A report on the ecological surveys undertaken at Middleton and Elizabeth Reefs, February 2006

Contributing personnel.

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EXECUTIVE SUMMARY

A survey of the Elizabeth and Middleton Reefs Marine National Nature Reserve was carried out during February 2006 over the period 9th -16th (Middleton) and 17th-18th (Elizabeth). The primary focus was on Middleton Reef and the provision of estimates of live coral cover, benthic invertebrate abundances including *Acanthaster, Drupella* and echinoids, black cod and reef shark abundances and a number of fish species endemic to the reserve. In addition abundances of holothurians were estimated.

A total of 397 formal samples were collected to estimate abundances of the above categories of organisms with the majority (351) being carried out at Middleton. Mean live coral cover at Middleton Reef was low with an overall mean of 11.4 per cent. This contrasts with estimates from reefs to the north that vary between 18-30 per cent live cover with some exceeding 40 per cent and also with the estimate of 25 per cent cover from Elizabeth Reef. Low coral cover is a consistent feature of Middleton Reef as the 2006 estimates were similar to those obtained in an earlier survey in 1994 using the same sites as in the present survey. The highest coral cover occurred on exposed reef fronts and crests and in the enclosed lagoon.

No evidence of recent coral bleaching or aggregations of the coral feeding gastropod Drupella were observed. A single small aggregation of *Acanthaster* on the south-east reef front was located counted and mapped. There was only limited evidence of recent *Acanthaster* feeding at the aggregation site and no evidence at any other locality examined. The 2006 findings on *Acanthaster* match those from the 1994 survey in which an aggregation of similar size was located and censused in the western lagoon.

Holothurians dominated by *Holothuria atra* were common only in lagoonal habitats. Their local distribution was strongly correlated with the presence of sand and sediment.

A total of 28 long-swim transects were done at Middleton Reef to census black cod (*Epinephelus daemelii*). These returned a mean estimate of 2.9 individuals per hectare with habitat-specific densities ranging from 1.2 to 4.1 per hectare. The highest

abundances were in sheltered and lagoonal environments while the lowest were on exposed reef fronts. Estimates of the abundance of the Galapagos shark *Carcharhinus galapagensis* varied by habitat with very high numbers, 12 per hectare being recorded from enclosed lagoonal environments. Both black cod and Galapagos shark abundances where greater than those achieved by equivalent species in protected lower latitude reef environments.

Abundance estimates of large labrid fishes including the doubleheader, an endemic wrasse, *Coris bulbifrons* and excavating and scraping parrot fishes, revealed high densities of these functionally important species. Abundances of *Coris bulbifrons* ranged from two to five per 1000 m^2 with the greatest abundances consistently recorded from sheltered and lagoonal habitats. Grazing and excavating parrotfishes achieved their greatest abundances on exposed reef fronts and crests in association with high coral cover. There is evidence that the large excavating parrotfish *Chlorurus microrhinos* feeds on established colonies of living coral and may be a significant source of coral removal. The most characteristic element of the Middleton Reef fish are the large schools of algal browsing herbivores including the sawtail surgeon fish *Prionurus maculatus* and the chub *Kyphosus pacificus*. These species were also characteristic of the outer reef slopes and crests achieving densities more than double those of parrot fishes. Algal grazing invertebrates primarily echinoids did not achieve high abundances at any locality.

Species lists of taxa encountered during the sampling were compiled and a comprehensive list of reef fish species developed. A total list comprised 322 species of reef fishes, of which 51 were new records for the Elizabeth/Middleton Reef system.

INTRODUCTION

Middleton Reef lies 600 km east of the Australian coast at 29°56'S 159°03'E in the northern Tasman Sea (Fig 1A). The adjacent Elizabeth Reef (Fig 1B) is 61 km to the south with Lord Howe Island 261 km further south. Both reefs rise independently from deep water (>2000m) and are thus separated by waters of oceanic depth. The nearest major coral formations of the southern Great Barrier Reef are 900 km to the north. Details of the Elizabeth and Middleton Reefs Marine National Nature Reserve are provided by Oxley et al (2003). In summary, the reserve covers an area of 188,000 hectares, and includes the southern-most open-ocean platform reefs in the world: Elizabeth Reef (~5,100 ha) and Middleton Reef (~3,700 ha). These high latitude reef systems lie close to the boundary between the Coral Sea and the Tasman Sea and thus provide habitats for both tropical and subtropical/warm temperate species.

The primary influences with respect to water movement are from the southward flowing East Australian Current and the Tropical Convergence. These prevailing currents provide a mechanism for colonisation by larvae from the extensive area of coral reefs to the north. The coastal ecosystems to the west are a potential source of propagules of temperate and subtropical species, so there is an expectation of a diverse fauna comprising both coral reef and subtropical elements. Water temperatures vary from 19 to 26° C. Both Middleton and Elizabeth Reefs are platform reefs associated with seamounts rising abruptly from water of 2000 m depth. Details of the geological history and the physical regime of Middleton Reef are provided by Slater & Goodwin (1973) and the Australian Museum (1992).

The summary features for Middleton Reef are as follows. The reef consists of an extensive lagoon surrounded by a well defined reef crest with characteristic spur and groove formations. The area of the whole reef complex is approximately 67 km^2. The southern, eastern and western crests of the reef are continuous; to the north a shallow back reef habitat provides an entrance to the lagoon. The prevailing winds are from east to southwest, resulting in very exposed reef front habitats on the southern face of the reef. However waves wrapping around the western and northeastern aspects of the reef ensure that these reef front habitats are also exposed to heavy seas.

The important biological features of this reef system relevant to management are: (1) lying at the latitudinal boundary of coral reef formation, it supports both tropical and subtropical elements; (2) as these are reef habitats with a high degree of isolation, there is an expectation that they would support endemic species or species that were generally rare over most of their range; and (3) their relative isolation indicates that they could support populations of species that have been impacted by fishing in other parts of their range and thus serve as refugia.

The specific requirements of the present survey were as follows:
i) to provide estimates of live coral cover expressed as % cover;
ii) to estimate coral condition and the abundance of invasive species such as crown of thorns starfish *Acanthaster planci*;
iii) to estimates abundances of black cod, *Epinephelus daemelii* and reef sharks;

iv) to estimate abundances of other reef fishes including the endemic doubleheader wrasse *Coris bulbifrons* and endemic damsel and butterflyfishes (*pomacentrids and chaetodontids*); and
v) to estimate local distribution and abundance of holothurians.

The survey addressed all of these requirements in such a way that both the basic information and an integrated picture of the ecological features of Middleton Reef could be made available to the sponsoring agency, the Department of Environment and Heritage. In addition, the estimates of coral cover and crown of thorns abundance from the current survey could be evaluated against results of a previous survey in 1994 and thus spatial and temporal comparisons of these important variables were available.

In order to develop an understanding of the important ecological properties of the system, we focussed on the following:
A) Cover of live coral. As geographic distribution and growth of corals is influenced by both temperature and light regimes, we would expect lower levels of live coral cover at high relative to low latitude reefs. It was important to focus on this aspect to prevent confounding between estimates of short term disturbance to coral cover and basic distributional aspects of Middleton Reef.
i) coral cover on exposed reef fronts, as this is where the structure of the reef is determined; If coral growth ceases on the seaward margins of the atoll, then in the long term the reef habitat will shrink;
ii) coral cover in the sheltered back reef and lagoonal habitats. This is important more in terms of habitat provision rather than the long-term structural integrity of the atoll.
Due to time constraints, weather conditions and remote diving considerations, the coral cover estimates were made largely in the 5-10m depth zone. However, as in many localities coral cover on the shallow crest may be higher than the reef slope, we took the opportunity to assess coral cover on the shallow exposed crests 1-3m depth. This unique opportunity was a reflection of the excellent weather and the quality of vessel support we received.

B) Other elements of the benthic biota including soft corals, macroscopic algae and turfing algae. Soft corals are potentially an important competitor for space occupied by hard corals; macroscopic algae is associated with grazing and browsing activities by fish and has the capacity to overgrow corals; turfing algae co-exists with corals and is a primary target for grazing fishes.

C) Grazing and browsing fishes. The primary purpose was to obtain species abundance and composition data of the fauna of nominally herbivorous fishes, fishes that have the property of removing algae that might inhibit coral recruitment and growth. The important members of this fauna are the grazers, largely of tropical origin. These comprise gazing parrotfishes and surgeon fishes. In addition many large parrotfishes (the excavators) have the capacity both to remove large amounts of calcareous substrate and living coral (Bellwood et al 2003). Browsing fishes feeding on macroscopic algae are more characteristic of subtropical reef systems and include drummers (Kyphosidae) and large subtropical surgeon fishes (*Prionurus*). Unlike lower latitude reefs, transitional habitats such as Middleton are likely to harbour large numbers of both types of fish.

D) Invertebrates capable of removing live corals. These include *Acanthaster* and *Drupella* aggregations. In addition we identified and obtained abundance estimates of grazing echinoids as these have the capability of removing small colonies of corals and algae through intensive grazing.

The survey was thus able to provide two types of information:
1) Estimates of abundance and habitat requirements of species that are vulnerable to or endangered by exploitation including black cod, reef sharks, large wrasses and small species endemic to the Elizabeth Middleton reef system. This information is of direct importance to species/specific management and conservation. A list of the target fish species, giving both scientific and common names, is provided in Table 1.
2) Information on the community structure and ecosystem properties of Middleton Reef including coral cover, coral predators benthic grazing and browsing fishes to assist in the provision of long term management plans appropriate for high latitude reef systems.

PREVIOUS STUDIES ON THE ELIZABETH AND MIDDLETON REEFS.

The present survey benefited from a number of previous studies on Elizabeth and Middleton Reefs carried out between 1981 and 2003. In these surveys, coral was a primary target. The main contribution of these surveys was to establish a taxonomic base for the investigation of hard corals to provide an accessible picture of the reef ecosystems and to indicate the consequences of past disturbances on the coral assemblages of both Elizabeth and Middleton Reefs. In addition, work on the Lord Howe Island coral fauna helped identify the unique properties of Elizabeth and Middleton Reefs and their oceanographic setting with respect to current systems important for recruitment.

The sequence of studies commenced with a survey by Done and Veron (1981) which provided a comprehensive taxonomic list of hard corals at Elizabeth and Middleton Reefs and a summary of coral distribution and status. This work was augmented by subsequent surveys by Done (1984) and the work of the Australian Museum expedition in 1987, which was summarised in the report of the expedition (Australian Museum, 1992). This report also included additional work on coral reproduction (Wallace & Christie, 1992). Subsequent to the 1987 survey, a James Cook University team surveyed coral assemblages on the perimeter and the lagoon of Middleton Reef in 1994. Finally, Harriott (1998) surveyed the corals of Middleton Reef. In addition to taxonomy, distribution and condition of corals, these surveys also provided information on the abundance and activity patterns of crown of thorns starfish.

The work on Middleton Reef helped resolve an issue with respect to differential patterns of coral cover on Elizabeth and Middleton Reefs. Previous work (summarised by the Australian Museum, 1992) suggested that live coral cover at Elizabeth Reef was significantly greater than that encountered at Middleton Reef. This was confirmed by the 2003 AIMS survey of Elizabeth Reef and the 2006 JCU survey of Middleton Reef, which yielded mean coral cover estimates of 25 per cent and 12 per cent respectively on outer reef slopes. It is clear that Middleton presently has relatively low coral cover. More importantly, the information from previous surveys suggests that low coral cover on the outer reef slopes of Middleton is a consistent feature. Although the 1981 and 1984 surveys of Middleton Reef did not provide estimates of abundance expressed as coral cover per unit area, it was noted that coral cover, especially Acropora in 1984 had declined from 1981 levels. This was confirmed in the 1994 survey in which live coral cover was established at less than 12 per cent. Harriott (1998) confirmed that coral cover, especially Acropora, was still low on Middleton with assemblages characterised by relatively small sizes and few recruits. This was again confirmed by the 2006 survey. There are two interpretations of this information. Coral cover on the outer reef slopes of Middleton is consistently low, a reflection of the natural dynamics of this reef system. Alternatively, the status of Middleton coral reflects a recent history of disturbance in which crown of thorns, bleaching and storm damage have reduced outer slope coral from a traditionally much higher level. This issue is considered in the discussion.

The other major service of the previous survey (especially Australian Museum, 1992) was to provide a baseline for the estimation of reef fish and coral biodiversity in this reef system and to provide preliminary information on black cod abundance and size structure. This baseline provided a valuable opportunity for the 2006 survey to add to the species lists for the reefs, especially reef fishes, and to determine the fish species of major functional importance and the most appropriate targets for abundance estimates.

METHODS

Comparison of methods: Australian Museum 1992, Aims 2003, JCU 2006.

The methodology associated with surveys of the Elizabeth and Middleton Reef systems has been modified as various objectives have been met. The initial goals were to obtain descriptions of the reef habitats and structure, the general distribution patterns of the main species groups and species lists of the primary survey targets – hard corals and reef fishes. The earlier surveys were accomplished by partitioning reefs into habitat zones and using abundance categories (per cent cover in benthic organisms, numbers of individuals in reef fishes) to estimate patterns of occurrence and abundance of the major biological groups. This was usually accomplished by extended swims of 200-400m within each habitat. In addition, more detailed information on abundance of the major benthic organism groups and reef fishes was carried out in each habitat by using belt transects which allowed the data to be expressed as numbers or percentage cover per unit area. For reef fishes, information was obtained through replicated belt transects and for corals, by video recordings of belt transects in which the percentage cover of corals was estimated by point sampling techniques.

The most important service of the surveys prior to 2003 was to provide a picture of reef structure and habitat partitioning and estimates of species identity numbers and abundance that allowed later surveys to identify key functional groups of organisms and to develop sampling designs. The AIMS 2003 and JCU 2006 surveys used similar sampling methods with two exceptions. As an alternative to rapid Assessment protocols, the 2006 survey used a long swim (400m) transect technique that allowed the abundance of larger reef fishes to be expressed as numbers per unit area. This was designed primarily for larger species such as black cod and Galapagos sharks but with suitable calibration counts, this provided estimates of other larger mobile species including groupers parrot fishes and surgeon fishes. This provided information that was more directly comparable between locations (Robbins et al 2006). Secondly, the 2006 survey used the well established line intercept transect protocol to estimate percentage cover of benthic organisms. This was done primarily to avoid the task of analysis of large numbers of video recordings. Finally, the focus for species lists was shifted to reef fishes for two reasons. Firstly corals were the subject of intensive surveys prior to 2003 by international experts who had provided comprehensive species lists. Secondly, previous surveys had indicated a strong possibility of new records of smaller reef fish, especially at Middleton Reef. This reflected the position of this reef at the tropical/subtropical convergence.

Present Methods

The most important elements of the benthic biota were as follows: live corals, as these provide the mechanism of reef growth and provide habitat structure; turfing algal assemblages 1-2 cm in height; macroscopic algae with larger thalli reaching 5-10cm in height; and soft corals. Both turfing and macroscopic algae are important nutritionally to grazing and browsing fishes. Both soft coral and macro algae may compete for space with hard corals.

Estimates of abundance of these organisms were obtained through 30m line intercept transects which provided estimates of percentage cover and mean colony sizes for the different categories per transect. Mean colony size for hard and soft corals was estimated as the length in cm of individual colonies along each line transect. For the purposes of size estimation, hard coral colonies were partitioned into four structural categories – branching, encrusting, plates and massive. Abundances of mobile invertebrates including asteroids, echinoids, holothurians and gastropods, where obtained from 30 m belt transects with transect width varying from 2 to 10m depending on the species.

Estimates of abundance of selected species of fishes were obtained by three methods. Large reef teleost and shark numbers were estimated from replicated 400x20 m long-swim transects. For this protocol, experienced observers (AMA teleost fishes, WDR sharks) swam clear of the substratum in waters of >10 m visibility. The substratum was not disturbed. Distances were calibrated by timed swims along 400 m distances determined by GPS readings. Time taken to cover the transect varied according to groups censused. For teleost fishes, the time per transect was 45 minutes, as it was necessary to scan crevices and overhangs. For sharks, the time was 20 minutes per transect.

Preliminary counts both at Middleton, Cocos-Keeling Island and the northern Great Barrier Reef were made to determine the most appropriate count protocol for different categories of reef fishes. Numbers of large reef fishes such as the Galapagos shark *Carcharhinus galapagensis* and the black cod *Epinephelus daemelii* were most appropriately estimated by 400m long-swim transects. Counts of *E. daemelii* by 400m and 30m protocols demonstrated that the latter gave highly inflated abundance estimates due to individuals following divers around once initial contact with the substratum had been made. These protocols for abundance estimates of serranid fishes were based on trialling by Pears (2006b) in both the Indian and Pacific Oceans. All counts of *E. daemelii* and sharks were made by 400 m transects. For smaller, more mobile species including large parrot fishes, (*C.microrhinos, S.altipinnis*) the endemic wrasses *C.bulbifrons* and the browsing herbivores (*P.maculatus, N.unicornis K.pacificus*), initial calibration counts indicated that the area counted by long-swim transects was less than 400x20 m. Accordingly, calibration counts for each of the species were made over marked 30x10 m areas as none of the species were found to be diver oriented (*C.bulbifrons* was only attracted to divers if sandy substratum was excavated or large coral fragments overturned). For each species the abundance per 400 m transect was scaled to the area counted, established from the calibration counts. Numbers were than adjusted to mean per 1000 m^2 and number per hectare. Small grazing fishes were estimated from 30 x 10m transects. For this protocol the distance of 30m was fixed by a tape attached to the benthos and swum out by the diver on the first pass of the transect. Lateral distances were estimated using a marked tape. Small reef fishes including endemic chaetodontids and pomacentrids and juvenile *Coris bulbifrons* were estimated from replicated 30x4m belt transects.

The sampling for reef fishes was designed to obtain: (i) abundance and size-frequency estimates of endemic vulnerable and endangered species; and (ii) abundance and distributional data on groups of reef fishes of functional importance in the Middleton Reef ecosystem.

Taxonomic data were recorded for reef fishes, corals, soft corals echinoids and holothurians. Initial observations indicated that there were a number of reef fish species present that had not previously been recorded from Middleton and Elizabeth Reefs. Accordingly, considerable effort was put into updating the current reef fish species lists and as far as possible obtaining digital records of each species. Although a working list of the coral taxa encountered during the survey was developed for Middleton Reef, no attempt was made to provide a comprehensive list as this material is available in the comprehensive list provided by Oxley et al (2003).

SAMPLING DESIGN

The basic sampling plan (Fig. 1A) required stratifying the reef by habitat, resulting in a major sampling effort being deployed on the reef fronts. There were three reasons for this: (i) reef fronts constituted the dominant habitat and are critical to ecological processes on isolated oceanic reefs; (ii) this habitat was strongly represented in the 2003 Elizabeth Reef survey; and (iii) sampling reef fronts was highly cost effective in terms of data return per unit effort of sampling. In addition, the calm weather that prevailed during the survey period allowed us to sample on the extreme reef crest and shallow slopes of the exposed reef front – which was impossible under normal conditions. Three reef front localities were sampled (Fig. 1A); Southern (the extreme southern end of the reef system, North-east (the eastern front of the reef extending to the north eastern horn) and Wreck (the northwestern quadrant of the reef adjacent to the wreck). The degree of exposure in the reef front localities is ordered as SE, NE, and Wreck. Increased sampling of the lagoon environment was considered as it constituted a large area of reef habitat but was difficult to access and consisted of large areas of shallow sandy flats of very low biological diversity. Consequently, we partitioned the sampling to establish only two sites within the lagoon for detailed sampling. These were the Western Lagoon, a shallow sheltered area open to the northern reef face and the Blue Holes, deep enclosed areas within the lagoon proper with access to the northern reef front at high tide only. In addition we carried out limited sampling of the northern back reef, a sheltered reef front habitat not represented at Elizabeth. This was done primarily to assess the most accessible reef habitat on Middleton for the abundance of black cod and the large endemic wrasse *Coris bulbifrons* and to check for *Acanthaster* aggregations.

