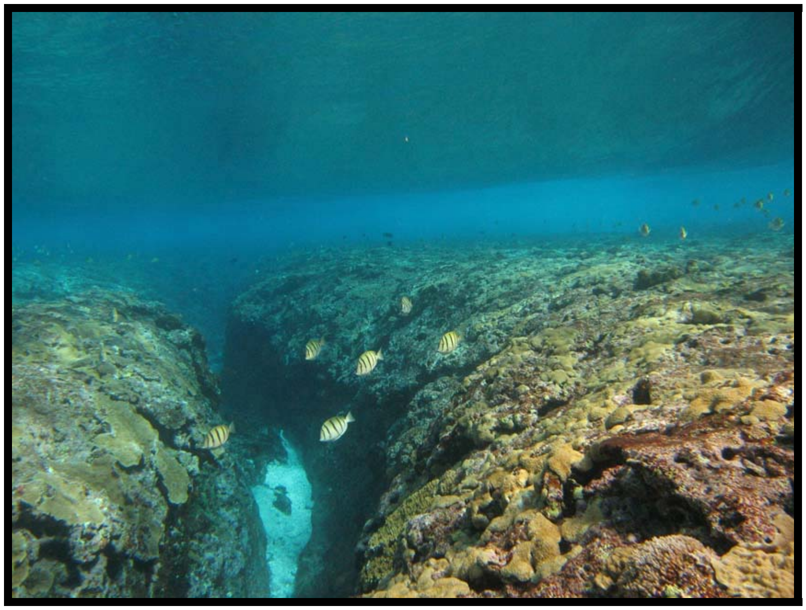
# MONITORING THE ECOLOGICAL STATUS OF ELIZABETH AND MIDDLETON REEFS, FEBRUARY 2007



**J-P. A. Hobbs and D.A. Feary**

School of Marine and Tropical Biology, James Cook University, Townsville, Qld, Australia, 4811.

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## EXECUTIVE SUMMARY

Elizabeth and Middleton Reefs are oceanic coral reefs located in the northern Tasman Sea, approximately 200 km north of Lord Howe Island. Their position in the tropical/temperate convergence and geographic remoteness has resulted in a unique marine community. The outstanding nature heritage values of the Reefs led to the formation of the Elizabeth and Middleton Reefs Marine National Nature Reserve in 1987. As part of an ongoing monitoring commitment at the Reefs, Department of the Environment and Water Resources personnel and marine researchers from James Cook University visited the Reefs from 18th to 21st of February 2007 to conduct a rapid visual assessment of reef health, as well as retrieve and deploy data loggers and collect black cod tissue samples.

Underwater visual surveys conducted at 12 sites across both Reefs produced estimates of 49% live coral cover at Elizabeth Reef and 27% at Middleton Reef. Although live coral cover is moderate, this is to be expected given the location and isolation of the Reefs, along with the past impacts of crown-of-thorns starfish (COTS). Although there was little evidence of threats such as coral bleaching, COTS, *Drupella*, or marine debris, unfavourable weather prevented surveys from being conducted on the exposed southern sides of the Reefs.

Based on comparisons with previous surveys, there did not appear to be any significant changes in the abundances of habitat forming species, important invertebrates, large fauna or endemic fishes. The abundance of holothurians, black cod, Galapagos shark, doubleheader wrasse and three-striped butterflyfish remains high at both Reefs. The low abundance of crayfish, tridacnid clams, trochus and conspicuous angelfish appears to be a natural phenomenon. The low abundance of the white snout anemonefish is a concern

given its small geographic range and habitat specialisation, and this species should be monitored closely.

The blue holes were identified as important areas at both Reefs, because they provided a unique lagoonal habitat that supported a distinct marine community. The blue holes contained an average of 62% live coral cover, mainly comprising branching *Acropora* corals, providing important 3-dimensional habitat for a range of marine fauna. This habitat was utilised exclusively by a range of species, with numerous species (including the white snout anemonefish) attaining their greatest densities in this habitat. The blue holes also appeared to form an important nursery habitat for the Galapagos sharks and black cod. Due to the uniqueness of this habitat, the community it supported, and the vulnerability of the major habitat forming coral to disturbances, we recommended that this area be monitored closely and given a high level of protection.

In addition to the rapid assessment of reef health, the 4 existing data loggers at the Reefs were successfully retrieved and a further 8 deployed to monitor the threat of increasing water temperature throughout the Reefs. To assist in the management of black cod populations, non-destructive methods were used to obtain 20 tissue samples for genetic analyses. Underwater observations also identified 2 species of coral goby as new records for the Reefs, raising the total number of fishes observed at the Reefs to 324 species.

## INTRODUCTION

Elizabeth Reef (29°56'S; 159°05'E.) and Middleton Reef (29°27'S; 159°07'E) are situated in the northern Tasman Sea, 600 km east of the New South Wales coastal town of Coffs Harbour, 200 km north of Lord Howe Island and 900 km south of the Great Barrier Reef. Elizabeth Reef is approximately 60 km south of Middleton Reef and the two reefs are separated by deep oceanic water (> 2500 m). These isolated reefs are the southernmost open ocean platform reefs in the world and are situated on top of volcanic seamounts (Director of National Parks, 2006). Detailed descriptions of the geological history, physical attributes and habitat structure of both Reefs have been provided by Slater and Goodwin (1973), the Australian Museum (1992), and Choat *et al* (2006). Both Reefs were declared part of the Elizabeth and Middleton Reefs Marine National Nature Reserves in 1987, due to their outstanding natural heritage values (Director of National Parks, 2006). This Reserve forms part of the National Representative System of Marine Protected Areas (Director of National Parks, 2006).

The combination of diverse coral reef habitats, geographic isolation and a blend of tropical and temperate waters have resulted in a diverse and unique marine community comprised of tropical, temperate and endemic species. Three hundred and twenty two fish species and 122 coral species have been recorded from Elizabeth and Middleton Reefs (Done and Veron in Australian Museum, 1992; Choat *et al*, 2006). During summer, the Reefs receive larvae from tropical species that have dispersed southward from the Great Barrier Reef via the East Australian Current. For many of these tropical species, Elizabeth and Middleton Reefs signify the southernmost limit of their geographic range. The Reefs also represent the northernmost limit of many temperate species, predominately those species distributed along the coastlines of southern Australia and New Zealand.

