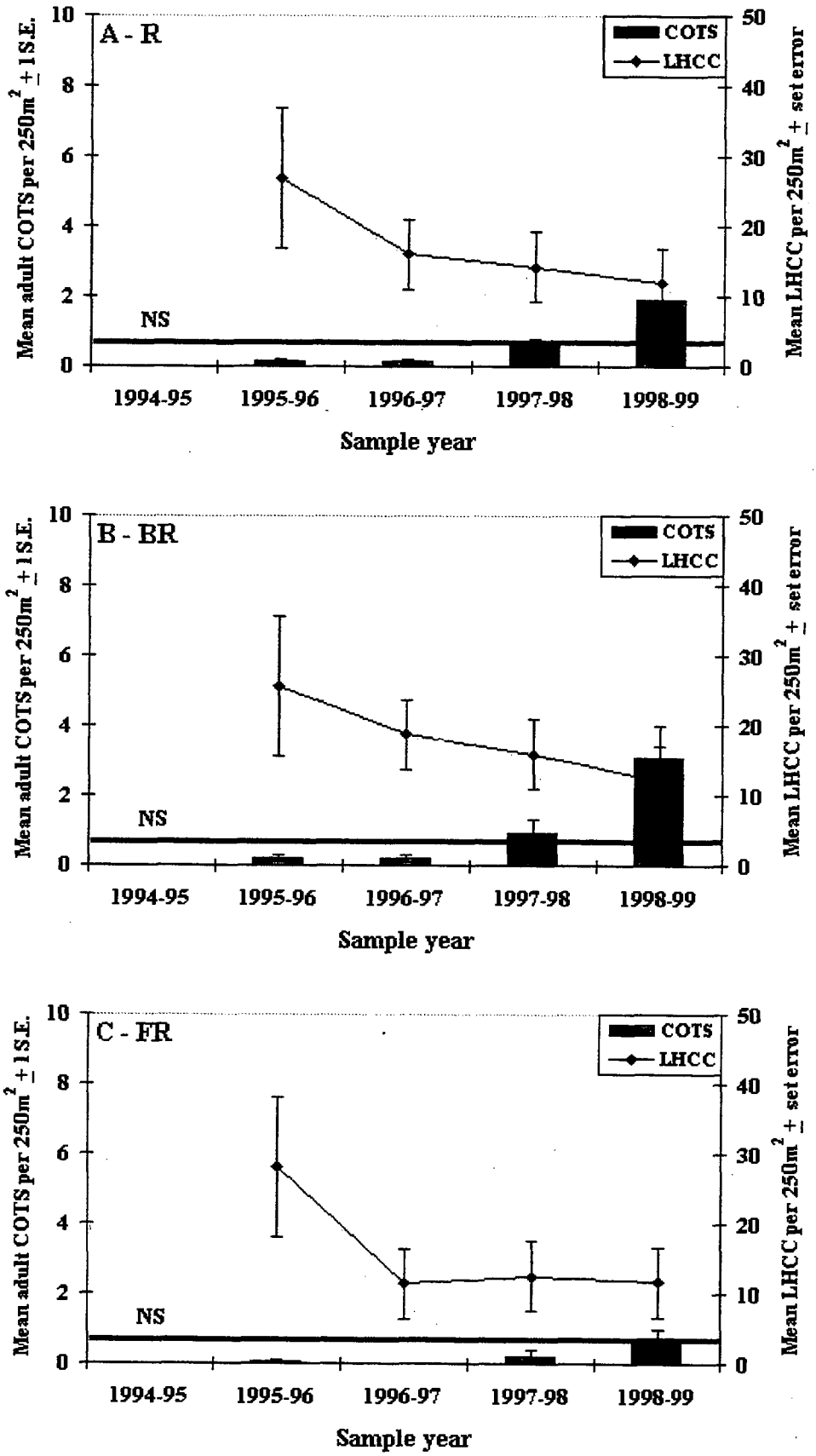


Figure 3.16.2 (A-C): Reef 17-034 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

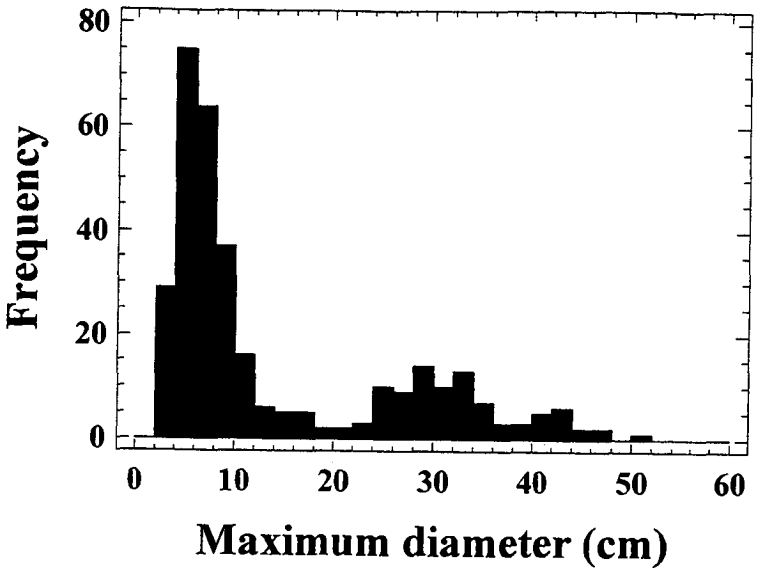


Figure 3.16.3: Size-frequency plot of *A. planci* observed at Reef 17-034 in March 1999.

Summary

The first signs of unsustainable densities of *A. planci* developing on Feather Reef (17-034) were recorded in 1997-98 when our surveys detected an Incipient Spot Outbreak (ISO) in the back reef zone of this reef. As predicted, an Active Spot Outbreak (ASO) developed in this zone within the 12-months period following our surveys.

The 1998-99 surveys detected unsustainably high densities of juvenile starfish in both reef zones. The front reef zone is now classified as a possible Future Spot Outbreak (FSO) suggesting that outbreaking densities may also develop in this zone within the next 18-24 months. The current Active Spot Outbreak (ASO) in the back reef zone is likely to intensify over the next 12 to 24 months as both sub-adult and juvenile starfish grow and approach maturity.

These latest results show a continuation of the gradual increases in starfish density and activity since the first survey in 1995-96. The initial slight increases in starfish population densities have been mirrored by correspondingly slight decreases in live hard coral cover, particularly in the back reef zone. However, our most recent survey results now suggest that both starfish densities and hard coral cover will both undergo more rapid population changes in the near future.

Figure 3.17: Eddy Reef (17-047)

Figure 3.17.1: Aerial photograph of Eddy Reef (17-047) with white dots indicating the approximate locations of the 20 sites surveyed in March 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	NO	NS
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	2.60±0.73 (52)	0.55±0.22 (11)	5.10±2.47 (102)	ASO
Front Reef (FR)	7.80±1.83 (156)	2.05±0.55 (41)	8.40±2.81 (168)	ASO
Entire Reef (R = BR & FR)	5.20±1.06 (208)	1.30±0.32 (52)	6.75±1.86 (270)	AO

Table 3.17 (A-B): Summary of reef status classifications for Reef 17-047 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

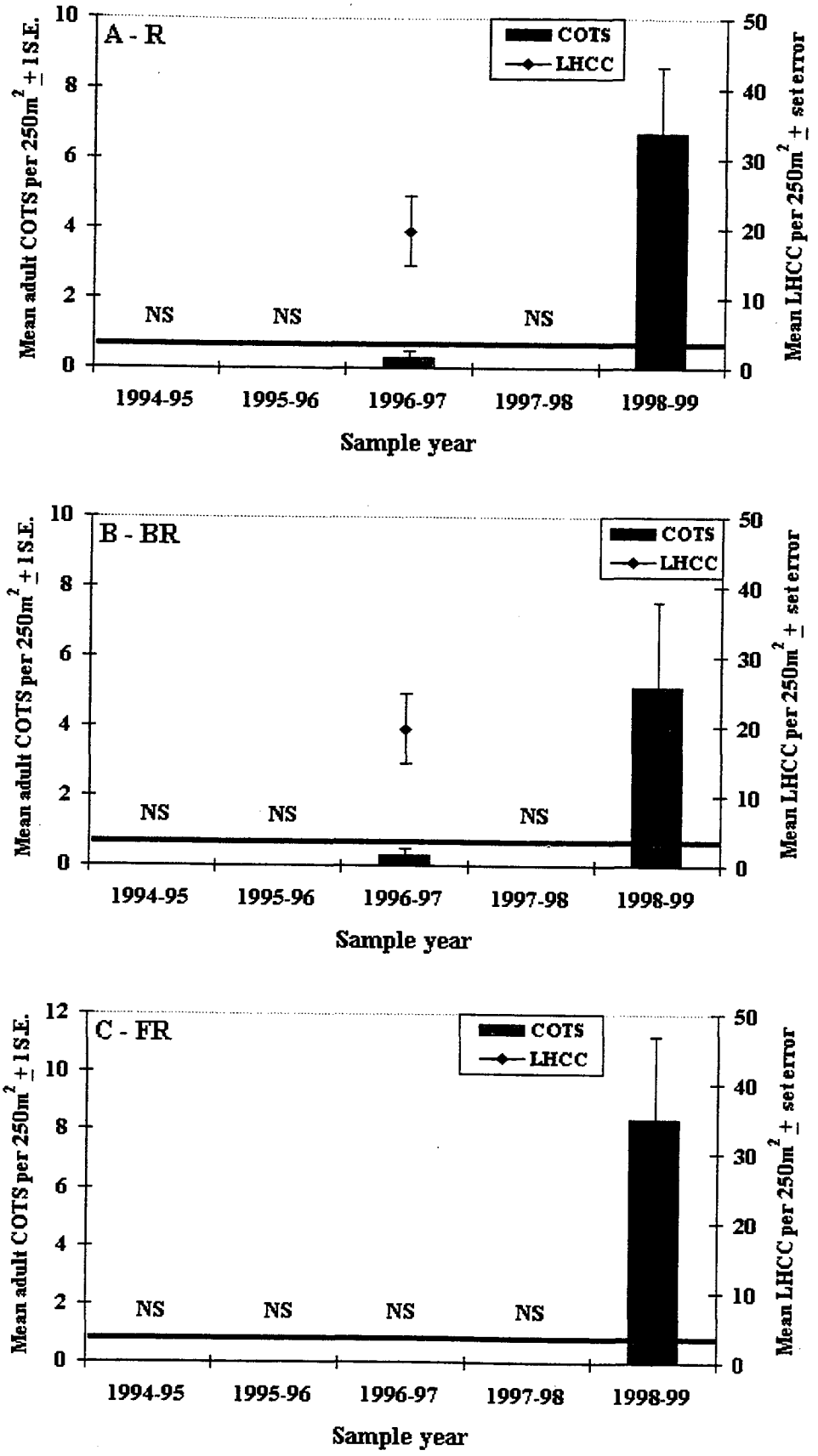


Figure 3.17.2 (A-C): Reef 17-047 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

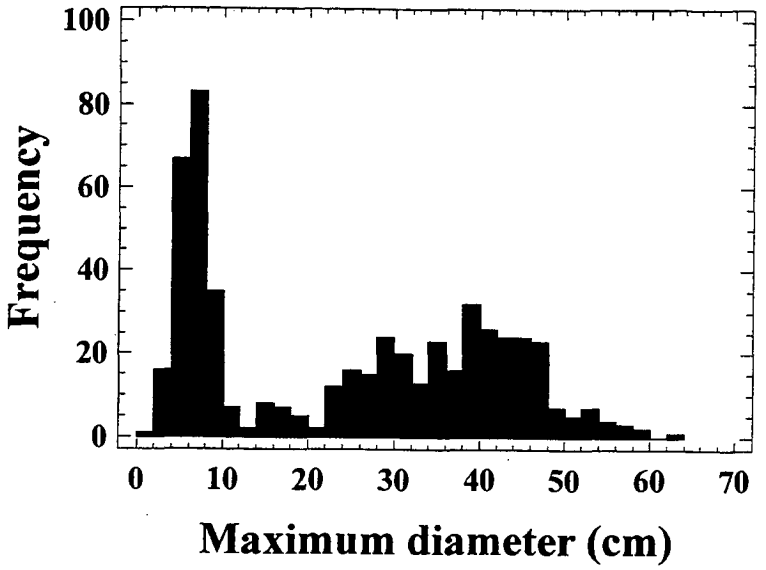


Figure 3.17.3: Size-frequency plot of *A. planci* observed at Reef 17-047 in March 1999.