In order to obtain a balance between detailed site-specific sampling and broader scale surveys, sampling was carried out at two spatial scales. For example, density estimates of *Acanthaster* were estimated from 30 x 10 m belt transects and by 400 m long swim counts. The former provided information on very local scale abundance patterns, the latter allowed us to identify aggregations and through multiple transects plot their extent and probable movement pattern. We were able to identify a significant *Acanthaster* aggregation on the SE front (the only one encountered in the survey) and plot its probable movement.

The numerical deployment of sampling effort among habitats and protocols is shown in Table 2. For Elizabeth Reef, sampling effort over the two days was restricted to outer reef fronts with a focus large fishes, *Acanthaster* abundances and coral condition (Fig. 1B). The total of 341 formal samples at Middleton Reef was supplemented by numerous observations and photographic records of species and habitats. The breakdown of each section was 63 long-swim transects (28 for black cod 35 for sharks) 88 30x10m grazing fish and calibration counts, 120 small endemic fish counts and 55 coral and mobile invertebrate counts, of which 15 were dedicated to coral identifications. Four temperature loggers were also deployed.

In addition to the present survey, the results of a previous survey funded by a University consortium carried out in 1994 were available. These provided a framework for temporal comparisons with the present survey. The primary finding from the 1994 survey was that live coral cover on exposed reef fronts was relatively low, varying between 3 and 13 per cent. Lagoonal sites were more variable with live coral cover ranging from 1 to 22 per cent. Systematic observations on reef crests were not possible due to wave action but live coral cover was higher on crests than on reef slopes, especially in the SE quadrant. For the 2006 coral surveys, the reef habitat was partitioned to provide for comparative 1994 vs 2006 reef front samples and due to the high variability encountered in 1994 lagoonal sites, an additional lagoonal locality was sampled in 2006. Estimates of *Acanthaster* abundance were also made in 1994. In addition, weather conditions made it possible to sample reef crest habitats at the three reef front sites.

In addition to the transect counts, four data loggers were placed on Middleton and Elizabeth Reefs at one outer reef and one lagoonal site on each reef for the purpose of collecting temperature data.

GPS positions:

Middleton
Logger 1 (lagoon) - 29º27.118S; 159º06.030E
Logger 2 (outer) - 29º27.004S; 159º04.123E

Elizabeth
Logger 1 (outer) - 29 55.464S; 159 03.459E
Logger 2 (outer) - 29 56.260S; 159 05.606E

RESULTS

Sessile benthic organisms

Information of the dominant sessile organisms is presented as estimates of percentage cover derived from line intercept transects. Reef front habitats and crests represent the most important areas of the reef system. Turfing algae is the dominant benthic element on reef front habitats with remarkably similar values for each reef locality and ranging from 78.7 to 81.7 per cent cover. Hard coral is dealt with in greater detail below but for all reef front localities at the 5-10m depth range, live coral cover was relatively low, ranging from 4.5 (Wreck) to 10.1 per cent (SE). Both soft coral and macroscopic algae were minority elements of the benthic assemblage but showed considerable local variation (Fig. 2).

Corals: Reef slopes and lagoons

Sampling of live coral cover in the 5-10 m depth range at 3 reef front localities (SE, NE, and Wreck) showed consistently low live coral cover, with relatively little variation among localities (Fig. 3). There was a trend of the lowest coral cover at the most sheltered reef front locality to highest at the most exposed. Lagoon localities showed more variable coral cover and significantly greater cover at one locality (Blue Holes) with over 20 per cent mean cover. The within-locality variation reflected the occurrence of extensive areas of live coral cover, often in the form of continuous stands of *Acropora* alternating with large areas of recently dead acroporid colonies (Fig. 4).

Corals: Reef crest

Percentage cover of living hard coral was assessed on the shallow crests (1-3m) of the three reef front localities. At two localities (Wreck and SE) coral cover was significantly greater on reef crests than on reef fronts (5-10m) (Fig. 5). The difference was greatest at the most exposed location (SE) where very high levels of living coral cover (> 30 per cent) were recorded, greater than at any other locality including lagoonal habitats. Reef crest corals were predictably dominated by encrusting species.

Corals: Colony size

Individual colony sizes for hard corals were analysed. Size structure may provide an initial assessment of the dynamics of coral assemblages. Size of coral colonies was relatively small throughout Middleton Reef front localities. Four structural categories of hard corals were analysed for reef front and lagoonal localities. For reef front localities, branching, encrusting and massive corals all showed relatively small colony sizes (linear distance across colony) varying between 10-15 cms. Plate corals had larger colony sizes but were relatively rare and occurred at only two of the reef front sites censused. Sheltered environments displayed two patterns of coral size structure. Western lagoonal localities had relatively small mean colony sizes while Blue Hole localities had the largest colonies. (Fig. 6) This reflects the presence of large stands of living branching corals in this habitat (Fig. 7)

Corals: 1994-2006

The 1994 survey of Middleton Reef provided the opportunity for a temporal comparison of benthic assemblages sampled over an interval of 13 years. The primary interest in these comparisons was in the levels of live coral cover at reef front and lagoonal sites. GPS information enabled us to return to the same sites. The comparative data are shown in Fig. 8. For the three reef front localities, similar low levels of live coral cover were recorded for 1994 and 2006 with the same rank order of coral abundance by locality. Coral cover in the western lagoon were slightly higher in 2006 but at both times among-transect variability was greater than on reef fronts. The Blue Hole habitat was sampled only in 2006. This recorded higher living coral cover than any other locality surveyed in 1994 and 2006. The levels of live coral cover on the exposed reef fronts is comparable between the two sampling periods, indicating that these estimates of coral cover are a consistent feature of Middleton Reef (Fig. 8) In addition, comparative data sets on four categories of benthic organisms, Turf algae, hard corals, soft corals and macro algae were obtained from each of the three reef front localities at both times.

Principle component analysis of the relationships between hard and soft corals, and macro and turf algae were examined (Fig. 9). This partitioning by locality and sampling period accounted for 70 per cent of the variation in percentage cover of the four categories of benthos. There is little evidence of any temporal changes in the benthic community over the 13-year period. Areas such as the Wreck reef front site that were dominated by turfing algae in 1994, were similar in 2006. Most temporal variation reflected differences at particular sites within each locality. For example, some sites on the NE front were characterised by higher cover of soft corals in 1994, while in 2006 some sites on the Wreck front had high cover of macroscopic algae. However, locality specific patterns (high cover of turfing algae at Wreck and high cover of coral at SE and NE) were consistent over both sampling periods. The spatial pattern in the distribution of the main benthic organisms was retained from 1994 to 2006.

Corals: Geographic comparisons

Data collected on outer reef slope transects by the Australian Institute of Marine Science long-term monitoring project provided a comparative picture of coral cover from equivalent habitats at lower latitudes on the GBR proper (Sweatman et al 1995, 2005). Most localities, extending from the northern (Cooktown) to southern (Capricorn-Bunker) regions of the reef had coral cover varying between 18-30 per cent with some exceeding 40 per cent. In addition, some localities showed substantial temporal variation in cover over the 12-year sampling period. Most of these had substantially higher coral cover than estimates obtained at Middleton Reef. Middleton Reef had lower coral cover than localities on the GBR proper and that this pattern was stable over a 13-year period (Fig. 10).

Mobile benthic organisms.

Acanthaster and Drupella

Invertebrate coral predators were present on Middleton Reef. The most important species were gastropods of the genus *Drupella* and the starfish *Acanthaster plancii*. *Drupella* was located in only five of the 55 transects completed with the greatest number in any 60 m^2 belt transect being three individuals. The most efficient predator of corals, the crown of thorns starfish (*Acanthaster plancii*), was present but generally low in abundance with only a single localised aggregation being recorded (Fig. 11). Two independent count protocols were made to survey *Acanthaster*. 400 x 5 m belt transects were swum to cover broader areas of reef substratum. A series of smaller (300 x 10 m) sets of transects, in which the substratum was carefully searched, were used to determine if cryptic individuals were present on the reef. Large numbers were recorded from only one site, a section of reef slope on the SE front. 400m belt transects returned an estimate of 23.2 per 2000 m^2. The smaller, more intensively searched transects, revealed no evidence of cryptic juveniles and recorded a similar mean density of adults when adjusted to 2000 m^2, 18.9. This site showed evidence of recent Acanthaster feeding but over a relatively small area.

Sampling for *Acanthaster* was carried out in 1994 using 30 x 10m belt transects in the lagoonal and three reef slope localities. As in 2006, no large aggregations were observed or recorded. Moderate numbers were recorded from only one locality the western lagoon. Here the mean density of adult *Acanthaster* when adjusted to 2000 m^2 was 12.2 adults. Limited sampling on Elizabeth Reef showed low numbers of *A. plancii*, with no evidence of aggregations.

Echinoids

Echinoids represent an additional group of invertebrates that can potentially influence coral cover by grazing activities. The action of echinoids on coral reefs is ecologically complex with both costs and benefits with respect to coral health. Larger active species such as members of the genus *Diadema* may remove algae that could inhibit coral growth. However, intensive grazing may also remove small sessile invertebrates including newly settled corals. Fig. 12 shows that echinoids, although present on Middleton Reef outer fronts, were never abundant. The small species *Echinometra mathaei* was the most abundant echinoid encountered being present in appreciable numbers, only at the relatively sheltered reef front locations of Wreck and NE. However, this species is semi-cryptic, being associated with depressions and crevices in the reef matrix. Experimental analysis of the Ningaloo Reef grazing assemblage shows that this species has only a minor impact on algal cover (F.Webster pers comm). *Diadema setosum* was present at all reef front localities sampled but never achieved anything other than very low abundances and was not recorded in the form of the grazing aggregations that characterise this species at other geographical locations.

Holothurians.

The most common species of holuthurian at Middleton Reef was the black sea cucumber, *Holothuria atra*. This species was nearly three times as abundant as the next most common species, the black teatfish, *H. nobilis*. Collectively, these two species comprised nearly 84 per cent of individuals counted. Holothurian abundances were low on the fronts of Middleton Reef, increasing three to four fold in the lagoon and Blue Holes (Fig. 13). As expected, there was a strong correlation between the density of holothurians and the area of sand surveyed in the transects.

Reef Fishes

There were two important features of the reef fish fauna. Firstly, the reef supports populations of species that are rare elsewhere due to endemism (natural distribution largely restricted to the Elizabeth/ Middleton reef system) or to fishing pressure over their ancestral range. Secondly, members of the reef fish fauna, primarily the grazing and excavating groups, have the potential to modify the abundance of important sessile organisms including corals and algae that are implicated in reef productivity and habitat structure.

For the present survey, the most important elements of the fish fauna were the large grouper *Epinephelus daemelii* (black cod) and the reef shark *Carcharhinus galapagensis.* Black cod have a restricted distribution, being confined to northern New Zealand, the Kermadec Islands and south-eastern Australian coast including offshore reef and islands such as Norfolk and Lord Howe Islands and the Elizabeth/ Middleton reef system. Large populations are now restricted to remote locations primarily offshore reefs and islands. The Galapagos shark has a much broader circumtropical distribution but is abundant only at a relatively small range of localities, primarily offshore islands and reefs. Many isolated populations of this species have been impacted by fishing. The Elizabeth/ Middleton Reefs represent the main population of this species in Australian waters and the southernmost population in terms of the global distribution.

Endemic species include the large wrasse *Coris bulbifrons* (doubleheader) restricted to reef environments of Lord Howe, Norfolk, Elizabeth and Middleton, and *Chaetodon tricinctus* and *Amphiprion mccullochi,* both of which have distributions similar to that of *C. bulbifrons.* The functionally important groups of fishes that were censused include the large abundant excavating (*Chlorurus microrhinos* and *C. frontalis*) and grazing (*Scarus altipinnis*) parrotfishes and the browsing herbivores *Prionurus maculatus* and *Kyphosus pacificus*. In addition, counts were made to estimate the abundances of juvenile fishes, primarily grazers and detrital feeders.

Large vulnerable and endemic species

Black cod (Epinephelus daemelii)

Sampling for black cod was partitioned by habitat with five replicate 8000 m^2 transects being counted on the three reef front locations and three sheltered locations, Western Lagoon, northern Back Reef and Blue Holes (Fig. 14). The overall mean abundance estimated from these transects was 2.9 adult individuals per hectare. Abundance estimates were relatively easy, due to the highly visible nature of adults (Fig. 15). There were significant differences in abundance associated with habitat structure and degree of exposure. The greatest number in any individual transect was six, which were recorded from the Wreck location and the western Lagoon. These transects were in sheltered environments. The tendency for this species to be associated with relatively shallow sheltered habitats is illustrated in Fig. 14. Exposed reef fronts (NE & SE) had the lowest numbers per hectare; the highest numbers were at the Wreck location and Blue Holes with a trend of larger numbers being recorded from the Western lagoon and Back Reef. The greatest abundances for the Wreck location were recorded from the eastern extremity of the reef front where it extends into sheltered lagoonal waters. On reef fronts, adult individuals were associated with surge channels and overhangs at the base of the reef front. These structure were searched during the course of the transect swims The lengths of the 65 black cod recorded during the formal surveys varied and there was little evidence of a peak length with uniform representation of individuals between 80 to 140 cm total length. Only two individuals smaller than 50 cm were recorded. (Fig. 16). No juveniles were recorded in the formal transects but searches of overhangs and crevices within the reef matrix, primarily in sheltered locations, revealed juveniles in the vicinity of 25-30cm TL. These were cryptic and retreated into the reef matrix when located.

A series of seven 400 m transects were swum at Elizabeth Reef (Fig. 1B). Due to the structural differences between Elizabeth and Middleton Reef (no extensive back reef and open lagoonal habitats in the former), counts were made exclusively on reef front locations on the NW and SW of the reef front. The overall mean of black cod in these counts was higher than those recorded from Middleton with a mean of 5.3 adults per hectare. In one transect of the NW front a total of seven individuals ranging from 80-130 cm TL were recorded.

Galapagos shark (Carcharhinus galapagensis)

Abundances of the Galapagos shark, *Carcharhinus galapagensis*, were estimated through underwater visual surveys at five locations on Middleton Reef. Shark surveys were conducted for 20 minutes, encompassing an area of 8000 m^2. Densities of Galapagos shark ranged between 1 to 2.8 individuals per hectare on the reef front, and from 0.4 – 12.1 individuals per hectare in the sheltered habitats (Fig. 17). The marked increase of individuals in the blue holes is a common feature of isolated reefs or atolls with deep sink holes. The combination of high productivity and quieter, warmer water, promotes growth in sharks. Such habitats are commonly used by smaller individuals as a form of refuge from the larger sharks.

Most individuals sighted appeared too small to be mature (<2.1 - 2.5 m). As such, it is likely that high densities of larger Galapagos sharks may be found in deeper water than this project surveyed. No other shark species were identified during formal counts. However, three tiger sharks, *Galeocerdo cuvier*, were observed feeding on the reef flat of Elizabeth Reef. Shark counts could not be undertaken at Elizabeth Reef due to time constraints.

Doubleheader Wrasse (Coris bulbifrons)

Abundances of the doubleheader wrasse, *Coris bulbifrons,* were estimated by 400m belt transects. These transects were calibrated for this species by replicated 30x10 m transects dedicated to *C.bulbifrons*, in which abundances were estimated in each of the localities surveyed. These data provided a basis for estimating the area of reef substratum monitored in the 400 m^2 transects (see Methods). The 400 m transects monitored an area of 5.1 km^2. Abundances were adjusted to fish per 1000 m^2. Abundances were estimated in six localities including the three reef front localities the western lagoon, northern Back Reef and Blue Holes. This species occurred in appreciable numbers at all localities sampled with an overall mean abundance of 3.3 individuals per 1000 m^2. There was significant variation in abundance among localities with greater numbers recorded from sheltered localities especially lagoonal and back reef habitats (Fig. 18). In these locations large groups of C.bulbifrons were encountered (Fig. 19). The lowest abundances were recorded from the exposed SE reef front. The modal size for the double header wrasse was 40 cm at all locations. The smallest and largest individuals were recorded from sheltered habitats, primarily the Back Reef and the Lagoon (Fig. 20). *Coris bulbifrons* is the largest *Coris* species in Australia and is thought to reach up to 1.4 m in length (Kuiter 1993)). However, no individuals above 65 cm were sighted at Middleton Reef and it is probable that this species does not attain this size at this location. A small number of *C.bulbifrons* were sampled to estimate ages. The largest individual (63 cm) had an estimated age of 14 years.

Smaller belt transects (30x4 m) were run to estimate juvenile abundances. Juveniles were located in only one locality the Western lagoon and were never abundant (mean 0.3 individuals per 120 m^2), suggesting that they are cryptic and associated with high areas of coral cover.

Small endemic species

Distribution of the endemic species *Amphiprion mccullochi* and *Chaetodon tricinctus* showed a high degree of habitat partitioning (Fig. 21). *A. mccullochi* was restricted to sheltered lagoonal habitats. The endemic three-striped butterfly fish *C. tricinctus* was found across a wider range of habitats but achieved greatest abundance on the exposed SE front reefs associated with relatively high coral cover. Both species achieved only modest abundances.

Functionally important species

Grazing and excavating parrotfishes

Middleton Reef supported a larger fauna of grazing fishes, primarily parrot fishes of the genera *Chlorurus* and *Scarus*. Members of the genus *Chlorurus* have the capacity to excavate calcareous substratum (Bellwood & Choat, 1990) and are increasingly recognised as consumers of living coral (Bellwood et al, 2003). The genus *Scarus* comprises species with a scaping mode of feeding that have the capacity to remove small sessile organisms from the reef surface. A member of each genus, the blunt-head parrotfish (*Chlorurus microhinos*), a large excavating species, and the minifin parrotfish (*Scarus altipinnis*), a large abundant grazer, occurred at Middleton Reef and were monitored at each of the sampling localities. Abundance estimates using calibrated 400m transects replicated in each of the six localities were made. Estimates were scaled to numbers per 1000 m^2. These species showed significantly different abundance patterns when compared with the other large labrid fish present at Middleton Reef *Coris bulbifrons*. Overall mean abundances were 8.2 per 1000m^2 for *C.microrhinos* and 13.9 for *S.altipinnis*, substantially greater than the 3.3 per 1000m^2 recorded for *C. bulbifrons*. Both species showed clear evidence of habitat associated partitioning in abundances. In contrast to *C. bulbifrons* the greatest abundances for each species were recorded from exposed reef front locations being found predominantly on the higher-dynamic, exposed outer reef fronts (Figs 22 & 23 respectively). *C. microrhinos* (Fig. 24) achieved its greatest abundance on the SE exposed reef front a habitat that supported a high cover of massive and encrusting coral especially on the shallow reef crest. The minifin parrotfish also showed within-habitat preferences, as it was consistently higher in abundance at the NE reef front, than the other reef fronts (Wreck and SE, which did not statistically differ). A third excavating parrotfish, the tan-faced parrotfish (*C. frontalis*), was also found predominantly on the reef fronts, although this species prefers the reef crest environment (Fig. 25). This species was a minority member of the parrotfish assemblage.

Large browsing fishes

The most abundant elements of the Middleton Reef larger reef fish fauna were the algal browsing species yellowspotted sawtail (*Prionurus maculatus*), the Pacific drummer (*Kyphosus pacificus*). In contrast to the parrotfishes, these species are explicitly herbivorous, browsing on the larger algal elements (thallus height 1-3cm) on exposed reef fronts and crests. Species of the surgeonfish genus *Prionurus* are characteristic of subtropical waters and are most abundant in transitional reef systems between temperate and tropical waters. Kyphosids (drummers) are present in low latitude reef systems but frequently achieve high abundances on high latitude coral reefs.