Elizabeth and Middleton Reefs are nationally and internationally important marine reserves for several reasons. Many species of coral, mollusc and fish are endemic to Elizabeth and Middleton Reefs and the local region (Director of National Parks, 2006), while the Reefs are also feeding grounds for the endangered Green turtle (*Chelonia* *mydas*) (Director of National Parks, 2006). The geographic remoteness of the Reefs has also provided a refuge from overfishing. For example, large predators, such as the Galapagos shark (*Carcharhinus galapagensis*) and black cod (*Epinephelus daemelii*), occur in relatively high abundances in both reef systems (Choat *et al*, 2006). The black cod has been overfished throughout most of its historical range in Australia and is listed as “Vulnerable” in New South Wales waters; Elizabeth and Middleton Reefs are one of the last remaining strongholds for this species. Although isolation can be beneficial to coral reef health (e.g. refuge from overfishing) it can also be a disadvantage. Recovery of the geographically isolated reef systems, such as Elizabeth and Middleton Reefs, following large disturbance events (e.g. cyclones, large waves, mass bleaching, outbreaks of crown-of thorns starfish) may take several decades if coral reef populations rely heavily on recolonisation by non-local planktonic larvae.

Coral reefs worldwide are under threat, with 20% of reefs already destroyed and a further 50% at risk of collapse (Wilkinson, 2004). The major threats to coral reefs include increased water temperature, which can lead to widespread coral bleaching, as well as destructive fishing practices, pollution, sediment runoff and overfishing. Biological threats to corals can include crown-of-thorns starfish (*Acanthaster planci*), corallivorous snails (*Drupella*) and coral disease. Many coral reef organisms are also threatened by overfishing, which can significantly reduce the abundance of commercially important species, particularly those whose life histories make them vulnerable to exploitation. Disturbance events may also interact, leading to broad-scale and long-term consequences for coral reef communities. For example, overfishing on Caribbean reefs has led to a phase shift in coral community structure, from one dominated by corals, to one where algal biomass dominates. Such changes in benthic composition have arisen due to a cascade of disturbance events, involving both disease outbreaks and destructive cyclones (Hughes, 1994). In terms of Elizabeth and Middleton Reefs, potential threats may include outbreaks of coral predators, such as crown-of-thorns and *Drupella*, coral bleaching due to increased water temperature, destructive storms, illegal fishing, coral disease and marine debris.

To maintain the outstanding natural heritage values and biological diversity of the unique marine communities at Elizabeth and Middleton Reefs, effective monitoring is required. Two areas critical to maintaining biological diversity that require monitoring are: 1. changes in habitat (e.g. coral cover, algae cover); 2. changes in potentially vulnerable species and ecologically important species. Potentially vulnerable species include those species that are endemic to the Reefs, and commercially valuable species that have been overfished in other locations (e.g. sharks, trochus, tridacnid clams, crayfish and holothurians). Ecologically important species include habitat formers, such as corals and algae, as well as species that can influence coral and algae abundance (e.g. crown-of-thorns starfish, *Drupella* and sea urchins). It is also important to monitor threats to reef health, such as increases in water temperature, the prevalence of coral bleaching and disease, along with increases in marine debris.

The specific requirements of the present monitoring trip were to:

1. Retrieve and replace water temperature data loggers
2. Collect biopsies from black cod to be sent to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for genetic analysis
3. If time and weather permitted, undertake a rapid visual assessment of the condition of the Reserve at 13 predetermined sites (7 at Elizabeth Reef and 6 at Middleton Reef) to check for evidence and/or the presence of invertebrate coral predators such crown of thorns starfish and *Drupella,* as well as evidence of coral bleaching and the presence of marine debris and pollution.

## METHODS

### *Data loggers*

Two data loggers were deployed at each Reef in February 2006 to monitor the threat of increased water temperature (Choat *et al*, 2006). These data loggers were to be retrieved by cutting the cable ties that attached the loggers to the star picket. The picket was then checked for stability and a new data logger attached in the same position using new cable ties. In addition to the 4 existing logger positions, a further 4 loggers were deployed at shallower areas within the near vicinity of the existing loggers. These 4 new loggers were each attached to star pickets that were driven into the sandy substrate.

*Black cod samples*

Elizabeth and Middleton Reefs are one of the last strongholds for black cod. This large serranid has been overfished throughout much of its range. Effective management plans for the recovery of this species require an understanding of their population connectivity. Determining population structure through genetic analysis requires tissue samples collected from different individuals in different locations. One of the aims of this monitoring trip was to collect tissue samples from 20 black cod individuals. To accomplish this in a non-destructive manner we used a combination of biopsy probes and fin clips. Biopsy probes (Robbins, 2006) were attached to spear guns and used when black cods were encountered whilst snorkelling. The probe lodges into a non-vital location on the fish and a small core is obtained (diameter 0.5cm) (Robbins, 2006). The probe disengages when the fish swims off and causes little visible distress to the fish.

To sample cod in deeper water we used line fishing methods. A simple hand line with hook, sinker and bait were deployed and when a black cod was caught it was brought slowly to the surface. Once on the surface, a small ($2cm^2$) portion of the pectoral fin was clipped using scissors and the fish was released promptly after removing the hook. Care was taken to ensure all fish were released in good condition. All samples obtained via biopsy probes and fin clips were preserved in 95% ethanol.

*Rapid visual assessment*

Sampling design

To monitor the health of Elizabeth and Middleton Reefs we conducted rapid visual assessments at 12 sites (8 at Elizabeth and 4 at Middleton) from the 18$^{th}$ to 21$^{st}$ of February 2007. Time and weather constraints prevented us from surveying all the predetermined sites (from 2002 survey) (Table 1). Two new sites were surveyed on the leeward (northern) side of Elizabeth Reef (2007 sites 11 and 12) and a lagoonal site (i.e. blue holes = BH) was surveyed at each Reef (Table 1). To enable comparisons with previous studies (Oxley *et al*, 2004; Choat *et al*, 2006), sites in the same location were grouped together in the analyses, resulting in 7 locations (Table 1, Figure 1). Two depth strata were surveyed, shallow (< 2m) and deep (6 - 8m). Underwater visual surveys focused on vulnerable and potentially vulnerable species (e.g. sharks, black cods, turtles, endemic fishes, crayfish, holothurians, trochus, tridacnid clams) as well as ecologically important species (algae, coral, crown-of-thorns, *Drupella*, sea urchins).