Summary

The 1998-99 surveys mark the first time that both the protected back reef zone as well as the exposed front reef zone at Eddy Reef (17-047) had been surveyed. Previously, the back reef zone only had been surveyed - once back in 1996-97.

Eddy Reef currently supports an Active reef-wide Outbreak (AO) with densities of adult *A. planci* being the highest of any of the reefs surveyed in 1998-99. Average numbers of adult starfish recorded in the front reef zone were more than 10 times above sustainable levels.

As a consequence of starfish feeding activity, live hard coral cover (LHCC) in both reef zones has declined to between 5 and 10% remaining cover. The combined feeding activities of the unsustainably high adult and juvenile populations observed are likely to further impact on the remaining hard coral cover.

Figure 3.18: Taylor Reef (17-064)

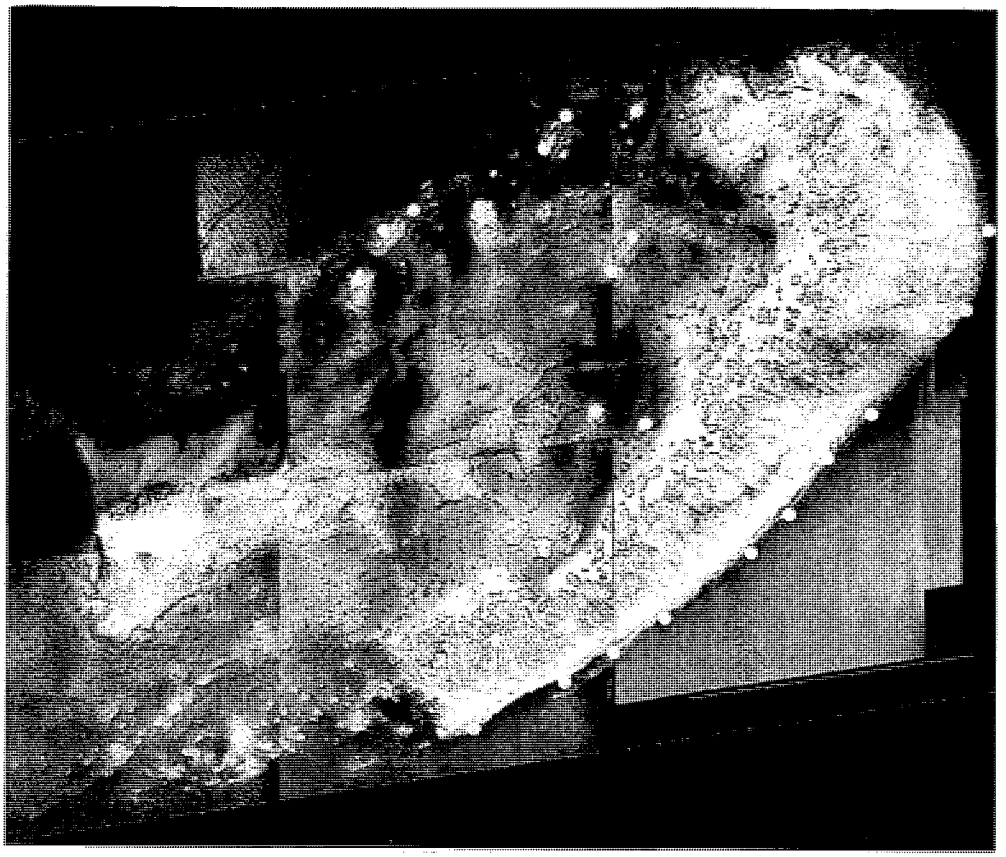
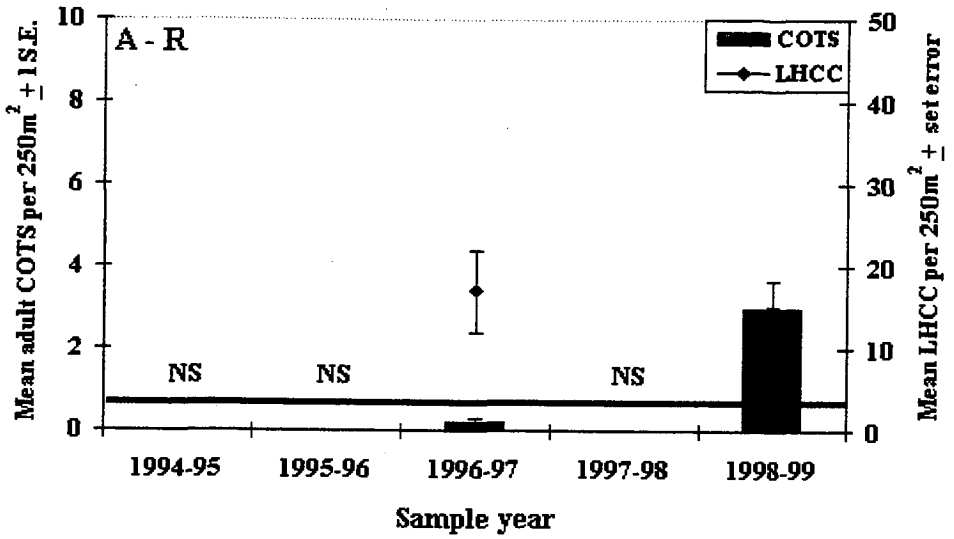
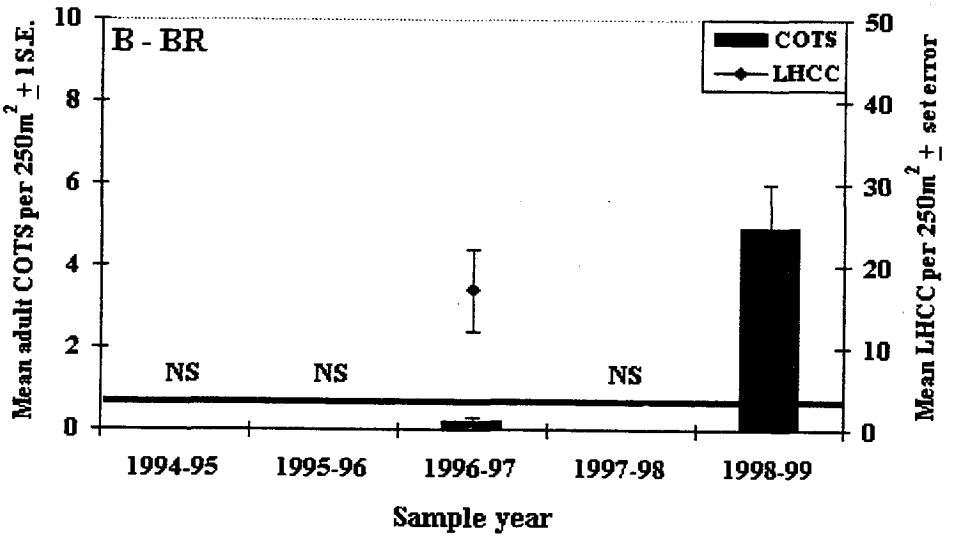


Figure 3.18.1: Aerial photograph of Taylor Reef (17-064) with white dots indicating the approximate locations of the 20 sites surveyed in March 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	NO	NS
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	5.85±1.60 (117)	0.95±0.40 (19)	4.95±1.06 (99)	ASO
Front Reef (FR)	8.80±1.44 (176)	0.90±0.39 (18)	1.05±0.44 (21)	ISO
Entire Reef (R = BR & FR)	7.33±1.09 (293)	0.93±0.28 (37)	3.00±0.65 (120)	ASO(BR) ISO(FR)

Table 3.18 (A-B): Summary of reef status classifications for Reef 17-064 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





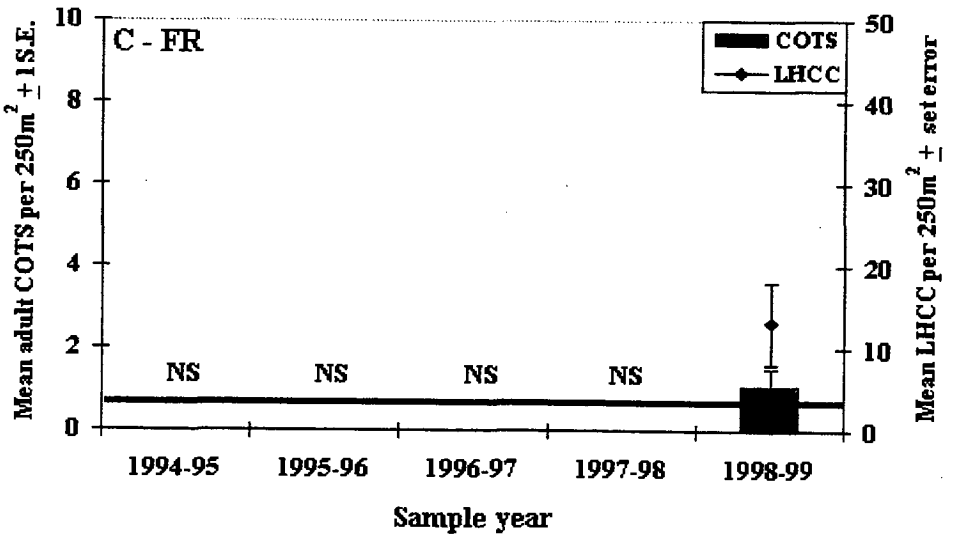


Figure 3.18.2 (A-C): Reef 17-064 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

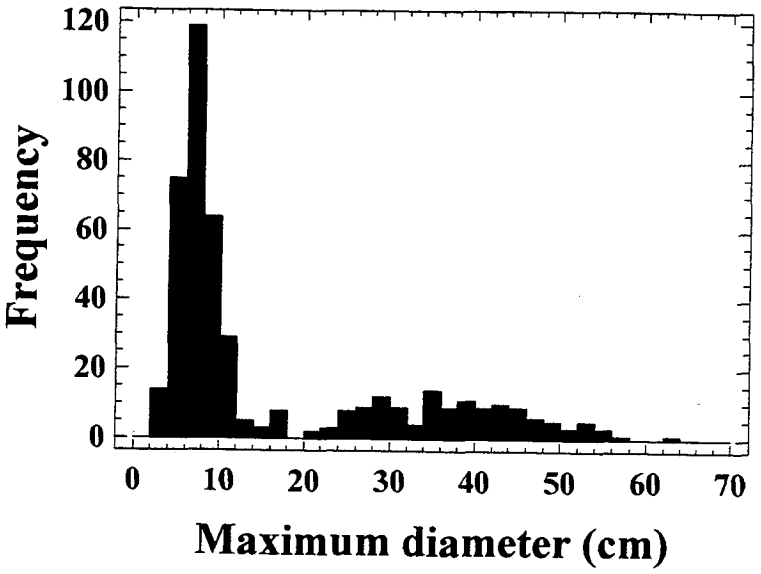


Figure 3.18.3: Size-frequency plot of *A. planci* observed at Reef 17-064 in March 1999.