Estimates of abundance made by 400 m transects were calibrated and scaled to 1000 m^2. Both species form extensive highly mobile schools (Fig. 26) and generate abundance estimates with characteristically high standard errors due to among-count variation. Overall mean numbers of both species were relatively high, 16.5 for *P. maculatus* (Fig. 27) and 31.5 for *K. pacificus* (Fig. 28). Although high variances made comparisons among localities difficult, there was a clear trend of highest abundances at the Wreck Reef front locality and the lowest at the sheltered localities. There was also a surprising degree of locality variation in abundance on reef fronts with low numbers recorded from the NE locality for both species. However, the mean numbers recorded from the Wreck locality 60.5 for *K. pacificus* and 32.8 for *P. maculatus* where higher for those recorded for any of the parrotfish estimates.

Both *Prionurus* and *Kyphosus* are signature groups for high latitude coral reefs. For comparative purpose we recorded abundances of the bluespine unicornfish (*Naso unicornis*) an algal browsing species characteristic of low latitude reef systems. Middleton Reef represents the southern extension of this species range. It occurred in low abundances across all the habitats of Middleton Reef (Fig. 29).

Smaller grazing and browsing species

The grazing assemblage of reef systems comprises numerous small and the juveniles of larger species including parrotfish and surgeonfish. These have the capacity to remove sessile organisms, primarily algae, from the interstices of reef habitats, grazing sites not accessible to larger fishes. As both large and small grazers and browsers may be important elements of the reef ecosystem, an analysis of the abundances partitioned by habitat was carried out on the 23 most abundant species on Middleton Reef through a replicated series of 30x10m belt transects. The large schooling species *P. maculatus* and *K. pacificus* were excluded from this series of counts due to the small transect dimensions.

Principal component analysis showed distinct habitat partitioning of the grazing species. The resultant biplot (Fig. 30) shows that the right side of the plot represents samples from sheltered lagoonal habitats The vector diagram demonstrates that the lagoonal assemblages are represented by small grazing species including *Ctenochaetus striatus, S. psitticus, S. schlegeli, C. sordidus, S. globiceps, S. flavipectoralis, S. niger Z. scopas*. These are all small species with a high feeding rate ingesting both detrital material and algal turfs. The left side of the plot was dominated by exposed reef front locations. The vector diagram shows that this includes the larger grazing and excavating parrot fishes *Cetoscarus bicolor, Chlorurus frontalis, C. microhinos, Scarus altipinnis and S. frenatus* and representatives of the algal browsing surgeonfishes *Acanthurus nigoris* and *Zebrasoma veliferum*). The analysis confirms the findings of the independent series of abundance estimates described above where it was shown that reef front localities supported high abundances of the larger grazing parrotfishes. The association of the smaller species with lagoonal habitats suggests that stands of branching corals may represent refuges or nursery areas for smaller fishes (Fig. 31).

Species diversity

Lists of species encountered during the sampling were compiled and a comprehensive list of reef fish species developed. A total list comprised 322 species of reef fishes, of which 51 were new records for the Elizabeth/Middleton Reef system. The richness of this fauna reflects the inputs from both tropical and temperate reef ecosystems. In addition we have provided taxonomic listing for the major groups encountered. Coral species are indicative only and a more comprehensive list is available in Oxley et al 2003.

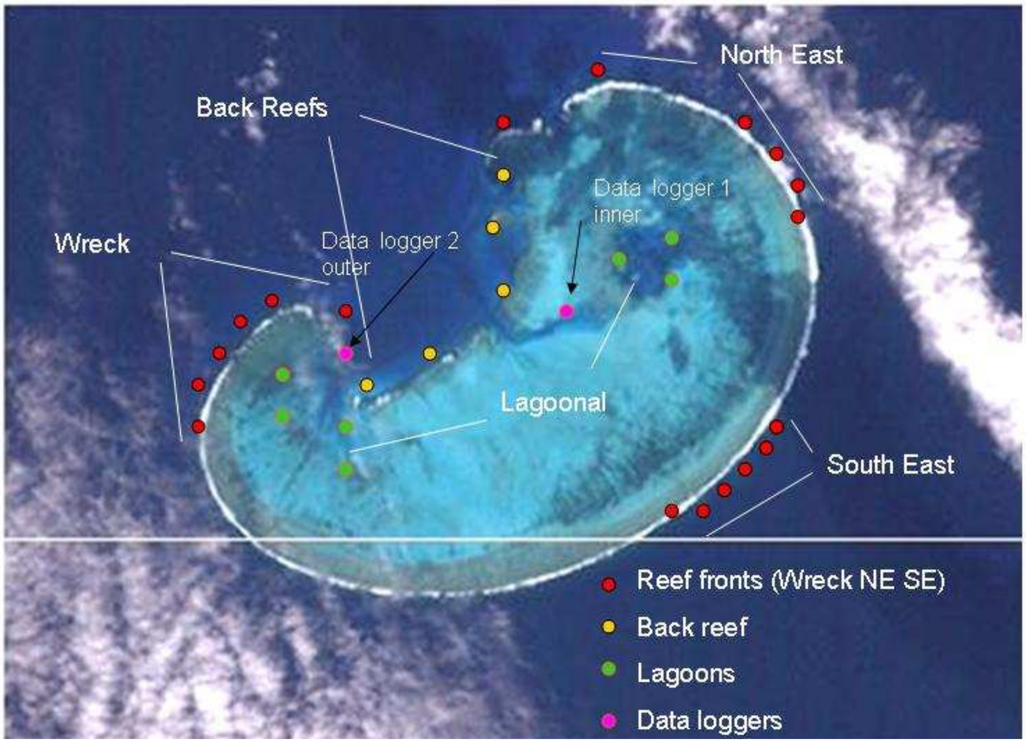

Figure 1A. Satellite image of Middleton Reef showing deployment of sampling sites nested within three habitat types, Reef fronts (3 localities), Lagoon (2 localities) and Back reef (1 locality). Position of data loggers also shown. Each site represents a GPS waypoint.

Figure 1B. Satellite image of Elizabeth Reef showing deployment of sampling sites on the northwest and southern reef fronts. Position of data loggers also shown. Each site represents a GPS waypoint.

Table 1. Common names of main fish study species at Middleton Reef.

Fish Family	**Scientific name**	**Common name**
Carcharinidae; whaler sharks	*Carcharhinus galapagensis*	Galapagos shark
Serranidae; groupers	*Epinephelus daemelii*	black cod
Kyphosidae; sea chubs	*Kyphosus pacificus*	Pacific chub
Chaetodontidae; butterflyfish	*Chaetodon tricinctus*	three striped butterflyfish
Pomacentridae; anemone fish	*Amphiprion mccullochi*	white snout anemone fish
Labridae; wrasses	*Coris bulbifrons*	doubleheader
Labridae; parrotfishes	*Chlorurus microrhinos*	steephead parrotfish
	Chlorurus frontalis	reef crest parrotfish
	Scarus altipinnis	minifin parrotfish
Acanthuridae; surgeonfishes	*Prionurus maculatus*	spotted sawtail

Table 2. Deployment of sampling effort. Middleton and Elizabeth Reefs Feb. 2006

	Habitat Categories (see figure 1)		
Sampling protocol and targets	**Exposed reef fronts**	**Lagoonal reefs**	**Back reefs**
400 x 20 m transects. Large reef fish	15	8	5
400 x 5 m transects. *Acanthaster* numbers	15	8	5
400 x 20 m transects. Dedicated shark counts	27	6	2
30 x 10 m transects. Grazing reef fishes	54	34	-
30 x 4 m transects. Small reef fishes. Chaetodontids & endemics	85	30	5
30 m line intercept and *30 x 2 m transects.* Corals, sessile invertebrates	33	19	3
30 m line transects. Coral species composition	15	---	---

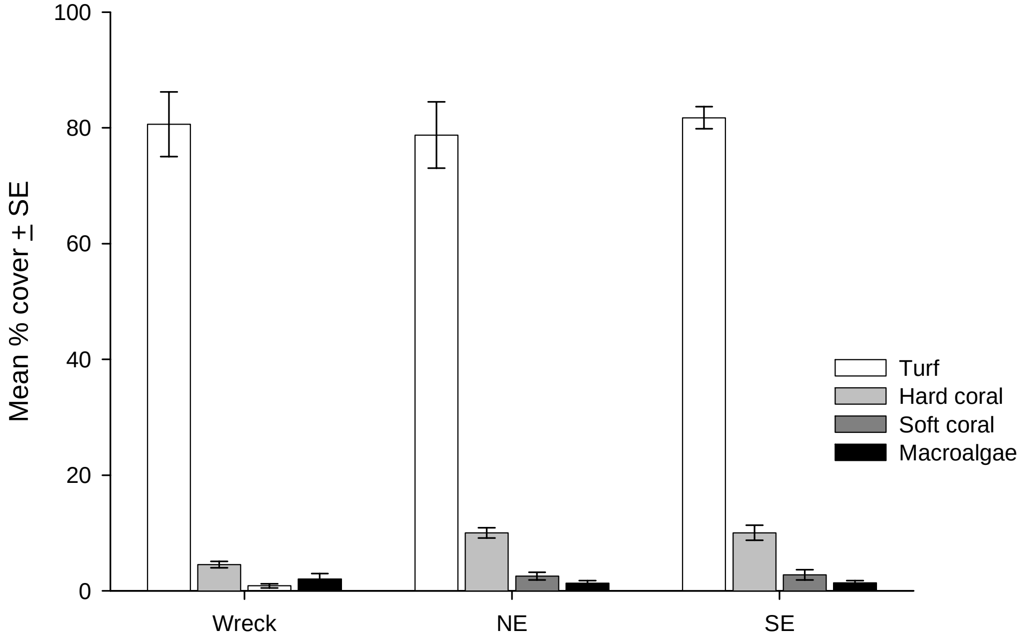

Figure 2. Percentage cover of four types of benthic organisms (turfing algae, hard coral, soft coral and macroalgae) on reef front habitats at three locations.

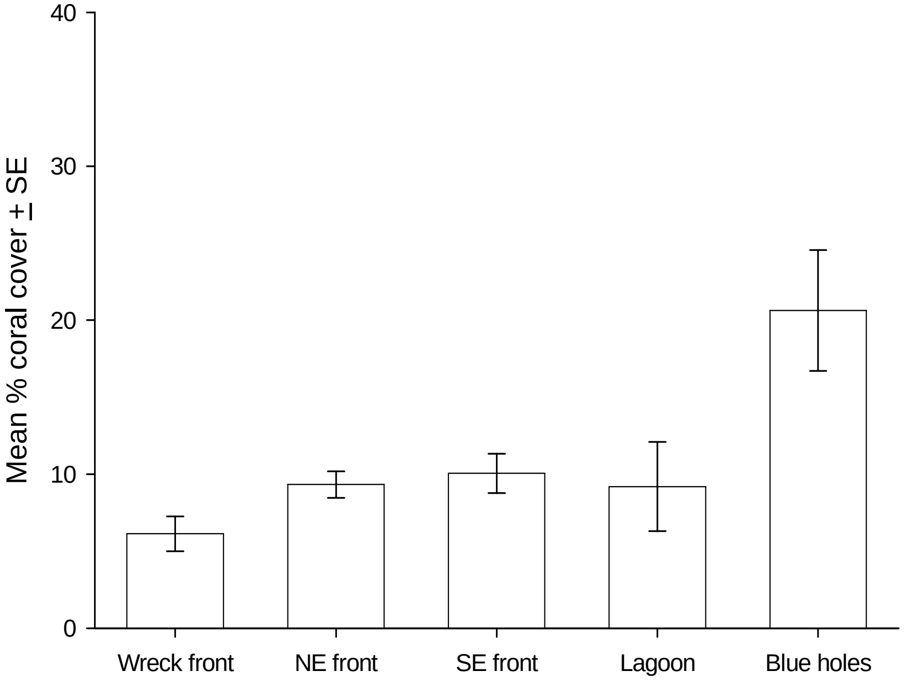

Figure 3. Percentage live coral cover by location at the three reef front and two lagoonal localities, Middleton Reef.

Figure 4. Acropore skeletal material in Western lagoon, serving as a framework for turfing algal growth and hard coral recruitment.

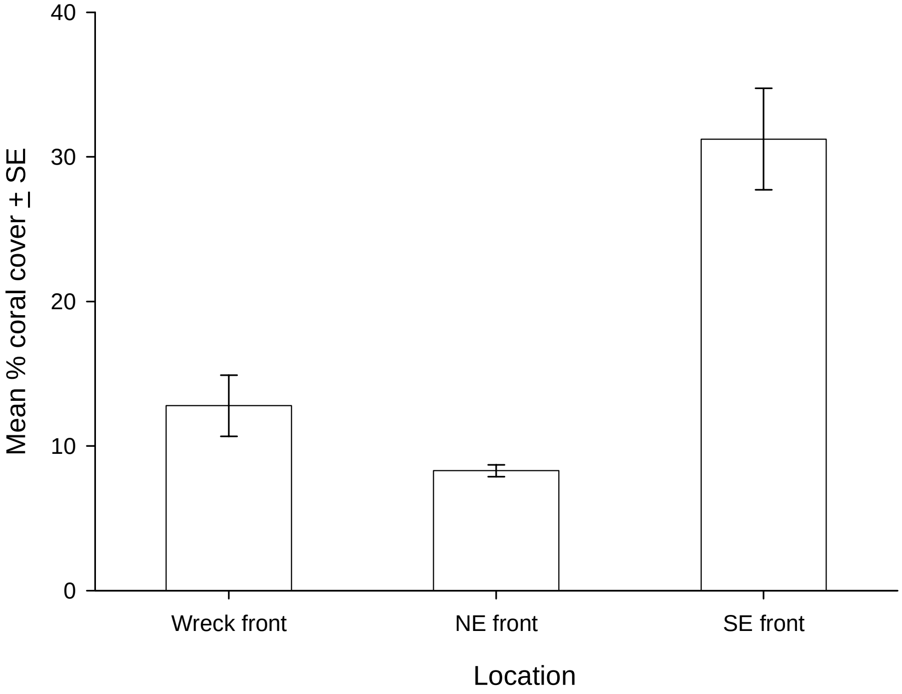

Figure 5. Percentage cover of coral on reef crests (1-3m) at three reef front locations. n=5.

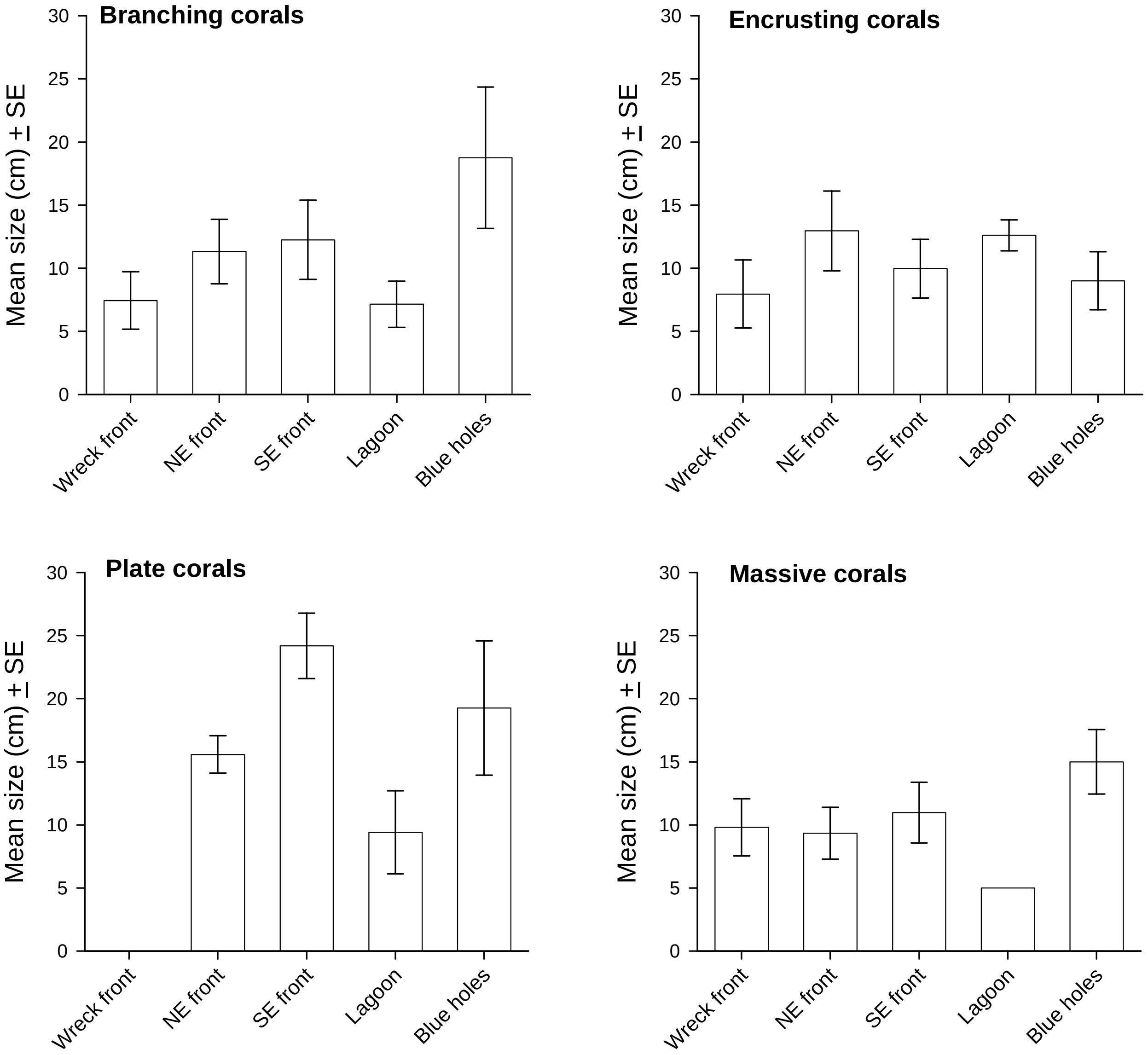

Figure 6. Mean colony size of each coral growth form by location, Middleton Reef.

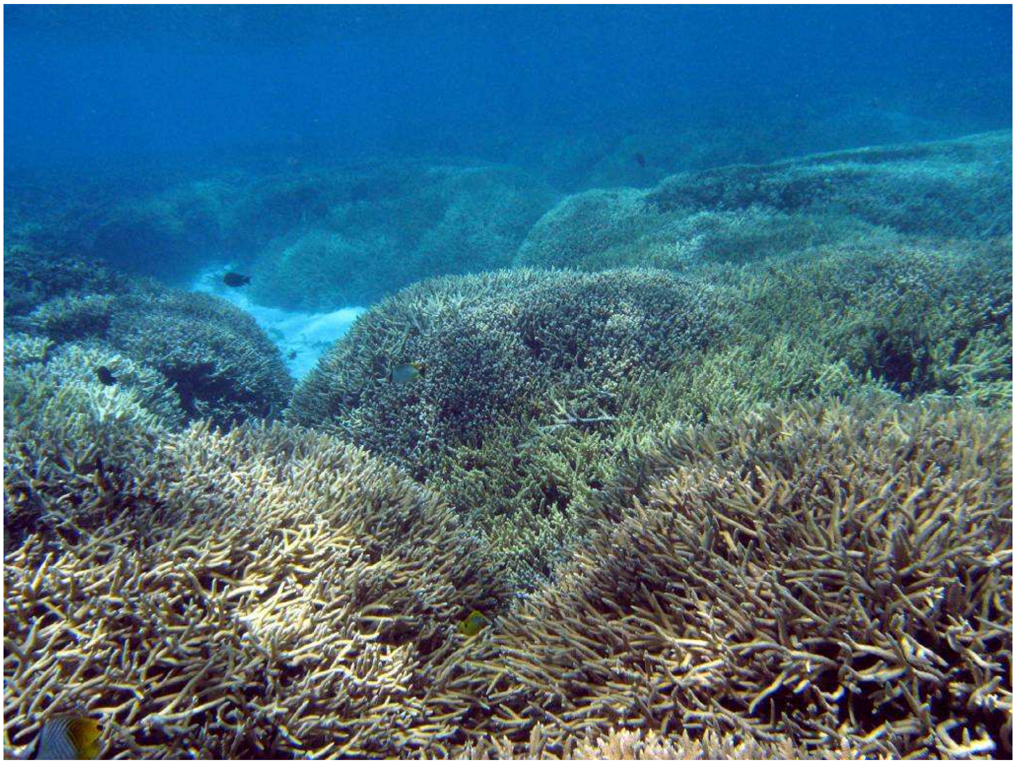

Figure 7. Continuous stands of live Acropora in Western lagoon.