**Table 1:** The co-ordinates of 12 sites (grouped into 7 locations) surveyed at Elizabeth and Middleton Reefs in February 2007. BH = Blue Holes.

| **Reef** | **Site co-ordinates** | **Site number** | | **Location** |
|---|---|---|---|---|
| | | 2002 | 2007 | |
| Middleton | 29 26.88 S; 159 03.31 E | 8 | 1 | NW Front |
| Middleton | 29 26.46 S; 159 03.29 E | | 2 | Lagoon (BH) |
| Middleton | 29 27.20 S; 159 03.74 E | 9 | 3 | Back Reef |
| Middleton | 29 26.50 S; 159 05.80 E | 10 | 4 | Back Reef |
| Elizabeth | 29 56.11 S; 159 05.60 E | 1 | 5 | NE Front |
| Elizabeth | 29 56.01 S; 159 06.24 E | 2 | 6 | NE Front |
| Elizabeth | 29 57.20 S; 159 01.20 E | 5 | 7 | NW Front |
| Elizabeth | 29 56.60 S; 159 01.10 E | 6 | 8 | NW Front |
| Elizabeth | 29 55.97 S; 159 01.39 E | 7 | 9 | NW Front |
| Elizabeth | 29 56.19 S; 159 03.14 E | | 10 | Lagoon (BH) |
| Elizabeth | 29 55.38 S; 159 02.41 E | | 11 | Back Reef |
| Elizabeth | 29 55.03 S; 159 03.39 E | | 12 | Back Reef |

Benthic composition

Benthic composition was surveyed using 4 x 3m line transects at each depth strata (<2m and 6 - 8m). Within each transect the proportion of all benthic biota intercepted by the 3m line transect was quantified. Four different categories in benthic composition were recorded: hard coral, soft coral, algae and other. Hard coral consisted of 5 different coral morphologies (Digitate, Plate, Branching, Massive, Encrusting). Algae encompassed 4 different morphological groups (Turfing, Coralline turf, Coralline paint and Encrusting), while “Other” included several categories (Pavement, Sand, Rubble, Rubble/Sand mixture).

Large vulnerable species

Using 100 x 10m visual counts, large animals (which consisted of the Galapagos shark, *Carcharhinus galapagensis*, the black cod, *Epinephelus daemelii*, large stingray, *Dasyatis* sp. and the green turtle, *Chelonia mydas*) were quantified at 2 depths (<2m and 6 - 8m).

As counts for all large animals on both reefs were small, transect counts on each reef were summed, and the average abundance of large animals across both reefs reported.

Endemic fishes

To determine the abundance of small endemic fishes (Table 2), 2 replicate 30 x 10m belt transects were conducted at the 2 depths (<2m and 6 - 8m) at each site.

**Table 2:** Surveyed fishes endemic to the Elizabeth and Middleton Reefs region.

| Family | Species | Common name | Distribution |
|---|---|---|---|
| Labridae (wrasse) | *Coris bulbifrons* | Doubleheader wrasse | Lord Howe, Norfolk, Middleton, Elizabeth, NSW |
| Pomacanthidae (angelfish) | *Chaetodontoplus conspicillatus* | Conspicuous angelfish | Qld, NSW, Lord Howe, Norfolk, Middleton, Elizabeth, New Caledonia |
| Chaetodontidae (butterflyfish) | *Chaetodon tricinctus* | Three striped butterflyfish | Lord Howe, Norfolk, Middleton, Elizabeth |
| Pomacentridae (damselfish and anemonefish) | *Amphiprion mccullochi* | White snout anemonefish, McCulloch's anemonefish | Lord Howe, Middleton, Elizabeth, NSW, Norfolk |
| Serranidae (cods and groupers) | *Epinephelus daemelii* | Black cod, saddletail grouper | Lord Howe, Middleton, Elizabeth, SE Australia, Kermadec, Northern New Zealand |

Coral condition

The condition of corals was recorded using 3 replicate 20 x 3m belt transects at 2 depths (<2m and 6 - 8m) at all sites. Corals that were white were examined closely to determine if the coral was bleached, diseased or had been eaten (by COTS or *Drupella*).

Ecologically and commercially important invertebrates

The abundance of commercially important invertebrates (e.g. crayfish, trochus, tridacnid clams and holothurians) and ecologically important invertebrates (crown-of-thorns, *Drupella* and sea urchins) were documented using 3 replicate 20 x 3m belt transects at 2 depths (<2m and 6 - 8m) at all sites. For sea urchins, only *Diadema* was recorded because these species play an important role as herbivores on the reef and can be easily observed.

Other sea urchins were not recorded because their small size and cryptic behaviour made it difficult to obtain accurate estimates of abundance.

Marine pollution/debris

To examine the impact of pollution on the Reefs, notes were taken on the abundance and type of pollution encountered during the 100 x 10m transects that were conducted for large vulnerable animals. Details were recorded on marine debris that had come off the shipwrecks, or had been swept onto the Reefs by currents, as well as any fishing gear and evidence of anchor damage.

## RESULTS

### *Data loggers*

The 4 existing data loggers were successfully retrieved and a new data logger was attached to each of the 4 star pickets. In addition, 4 new star pickets and data loggers were deployed in shallower areas in the near vicinity of each of the 4 existing data loggers to provide a comparison between shallow (1-2 m) and deep (4-7 m) water temperatures. In total there are now 8 data loggers covering 2 depths at the two major habitats (lagoon and outer reef) at both Reefs (Table 3).

**Table 3:** Site co-ordinates, location and depths that 8 data loggers were deployed at Elizabeth and Middleton Reefs in February 2007.

| Reef | Site co-ordinates | Depth | Location |
|---|---|---|---|
| Middleton | 29 27.118 S; 159 06.030 E | 1.3m | Lagoon entrance |
| Middleton | 29 27.118 S; 159 06.030 E | 4.4m | Lagoon entrance |
| Middleton | 29 27.004 S; 159 04.123 E | 2.3m | NW horn |
| Middleton | 29 27.004 S; 159 04.123 E | 7.3m | NW horn |
| Elizabeth | 29 56.14 S; 159 05 38 E | 1.0m | Lagoon entrance |
| Elizabeth | 29 56.260 S; 159 05.606 E | 4.3m | Lagoon entrance |
| Elizabeth | 29 55.30 S; 159 03.30 E | 1.2m | Back reef/leeward |
| Elizabeth | 29 55.464 S; 159 03.459 E | 5.3m | Back reef/leeward |

### *Black cod samples*

The quota of 20 black cod (*E. daemelii*) samples were achieved through a combination of biopsy probes and fin clips collected from both Reefs. Five samples were obtained from

Middleton Reef and 15 from Elizabeth Reef. No cod was sampled more than once and all fish were released alive and in good condition. Tissue samples were preserved in 95% ethanol and have been sent to CSIRO for genetic analyses.

*Rapid visual assessment*

<u>Benthic composition</u>

At Elizabeth Reef, the benthic cover in the surveys was dominated by both hard coral and algal biomass (Figure 2). In comparison, the benthic composition of Middleton Reef was dominated by algal biomass, other substrata (including pavement and sand) and hard coral (Figure 3). Within Elizabeth Reef, across all sites and depths, the mean cover of hard coral was 35%, while the mean cover of algae (both turfing and encrusting forms) was 49%. The deep site at the Blue Hole held the highest hard coral cover, with 61% cover, while the shallow site at Blue Hole held the second highest coral cover, with 54% live coral cover (Figure 2). In comparison, across all sites and depths at Middleton Reef, the mean cover of hard coral was 27%, the mean cover of algae was 35%, while the average cover of other substrata was 37% (Figure 3). Within Middleton Reef, the highest cover of live coral was apparent in the Blue Hole location, with 50% and 81% live coral cover apparent at the shallow and deep sites, respectively.