Summary

The 1998-99 surveys mark the first time that both the protected back reef zone as well as the exposed front reef zone at Taylor Reef (17-064) had been surveyed. Previously, the back reef zone only had been surveyed - once back in 1996-97.

The back reef zone at Taylor Reef currently supports an Active Spot Outbreak (ASO) with densities of adult *A. planci* recorded as being more than 6 times above sustainable levels.

As a consequence of starfish feeding activity, live hard coral cover (LHCC) in the back reef zone has declined to 5-10% cover, down from approximately 15-20% recorded in 1996-97. The combined feeding activities of the unsustainably high adult and juvenile populations of *A. planci* observed at Taylor Reef in 1998-99 are likely to further impact on the remaining hard coral cover.

Figure 3.19: Little Kelso Reef (18-031)

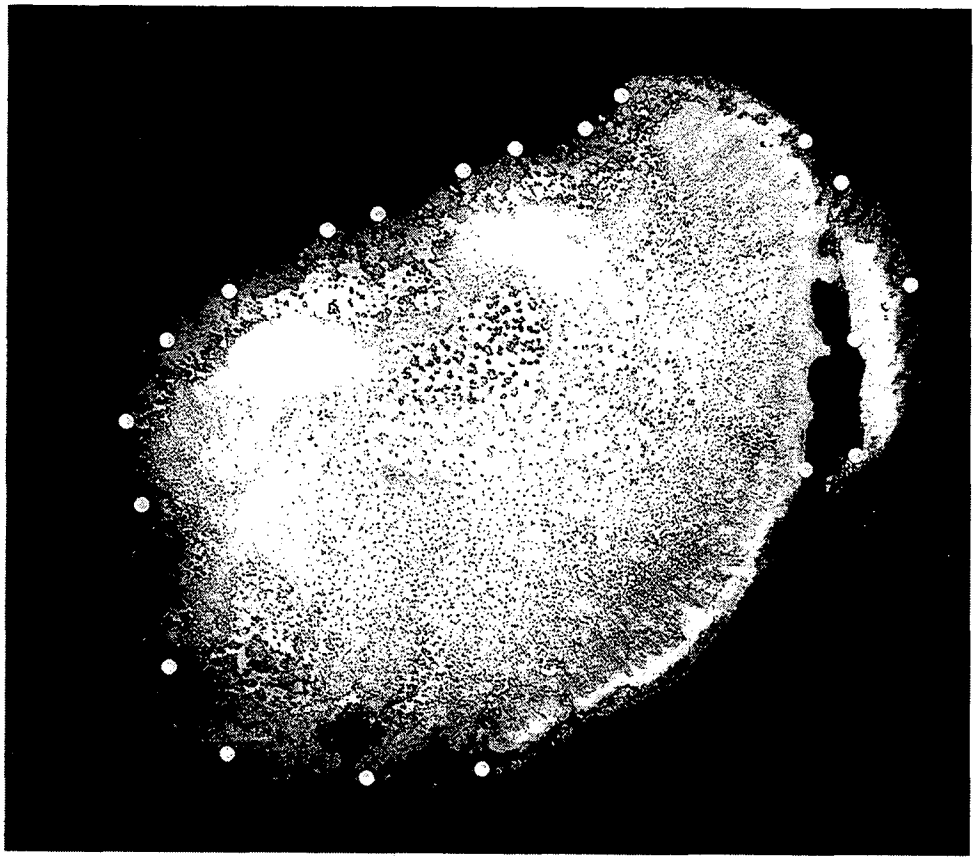


Figure 3.19.1: Aerial photograph of Little Kelso Reef (18-031) with white dots indicating the approximate locations of the 20 sites surveyed in April 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	NS	ASO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.10±0.07 (2)	0.30±0.18 (6)	1.30±0.19 (26)	ASO
Front Reef (FR)	0.90±0.29 (18)	0.30±0.15 (6)	1.30±0.89 (26)	NO
Entire Reef (R = BR & FR)	0.50±0.16 (20)	0.30±0.11 (12)	1.30±0.45 (52)	ASO(BR)

Table 3.19 (A-B): Summary of reef status classifications for Reef 18-031 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.

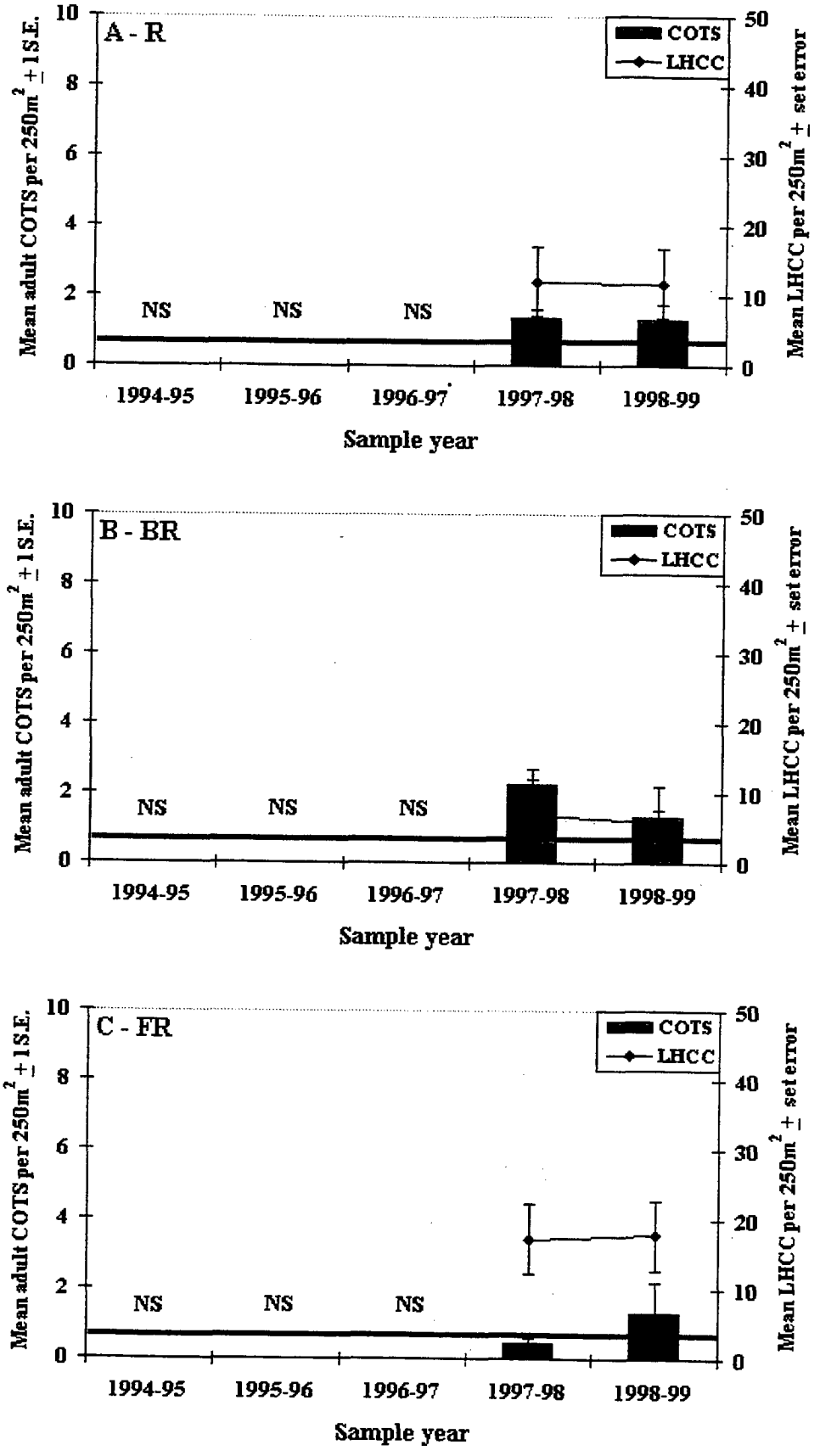


Figure 3.19.2 (A-C): Reef 18-031 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

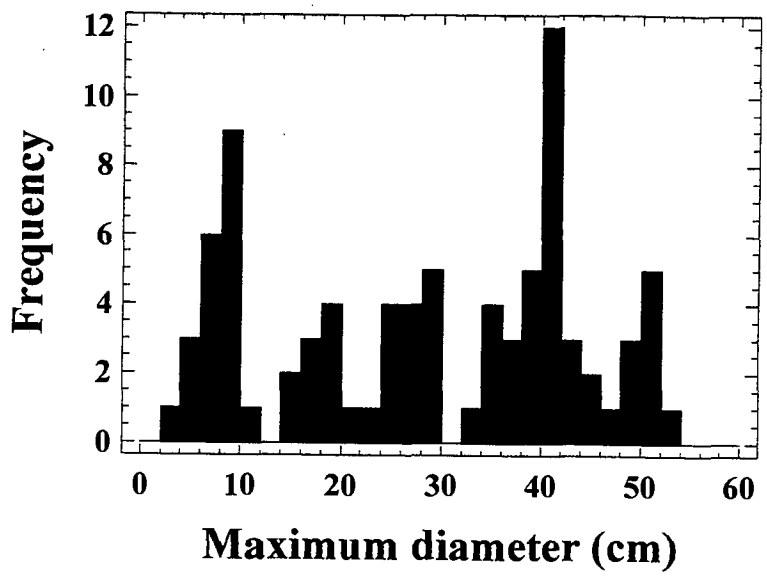


Figure 3.19.3: Size-frequency plot of *A. planci* observed at Reef 18-031 in April 1999.

Summary

Little Kelso Reef (18-031) was first surveyed in 1997-98 when an Active Spot Outbreak (ASO) was recorded in the back reef zone. Whilst the density of adult *A. planci* has marginally declined, the back reef zone remains classified as actively outbreaking. Live hard coral cover (LHCC) also remains low at around 5 to 10% cover.

The adult starfish population in the front reef zone has increased slightly, however, it remains below outbreaking density at this stage. The juvenile *A. planci* observed in this zone suggest that there is a potential for further increases in starfish density in the near future. The current live hard coral cover (LHCC) of around 15-20% is clearly sufficient for the latest cohort to grow and reach maturity.