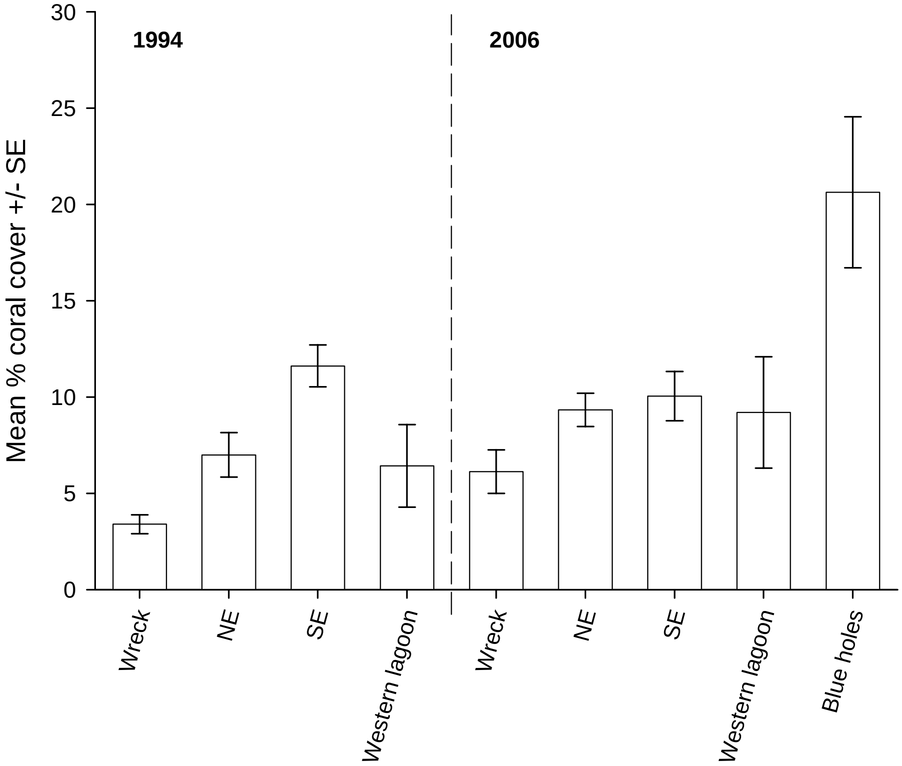

Figure 8. Percentage coral cover for three reef front and one lagoonal location Middleton Reef, 1994 and 2006. Blue holes sampled in 2006 only.

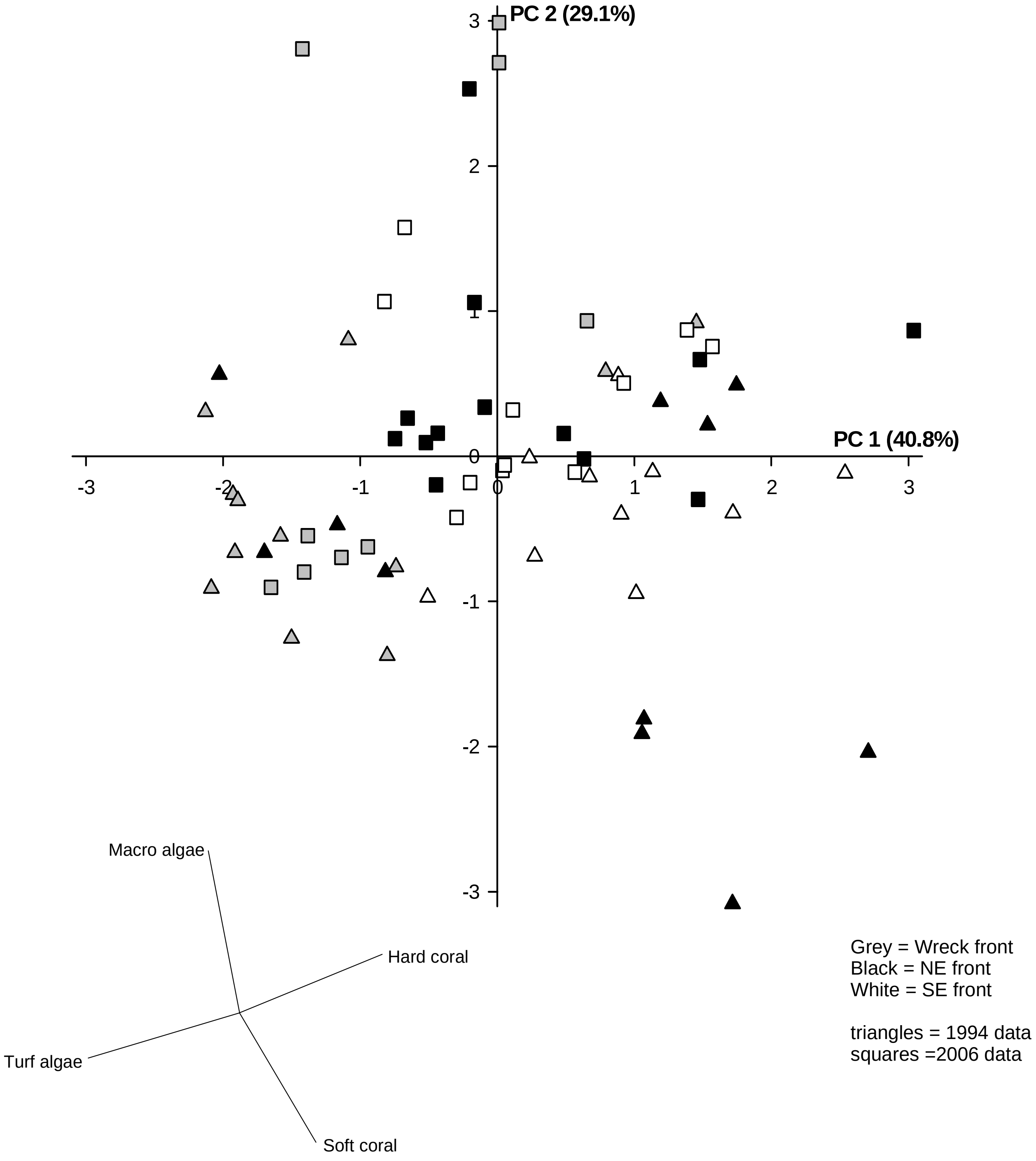

Figure 9. Principal component analysis of percentage cover of four categories of benthic organisms at three reef front locations, Middleton Reef. Surveys were conducted in 1994 and 2006 (this study). Data arcsine-transformed. Influence of each category shown in vector diagram.

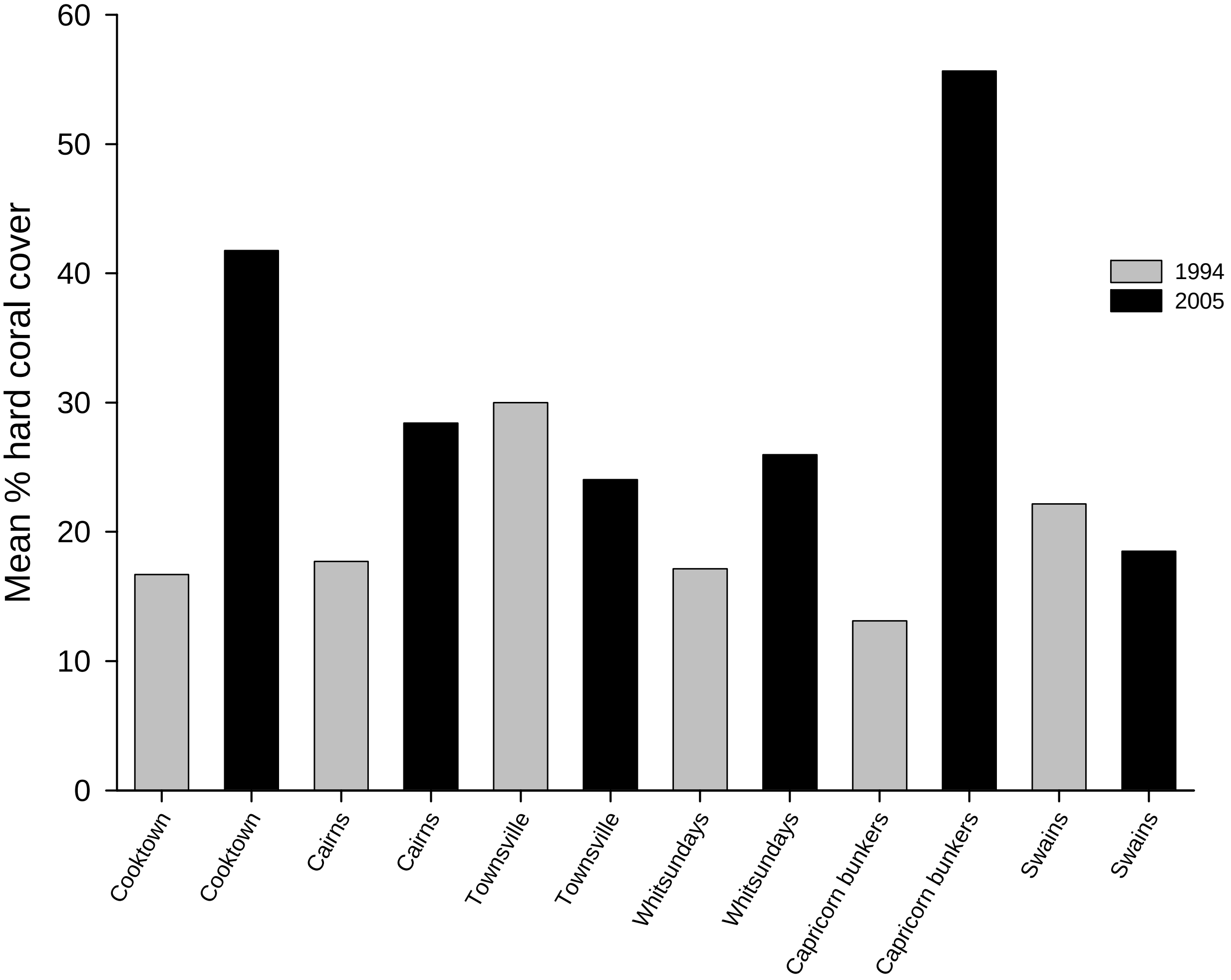

Figure 10. Comparisons of mean percentage hard coral cover from six Great Barrier Reef locations, sampled at two time periods, 1994 and 2005, Australian Institute of Marine Science Long Term Monitoring project. All surveys were conducted on reef north east fronts.

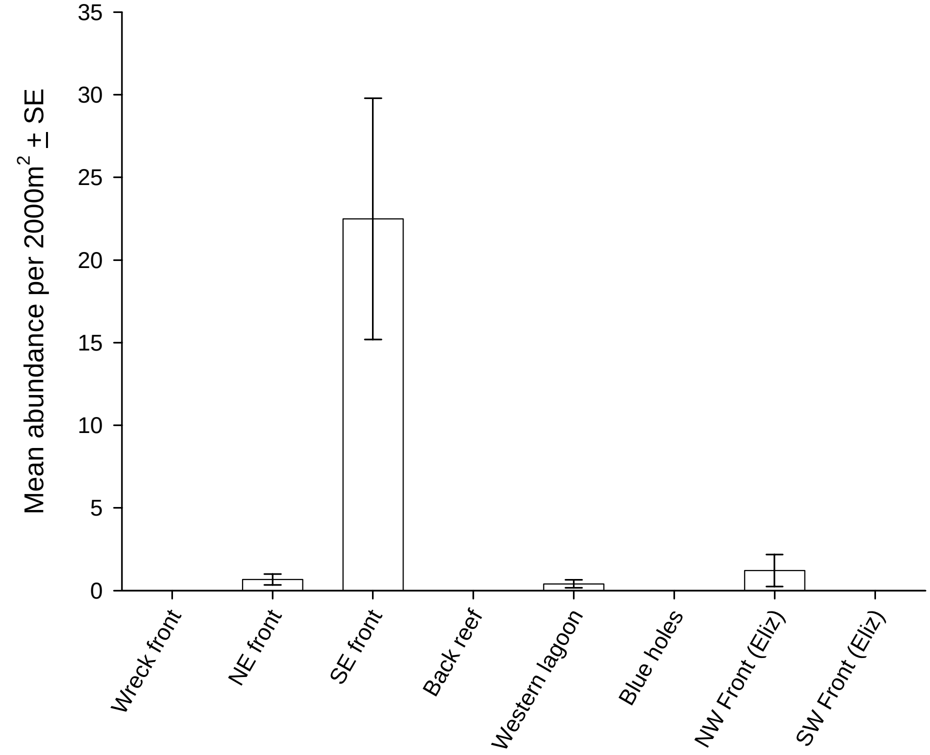

Figure 11. Distribution and abundance of crown-of-thorn starfish, *Acanthaster plancii* at Middleton and Elizabeth Reefs, February 2006. Abundance estimates are number per 2000 m^2.

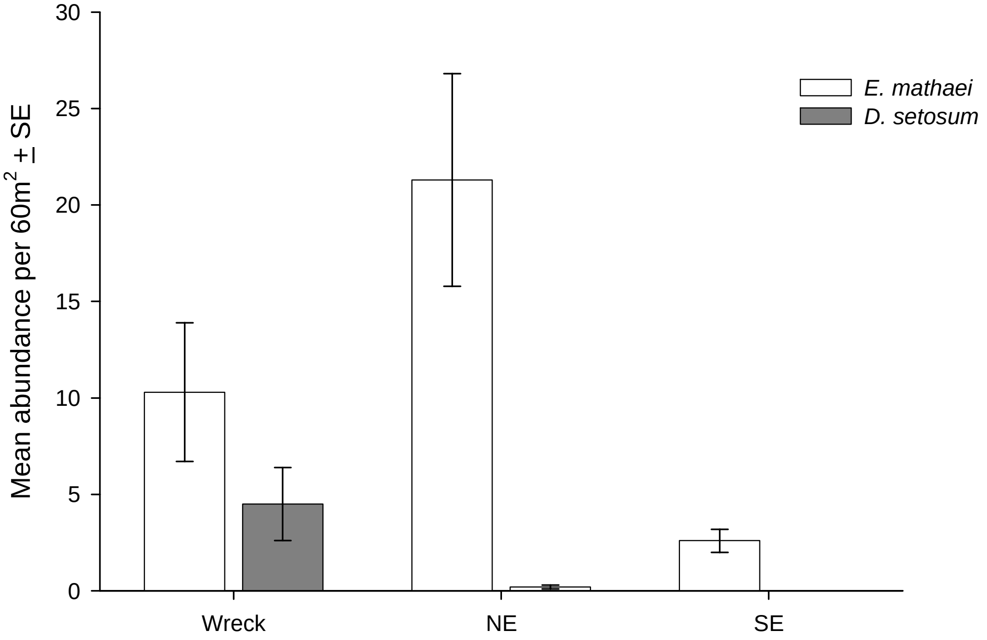

Figure 12. Abundance of echinoids *Echinometra mathaei* and *Diadema setosum* per 60 m^2 on three reef front localities.

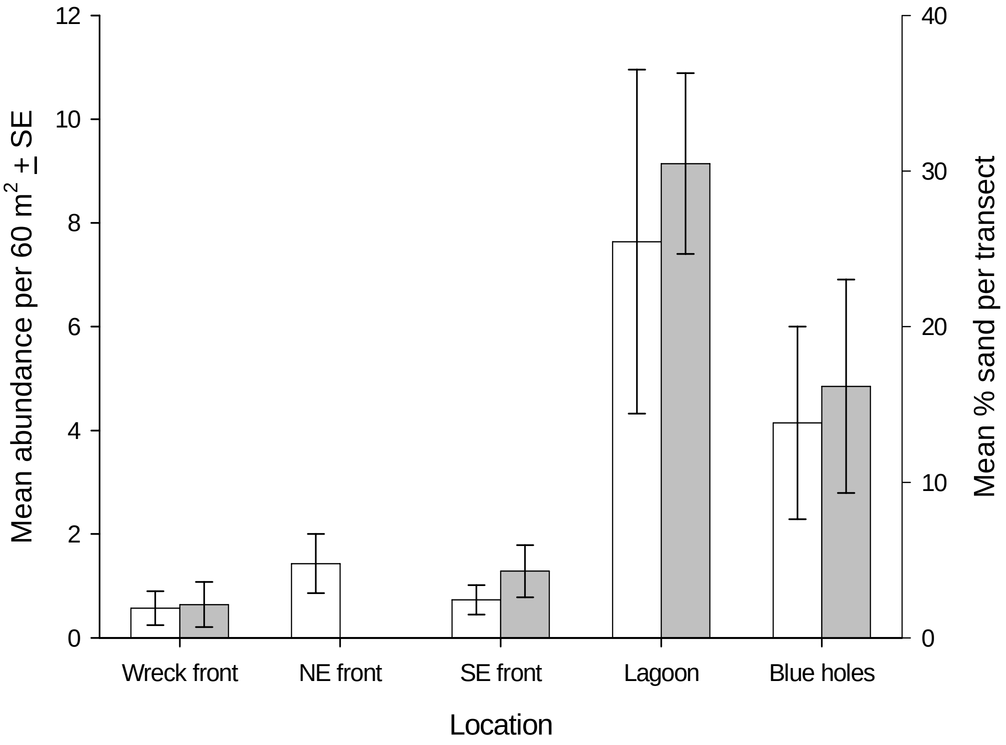

Figure 13. Distribution and abundance of holothurians at Middleton Reef (open bars). Also shown is mean percentage of sand per transect (closed bars).

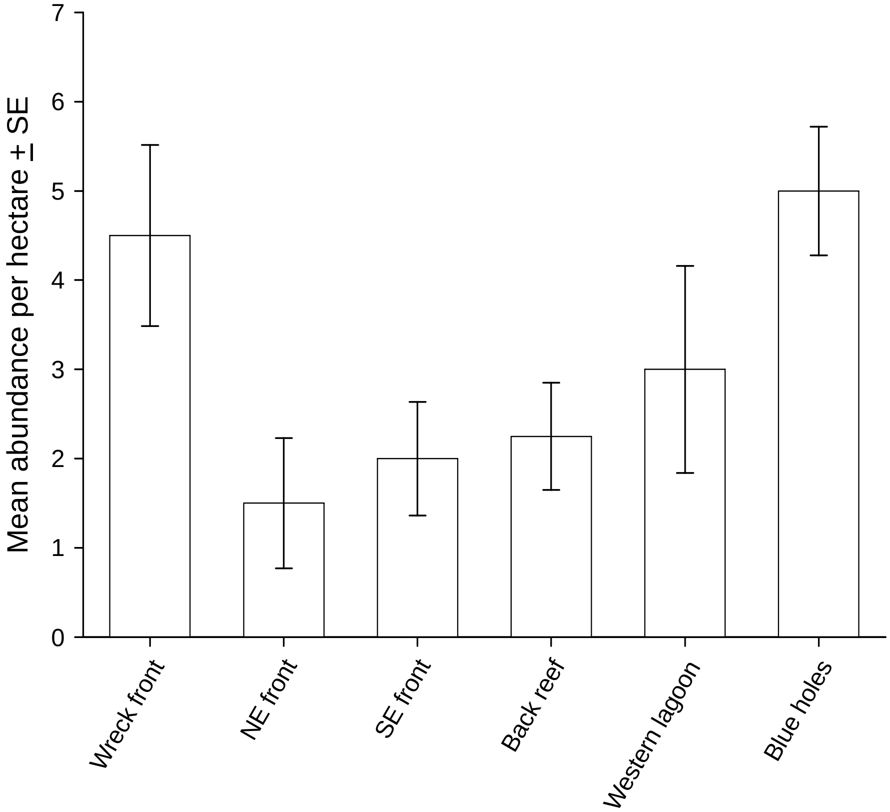

Figure 14. Distribution and abundance of the black cod, *Epinephelus daemelii*, estimated through underwater visual surveys at six locations, Middleton Reef. Abundances have been rescaled from 8000 m^2 to 10000 m^2.