<u>Hard coral composition</u>

The hard coral cover in the shallow transects at Elizabeth Reef comprised a range of coral morphotypes (Figure 4). However, within each location at Elizabeth Reef the benthic composition of the hard coral cover was dominated by branching and/or encrusting morphotypes. In comparison, the deep transects at Elizabeth Reef held a much more varied array of hard coral morphotypes, with branching, massive, plate, digitate and encrusting morphotypes present.

The hard coral cover in both shallow and deep transects at Middleton Reef was much less diverse than at Elizabeth Reef, with only branching, digitate and encrusting morphotypes present (Figure 5). In comparison to both the NW Front and Blue Hole locations, no hard coral cover was apparent at the Back Reef locations between both depths.

Large vulnerable fauna

The 4 large and potentially vulnerable species observed in the transects were (in decreasing order of abundance): the Galapagos shark, *Carcharhinus galapagensis*, the black cod, *Epinephelus daemelii*, large ray *Dasyatis* sp. and the green turtle, *Chelonia mydas*) (Figure 6). No other sharks, rays or turtles were observed at the Reefs. The location that had the greatest densities of large animals was the Blue Holes, which were dominated by *C. galapagensis*.

The mean density of *C. galapagensis* across all sites and depths was 1.77 individuals per 1000 $m^2$. *Carcharhinus galapagensis* was more abundant in the deeper water (1.9 per 1000 $m^2$) than shallow water (1.6 per 1000 $m^2$). The abundance of *C. galapagensis* was greatest in the Middleton Lagoon and Back Reef (Figure 6). *Epinephelus daemelii* were moderately abundant throughout both Elizabeth and Middleton Reef. Across all sites and depths, the mean density of *E. daemelii* was 1 individual per 1000 $m^2$, and there appeared to be no noticeable differences in abundance between shallow and deep surveys. As for *C. galapagensis* population abundance, the greatest abundances of *E. daemelii* occurred in the Blue Hole locations (Figure 6).

Endemic fishes

The mean density of *Coris bulbifrons* across all sites and depths was 1.17 individuals per 300 $m^2$. *C. bulbifrons* was slightly more abundant in shallower water (1.4 per 300 $m^2$) than deeper water (0.93 per 300 $m^2$) and was recorded in greatest abundance in the Middleton Lagoon and Back Reef (Figure 7). Four of the 6 Juveniles recorded in the transects were in the deeper waters of NE Front at Elizabeth Reef.

The mean density of *Chaetodon tricinctus* across all sites and depths was 1.38 individuals per 300 $m^2$. There were higher abundances of *C. tricinctus* at shallow sites (1.96 per 300 $m^2$) than deeper sites (0.79 per 300 $m^2$) and their greatest abundance was recorded in the Middleton Lagoon (Figure 7).

The endemic anemonefish *Amphiprion mccullochi* was restricted by the distribution and abundance of its host anemone. It was observed in low abundance (mean of 0.14

individuals per 300 $m^2$ across all sites and depths) and was generally found in shallow waters. *Amphiprion mccullochi* was only observed at 3 locations and its greatest abundance was recorded in the Middleton Lagoon (Figure 7). Although the angelfish *Chaetodontoplus conspicillatus* was seen at both Reefs, no individuals were encountered in the transects.

Coral condition

The incidence of bleached or recently killed corals was very low across the majority of sites (mean of 0.22 colonies per 60 $m^2$ across all sites and depths (Figure 8). Only one site (Elizabeth lagoon) exhibited moderate levels of recently killed corals (shallow = 5.3 per 60 $m^2$, deep = 2.3 per 60 $m^2$). These corals were colonies of *Acropora* and *Seriatopora*, and appeared very pale. Although the corals may have bleached this could not be confirmed. Across all sites and depths, 5 coral colonies had bleached and 1 colony exhibited COTS feeding scar. No obvious signs of coral disease were recorded in the surveys.

Ecologically and commercially important invertebrates

The mean density of holothurians was 3.87 individuals per 60 $m^2$ across all sites and depths (Figure 9). The mean density of holothurians across most sites was between 0 and 7.33 per 60 $m^2$, however Middleton Back Reef had exceptionally high densities (shallow = 19.67 per 60 $m^2$, deep= 20.57 per 60 $m^2$).

*Diadema* sea urchins had a mean density of 1.20 individuals per 60 $m^2$ (across all sites and depths), however they were recorded in much greater abundance in deeper (2.07 per 60 $m^2$) than shallower water (0.33 per 60 $m^2$) (Figure 9). The greatest densities of *Diadema* were recorded at Elizabeth Back Reef, NW Middleton and Middleton Back Reef (3.67-3.83 per 60 $m^2$).

Tridacnid clams were recorded in low abundances (0.03 per 60 $m^2$) and were only observed at NW Elizabeth and NW Middleton (Figure 9). Coral predators, such as COTS and *Drupella*, were not observed in any transect, across all sites and depths. No trochus were observed in the surveys. Only 1 crayfish (*Panulirus longipes*) was observed in the transects, although 3 others were observed outside the transects on the outer reef.

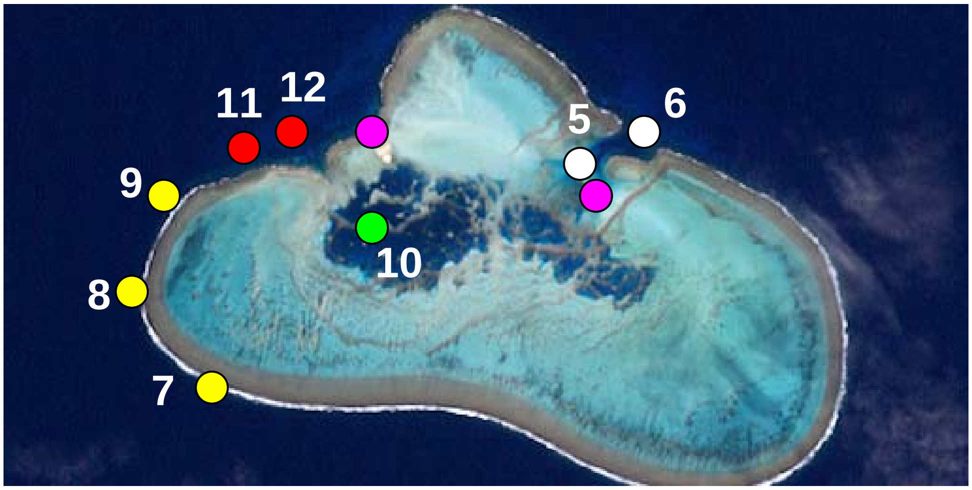
Marine pollution/debris

Although numerous shipwrecks exist at Middleton and Elizabeth reefs, no debris was recorded in transects, and no discharge (e.g. oil, fuel) was observed. No fishing gear or evidence of anchor damage was seen in the surveys.