Figure 3.20: John Brewer Reef (18-075)

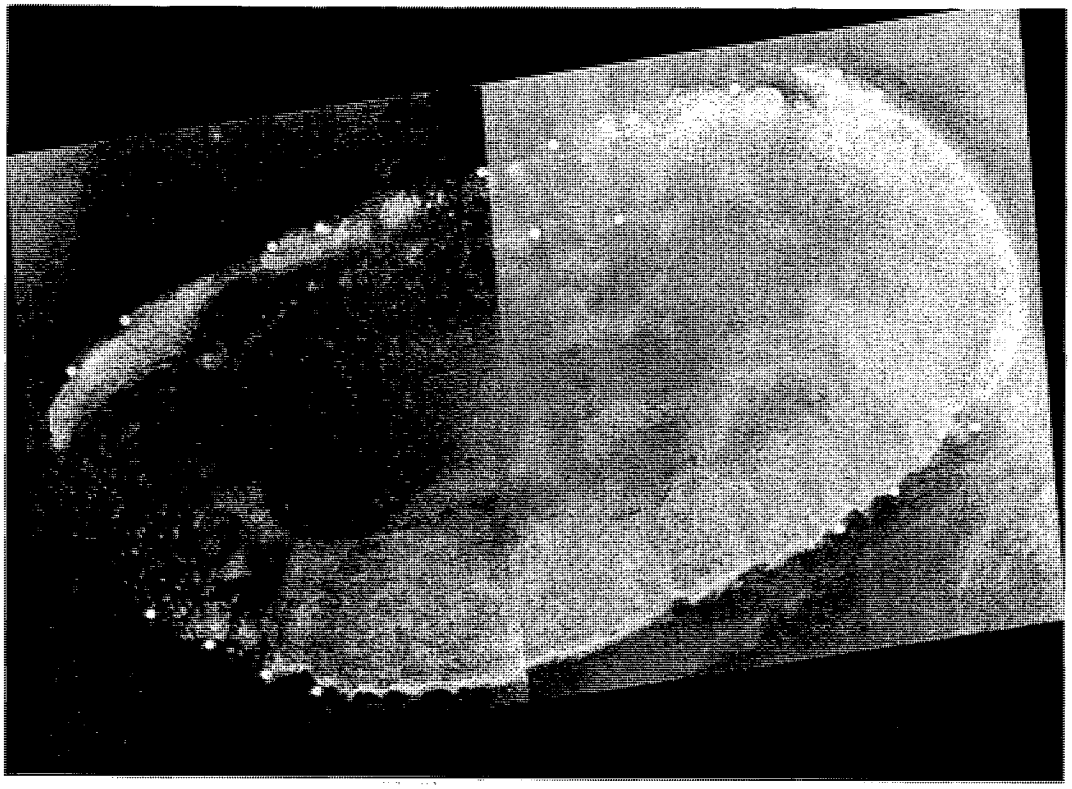
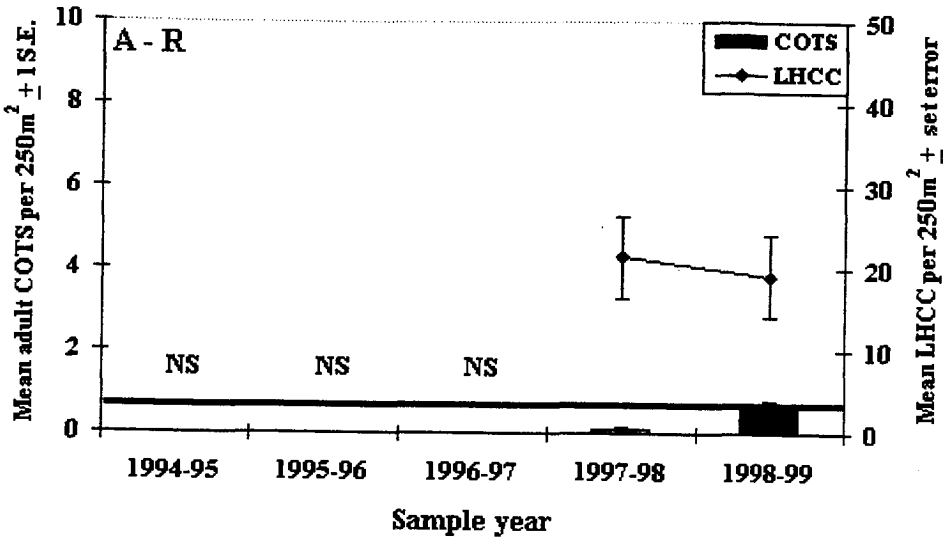
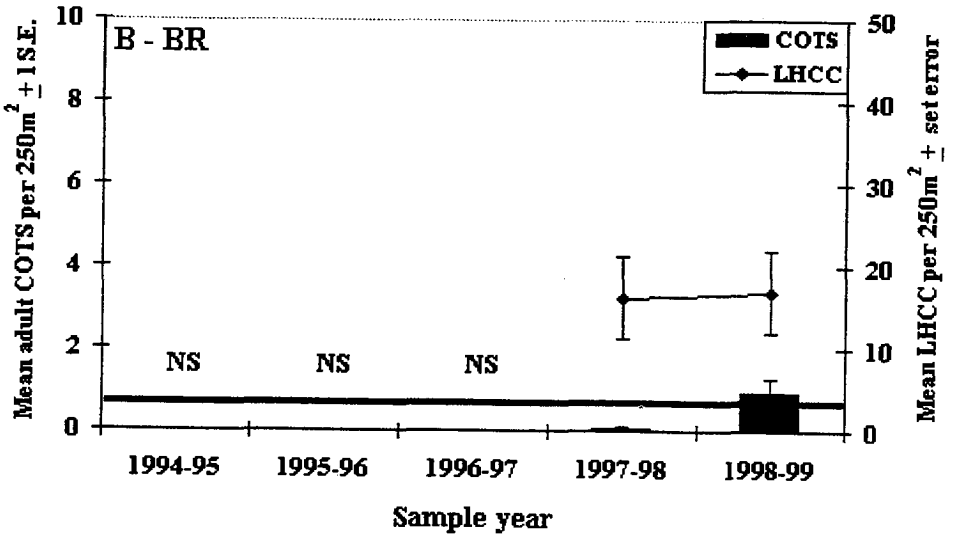


Figure 3.20.1: Aerial photograph of John Brewer Reef (18-075) with white dots indicating the approximate locations of the 20 sites surveyed in April 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	NS	NO
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.20±0.12 (4)	0.10±0.07 (2)	0.95±0.26 (19)	NO
Front Reef (FR)	0.75±0.23 (15)	0.20±0.12 (4)	0.25±0.14 (5)	NO
Entire Reef (R = BR & FR)	0.48±0.13 (19)	0.15±0.07 (6)	0.60±0.18 (24)	NO

Table 3.20 (A-B): Summary of reef status classifications for Reef 18-075 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





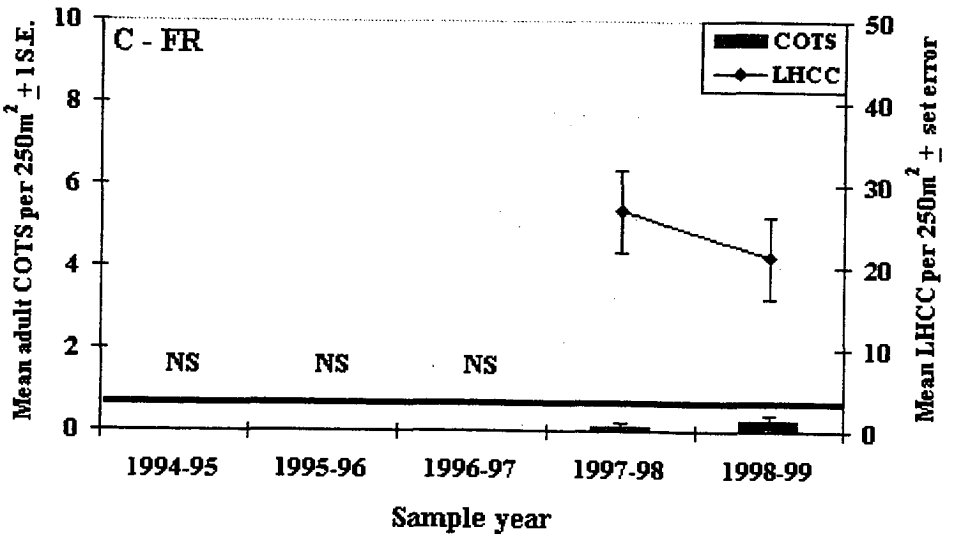


Figure 3.20.2 (A-C): Reef 18-075 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

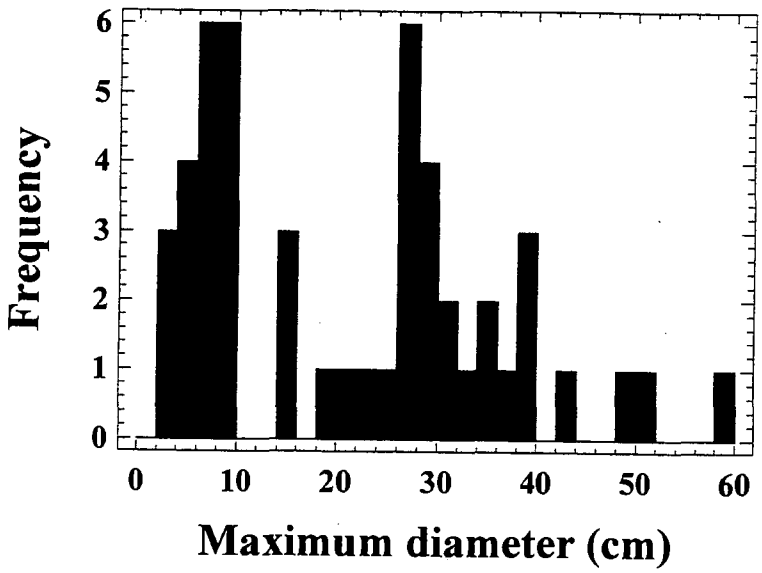


Figure 3.20.3: Size-frequency plot of *A. planci* observed at Reef 18-075 in April 1999.

Summary

John Brewer Reef (18-075) was first surveyed in 1997-98 when little starfish activity was evident. Whilst the density of adult *A. planci* has marginally increased in both the back and front reef zone, the reef remains classified as Non - Outbreaking (NO). Live hard coral cover (LHCC) across the reef has also remained relatively stable at around 20% cover.

However, the juvenile *A. planci* observed in the front reef zone and to a lesser degree in the back reef zone suggest that there may be some potential for further increases in starfish density in the near future. The current live hard coral cover (LHCC) of around 20% is clearly sufficient for the latest cohort to grow and reach maturity.