Figure 15. Black cod on reef front habitat.

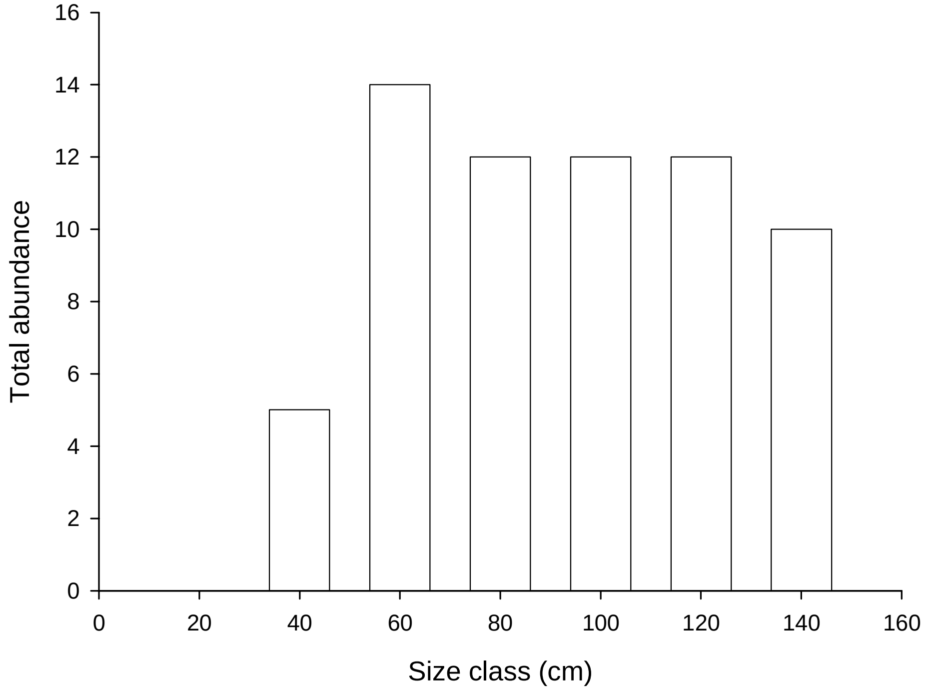

Figure 16. Size frequency of black cod estimated for all transects in six localities.

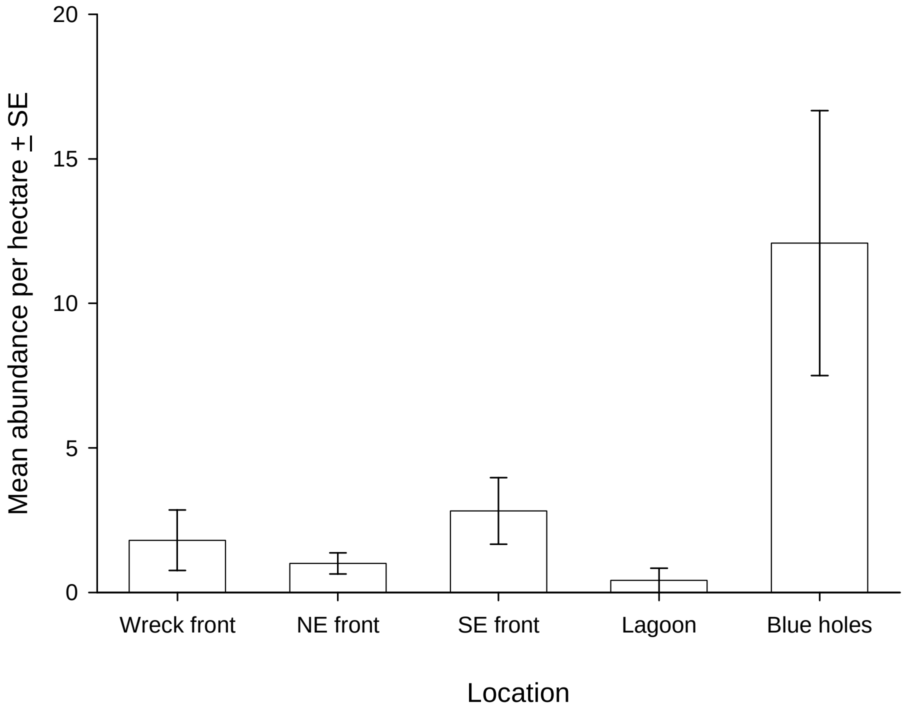

Figure 17. Distribution and abundance of the Galapagos shark, *Carcharhinus galapagensis*, estimated through underwater visual surveys at five locations, Middleton Reef. Abundances have been rescaled from 8000 m^2 to 10000 m^2.

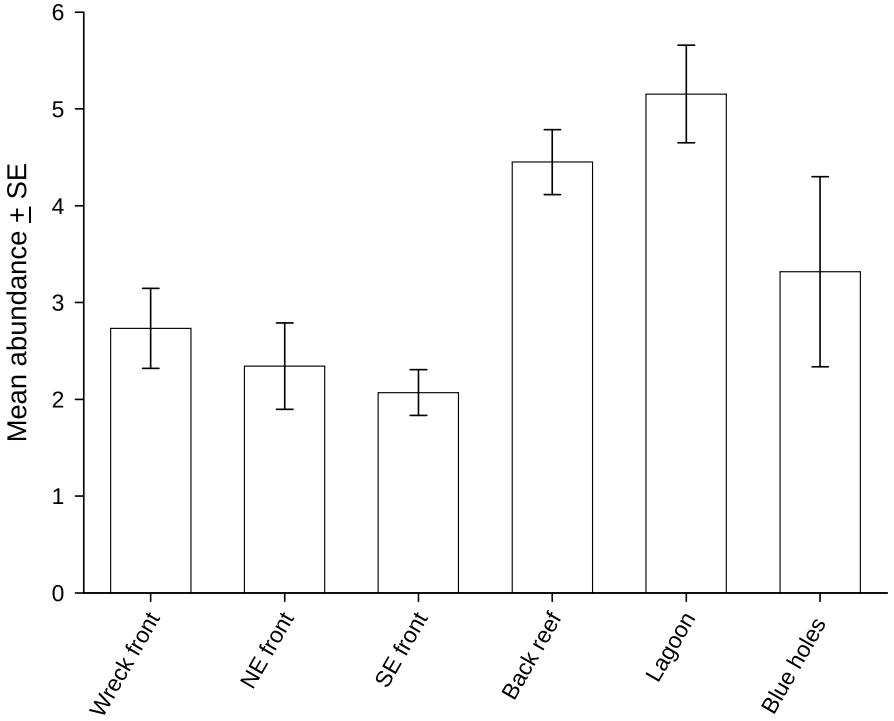

Figure 18. Distribution and abundance of the doubleheader wrasse *Coris bulbifrons* at six location, Middleton Reef. Abundances have been rescaled to 1000 m^2.

Figure 19. Large group of doubleheader, *Coris bulbifrons,* characteristic of sheltered back reef habitats.

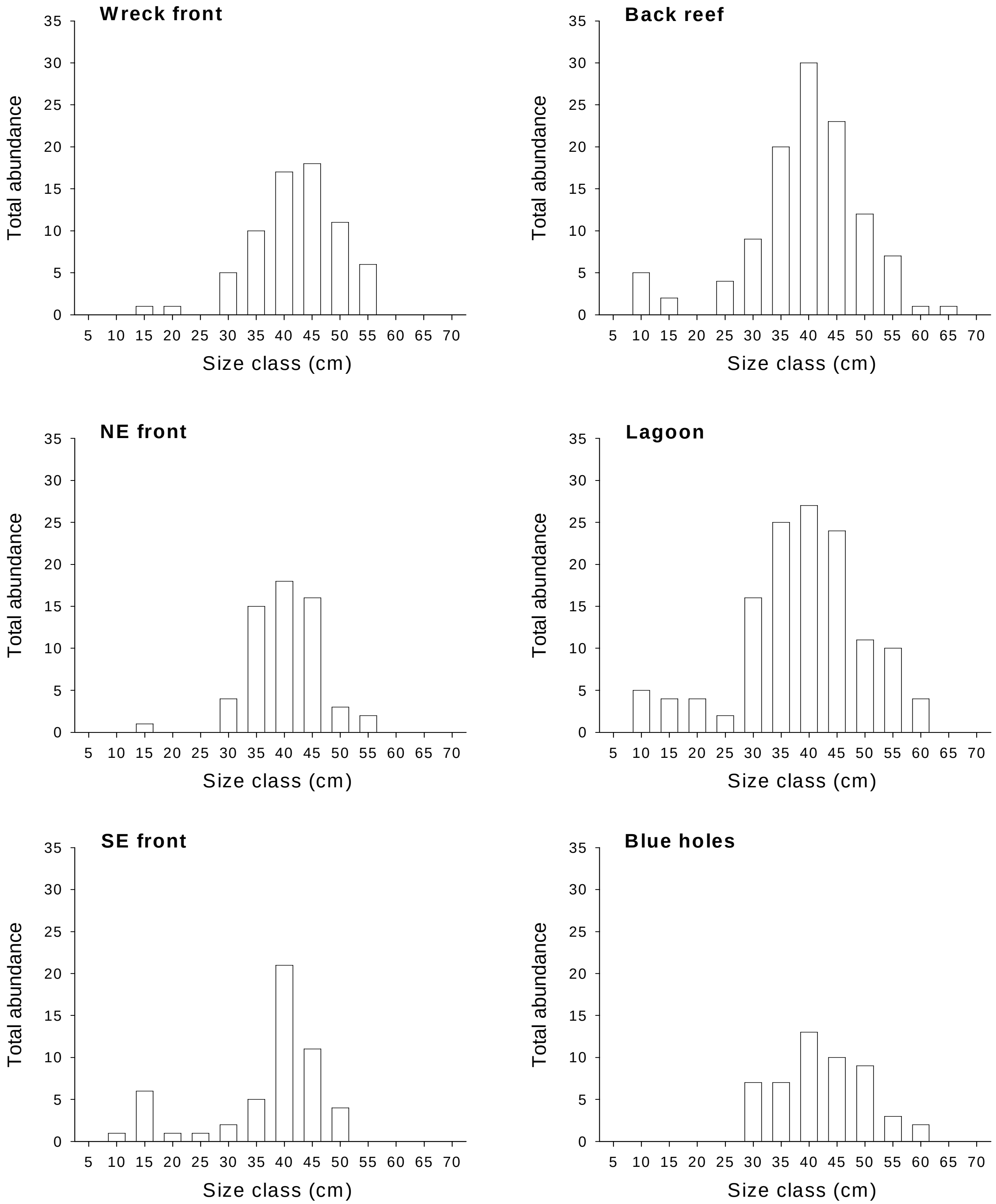

Figure 20. Size-frequencies of doubleheader, *Coris bulbifrons* partitioned by sampling location at Middleton Reef.

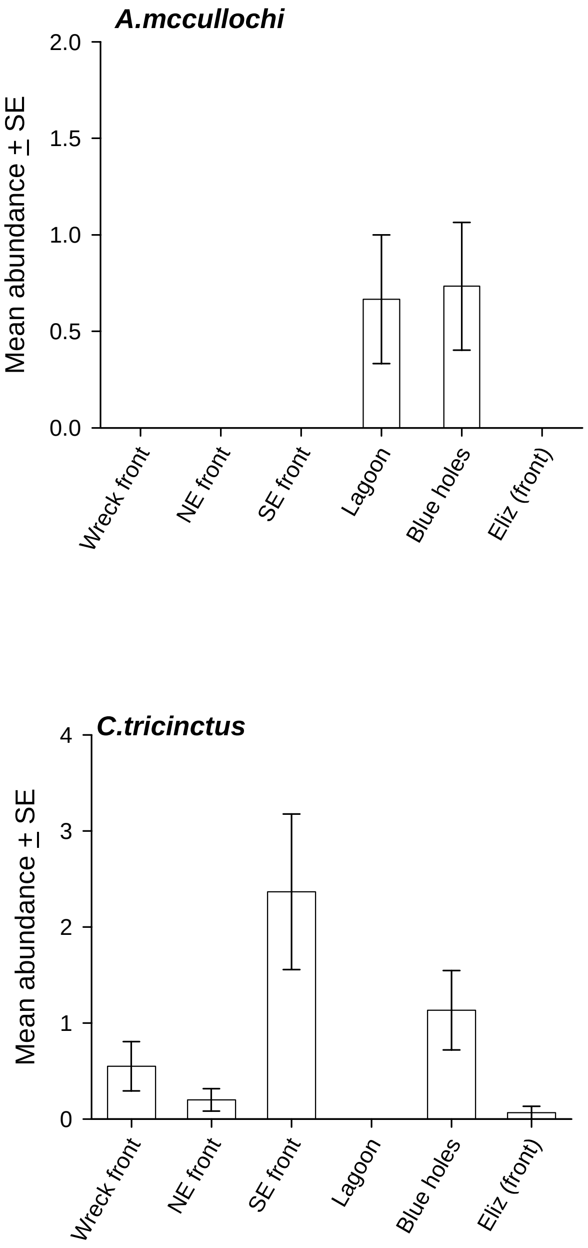

Figure 21. Abundances of small endemic reef fishes the anemone fish *Amphiprion mccullochi* and the butterfly fish *Chaetodon tricinctus* at Middleton and Elizabeth Reefs, estimated from 30 x 4m transects.

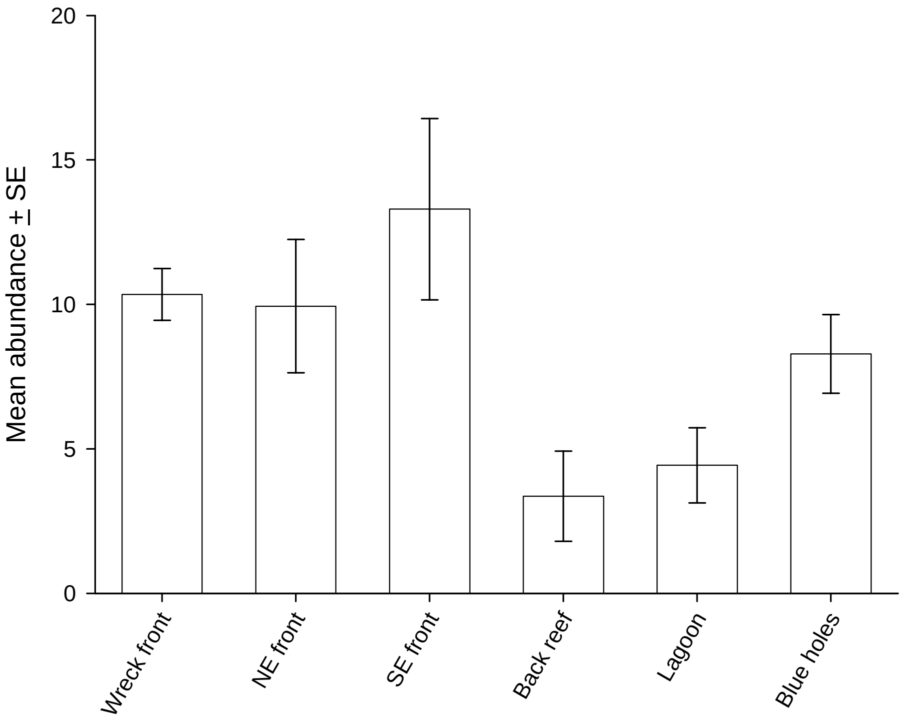

Figure 22. Distribution and abundance of the excavating parrotfish *Chlorurus microhinos* at six locations, Middleton Reef. Abundances have been rescaled to 1000 m^2.

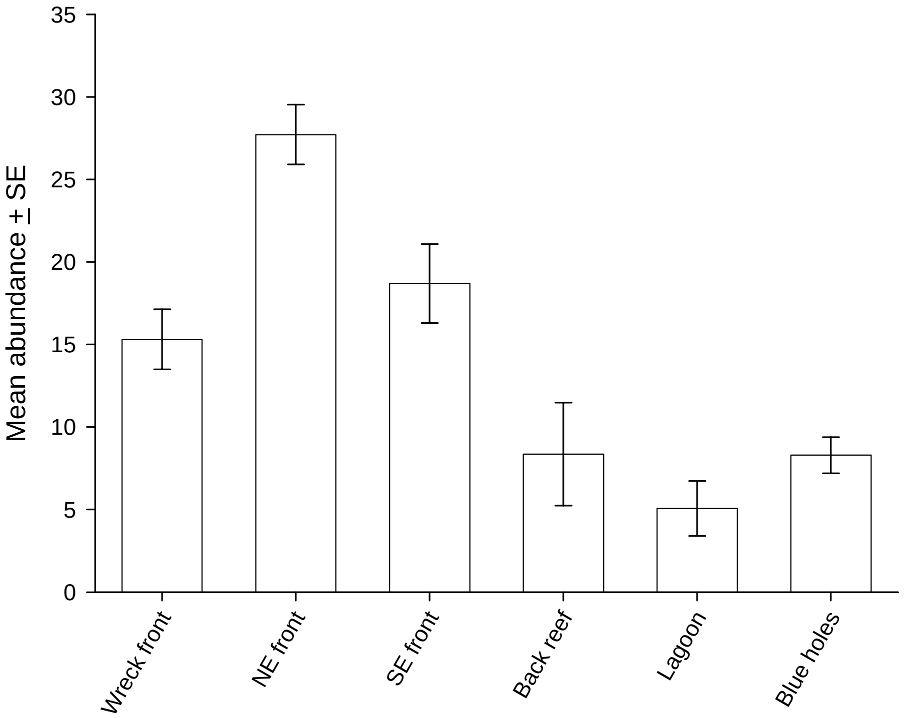

Figure 23. Distribution and abundance of the scraping parrotfish *Scarus altipinnis* at 6 locations, Middleton Reef. Abundances have been rescaled to 1000 m^2.

Figure 24. Large excavating scarid *Chlorurus microrhinos* abundant on reef front habitats, Middleton Reef.

Figure 25. Large excavating scarid *Chlorurus frontalis* characteristic of reef crest habitats, Middleton Reef.

Figure 26. Mixed school of large browsing fishes *Prionurus maculatus* and *Kyphosus pacificus,* characteristic of reef front and crest habitats, Middleton Reef.

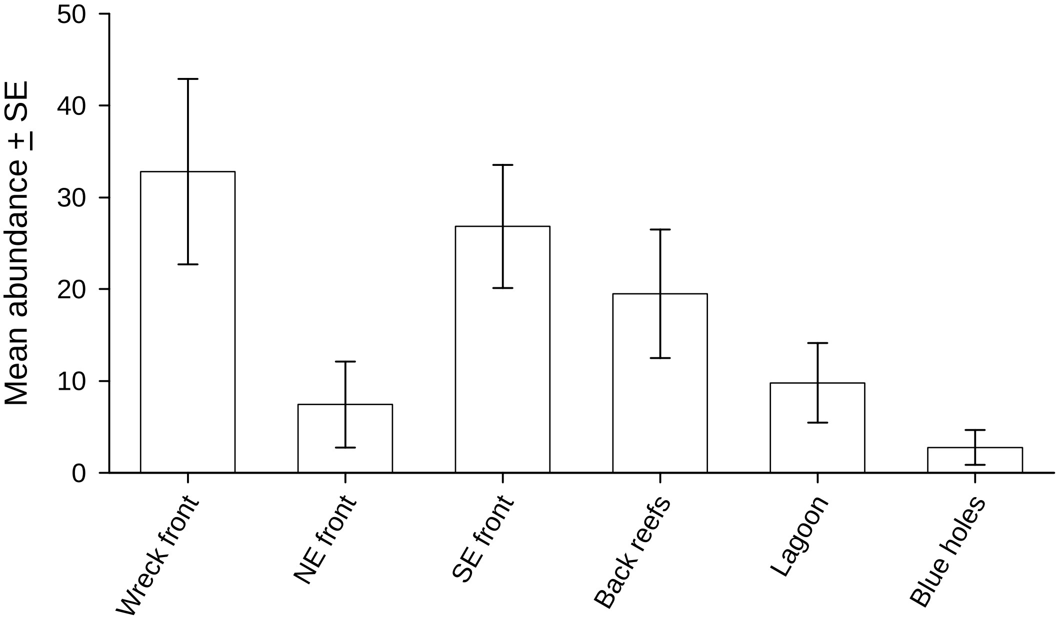

Figure 27 Distribution and abundance of the surgeonfish *Prionurus maculatus* at six locations, Middleton Reef. Abundances have been rescaled to 1000 m^2.