New records

Two new records of reef fish were observed. Seven individuals of the coral-dwelling goby *Paragobiodon xanthosomus* were observed residing in the coral colonies of *Seriatopora hystrix* at the western end of the Middleton lagoon. Three individuals of the coral-dwelling goby, *Gobiodon citrinus*, were observed resting on an arborescent species of *Acropora* coral in the lagoon at Elizabeth Reef. These new records increase the combined total number of reef fishes recorded at Elizabeth and Middleton Reefs to 324 species (see Choat *et al*, 2006).

a

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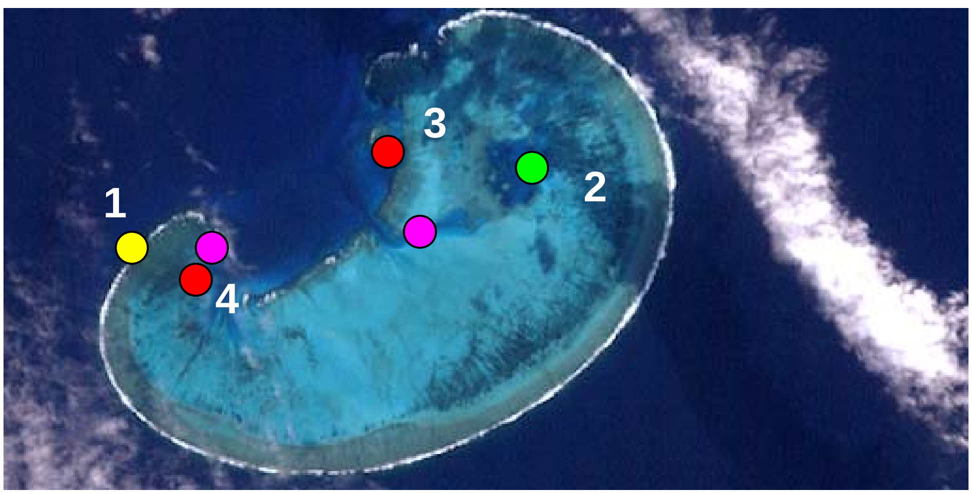


Figure 1. Location of sites surveyed at (a) Elizabeth Reef and (b) Middleton Reef in February 2007. Sites grouped by locations as follows: yellow = NW Front, red= Back Reef, green = Blue Holes, and white = NE Front. Numbers represent the 2007 site numbers. Note sites are presented in their approximate positions, for exact position see Table 1. The approximate position of the data loggers is represented by pink dots, for exact position consult Table 3.

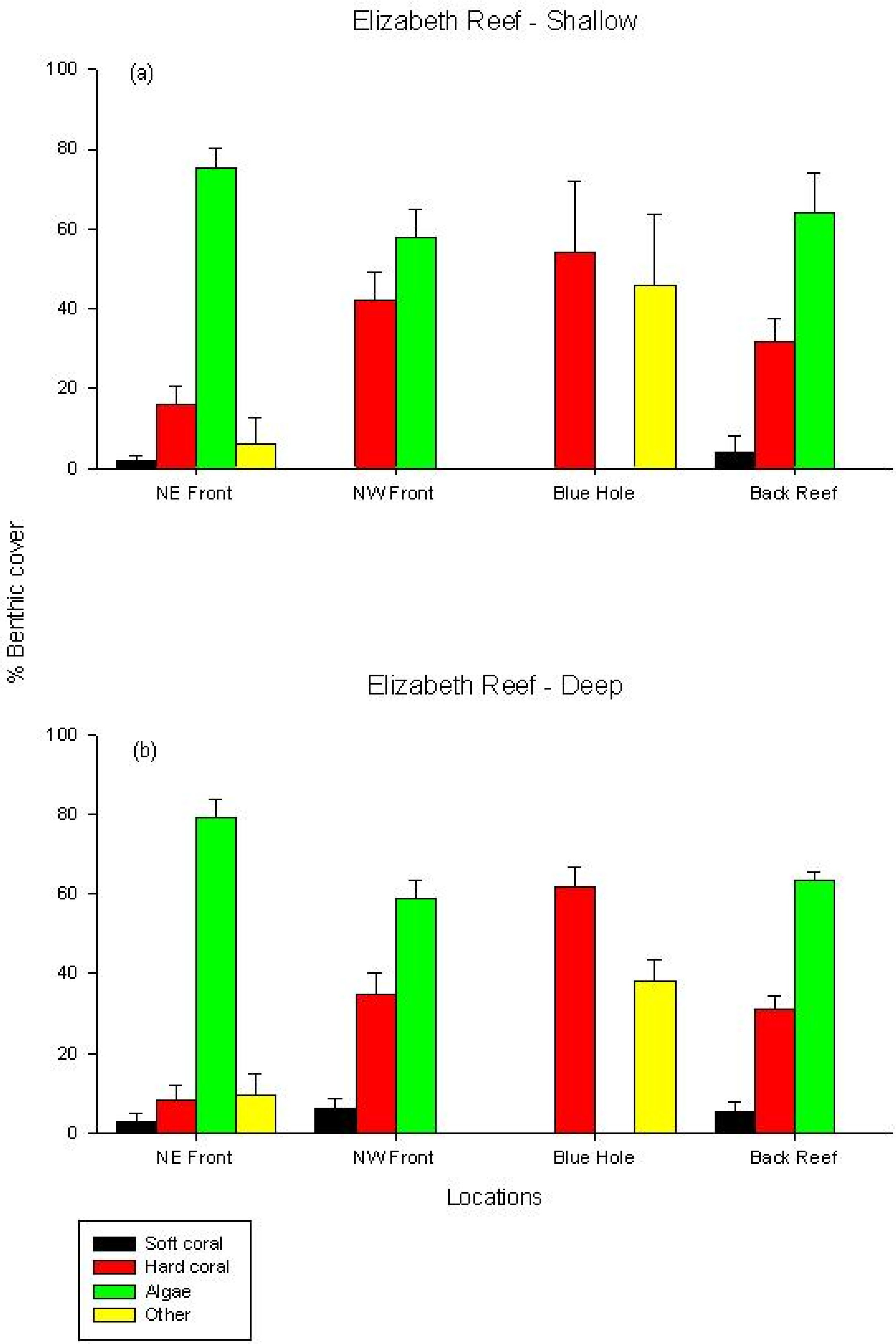
Elizabeth Reef - Shallow
(a)
100
80
60
40
20
0
NE Front
NW Front
Blue Hole
Back Reef
% Benthic cover
Elizabeth Reef - Deep
(b)
100
80
60
40
20
0
NE Front
NW Front
Blue Hole
Back Reef
Locations
Soft coral
Hard coral
Algae
Other

Figure 2: Benthic composition at Elizabeth Reef (a) shallow (<2m) and (b) deep (6 – 8m). Data presented as percentage cover.