Figure 3.21: Lodestone Reef (18-078)

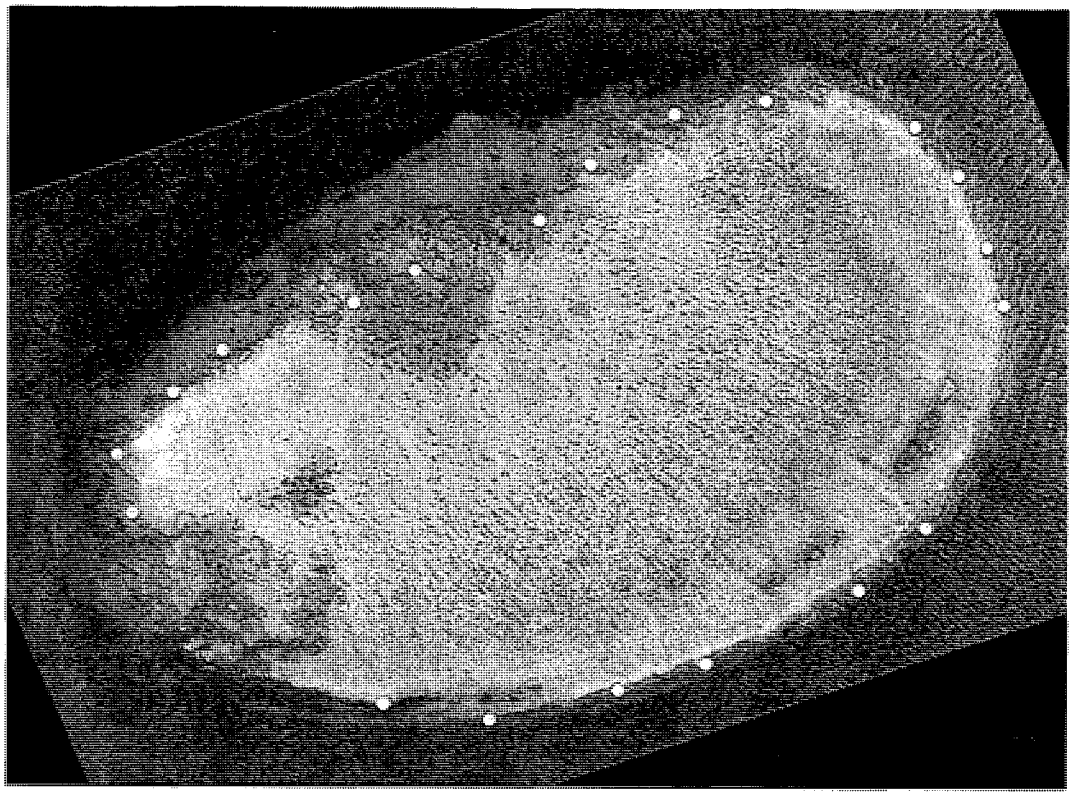
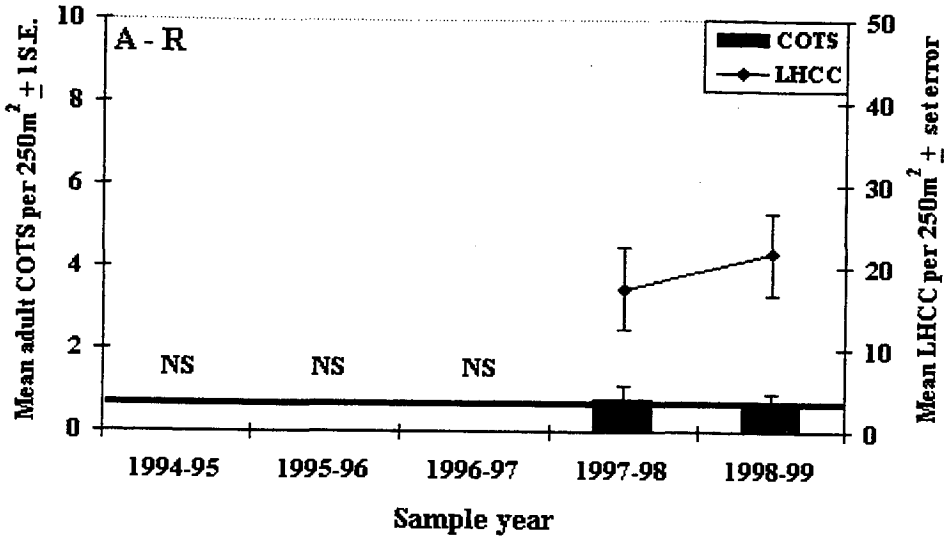
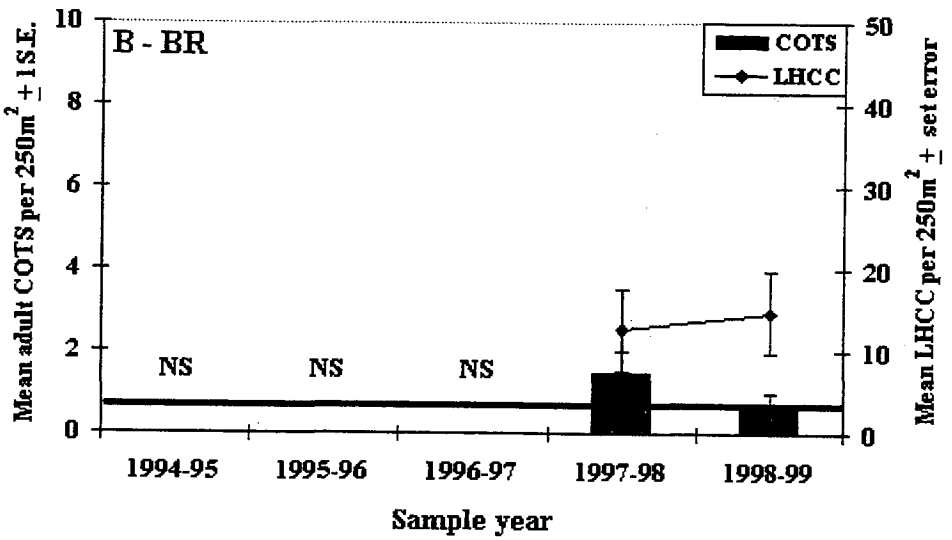


Figure 3.21.1: Aerial photograph of Lodestone Reef (18-078) with white dots indicating the approximate locations of the 20 sites surveyed in April 1999.

A - Sample year	1994-95	1995-96	1996-97	1997-98
Reef status	NS	NS	NS	ASO(BR)
B - 1998-99 Sample area	**Juveniles (est. age 1)**	**Sub-adults (est. age 2)**	**Adults (est. age 3 or older)**	**Reef status 1998-99**
Back Reef (BR)	0.10±0.07 (2)	0.00±0.00 (0)	0.70±0.26 (14)	PSO
Front Reef (FR)	1.55±0.38 (31)	0.80±0.32 (16)	0.80±0.31 (16)	NO
Entire Reef (R = BR & FR)	0.83±0.22 (33)	0.40±0.17 (16)	0.75±0.20 (30)	PSO(BR)

Table 3.21 (A-B): Summary of reef status classifications for Reef 18-078 since 1994-95 (A) and mean densities (±1 S.E.) per 250 m^2 of estimated age classes of *A. planci* across reef zones in 1998-99 (B). Values shown in brackets are total *A. planci* counts.





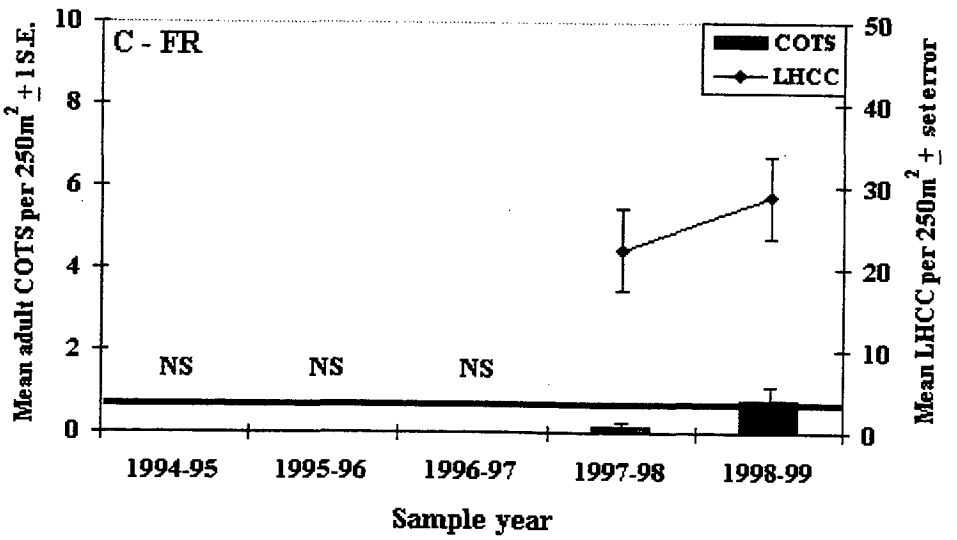


Figure 3.21.2 (A-C): Reef 18-078 - Recent trends in the mean number of adult COTS (estimated age of 3 years or older) and mean live hard coral cover (LHCC) across the entire reef (A-R), in the back reef zone (B-BR) and in the front reef zone (C-FR). The line at 0.75 adult COTS per 250 m^2 indicates the upper limit of a sustainable, non-outbreaking population.

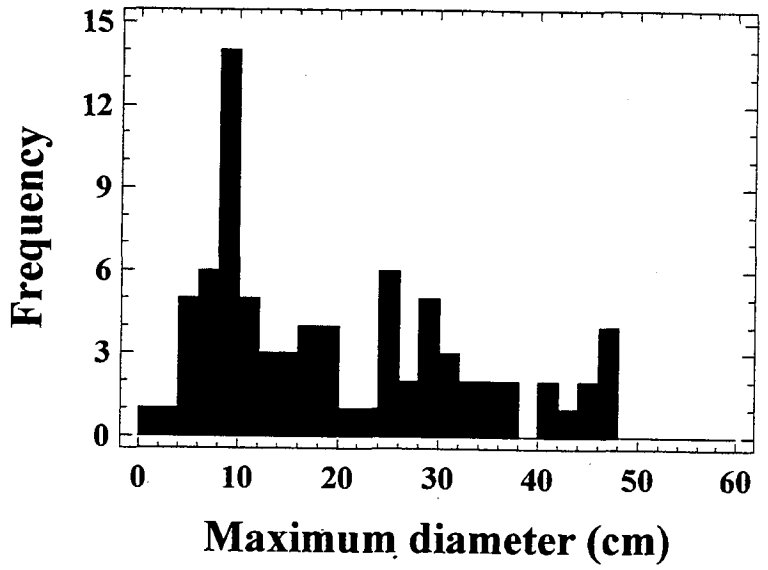


Figure 3.21.3: Size-frequency plot of *A. planci* observed at Reef 18-078 in April 1999.

Summary

Lodestone Reef (18-078) was first surveyed in 1997-98 when an Active Spot Outbreak (ASO) was recorded in the back reef zone. The density of adult *A. planci* in this zone has now declined to below outbreaking densities. Live hard coral cover (LHCC) in the back reef zone has remained at around 15% cover.

However, the population of both adult and juvenile starfish population recorded in the front reef zone has increased significantly. Whilst the adult population remains just below outbreaking density, the numbers of juvenile *A. planci* observed in this zone suggest that there is a potential for further increases in starfish density in the near future. As the current live hard coral cover (LHCC) in the front reef zone is approaching 30%, available coral resources are clearly sufficient for the latest starfish cohort to grow and reach maturity.

3.3 Differences in the abundance of *A. planci* across 3 spatial scales

3.3.1 Regional-scale (latitudinal) differences in the abundance of *A. planci*

We detected significant regional differences in the median abundance of all three age classes of *A. planci*. Table 4 provides an overview of the statistics calculated in identifying these latitudinal differences.

Latitudinal band (LAT_BAND)	**Sample size (transects)**	**Average rank Juveniles (est. age 1)**	**Average rank Sub-adults (est. age 2)**	**Average rank Adults (est. age 3 or older)**
1 (14°31' - 16°00'S)	240	289.58	384.83	344.38
2 (16°01' - 17°30'S)	240	427.31	335.60	316.99
3 (17°31' - 19°00'S)	240	364.60	361.07	420.13
Test statistic	-	**54.50**	**10.57**	**43.91**
P - value	-	**0.00**	**0.005**	**0.00**

Table 4: Summary of Kruskal-Wallis statistics resulting from tests for significant differences in the median densities of estimated age classes of *A. planci* across three latitudinal bands sampled in 1998-99.