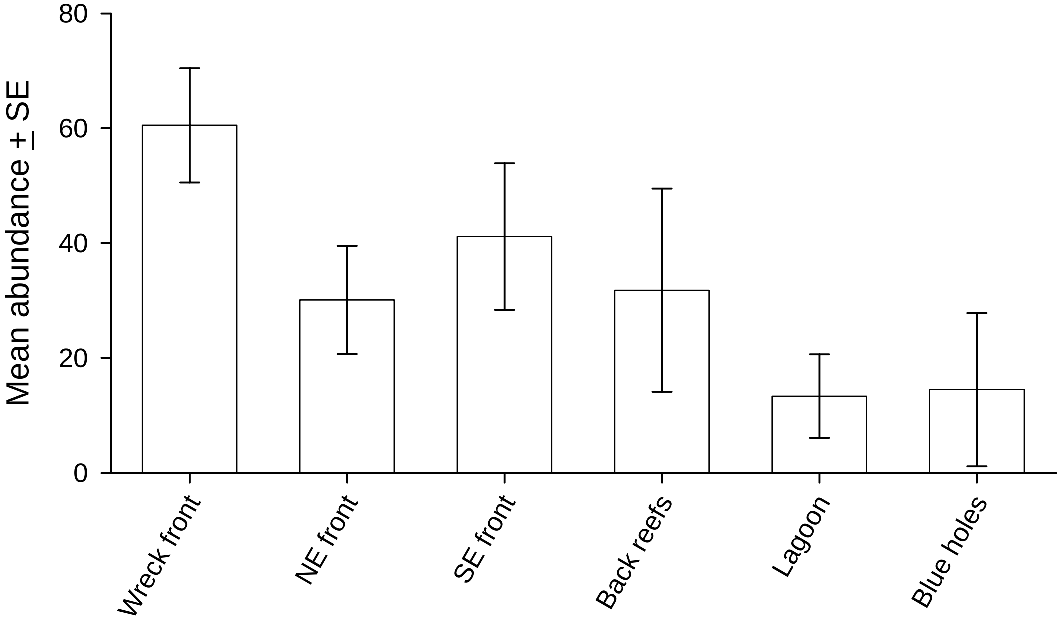

Figure 28 Distribution and abundance of the chub *Kyphosus pacificus* at six locations, Middleton Reef. Abundances have been rescaled to 1000 m^2.

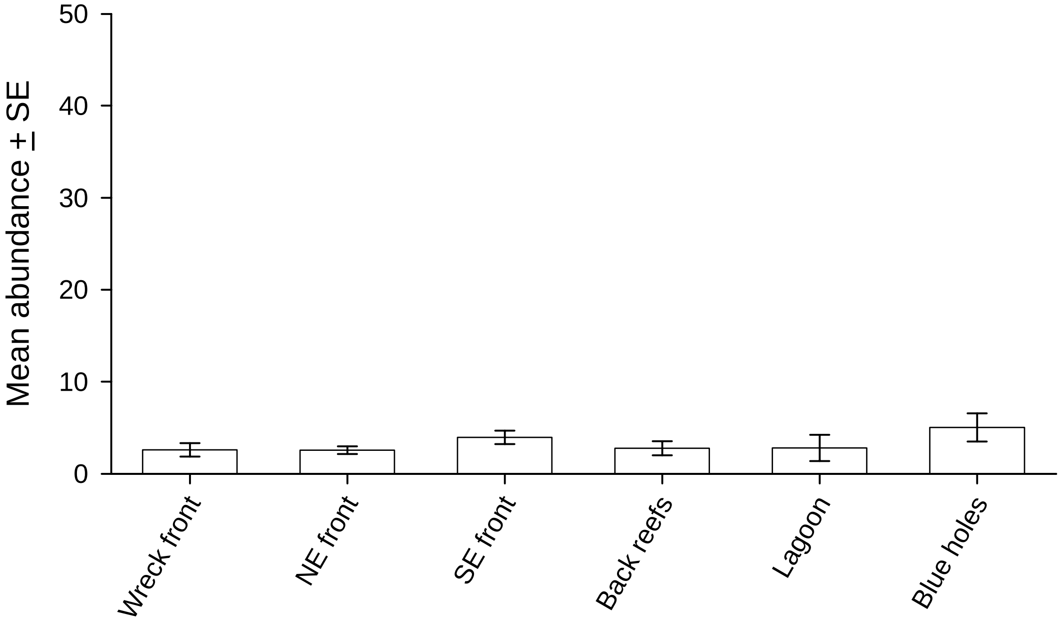

Figure 29 Distribution and abundance of the unicorn fish *Naso unicornis* at six locations, Middleton Reef. Abundances have been rescaled to 1000 m^2.

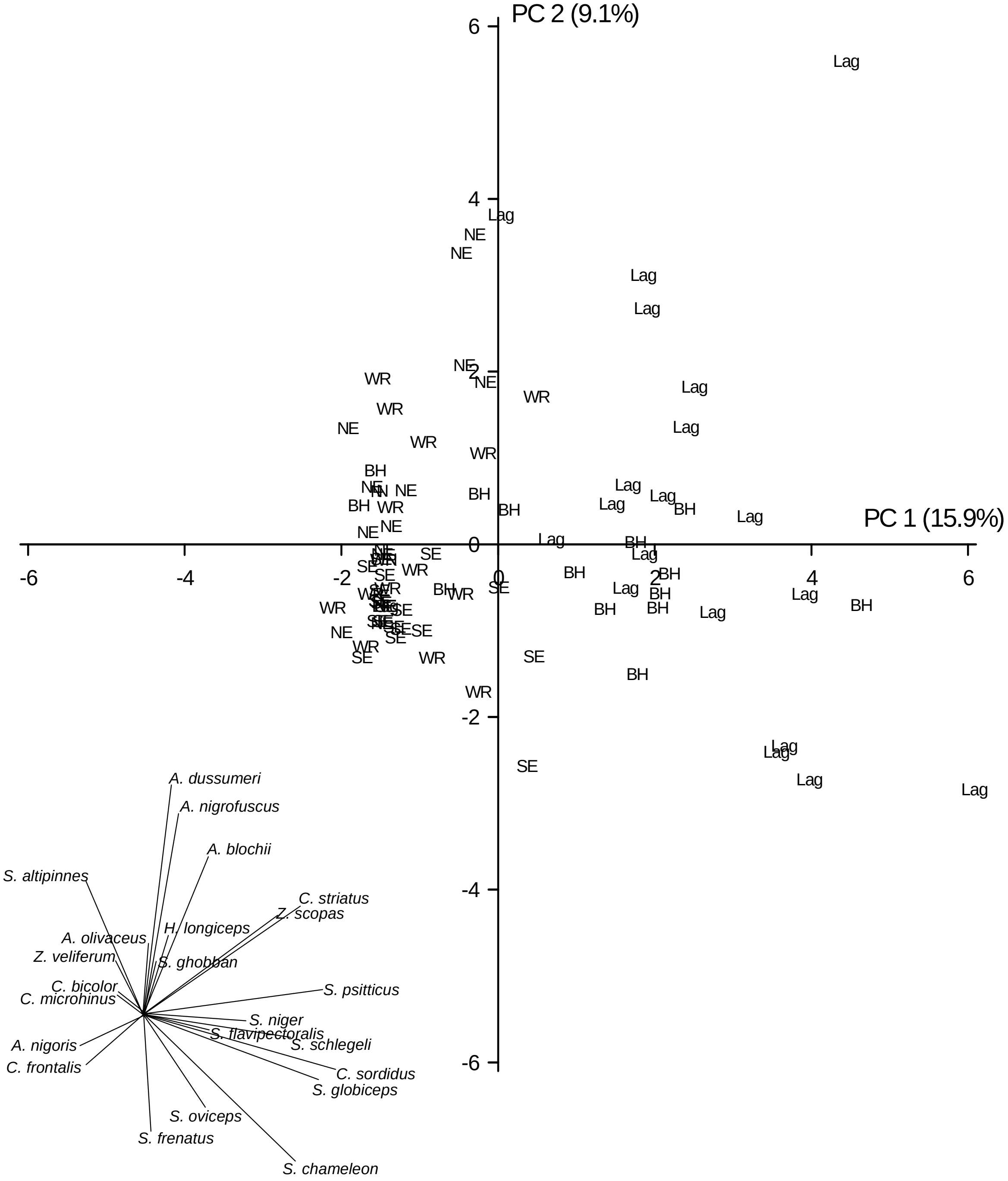

Figure 30. Principal component analysis of smaller scarids and acanthurids from Middleton Reef. Surveys were conducted at Wreck front, NE front, SE front, Lagoon and Blue Holes locations. Data natural log-transformed. Vector diagram indicates species/habitat associations.

Figure 31. Concentrations of small grazing species associated with living and dead coral stands characteristic of lagoonal habitats, Middleton Reef.

Figure 32. Living reef front corals showing skeletal cropping, the results of feeding by large excavating scarids, reef front habitats, Middleton Reef.

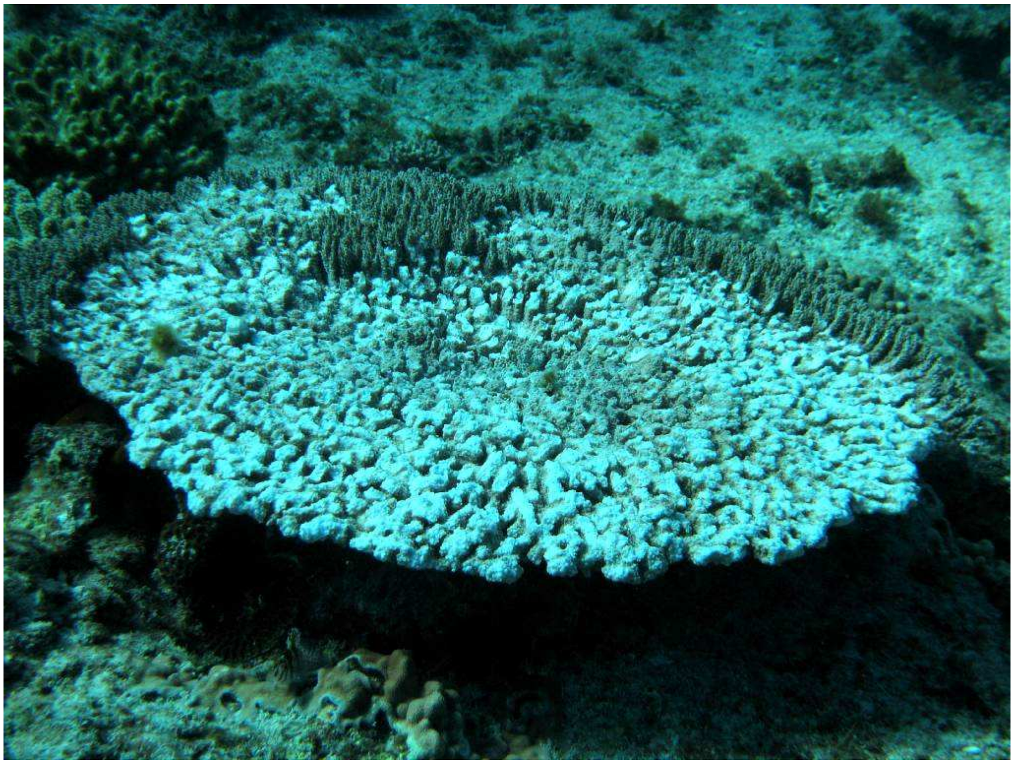

Figure 33. Living reef front corals showing skeletal cropping, the results of feeding by large excavating scarids, reef front habitats, Middleton Reef.

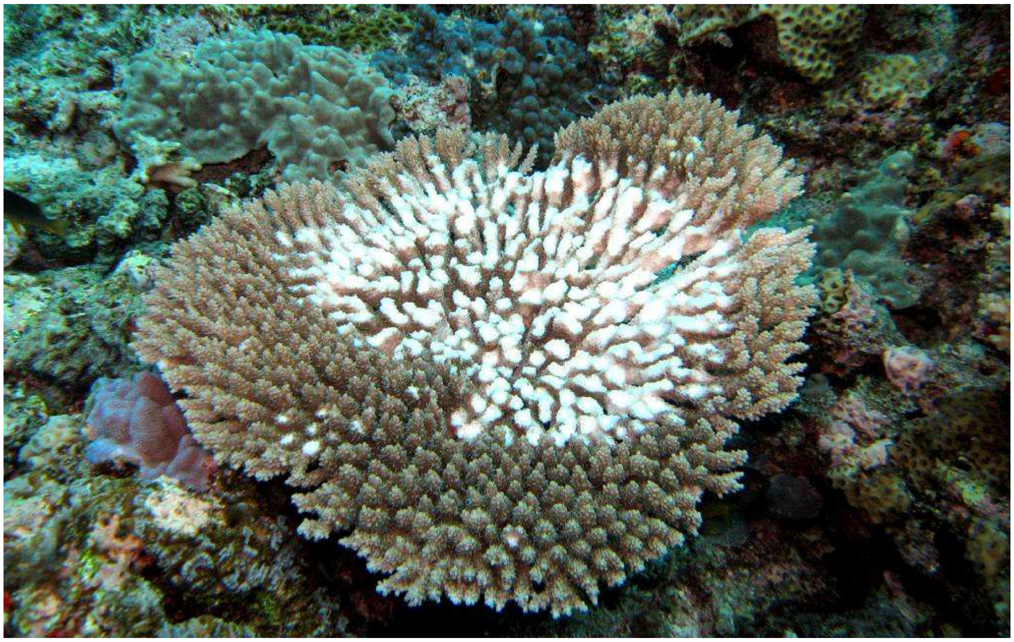

Figure 34. Living reef front corals showing skeletal cropping the results of feeding by large excavating scarids, reef front habitats, Middleton Reef.

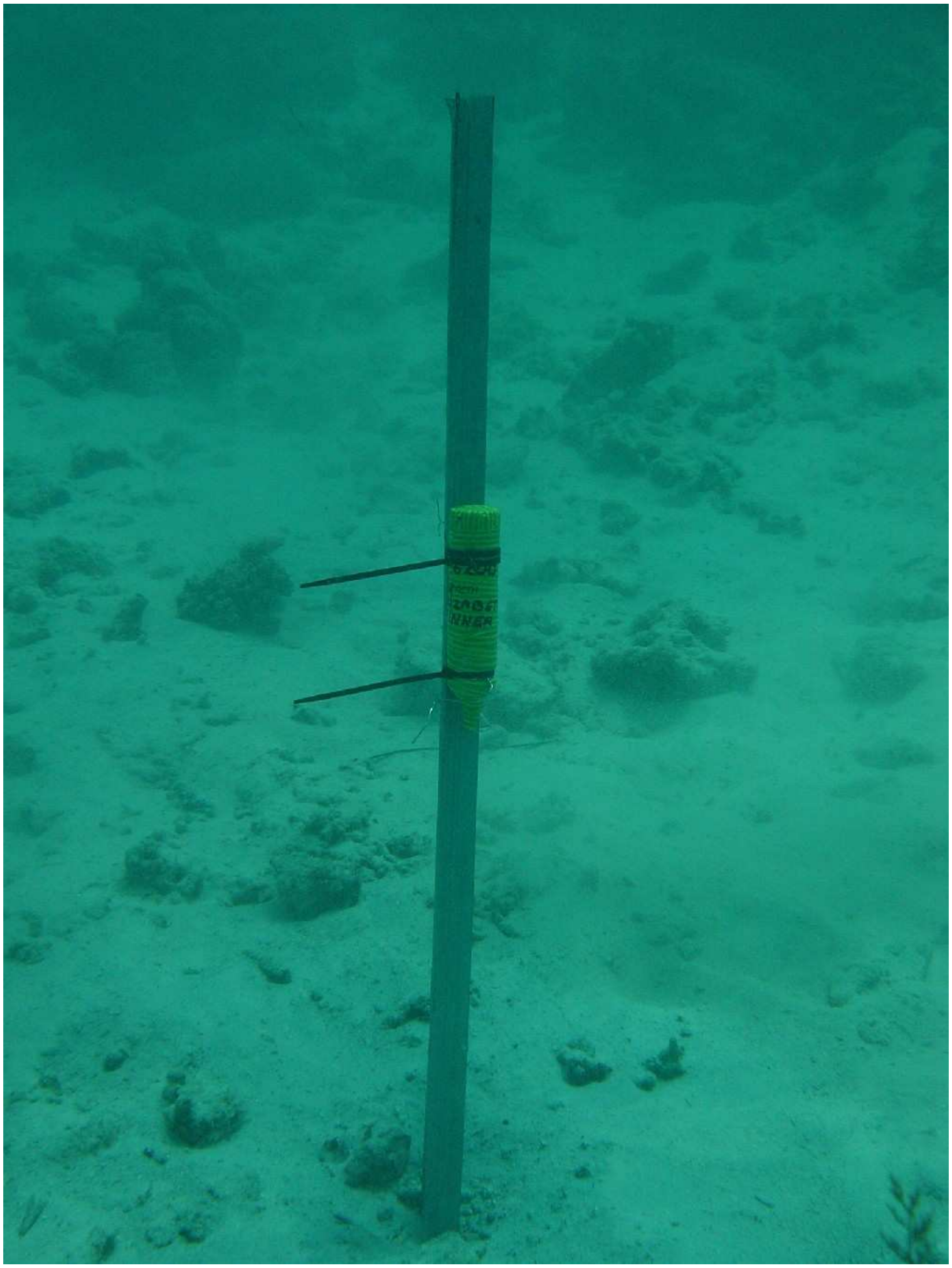

Figure 35. Outer data logger deployed at Middleton Reef, February 2006.

DISCUSSION

The survey of Middleton Reef, although undertaken over a relatively short time period, provided the opportunity to develop a comprehensive picture of the local abundance patterns of the key organisms identified in the terms of reference. This included estimates of hard coral cover and condition, abundances of coral predators, primarily *Acanthaster,* holothurians and a number of reef fish species included the endangered black cod, reef sharks and a number of species endemic to the Elizabeth-Middleton reef system. Of equal importance were estimates of the abundance and local distribution of groups including grazing and browsing fishes that have a potentially significant role in transitional coral reef ecosystems.

High latitude coral reef systems hold a special fascination for reef biologists and biogeographers. They represent transitions from biologically complex tropical habitats dominated by scleractinian corals to temperate habitats with a greater biomass of macroscopic algae (Crossland 1988, Johannes et al 1983). Care is required in separating anthropogenic influences from normal biological process in these poorly studied reef systems. For this reason, the survey has emphasised two elements of the reef community structure: estimates of abundance of species considered to be vulnerable to human disturbance and exploitation and the assemblages of functionally important species that have the potential to influence reef structure, especially live coral cover.

Middleton Reef located at 29^{o}S, presents both an opportunity and a challenge to the understanding of coral reef ecosystems. The accumulating information on the Elizabeth and Middleton Reef system highlights two issues central to their continued conservation and management.

Firstly, as isolated and relatively inaccessible reefs, many species and especially the larger reef fishes have been protected from the overfishing characteristic of coastal ecosystems. The extreme vulnerability of reef sharks, groupers and large wrasses to fishing pressure emphasises the need to ensure that the presently healthy populations at Middleton are provided with adequate protection under future management regimes.