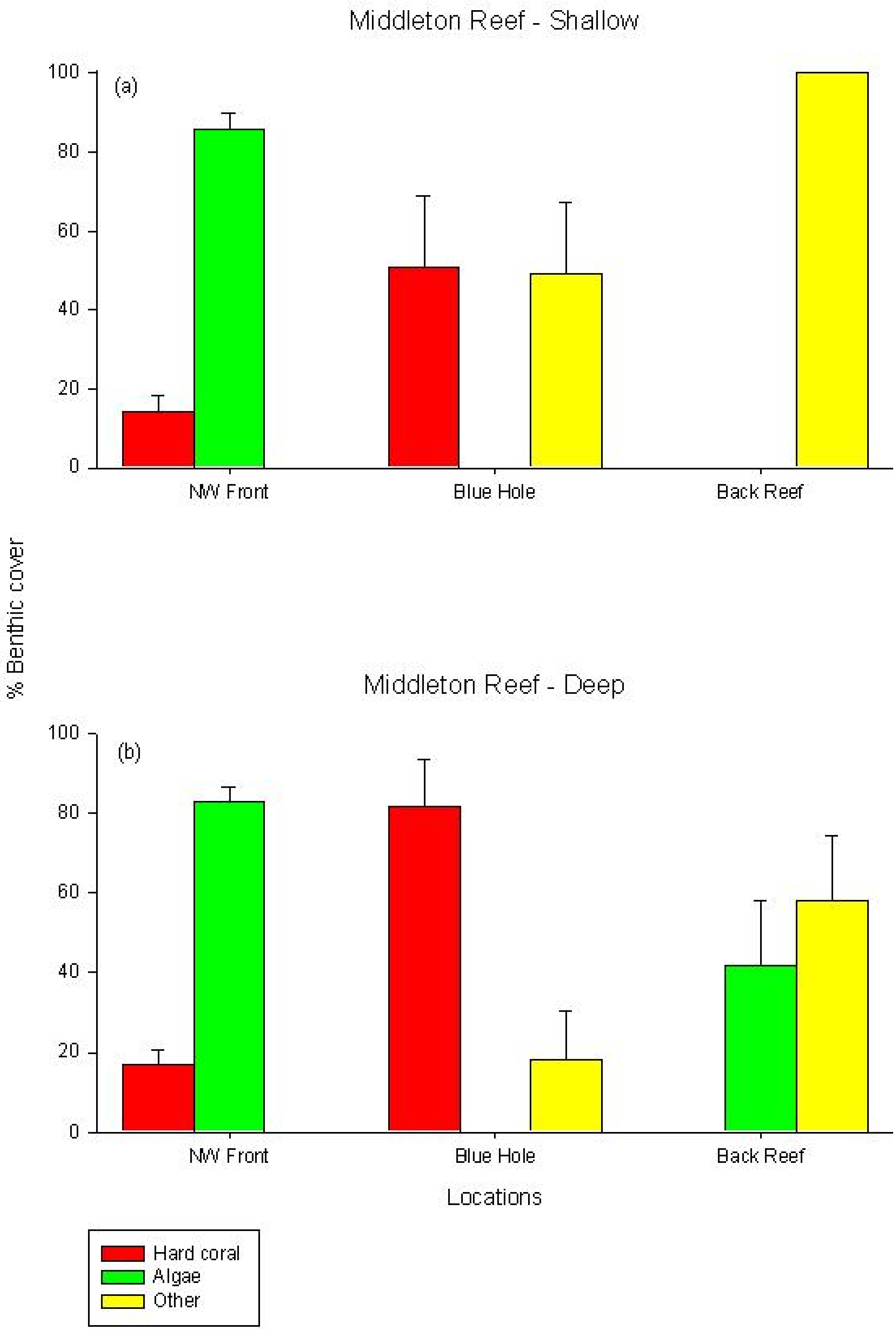

Figure 3: Benthic composition at Middleton Reef (a) shallow (<2m) and (b) deep (6 – 8m). Data presented as percentage cover.