Median notches as shown on the relevant Box-and-Whisker plots (Figure 4) identify the existence of the following statistically significant differences in the abundance of the three estimated age classes of *A. planci* across the selected latitudinal bands:

For juvenile COTS: LAT_BAND 2 > LAT_BAND 3 > LAT_BAND 1,
For sub-adult COTS: (LAT_BAND 3 = LAT_BAND 1) > LAT_BAND 2,
For adult COTS: LAT_BAND 3 > (LAT_BAND 2 = LAT_BAND 1).

Adult starfish (est. age 3 or older) were significantly more abundant in latitudinal band 3 (on reefs located in the Innisfail to Townsville region) compared to the other two bands. There was also a more marginal yet statistically significant difference in the density of adult starfish between latitudinal bands 1 and 2, with adult densities in the northernmost region (band 1) higher than in the offshore Port Douglas / Cairns region (band 2).

Sub-adult starfish (est. age 2) on reefs located within latitudinal band 2 (offshore Port and Cairns) were less abundant here than in any of the other regions. Densities of sub-adult starfish differed only marginally between latitudinal bands 1 and 3. However, this difference was not statistically significant.

Juvenile starfish (est. age 1) were significantly more abundant on reefs within latitudinal band 2 (reefs located offshore Port Douglas and Cairns) than any of the other two bands. Reefs located in the Innisfail to Townsville region (latitudinal band 3) had significantly higher densities of juveniles than reefs in the northern region offshore Cooktown (latitudinal band 1).

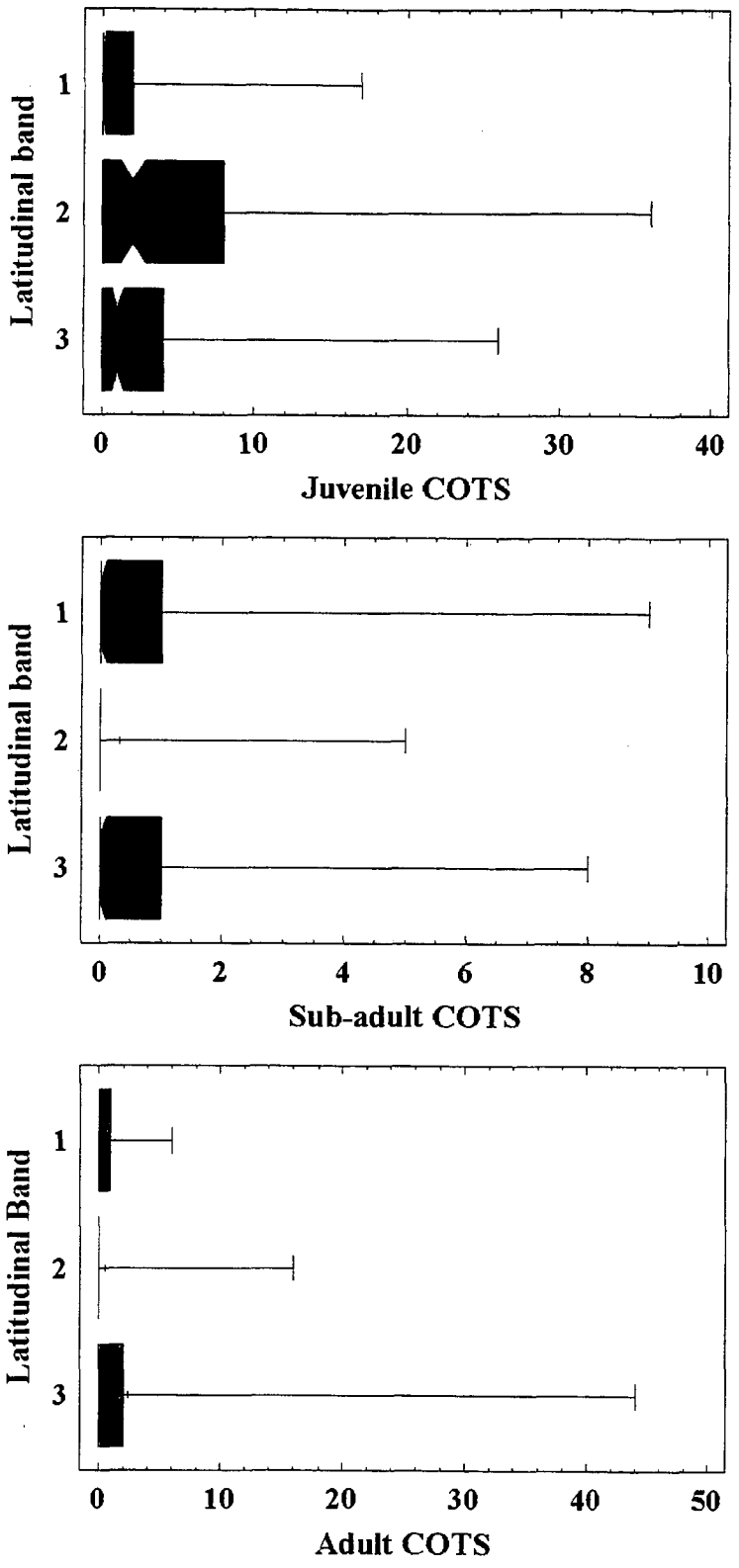


Figure 4: Box-and-Whisker plots showing density distributions of estimated age classes of *A. planci* across the three latitudinal bands surveyed in 1998-99. Notches were used to assess the significance of differences in median densities (Kruskal-Wallis tests). Plus (+) signs indicate the actual mean density for the respective age classes.

3.3.2 Reef-scale (local) differences in the abundance of *A. planci*

The analyses detected significant differences in the median abundance of *A. planci* at a local or between-reef scale for all three estimated age classes. In all cases, statistical differences were highly significant with P values ranging from 0.00 to <0.001. Table 5 provides an overview of the statistics calculated in identifying reef-scale differences. Median notches shown in Figure 5 again identify which sampling units (reefs) differ from which others.

Reef ID number	Sample size (transects)	Average rank Juveniles (est. age 1)	Average rank Sub-adults (est. age 2)	Average rank Adults (est. age 3 or older)
14-132b	40	279.46	358.94	241.74
15-019	40	222.66	396.08	411.08
15-024	40	270.33	363.34	389.70
15-070	40	345.60	400.33	370.51
15-084	40	337.10	430.13	375.29
15-095	40	282.35	360.16	277.99
16-023	40	495.06	365.89	332.59
16-024	40	362.09	272.13	304.86
16-057	40	378.05	324.63	301.39
16-060	40	543.23	395.13	324.56
16-068	40	413.59	301.05	265.53
17-004	40	371.86	354.81	373.03
17-034	40	484.28	395.55	422.29
17-047	40	444.69	445.93	499.66
17-064	40	503.51	382.36	475.65
18-031	40	240.60	321.30	433.80
18-075	40	244.11	298.38	334.88
18-078	40	270.44	322.90	354.48
Test statistic	-	**178.61**	**54.40**	**108.97**
P -value	-	**0.00**	**<0.001**	**0.00**

Table 5: Summary of Kruskal-Wallis statistics resulting from tests for significant differences in the median densities of three estimated age classes of *A. planci* across individual survey reefs sampled in 1998-99.

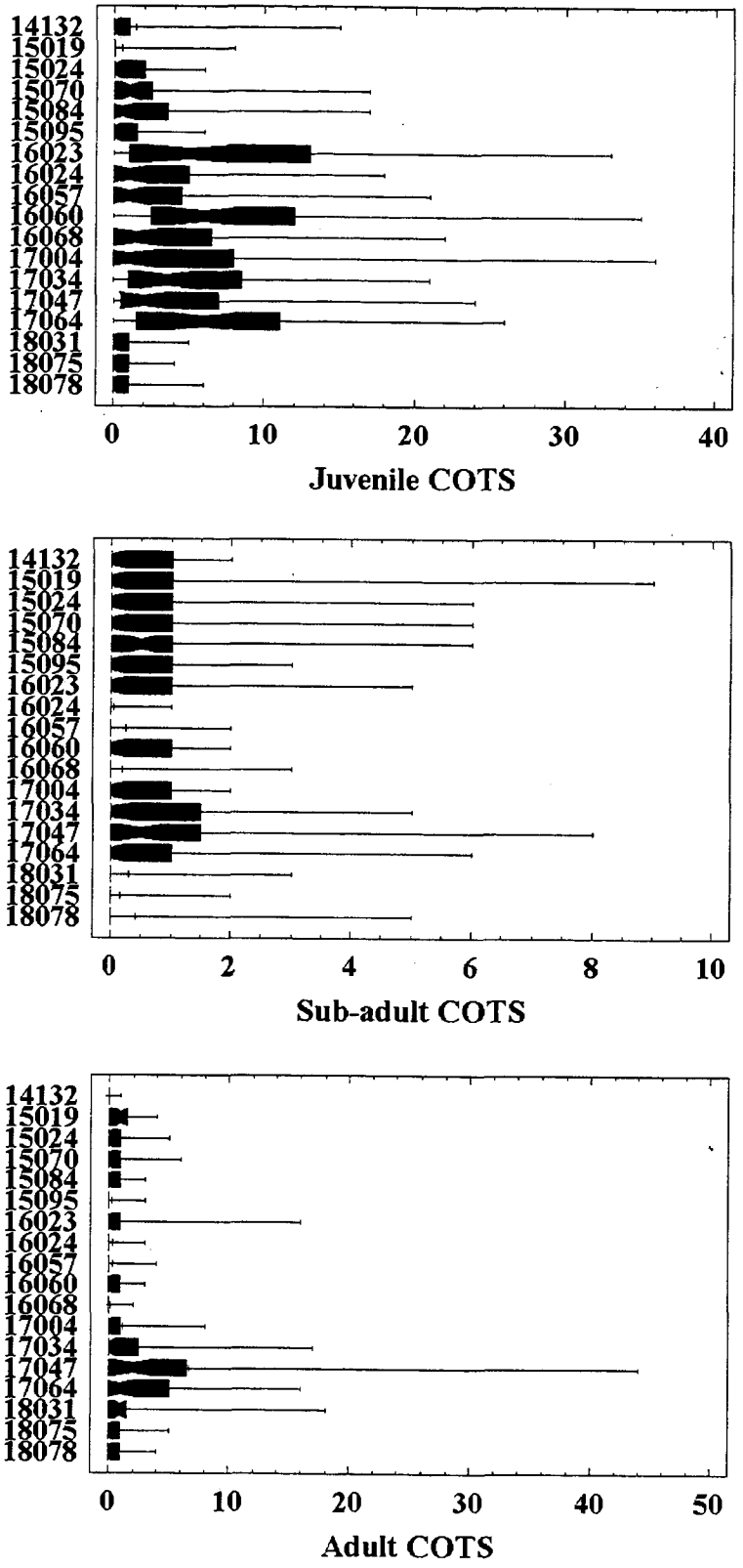


Figure 5: Box-and-Whisker plots showing density distributions of estimated age classes of *A. planci* across individual reefs surveyed in 1998-99. Notches were used to assess the significance of differences in median densities (Kruskal-Wallis tests). Plus (+) signs indicate the actual mean density for the respective age classes at the reef scale.

3.3.3 Within-reef-scale (zonal) differences in the abundance of *A. planci*

Kruskal-Wallis analyses detected statistically significant differences in the median abundance of all three estimated age classes of *A. planci* at the within-reef (zonal) scale. Table 6. provides an overview of the test statistics resulting from these analyses.