Secondly, the ecosystem processes and biological dynamics of high latitude reef systems are not well understood. The results of past surveys suggest that the low live coral cover at Middleton Reef represent a long and slow recovery phase. Low coral cover is a consequence of past *Acanthaster* outbreaks and that recovery should lead to higher levels of cover. An alternative view is that low coral cover at Middleton Reef is the norm, a consistent feature of these high latitude reefs and reflects a more dynamic system with high recruitment and morality rates.

Finally, although the three reefs Lord Howe, Elizabeth and Middleton lie within 300 km of each other, they display different patterns of coral assemblage structure and abundance. Lord Howe differs from the two more northern reefs in that the diversity and percentage cover of live corals is lower with only 83 species of hard coral being reported from Lord Howe (Harriott et al 1995) as opposed to 122 from Elizabeth and Middleton (Oxley et al 2003). There are two potential reasons for this. Firstly Lord Howe is a continental island, so suitable reef substratum is limited. Secondly, Lord Howe lies below the convergence zone of the boundary between the Coral and the Tasman seas and thus is not exposed as directly to the southward flowing currents that reach Elizabeth and Middleton Reefs. One consequence of this is the relative isolation of Lord Howe with respect to the genetic structure of reef corals (Miller and Ayre 2004). Although Elizabeth and Middleton share taxonomically similar coral assemblages (Australian Museum 1992), the percentage of living coral cover at the latter reef is approximately half that recorded from Elizabeth. This appears to be a long term (decadal) feature of these reefs. The other major difference between the two northern reefs lies in the configuration of the lagoon systems. For Elizabeth Reef, the lagoon is almost completely enclosed and the northern and northwest reef perimeters consist of steep reef slopes exposed to open ocean conditions. Middleton presents a contrasting condition in which the lagoonal system is open to the north west with a deeply indented and sheltered backreef area that provides a habitat feature unique to this reef system. The importance of this with respect to comparisons between Elizabeth and Middleton reef fish faunas is discussed below.

Large vulnerable reef fishes

The 400 m long swim transects provided consistent abundance estimates of black cod, Galapagos sharks and doubleheader wrasse. The overall mean abundance of black cod was 2.9 individuals per hectare. Black cod achieved their highest abundance in sheltered sites (mean abundance 4.1 per hectare) on the northern reef front and were relatively uncommon on exposed easterly and southern reef fronts. This species is one of the most common of the larger shallow water epinepheline serranids. Estimates of abundance of two equivalent sized serranids occupying similar shallow water habitats on the northern GBR were obtained. Pears (2006a and 2006b) estimated abundance of *Epinephelus fuscoguttatus* (flowery cod) and *Epinephelus tukula* (potato cod) in protected habitats as 2.9 and 0.9 per hectare respectively. At no sites were these two species recorded as exceeding three per hectare. Moreover, limited counts on reef front sites at Elizabeth Reef provided even higher estimates (5.3 per hectare). The data confirm that this species is one of the most abundant and accessible of the larger serranids.

Shark abundance estimates showed the same general pattern as the black cod data set. We recorded very high abundances of the reef shark *C. galapagensis* at a number of reef localities. Abundances were ~ 1.6 sharks per hectare, significantly higher than reef shark species on most northern and central Great Barrier reefs; and equivalent to those obtained for other reef shark assemblages in pristine environments, preservation zones on the northern Great Barrier Reef and the Cocos Keeling Islands (Robbins et al 2006). However Galapagos shark abundances at one location, the lagoonal Blue Holes habitat were very high, with approximately 12 individuals per hectare. Distribution of sharks was highly localised. Although no movement data are available for Middleton Reef, studies on smaller whaler sharks on the Great Barrier Reef (Robbins et al 2006) suggest that little movement between reefs is shown by this group, although movement between habitats within reefs does occur. Material for resolving the degree of isolation between reefs and divergence between Elizabeth and Middleton populations through analysis of mitochondrial genomes is presently being processed as a part of the broader study of shark and black cod population structure. At present the most appropriate management procedure for reef associated whaler sharks is to manage each reef as if populations were restricted to that reef.

The large endemic wrasse *Coris bulbifrons* achieved overall abundances of 33 individuals per hectare, far higher than that recorded for large, more tropical wrasses (Choat et al 2006). The greatest numbers (approximately 43 per hectare) were recorded from the sheltered back northern reef and lagoonal environments. Very few juveniles were recorded for either black cod or doubleheader wrasse. These observations indicate that juveniles were cryptic and confined to sheltered reef habitats. The greatest numbers of adults were recorded from backreef habitats. The absence of the equivalent back reef habitat at Elizabeth Reef strongly suggests that Middleton Reef will support the highest abundances of this endemic species.

An important characteristic of both Elizabeth and Middleton Reefs were the large schools of herbivorous fishes on the exposed reef fronts, especially the SE and Wreck quadrant. These were dominated by acanthurids and kyphosids (*Pionurus maculatus*, *Kyphosus pacificus*). The blue fish *Girella cyane, a* a striking species characteristic of offshore islands, was always rare with small numbers being recorded on the southern and northeastern reef fronts. Studies from the 1994 survey demonstrated that this species was a true herbivore, feeding on green algae and using fermentative digestion (Clements & Choat 1997). The distribution of this species is similar to that of the black cod, extending from the SE Australian subtropical reefs and offshore island to northeastern New Zealand and the Kermadecs. Extensive surveys carried out in northeastern New Zealand (Meekan & Choat 1997) demonstrated that *G. cyanea* was always a minority component of the grazing fish fauna and confined largely to offshore island. No records of this species were obtained from coastal sites, even in marine reserves. The only locality in which this species achieves high abundances appear to be the Kermadec Islands (Schiel et al 1986).

All of the above fish species have restricted natural distributions in Australian waters. The importance of the Elizabeth/Middleton Reefs lies in the fact that this location represents the centre of abundance both for species endemic to this system and for species with wider distributions such as the black cod and sharks that have been exposed to fisheries at other locations. The most significant feature of these findings is that for the three species most vulnerable to line fishing – black cod, doubleheader wrasse and Galapagos sharks – all have their greatest abundances in shallow sheltered water that would be most accessible to human activity. This information reinforces the conclusion that the sheltered reef and lagoonal environments of Elizabeth and Middleton Reefs are of profound importance both as juvenile and adult reef fish habitats.

Coral cover and ecosystem processes at Middleton Reef

An important finding of the survey was that mean coral cover at Middleton Reef was relatively low across all reef front and lagoonal habitats with an overall mean of 11.4 per cent live coral cover. This confirms conclusions from previous surveys (Oxley et al 2003 and references therein) that live coral in these high latitude reefs is presently low compared to more northern reefs and that mean colony size is relatively small. An important conclusion from previous surveys is that the moderate level of coral cover is consistent with a reef recovering from disturbances including past episodes of *Acanthaster* outbreaks and the impact of wave action (Oxley et al 2003 and references therein).

The results of the present survey offer some support for this viewpoint. Coral cover, especially on the reef fronts and crests of exposed reefs was relatively low and mean coral colony size small. Moreover, evidence of *Acanthaster* activity was found on the reef front habitat and stands of recently dead *Acropora* were found in lagoonal habitats. An important corollary of the hypothesis of recovery from disturbance is that in the absence of *Acanthaster* feeding and with a more moderate wave regime, coral cover on these reefs would be much higher. Contrasting Elizabeth and Middleton Reef with lower latitude reefs reinforces the assumption that both coral cover and coral recruitment rates are very low.

However, the information available provides for an alternative view. Low coral cover, small colony size and evidence of coral recruitment on dead stands suggest a dynamic assemblage with high mortality and recruitment rates. Low coral cover on reef fronts is the norm and not a result of recent disturbance.

While a more adequate time series with information on growth and recruitment rates is required to clarify the dynamics of the coral assemblages, comparisons with more northern reefs should be made cautiously. There are four reasons for this. Firstly, ecosystem processes and biological dynamics of high latitude reef systems are not well understood and they lie towards the geographical limits of bleaching and cyclonic impacts. Although wave surge may be consistently higher on exposed oceanic reefs this is likely to be a consistent habitat feature and distinct from the impact of cyclones that act as an intense pulse disturbance over a relatively small geographic area and result in massive local coral damage. Reef front gutters and surge channels at Middleton Reef did not contain the accumulations of coral skeletal material that is characteristic of northern reef fronts and indicative of wave damage**.**

Secondly, the role of the very abundant schools of grazing and browsing fishes characteristic of reef fronts has not been clarified. A surprising feature of the current survey was that grazing and excavating parrotfishes that can have both beneficial and detrimental effects on coral recruitment and growth were as abundant at the high latitude reefs as on lower latitude reefs. However, unlike low attitude reefs, the Middleton Reef front also supported very high abundances of browsing fishes. The collective significance of this diverse and abundant mobile fauna with respect to cover and growth of sessile assemblages is presently unknown.

Thirdly, the limited temporal data sets suggest a more static picture in terms of coral cover than a scenario in which high coral cover is substantially depleted by *Acanthaster* and wave action. Estimates of coral cover obtained in the 2006 survey appear to reflect a consistent feature of the Middleton Reef system. 1994 survey data using the same methodology and sampling precisely the same locations (excluding Blue Holes) returned estimates of overall mean percentage cover of 7.5 per cent in 1994 and 8.7 per cent for 2006 One interpretation is that low coral cover on Middleton Reef front environments is a consistent feature and does not imply sudden declines in the cover of live corals. This is reinforced by the PCA analysis using four categories of benthic organisms sampled in three locations over the two time periods. The structure in this data set is largely spatial, with no evidence of temporal trends. The tendency for the most sheltered reef slope location (Wreck) to be dominated by turfing algae and the most exposed (SE) to have higher cover of corals is retained over the two time periods.

Fourthly, there is an issue of the scale of disturbance. If the activities of *Acanthaster* are invoked to explain the low levels of coral abundance on Middleton Reef, then we might expect to see clear evidence of this activity. *Acanthaster* on whole reef scales is a point source of coral mortality with high density fronts moving over localised areas of the reef, leaving behind highly visible bleached but intact coral skeletons (Kenchington & Morton 1976). In the case of dense aggregations sufficient to reduce the coral cover of an entire reef, there is a mosaic of active feeding, recently dead coral stands, older stands covered with turfing algae and still older areas with evidence of skeletal collapse and in some instances, recruitment of new coral colonies (Moran 1988). The patchy nature of *Acanthaster* feeding is reinforced by sporadic annual recruitment levels (Birkeland & Lucas 1990). There is a consistent ecological trademark of *Acanthaster* activity that can be used to reconstruct the pattern of the outbreak and its subsequent history. The reef front coral assemblages at Middleton Reef that were uniformly low at two sampling intervals showed no evidence of major past feeding episodes. Only one small aggregation of *Acanthaster* was observed. This occurred on the SE reef front, was restricted in occurrence to a single site and harboured a mean of 22 individuals per 2000 $m^{2.}$ In terms of the aggregation size and density of individuals, it did not represent a significant outbreak. Sampling in 1994 revealed a very similar picture with *Acanthaster* being absent from most localities with only a single small aggregation detected.

In the absence of evidence of actively feeding *Acanthaster* aggregations at levels sufficient to reduce coral cover over the entire reef front, alternative explanations for the observed low coral cover should be considered. Other potential predators such as *Drupella* and echinoids were present in very small numbers. The location of Middleton Reef at the southern limit of coral reef distribution may result in reduced reproductive and settlement rates. In addition, the very high densities of grazing and browsing fishes may have an impact on the survival of small corals. Both positive (removal of sessile competitors for space) and negative (direct removal of newly settled coral by grazing) can be visualised. This aspect of sessile organism dynamics is still an ecological black box. There was some evidence of direct predation on adult corals. In a number of instances reef front corals, primarily acroporids, showed marked evidence of physical damage in the form of removal of branches in digitate corals (Figs 32-34). The damage was consistent with systematic removal of large sections of the carbonate matrix and does not represent the activities of coral feeding invertebrates, which tend to remove soft tissues and not the matrix. Direct observation on the Great Barrier Reef has confirmed that only excavating parrotfishes (including *Chlorurus microrhinos*), with their enhanced jaw musculature and articulation leading to increased biting power, are capable of removing elements of the coral matrix in this fashion (Bellwood & Choat 1990). Excavating parrotfishes, primarily *C. microrhinos* and *C. frontalis,* were abundant at reef front localities with means ranging from 9.9 to 13.3 adults per 1000 m^2. Estimates of abundances on northern reef fronts of the Great Barrier Reef ranged from 9.3 to 12.5 individuals per 1000m^2. Given the relatively low levels of live coral on Middleton Reef, slopes parrotfishes of the genus *Chlorurus* are large and abundant enough to constitute a source of coral mortality or to reduce the size of individual colonies through grazing.

To reiterate, low coral cover on reef fronts may be the norm and representative of the dynamics of high latitude reefs and not a result of recent disturbance.

Finally, the isolated latitudinally transitional reef systems of the northern Tasman Sea are an also important component of Australia's reef biodiversity. The reef fish fauna is highly diverse and contains elements of both temperate and tropical species including a number of endemics. The smaller endemics, the butterfly fish *Chaetodon tricinctus* and the anemone fish *Amphiprion mccullochi* as the larger wrasse *Coris bulbifrons* were abundant, but only at particular localities. The butterfly fish achieved its greatest abundance on the relatively coral rich SE reef fronts and crests while the anemone fish was restricted to lagoonal waters. Surveys of reef fishes increased the species list to 322 species of which 51 were new records for the area.

As the reefs lie south of the cyclone belt and do not appear to be directly influenced by the major bleaching events characteristic of lower latitudes, the prospects of long-term stability of the system appears to be good. However although crown of thorns starfish aggregations that were directly observed were always localised, with relatively minor effects the possibility of a large outbreak cannot be discounted. The removal of large tracts of living coral from the slopes and crests of exposed reefs may influence the capacity of the reef to maintain positive growth in the longer term. This is a reflection of the limited coral cover present on Middleton and the possibility that large excavating parrot fishes may also be removing appreciable amounts of living coral. There is no direct remedy for this. However the unique properties of the system demand a better data base in order to evaluate changes in coral cover over time, to better understand the influence of the grazing fishes on outer reef slopes and to determine the probability of a large scale *Acanthaster* outbreak. One unique property of the reef is the abundance of large predatory fishes, populations of which are degraded in more accessible areas. A primary management goal is to ensure that abundances of large apex predators are maintained.

CONCLUSIONS

The Middleton Reef system represents both opportunities and challenges to the management and conservation of Australia's reef environment. The reef harbours healthy stocks and high abundances of a number of large reef fish species with restricted distributions. These include large groupers wrasses and reef sharks, groups that have suffered drastic reductions in abundance in reef ecosystems subject to even moderate fishing pressures. Our distribution and abundance data demonstrates the nature of their vulnerability. All three species, black cod, Galapagos sharks and doubleheader wrasse are large, active and inquisitive and achieve their greatest abundances in shallow sheltered reef habitats, the most obvious locations for sustained fishing.

A better understanding of the ecosystem processes that underlie the local distribution and abundance of the primary reef building and maintenance organisms – hard corals – is necessary for sustainable management of these reefs. Although coral cover is relatively low, the effects of major destructive processes, bleaching and cyclone damage are likely to be mitigated by the reefs high latitude location. Moreover, although *Acanthaster* is present on the reef, the temporal record suggests that low coral cover and moderate *Acanthaster* activity is a long term feature of this reef. However, as larger aggregations of *Acanthaster* have been reported, assessment of future outbreaks is a priority.

The dominant and functionally critical groups on the reef are the abundant grazing and browsing fishes that remove algal stands. Moreover, live coral, including adult colonies may be removed by parrotfish feeding. If the reef front assemblages that maintain low but healthy coral cover are as dynamic as the preliminary information suggests then small shifts in the probability of bleaching or an increased recruitment of *Acanthaster* may have substantial effects. A more explicit monitoring of the reef front coral assemblages is required to resolve this issue.

RECOMMENDATIONS

The large populations of black cod, Galapagos sharks and doubleheader wrasse that are characteristic of Middleton Reef require comprehensive protection. Recent work has shown these groups and especially reef sharks to be highly sensitive to even moderate fishing pressure. Although these populations appear to maintain high abundances at Middleton Reef, habitat-specific sampling demonstrated that for each group the greatest abundance occurred in shallow sheltered waters. All three species are vulnerable to line fishing. As with most large wrasses, the doubleheader appears to be a fast growing species. However, work on other large wrasses (Choat et al 2006) demonstrates that this is not a buffer against overfishing.

Conservation of all three species, which have very restricted distributions within Australian waters, requires additional information on population dynamics and population structure. This is especially critical in the case of Galapagos sharks, which lack a dispersive stage in the life history.

An unexpected finding of the survey was the very high local abundances of both tropical (grazing and excavating parrotfishes) and warm temperate (large algal browsers) fish. The coral assemblage, especially on the reef front, may be influenced by the activities of these mobile grazers and browsers, some of which appear to direct predators of live coral. A better understanding of the role of this fauna in transitional reef environments such as Middleton Reef is required.

Monitoring of both reef front and lagoonal coral assemblages on a three-year basis is recommended, as well as regular Sea Surface Temperature (SST) monitoring. This will provide a framework for distinguishing short term ‘pulse’ environmental disturbances from more consistent ecosystem processes, including coral recruitment and growth and interactions with the abundant grazing and browsing fauna that characterise reef front and crest habitats.

The reef fish fauna is highly diverse and contains elements of both temperate and tropical species, including a number of endemics and species for which Middleton Reef system serves as a refuge. Surveys of reef fishes increased the species list to 322 species, of which 51 were new records for the area. The isolated latitudinally transitional reef systems of the northern Tasman Sea are an important component of Australia’s reef biodiversity and warrant more detailed study.

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APPENDIX 1. List of fishes and other vertebrates seen during the February 2006 Middleton and Elizabeth Reef surveys and a comparison with previous surveys.

A number of small secretive fish species were probably not recorded in the present survey. Survey Key: AM – Australian Museum List; PS – Previous JCU survey Mar 1994; AS – AIMS survey of Elizabeth Reef, Dec 2003; TS – This survey. For the present survey a rough estimate of abundance is given using four categories: Abundant (A) – over 500 seen on every dive; Common (C) - up to 100 seen on every dive; Occasional (O) - only 50-100 individuals seen in total; Rare (R) – less than five individuals seen in total.