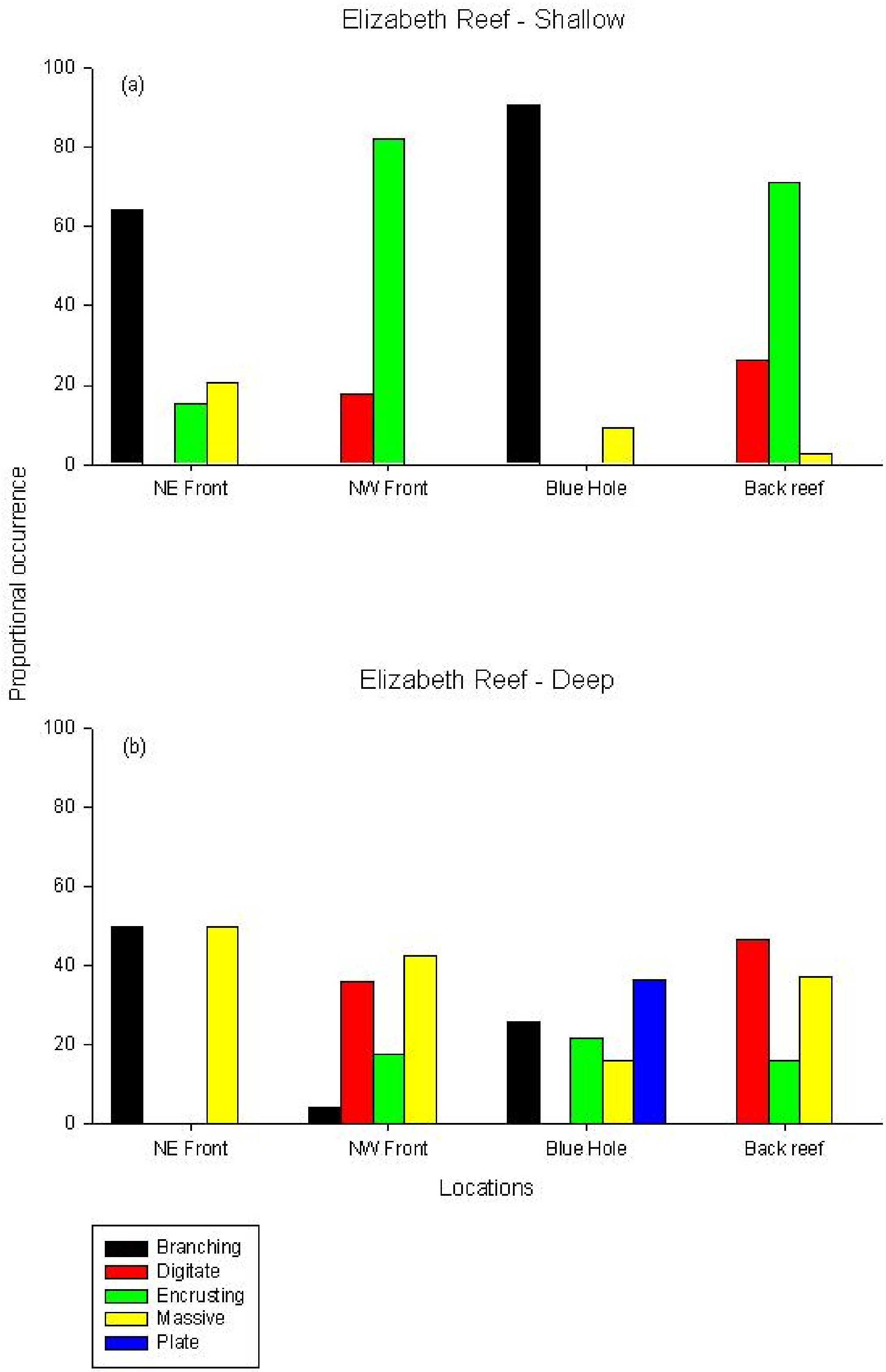

Figure 4: The percentage cover of coral morphotypes at Elizabeth Reef at (a) shallow (<2m) and (b) deep (6 – 8m) surveys.

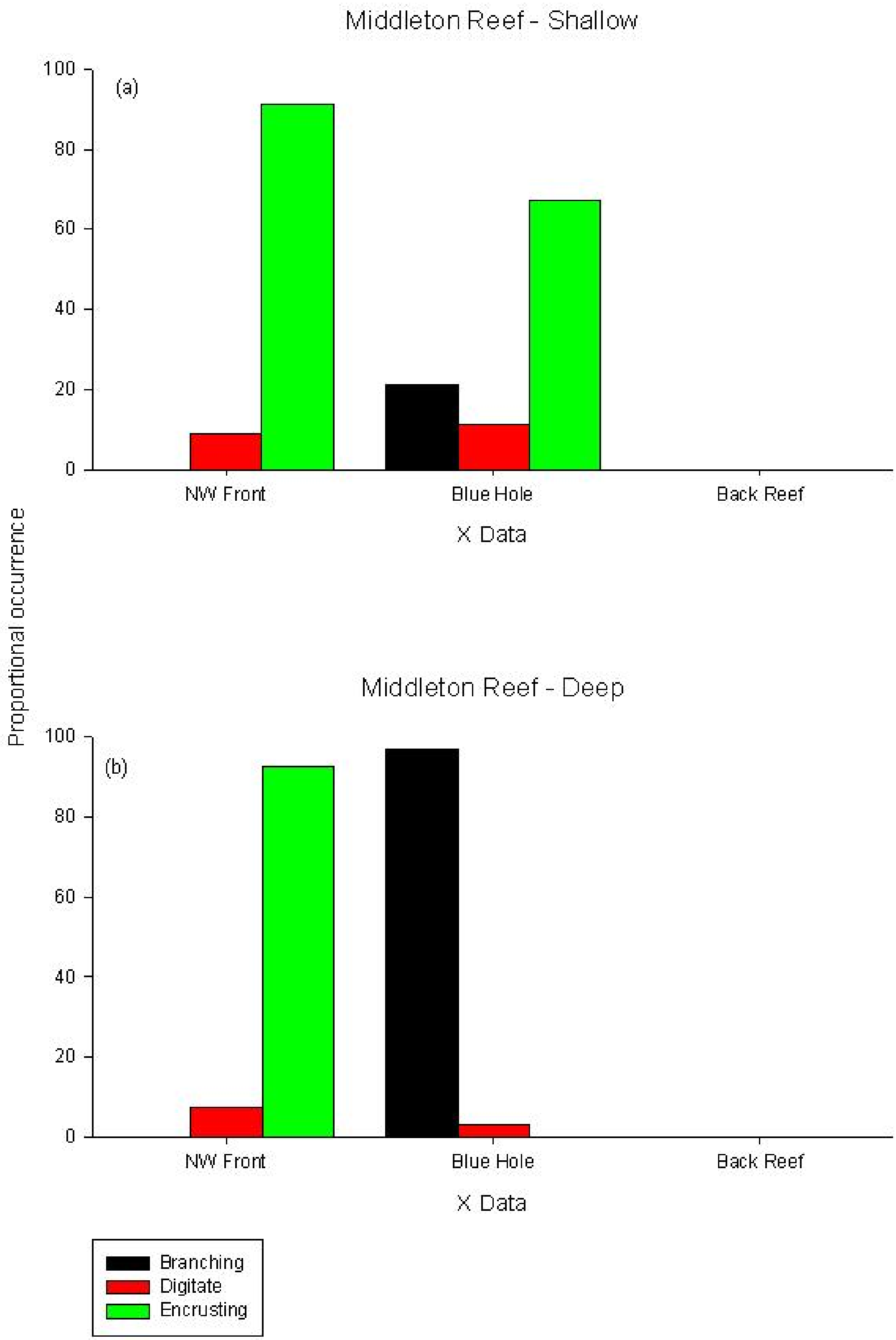

Figure 5: The percentage cover of coral morphotypes at Middleton Reef at (a) shallow (<2m) and (b) deep (6 – 8m) surveys.