Within-reef scale (zonal)	**Sample size (transects)**	**Average rank Juveniles (est. age 1)**	**Average rank Sub-adults (est. age 2)**	**Average rank Adults (est. age 3 or older)**
Back reef zone (BR)	360	283.75	339.00	407.50
Front reef zone (FR)	360	437.25	382.00	313.50
Test statistic	-	**108.71**	**12.09**	**50.98**
P - value	-	**0.00**	**0.0005**	**0.00**

Table 6: Summary of Kruskal-Wallis statistics resulting from tests for significant differences in the median densities of three estimated age classes of A. planci across within-reef zones sampled in 1998-99.

Figure 6 graphically illustrates the identified significant within-reef patterns of abundance. Zonal differences were most pronounced for juvenile starfish where significantly higher densities of individuals were found in the exposed front reef zone (FR) compared to the protected back reef zone (BR) ($P = 0.00$). The reverse was true for adult starfish with the protected back reef zone (BR) having significantly higher median densities ($P = 0.00$). Zonal differences also existed for sub-adult starfish which were significantly more abundant within the exposed front reef zone (FR) ($P < 0.001$).

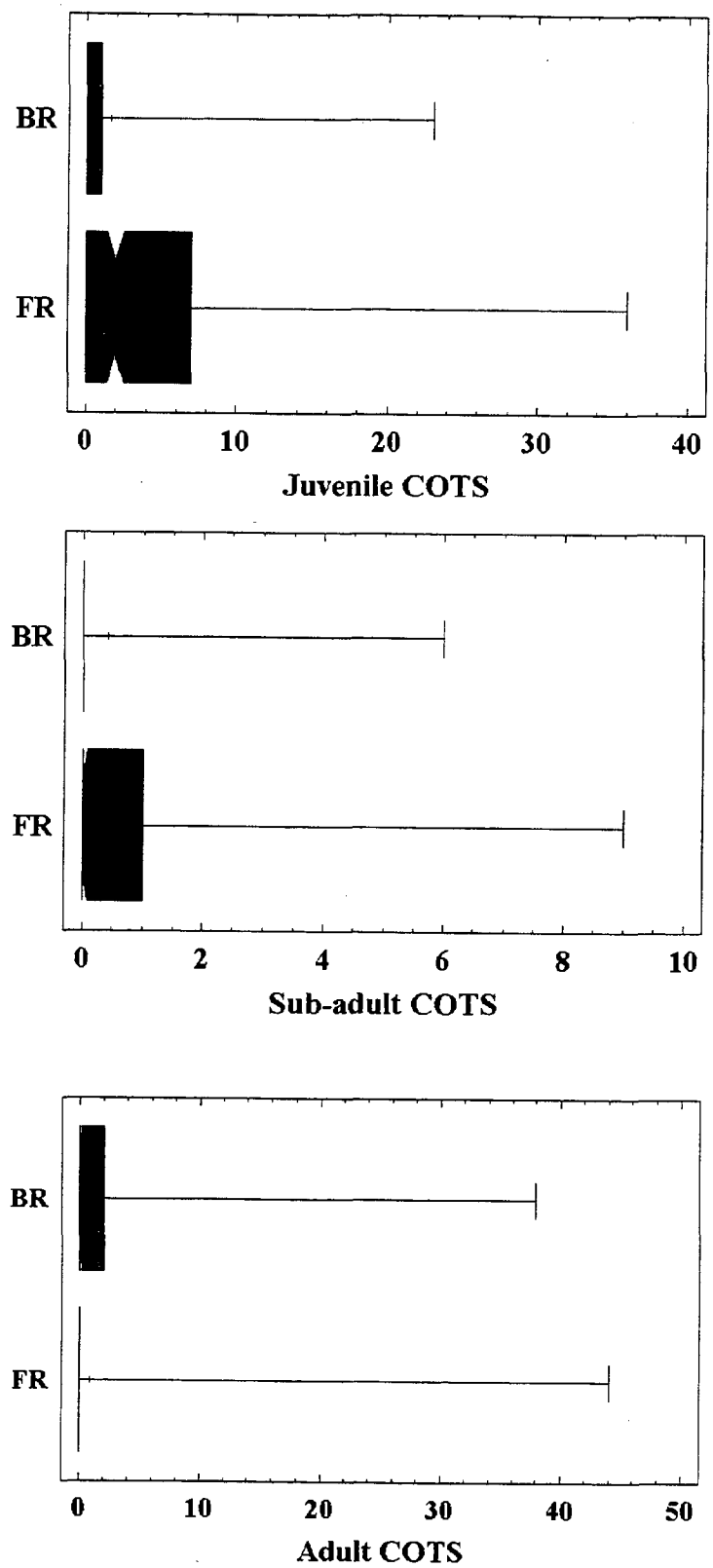


Figure 6: Box-and-Whisker plots showing density distributions of estimated age classes of *A. planci* across two different reef zones. Notches were used to assess the significance of differences in median densities (Kruskal-Wallis tests). Plus (+) signs indicate the actual mean density for the respective age classes at the zonal scale.

4. DISCUSSION

4.1 Latitudinal and reef-scale patterns of distribution and abundance

Densities of juvenile *A. planci* (estimated age 1) observed on many of the reefs surveyed in 1998-99 were at their highest level since the initiation of the fine-scale survey program in 1994-95. Furthermore, comparable densities of small crown-of-thorns starfish have never before been recorded by any other sampling or monitoring program within the Great Barrier Reef region. It is certain that, due to the highly cryptic behaviour of small starfish, our calculated relative densities are in fact considerable underestimates, with 'true' density values likely to be much higher. The average density of juvenile starfish across all reefs and transects was found to be 13.75 times higher than the previous highest density recorded in 1995-96. However, the two sets of reefs surveyed in those years were not totally identical. Hence, the actual magnitude of the observed differences in juvenile abundance between individual survey years could be subject to some inherent bias. However, as the observed difference is greater than one order of magnitude that there can be little doubt about the significant nature of the 1997-98 recruitment pulse of *A. planci.*

Our findings strongly suggest that the 1997-98 summer spawning season of *A. planci* is likely to have been characterised by environmental conditions highly favourable for successful reproduction and recruitment. Conditions favouring reproductive success are likely to have occurred over a wide geographic area spanning at least three degrees of latitude from approximately 14°30' to 17°50'S.

The fact that such significant and possibly unsustainable densities of juvenile starfish were recorded points to a high probability of further population increases throughout much of the survey area within the foreseeable future. In the absence of any catastrophic mortality events (i.e. outbreak of major disease), there is a high likelihood of new active *A. planci* outbreaks developing within the next 18 to 24 months. The highest probability of this occurring is on reefs located within the latitudinal band from 16°00' to 17°30'S that includes the area from offshore Port Douglas, Cairns down to offshore Innisfail.

Unsustainably high juvenile densities were found in reef areas mostly unaffected by recent outbreaks but also in areas that had already suffered significant starfish-induced coral mortality over recent years. In areas with low remnant live hard coral cover (<10% LHCC) we noted an obvious preference of juvenile starfish for feeding on the smallest most recently recruited hard

corals. These observations suggest that this latest starfish cohort has the potential to significantly impact on the onset and progress of the coral recovery phase on these reefs. Whilst current levels of hard coral cover in such areas may be considered insufficient for starfish to reach full size and maturity there remains a strong potential for further detrimental effects on the already depleted coral resources on these reefs.

On reefs with relatively higher average coral cover (>10%) juvenile cohorts are more likely to successfully grow and reach maturity within the next 18 to 24 months. Recent observations suggest that the 1997-98 cohort is currently in an exponential growth phase with average body diameter having increased from approximately 2 to 3 cm measured in October 1998 to an average size of about 12 to 13 cm as recorded in May 1999 (Engelhardt, unpublished data). These size measurements correspond closely with published data on growth rates of *A. planci* observed in both field and laboratory environments (Yamaguchi 1974, Zann 1987).

Field investigations into natural mortality levels in juvenile and sub-adult populations of *A. planci* have shown that mortality rates drop off rapidly with increasing size of the starfish (Keesing and Halford 1992, Sweatman 1995). Natural mortality rates of starfish in the 12-13 cm size range or larger are typically very low further supporting our prediction that densities of sub-adult starfish are likely to rise on many survey reefs in the near future.

If these projections were to prove correct, then renewed *A. planci* outbreaks in the Port Douglas to Cairns region would have developed within just a few years of the previous outbreak peak that was observed in this region between late 1995 and early 1998 (Engelhardt *et. al.* 1997). This would indicate a possible shift away from the previously recorded outbreak cyclicity of 15 to 17 years (Moran *et al.* 1992), with possible serious implications for reef recovery and long-term sustainability of outbreak episodes. However, it is possible that similar large-scale events may in fact have occurred in the past but went unnoticed as a result of the use of monitoring techniques that were unable to reliably record the early signs of major recruitment pulses of *A. planci*.

Whilst dedicated fine-scale surveys were only conducted on mid-shelf reefs, there is now reliable evidence that both outer- and inner-shelf reefs in the Cairns Section of the Marine Park have also been affected by the strong 1997-98 recruitment pulse of *A. planci*. A number of site-specific surveys of key reef tourism sites conducted by the senior author between April and June 1999 detected unsustainably high populations of juvenile starfish on outer-shelf reefs such

as Opal Reef (off Port Douglas) as well as inner-shelf reefs such as Normanby Island Reef (south of Cairns). Anecdotal reports provided by other Reef-users also suggest that starfish densities are increasing in the Agincourt Reef complex offshore Port Douglas as well as in the area around Norman Reef offshore Cairns (Engelhardt, unpublished data).

As the ultimate cause of *A. planci* outbreaks on the GBR remains unknown, we suggest that the observed cyclicity and the possible changes indicated in this study, need to be investigated further. This is particularly important as our results show the possibility of a significant shortening in outbreak cyclicity with possible serious implications for the ecological sustainability of hard coral cover in this part of the Great Barrier Reef.

4.2 Within-reef (zonal) patterns of abundance

Significantly more juvenile starfish (est. age 1, 1997-98 recruits) were recorded in the exposed front reef zone compared to the more sheltered back reef zone. This finding is in line with results of previous studies (Laxton 1974, Moran *et al.* 1985). Juvenile *A. planci* have been found across the various reef front environments from shallow reef flats (Zann *et. al.* 1987, 1990) down to deep slopes (Pearson and Endean 1969, Yokochi and Ogura 1987, Doherty and Davidson 1988). We also recorded juvenile *A. planci* on front reef slopes at depths of between 0.5 and 15 metres. However, it remains unclear whether or not the observed within-reef patterns of distribution of juvenile starfish are the result of (i) settlement preferences of actively searching *A. planci* larvae for exposed front reef zones, (ii) passive larval dispersal controlled largely by reef-scale hydrodynamics (Black and Gay 1987, Black 1988), (iii) habitat-related differences in food availability (Yamaguchi 1973, Lucas 1975) or (iv) are a product of predator-induced differential mortality rates of early juvenile starfish.

In contrast, adult *A. planci* (est. age 3 and older) were significantly more abundant in the protected back reef zone. Again, this finding is entirely consistent with previous studies. Size-related increases in susceptibility to strong water movement and increased risk of dislodgment have been suggested as possible reasons why larger *A. planci* are more commonly found in sheltered areas (Ormond and Campbell 1971, Laxton 1974, Moran et al. 1985). While outbreaking populations may initially appear in exposed reef front environments (Pearson 1972, Endean 1976, Birkeland and Randall 1979, Moran *et al.* 1985), they may subsequently move into back reef areas (Laxton 1974, Kenchington 1976, Moran *et al.* 1985).