Family	**Species**	**AM**	**PS**	**AS**	**TS**
TOTAL FISH SPECIES:		301	237	179	322
FISHES:					
Triakidae	*Galeorhinus galeus*	X			
Carcharhinidae	*Carcharhinus galapagensis*	X	X	X	C
	C. amblyrhynchos	X		X	
	Galeocerdo cuvier	X			R
Dasyatididae	*Dasyatis sp.?*	X	X	X	O
Muraenidae	*Echidna nebulosa*				R
	Enchelycore ramosa	X	X	X	R
	Gymnothorax prasinus	X	X		O
	G. eurostus	X	X		O
	G. meleagris			X	
	G. chilospilus	X			
	G. annasona	X			
	G. porphyreus	X			
	Siderea thrysoidea		X		O
	Anarchias sp.	X			
Ophicthyidae	*Myrichthys colubrinus*				R
	M. maculosus	X			R
	Muraenichthys laticaudata	X			
	Pseudomyrophis sp.	X			
Plotosidae	*Plotosus lineatus*	X			O
Gobiesocidae	*Creocele cardinalis*	X			
	Lepadichthys frenatus	X			
Antennariidae	*Antennarius coccineus*	X			
Moridae	*Lotella phycis*	X			

Ophidiidae	*Brotula multibarbata*	X			
	Dinematichthys spp.	X			
Synodontidae	*Synodus variegatus*	X	X	X	C
	S. dermatogenys	X	X		O
	S. cf. *binotatus*	X			
Hemirhampidae	*Euleptorhamphus viridis*	X	X	X	C
Exocoetidae	*Cheilopogon furcatus*	X	X	X	C
Belonidae	*Platybelone argala*	X			R
Atherinidae	*Hypoatherina tropicalis*	X			C
Holocentridae	*Myripristes murdjan*	X	X		O
	M. kuntee	X		X	
	Neoniphon sammara				R
	Sargocentron diadema.	X			O
	Plectrypops lima	X			
Aulostomidae	*Aulostomus chinensis*	X	X	X	C
Fistulariidae	*Fistularia commersonii*	X	X	X	C
Syngnathidae	*Halicampus* sp.?				R
	Cosmocampus howensis	X			
	Halicampus brocki	X			
Caracanthidae	*Caracanthus unipinna*				O
	C. maculatus	X			O
Scorpaenidae	*Pterois volitans*	X	X	X	O
	P. antennata	X			R
	Dendrochirus zebra	X		X	R
	Scorpaenopsis diabolus	X			R
	Scorpaenopsis spp.	X			
	Scorpaena cookii	X	X		R
	Scorpaena sp.	X			R
	Sebastapistes sp.				O
	Ablabys taeianotus	X			
	Scorpaenodes spp.	X			
	Synanceia verrucosa	X			
Serranidae	*Pseudanthias pictilis*	X	X		O
	P. squamipinnis	X	X	X	O
	Cephalopolis argus	X	X	X	C

	C. cyanostigma	X			
	C. miniata	X	X	X	O
	C. urodeta				R
	Hypoplectrodes sp.	X			
	Epinephelus fasciatus	X	X	X	C
	E. areolatus	X			
	E. merra	X	X	X	O
	E. daemelii	X	X	X	C
	E. cyanopodus	X	X		O
	E. fuscoguttatus				R
	E. maculatus	X			R
	E. rivulatus	X	X		R
	E. tauvina		X		R
	E. polyphekadion	X	X		R
	E. lanceolatus	X			
	E. quoyanus		X		
	Variola louti	X	X	X	O
	Plectropomus. laevis		X		R
	P. leopardus	X			R
	Trachypoma macracanthus	X			R
	Acanthistius cinctus	X	X	X	R
	A. ocellatus	X			
	Grammistes sexlineatus				O
	Liopropoma susumi	X			
Pseudochromidae	*Pseudochromis fuscus*				O
	P. novaehllandiae	X		X	O
	Pseudoplesiops howensis	X			
	Cypho purpurascens	X			
Plesiopidae	*Plesiops* sp.	X			
Acanthoclinidae	*Belonepterygion fasciolatum*	X			
Cheilodactylidae	*Cheilodactylus vestitus*	X	X	X	C
	C. ephippium	X	X	X	O
Cirrhitidae	*Paracirrhites arcatus*	X	X	X	O
	P. forsteri	X	X	X	O
	Cirrhitus splendens	X	X	X	O
	Cirrhitichthys falco	X	X	X	A
Apogonidae	*Apogon aureus*				O
	A. cf.*aureus*				O
	Apogon sp. Large barred		X		O
	A. coccineus	X			
	A. compressus	X			

	A. doederleini	X	X	X	R
	A. cyanosoma			X	
	A. nigrofasciatus	X			
	A. norfolcensis	X		X	R
	Cheilodipterus quinquelineata	X	X	X	R
	C. macrodon				O
	Fowleria aurita	X			
	Rhabdamia sp.	X			
	Vincentia chrysusus	X			
Priacanthidae	*Priacanthus cruentatus*	X			R
	P. macracanthus	X			
Malacanthidae	*Malacanthus brevirostris*	X			O
Echeneididae	*Echeneis naucrates*	X	X	X	O
Carangidae	*Caranx melampygus*.	X	X		R
	C. lugubris	X	X	X	O
	C. ignobilis	X			
	Carangoides orthogrammus			X	R
	Pseudocaranx dentex	X	X	X	C
	Elagatis bipinnulata	X	X	X	R
	Seriola lalandi	X	X	X	O
	S. rivoliana	X	X	X	O
Arripidae	*Arripis trutta*	X			
Lutjanidae	*Lutjanus bohar*	X	X	X	C
	L. kasmira	X			O
	Aphareus furca			X	O
	Aprion virescens	X	X	X	R
	Macolor niger				R
	Paracaesio xanthura	X	X	X	A
Haemulidae	*Plectorhynchus picus*	X	X	X	C
Nemipteridae	*Scolopsis bilineatus*	X	X		R
Lethrinidae	*Lethrinus nebulosus*	X			R
	Gnathodentex aurolineatus				O
	Monotaxis grandoculis		X		O
	Gymnocranius euanus	X	X	X	O
	Gymnocranius sp.	X	X		O
Mullidae	*Mulloidichthys vanicolensis*	X			O
	M. flavolineatus				O

	Parupeneus cyclostomus	X	X		O
	P. multifaciatus	X	X	X	C
	P. pleurostigma	X	X	X	C
	P. signatus	X	X	X	A
Pempheridae	*Pempheris* sp.	X			O
Kyphosidae	*Kyphosis bigibbus*	X	X	X	A
	K. sydneyanus			X	O
Girellidae	*Girella cyanea*	X	X	X	O
Scorpididae	*Scorpis violaceus*	X	X		
Microcanthidae	*Atypichthys latus*		X		
	Microcanthus strigatus	X			
Chaetodontidae	*Chaetodon baronessa*				R
	C. lineolatus	X	X	X	O
	C. ulietensis	X	X		O
	C. melannotus	X	X	X	O
	C. vagabundus	X	X	X	O
	C. auriga	X	X	X	C
	C. unimaculatus	X	X	X	O
	C. speculum	X	X		R
	C. bennetti	X			
	C. plebeius	X	X	X	C
	C. mertensii	X	X	X	C
	C. kleinii	X	X	X	O
	C. lunula		X		R
	C. pelewensis	X	X	X	O
	C. citrinellus	X	X	X	O
	C. guentheri	X	X	X	R
	C. flavirostris	X	X	X	C
	C. lunulatus	X	X	X	O
	C. ornatissimus		X		R
	C. ephippium	X	X	X	O
	C. trifascialis	X		X	C
	C. tricinctus	X	X	X	A
	C. auriga x C. lunula?				R
	Heniochus chrysostomus		X		R
	Forcipiger flavissimus	X	X	X	C
Pomacanthidae	*Chaetodontoplus conspicillatus*	X	X	X	O
	C. meredithi		X		
	Pomacanthus semicirculatus		X		R
	Centropyge heraldi				R

	C. bispinosus	X	X		O
	C. tibicen	X	X	X	C
	C. bicolor	X			
	C. vrolikii	X		X	R
	Genicanthus semicinctus	X	X	X	O
	G. watanabei				R
Pentacerotidae	*Evistius acutirostris*		X		R
	Pentaceros decacanthus	X			
Pomacentridae	*Abudefduf vaigiensis*	X	X		O
	A. sexfasciatus	X			R
	A. whitleyi	X			
	A. vaigiensis x A. bengalensis?				R
	Amphiprion mccullochi	X	X	X	O
	A. latezonatus				R
	Plectroglyphidodon imparipennis			X	R
	P. dickii	X	X	X	O
	P. johnstonianus	X	X	X	O
	P. lacrymatus				R
	P. leucozonus		X		O
	Chromis atripectoralis	X	X	X	O
	C. viridis	X	X		O
	C. vanderbilti	X	X	X	C
	C. agilis	X	X		O
	C. flavomaculata	X	X	X	C
	C. iomelas		X		O
	C. margaritifer	X	X	X	O
	C. xanthura				R
	C. chrysura		X		O
	C. hypsilepis	X	X	X	A
	C. ternatensis	X			
	Chrysiptera notialis	X	X	X	A
	Dascyllus aruanus	X	X	X	C
	D. reticulatus	X	X	X	O
	D. trimaculatus	X	X	X	O
	Neoglyphidodon polyacanthus	X	X	X	C
	Parma polylepis		X	X	C
	Pomacentrus parvo				R
	P. australis	X			
	P. vaiuli				R
	P. cf. *reidii*	X			
	P. coelestis	X	X	X	O
	Stegastes fasciolatus	X	X	X	A
	S. gascoynei	X	X	X	A
Sphyraenidae	*Sphyraena barracuda*				R

Labridae	*Bodianus diana*				R
	B. axillaris	X	X	X	O
	B. mesothorax			X	O
	B. loxozonus			X	R
	B. perdito	X	X	X	O
	Choerodon graphicus		X		
	Cheilinus fasciatus				R
	C. chlorurus	X	X	X	O
	C. trilobatus		X	X	O
	Cheilinus undulatus	X	X		
	Oxycheilinus diagramma	X	X		O
	O. bimaculatus		X	X	R
	O. unifasciatus	X	X	X	O
	Wetmorella nigropinnata				R
	Novaculichthys taeniourus		X	X	O
	Xyrichthys pavo			X	R
	X. celebicus ?				R
	Cirrhilabrus punctatus	X	X		C
	C. laboutei	X	X	X	O
	Pseudocheilinus hexataenia	X	X		O
	P. evanidus		X		
	Anampses neoguinaicus	X	X	X	C
	A. geographicus		X	X	O
	A. caeruleopunctatus			X	O
	A. femininus	X	X	X	C
	A. elegans	X	X	X	C
	A. twistii		X		
	Coris aygula	X	X	X	O
	C. bulbifrons	X	X	X	C
	C. batuensis		X		R
	C. dorsomacula		X		O
	C. gaimard		X	X	O
	C. picta	X	X	X	C
	C. pictoides			X	R
	C. sandageri	X			
	Epibulus insidiator		X		
	Halichoeres hortulanus	X	X		R
	H. trimaculatus	X	X		C
	H. margaritaceus	X	X		O
	H. nebulosus		X		O
	H. biocellatus		X		O
	Hemigymnus melapturus	X	X	X	O
	H. fasciatus		X	X	O
	Hologymnosus annulatus		X	X	O
	H. doliatus		X		R
	H. longipes				R

	Suezichthys arquatus		X		O
	Cheilio inermis	X	X	X	R
	Gomphosus varius	X	X	X	O
	Macropharyngodon choati				R
	M. meleagris	X	X	X	O
	M. negrosensis	X	X	X	R
	M. kuiteri		X		
	Stethojulis bandanensis	X	X	X	C
	S. interrupta				R
	S. strigiventer	X	X	X	R
	Pseudolabrus luculentus	X	X	X	A
	Thalassoma lunare	X	X	X	C
	T. amblycephalum	X	X	X	A
	T. lutescens	X	X	X	A
	T. jansenii	X	X	X	O
	T. hardwicke	X	X	X	O
	T. purpureum	X	X	X	C
	T. trilobatum		X	X	C
	T. quinquevittatum		X	X	C
	Labrichthys unilineatus	X	X		O
	Labroides bicolor	X	X		O
	L. dimidiatus	X	X	X	A
	L. pectoralis		X		
	Labropsis australis			X	O
	Pseudodax moluccanus		X	X	
	Pseudocoris yamashiroi		X	X	
	Pterogogus cryptus		X	X	
Scaridae	*Cetoscarus bicolor*		X	X	R
	Chlorurus microrhinos	X	X	X	C
	C. sordidus	X	X	X	C
	C. frontalis		X	X	C
	Scarus rubroviolaceus	X	X		R
	S. ghobban	X	X	X	C
	S. frenatus	X	X	X	C
	S. niger	X	X	X	O
	S. forsteni		X		R
	S. rivulatus	X	X		R
	S. psittacus	X	X	X	A
	S. globiceps	X	X	X	C
	S. oviceps	X	X		O
	S. dimidiatus	X	X		R
	S. spinus				R
	S. longipinnis	X	X	X	O
	S. altipinnis	X		X	C
	S. schlegeli	X	X	X	A
	S. flavipectoralis				R

	S. chameleon	X	X	X	C
	Calotomus carolinus				R
	Hipposcarus longiceps		X		O
Pinguipedidae	*Parapercis hexophthalma*	X	X	X	O
	P. cylindrica	X			O
	P. millepunctata				R
Opistognathidae	*Opistognathus* sp.	X			R
Creediidae	*Limnichthys* cf. *donaldsoni*	X			
Blenniidae	*Aspidontus taeniatus*	X			R
	Plagiotremus tapeinosoma	X	X	X	C
	P. rhinorhinchus				R
	Meiacanthus phaeus	X	X		C
	Cirripectes alboapicalis	X	X	X	O
	C. castaneus	X		X	O
	C. chelomatus				R
	Cirripectes sp.	X			
	Ecsenius fourmanoiri	X	X	X	A
	Exalias brevis				O
	Crossosalarias macrospilus				R
	Istiblennius sp.	X			O
	I. periophthalma	X			
	Salarias fasciatus	X			O
	Stanulus talboti	X		X	O
	Enchelyurus ater	X			
Tripterygiidae	*Norfolkia squamiceps*	X			
	Vanclusella sp.	X			
	V. rufopilea	X			
Microdesmidae	*Nemateleotris magnifica*		X	X	O
	Ptereleotris evides	X	X	X	O
	P. zebra		X	X	O
	P. monoptera		X	X	O
Gobiidae	*Valenciennea strigata*				R
	Gobiodon unicolor				O
	G. brochus				O
	G. rivulatus				O
	G. erythrospilos				O
	G. quinquestrigatus				O
	Paragobiodon echinocephalus				O
	Various goby species	23			

Zanclidae	*Zanclus cornutus*	X	X	X	C
Acanthuridae	*Zebrasoma scopas*	X	X	X	O
	Z. veliferum	X	X	X	C
	Acanthurus triostegus	X	X		O
	A. olivaceus	X	X		C
	A. dussumieri	X	X	X	C
	A. blochii	X	X	X	O
	A. nigroris		X		O
	A. albipectoralis		X	X	C
	A. nigrofuscus	X	X	X	A
	A. pyroferus		X		
	A. xanthopterus		X		
	Paracanthurus hepatus	X	X		O
	Ctenochaetus striatus		X	X	C
	C. binotatus		X		R
	Prionurus maculatus	X	X	X	A
	Naso lituratus		X		O
	N. vlamingi		X	X	R
	N. unicornis	X	X	X	C
	N. brevirostris	X	X	X	O
	N. tonganus	X	X		O
	N. cf caesius		X		R
Siganidae	*Siganus argenteus*	X	X	X	O
Scombridae	*Euthunnus affinis*				O
	Acanthocybium solandri	X			
	Thunnus albacares	X			
Coryphaenidae	*Coryphaena hippurus*			X	R
Pleuronectidae	*Samariscus triocellatus*	X			
Bothidae	*Bothus mancus*				R
Balistidae	*Pseudobalistes fuscus*		X		O
	Sufflamen fraenatus	X	X	X	C
	S. chrysopterus	X	X	X	C
	Melichthys niger	X			
	Balistoides conspicillum				R
	Balistapus undulatus				R
	Rhinecanthus rectangulus		X		O
	R. aculeatus	X	X		R
	R. lunula		X		O
Monocanthidae	*Aleuteres monoceros*	X			

	Cantherhines pardalis		X	X	C
	C. dumerilii	X		X	O
	C. fronticinctus			X	
	Pervagor alternans	X	X		R
	P. melanocephalus	X	X		R
	P. janthinosoma	X			R
	Oxymonacanthus longirostris	X			R
	Paralueres prionurus				R
Ostraciidae	*Ostracion cubicus*	X	X	X	C
Tetradontidae	*Canthigaster coronata*	X	X		O
	C. valentini	X	X	X	C
	C. janthinoptera	X	X		R
	C. callisterna	X	X		O
	Lagocephalus scleratus	X			
Diodontidae	*Diodon hystrix*	X	X	X	C
	D. holocanthus	X			
REPTILES:					
green turtle	*Chelonia mydas*				
DOLPHINS					
bottlenose dolphin	*Turciops truncatus*				

APPENDIX 2. List of algal coral and other invertebates species from Elizabeth and Middleton Reefs.

Note: List compiled from eight days of diving on Middleton Reef and two days on Elizabeth Reef. Acroporid coral list not complete.

	Abundance	Comments
ALGAE:		
Halimeda sp.	O	
Caulerpa racemosa	O	
Codium geppii	A	
Codium spongiosum	A	
Padina sp.	C	
Red surge channel alga	C	
SEAGRASSES:		
Halophila ovalis	O	Middleton Reef lagoon
SPONGES:		
Various encrusting sponges	O	
HARD CORALS	61 spp.	
Pocilloporidae		
Pocillopora damicornis	A	Common in all habitats
Stylophora pistillata	C	
Seriatopora hystrix	C	
Acroporidae		
Montipora mollis	O	
M. turgescens	C	
M. danae	R	
M. venosa	R	
M. aequituberculata	O	
M. nodosa	C	Common in the lagoon
M. capricornis	R	
M. grisea	R	
Montipora sp.	O	
Acropora anthocercis	R	
A. chersterfieldensis	O	
A. digitifera	O	
A. donei	R	
A. formosa	O	
A. gemmifera	O	
A. glauca	O	

A. hyacinthus	O	
A. lovelli	C	Common in the lagoon
A. nana	O	
A. palifera	A	
A. elizabethensis	C	Common in sheltered lagoon habitat
A. robusta	O	
A. solitaryensis	O	
A. valida	C	
A. yongei	O	
Poritidae		
Porites lichen?	O	
P. heronensis	C	
Siderasteridae		
Psammocora contigua	R	
P. superficialis	O	
Coscinarea columna	O	
Agariciidae		
Pavona duerdeni	R	
P. maldivensis	R	
P. varians	C	
Fungiidae		
Fungia sp.	R	
Pectiniidae		
Echinophyllia aspera	O	
Mussidae		
Acanthastrea echinata	O	
A. lordhowensis	O	
A. hillae	R	
Lobophyllia hemprichii	C	Only common below 10m
Merulinidae		
Hydnophora exesa	O	
Scapophyllia cylindrica	?	Probably confused with *Leptoria*
Faviidae		
Favia speciosa	A	
Favia sp.	O	
Favites halicora	O	
F. flexuosa	O	
F. russelli	R	
Platygyra pini	C	

P. daedalea	C	
Goniastrea australensis	R	
Montastrea curta	A	Common in all habitats
Leptoria phrygia	A	
Plesiastrea versipora	R	
Leptastrea transversa	O	
Cyphastrea serailia	C	
C. microphthalma	O	
Dendrophylliidae		
Turbinaria mesenerina	O	Only below 10m
T. heronensis	R	Elizabeth Reef only
T. peltata	R	
ANEMONIES:		
Heteractis sp.	R	
Palythoa sp. zoanthid	O	
SOFT CORALS:		
Sinularia sp.	C	
Sarcophyton sp.	O	
Lobophytum sp.	C	
Briareum sp.	O	
Cladiella sp.	O	
MOLLUSCS:		
Tridacna derasa	O	Seen on lagoon reef flat
T. maxima	O	
Hexabranchus sanguineus Spanish dancer	C	
Aplysia dactylomela	R	
Halgerda sp.	R	
White dorid nudibranch	R	
CRUSTACEANS		
Lysmata amboinensis cleaner shrimp	R	
Stenopus hispidus banded coral shrimp	O	
Panulirus pencillatus crayfish	O	
Stomatopod unidentified mantis shrimp	R	
ECHINODERMS:		
Linkia laevigata blue seastar	C	

Ophidiaster confertus	A	
Acanthaster planci	C	
Culcita novaeguineae	O	
Pentaster sp.	R	
Mithrodia sp.	R	
Diadema setosum long-spined urchin	A	
Echinothrix calamaris	O	
Eucidaris sp.	R	
Echinometra mathaei	A	
Echinostrephus sp.	A	
Centrostephanus rodgersi	O	
Heterocentrotus mammillatus	O	
Bohadschia argus spotted holothurian	O	Lagoon habitat only
Holothuria atra black holothurian	A	
H. edulis black/pink holothurian	C	
H. nobilis	A	
H. impatiens	O	
H. hilla	R	
H. leucospilota	O	
Synapta sp.	R	
Stichopus variegata	O	Lagoon habitat only
S. horrens	R	
Crinoid feather star	R	