The apparent size-specific patterns of within-reef distribution have important implications for future monitoring studies. If the main objective is the early detection of developing outbreaks (*forecasting capability*), then it would appear that considerable effort should go into sampling reef front environments. In contrast, if the main objective is an assessment of past recruitment events on reefs (*hindcasting capability*), then back reef environments may provide a more complete insight into the probable age structure of resident starfish populations.

4.3 Conclusions and recommendations

Our survey results clearly demonstrate the capacity of intensive transect-based surveys to reliably detect the early signs of possible future outbreaks of crown-of-thorns starfish. The record numbers of small juvenile starfish recorded in 1998-99 provide a strong indication of possible renewed outbreaks likely to develop on many reefs in the Cairns Section of the GBR Marine Park over the next 18 to 24 months. As the identified cohort of small *A. planci* is not only the largest but also the geographically most widespread age class of young starfish recorded on the Great Barrier Reef to date there should be serious concern about their likely future impact on local and regional coral reef communities.

If renewed outbreaks develop within the predicted time frame, a second peak in *A. planci* activity would have affected reefs in the central GBR region within the space of only 4 to 5 years. Such a pattern would suggest a possible shift away from the previously observed 15 to 17 year cyclicity of outbreak episodes in this region. A significant shortening of cycle periodicity is likely to be unsustainable in the long term as hard coral communities on affected reefs would be left without sufficient time for complete recovery and regeneration. Such a scenario could result in an increased number of permanently degraded reef areas unable to recover from an increasingly chronic source of disturbance. As our survey area includes many reefs located directly offshore the Reef tourism centres of Port Douglas and Cairns, any such trends could have serious implications for the future operations of the regional tourism industry.

Efforts aimed at assessing possible indications of such trends and conditions should be given a high priority. Intensive fine-scale monitoring of *A. planci* and associated live hard coral cover should not only be continued but extended to maximise the chances of identifying possible signs of further reef degradation and reduced coral recovery rates in the study area in a timely manner.

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APPENDIX A

Overviews and summaries of individual survey reefs and their respective classifications with regard to outbreaks of *A. planci*.

Table 7: Overview of the respective status of individual reefs surveyed since 1994-95 using the *A. planci* fine-scale survey methodology. (*NB: Only reefs surveyed with funding from the CRC Reef Research Centre (CRC Reef) and the Great Barrier Reef Marine Park Authority (GBRMPA) as part of CRC Reef Task 1.6.1 are shown. Reasons for the deletion or addition of individual survey reefs from the annual sampling program are also stated).*

GBRMPA Reef ID	*Reef Name*	*Status 1994-95*	*Status 1995-96*	*Status 1996-97*	*Status 1997-98*	*Status 1998-99*
14-116	Lizard Island Reef[1]	AO	NS	NS	NS	NS
14-143	North Direction Reef[1]	ASO(BR)	AO	AO	NS	NS
14-132b	Rocky Islets Reef (b)	IO	AO	AO	AO	PO
14-133	U/N[2]	IO	AO	NS	AO	NS
15-019	Long Reef	ASO(BR)	AO	AO	ASO(BR) PSO(FR)	PO ISO(FR)
15-024	Mackay Reefs	ASO(BR)	AO	AO	AO	ASO(BR) PSO(FR)
15-033	Lark Reef (East)[5]	NO	ASO(BR)	ASO(BR)	ASO(BR)	NS
15-043	U/N[2]	IO	IO	NS	NS	NS
15-070	U/N	NO	ASO(BR)	ASO(BR)	ASO(BR)	ASO(BR)
15-084	Irene Reef	ASO(BR)	ASO(BR)	ASO(BR)	ASO(BR)	PSO(BR)
15-089	Endeavour Reef (East)[5]	ASO(BR)	ASO(BR)	ASO(BR)	ASO(BR)	NS
15-095	Evening Reef	ASO(BR)	ASO(BR)	ASO(BR)	PSO(BR)	PSO(BR)
16-015	Mackay Reef[1]	ASO(BR)	NS	NS	NS	NS
16-023	Rudder Reef (East)	NO	IO	AO	ASO(BR) PSO(FR)	ASO(BR) PSO(FR)
16-024	U/N	NO	IO	AO	AO	PO FSO(FR)
16-026	Tongue Reef (West)[3]	NO	NS	NS	NS	NS
16-026	Tongue Reef (East)[3]	NS	ASO(BR)	NO	NS	NS
16-057	Hastings Reef[4]	NO	NO	NS	NS	FSO(FR)
16-060	Michaelmas Reef[6]	NS	NS	NS	NS	FO

GBRMPA Reef ID	*Reef Name*	*Status 1994-95*	*Status 1995-96*	*Status 1996-97*	*Status 1997-98*	*Status 1998-99*
16-064	Arlington Reef (West)[3]	ASO(FR)	NS	NS	NS	NS
16-064	Arlington Reef (East)[3]	NS	ASO(BR)	ASO(BR)	NS	NS
16-049	Green Island Reef[1]	NO	IO	NS	NS	NS
16-068	Thetford Reef	NO	NO	ASO(BR)	PSO(BR)	PSO(BR) FSO(FR)
16-071	Moore Reef[6]	NS	NS	NS	NS	ASO(BR) FSO(FR)
16-073	Elford Reef (East)	NO	NO	NO	NO/NS*	NS
17-001	Sudbury Reef[3]	NO	NS	NS	NS	NS
17-004	Scott Reef	NS	ISO(BR)	ASO(BR)	ASO(BR)	ASO(BR) FSO(FR)
17-006	Maori Reef[3]	NO	NS	NS	NS	NS
17-011	Coates Reef	NS	AO	AO	AO	PSO(BR) NS*
17-016	McCulloch Reef[3]	NO	NS	NS	NS	NS
17-023	Cayley Reef	NS	NS	AO	ASO(BR) PSO(FR)	ASO(BR) NS*
17-034	Feather Reef	NS	NO	NO	ISO(BR)	ASO(BR) FSO(FR)
17-047	Eddy Reef[4]	NS	NS	NO/NS*	NS	AO
17-064	Taylor Reef[4]	NS	NS	NO/NS*	NS	ASO(BR) ISO(FR)
18-026	U/N[3]	NS	NS	NO/NS*	NS	NS
18-030	Kelso Reef[5]	NS	NS	NS	ISO(BR)	NS
18-031	Little Kelso Reef	NS	NS	NS	ASO(BR)	ASO(BR)
18-075	John Brewer Reef	NS	NS	NS	NO	NO
18-078	Lodestone Reef	NS	NS	NS	ASO(BR)	PSO(BR)

Key to codes (numbers shown in superscript; see Table 7) used to indicate operational changes to the annual sampling program.

1 Reefs that were dropped from the annual sampling program due to the local introduction of *A. planci* control programs that potentially modified the natural dynamics and characteristics of the local starfish population;

2 Reefs that were dropped from the annual sampling program to accommodate the staged southward expansion of the survey area;

3 Reefs that were dropped from the annual sampling program due to logistic and/or operational difficulties such as highly patchy distribution of suitable continuous reef habitats or exceedingly large size of reef structure with a corresponding need for extended travel away from the mother ship;

4 Entire reef or individual reef zone not surveyed during certain years due to cyclonic activity in the survey area;

5 Reefs dropped from the annual sampling program due to financial constraints arising from operational changes to the crown-of-thorns starfish research program;

6 Additional reefs located directly offshore Cairns - opportunistic once-off surveys in 1998-99 due to the availability of limited carry over funds;

* Front reef zone not surveyed due to severe weather conditions.

Note: All reefs added to the annual sampling program in order to (i) either replace previously sampled reefs or (ii) to geographically expand the survey area were selected haphazardly.

Table 8: Summary counts of respective reef classification categories as assigned to individual survey reefs since 1994-95 ***(complete set of ALL survey reefs).***

Reef status classification	*Status 1994-95*	*Status 1995-96*	*Status 1996-97*	*Status 1997-98*	*Status 1998-99*
Reefs	**24**	**22**	**22**	**21**	**21**
AO	1	6	8	5	1
ASO	8	7	8	10	9
IO	3	4	0	0	0
ISO	0	1	0	1	2
PO	-	-	-	1	3
PSO	-	-	-	2	6
NO	12	4	6	1	1

Figure 7: Bar chart of observed annual trends in the percentage of survey reefs classified as actively outbreaking (AO/ASO), post-outbreaking (PO/PSO) and non-outbreaking (NO) ***(complete set of ALL survey reefs).***

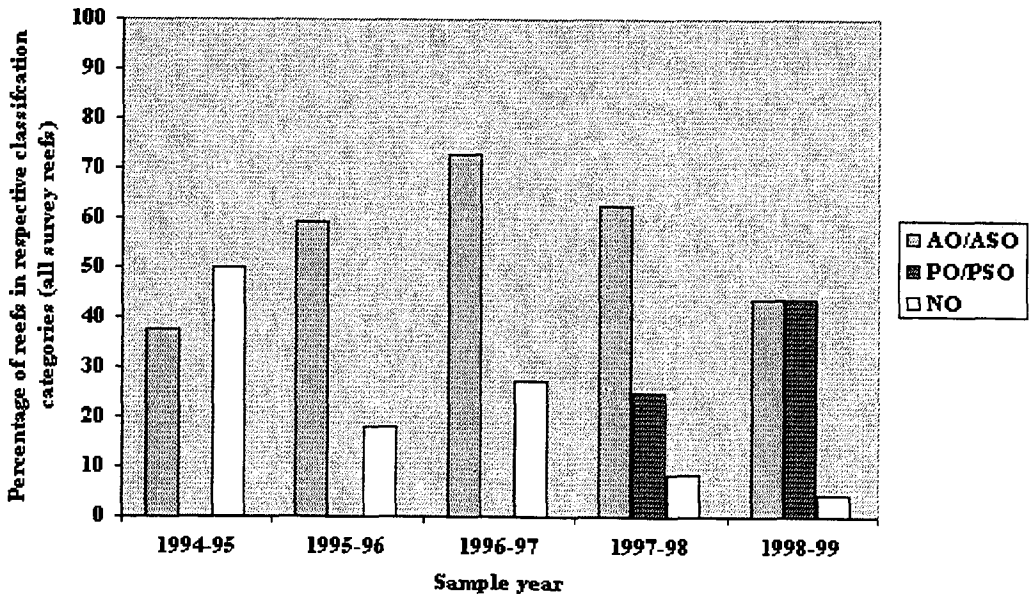

Table 9: Summary counts of respective reef classification categories as assigned to individual survey reefs since 1994-95 ***(sub-set of nine reefs surveyed every year).***

Reef status classification	*Status 1994-95*	*Status 1995-96*	*Status 1996-97*	*Status 1997-98*	*Status 1998-99*
Reefs	**9**	**9**	**9**	**9**	**9**
AO	1	3	5	3	0
ASO	4	3	4	4	3
IO	1	2	0	0	0
ISO	0	0	0	0	1
PO	0	0	0	0	3
PSO	0	0	0	4	5
NO	3	0	0	0	0

Figure 8: Bar chart of observed annual trends in the percentage of survey reefs classified as actively outbreaking (AO/ASO), post-outbreaking (PO/PSO) and non-outbreaking (NO) *(sub-set of nine reefs surveyed every year).*