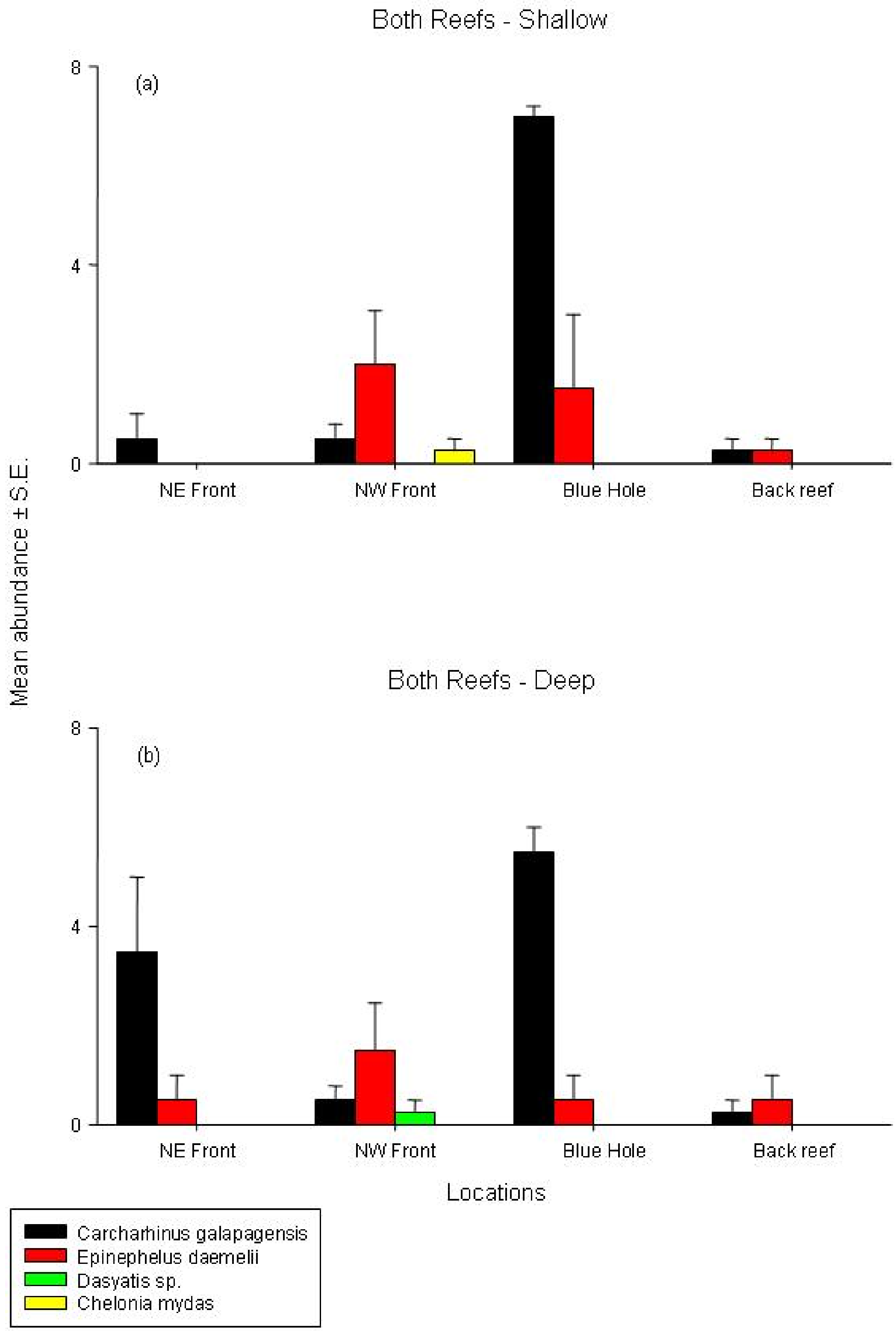

Figure 6: The mean density (per 1000 $m^2$ +/-SE) of large fauna observed at Elizabeth and Middleton Reefs. Data are combined for both Reefs and present as (a) shallow (<2m) and (b) deep (6 – 8m) surveys.

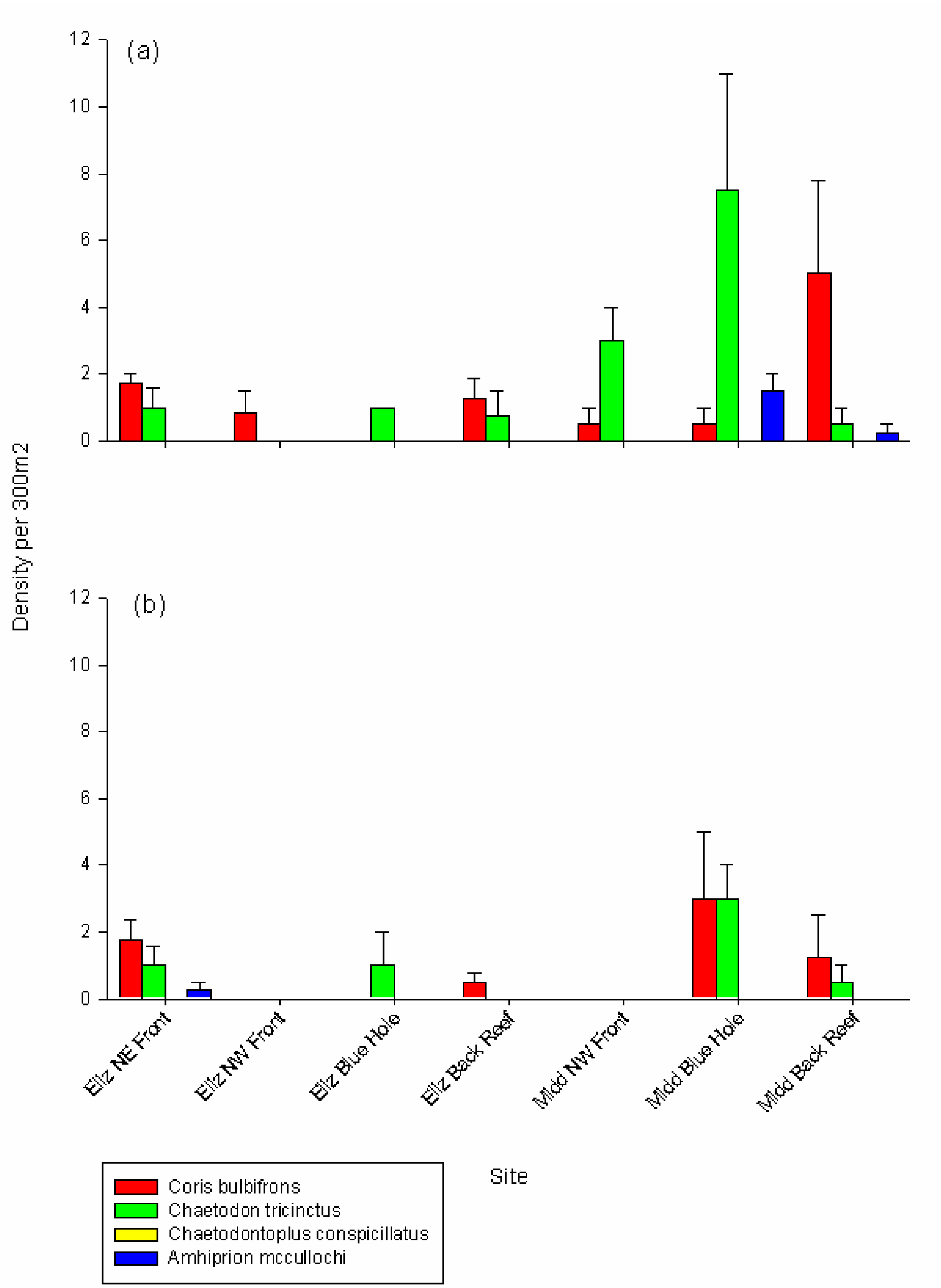

Figure 7: The mean density (per 300 $m^2$ +/-SE) of fish species endemic to Elizabeth and Middleton Reefs and the surrounding area. Data presented for both Reefs according to depth: (a) shallow (<2m) and (b) deep (6 – 8m).

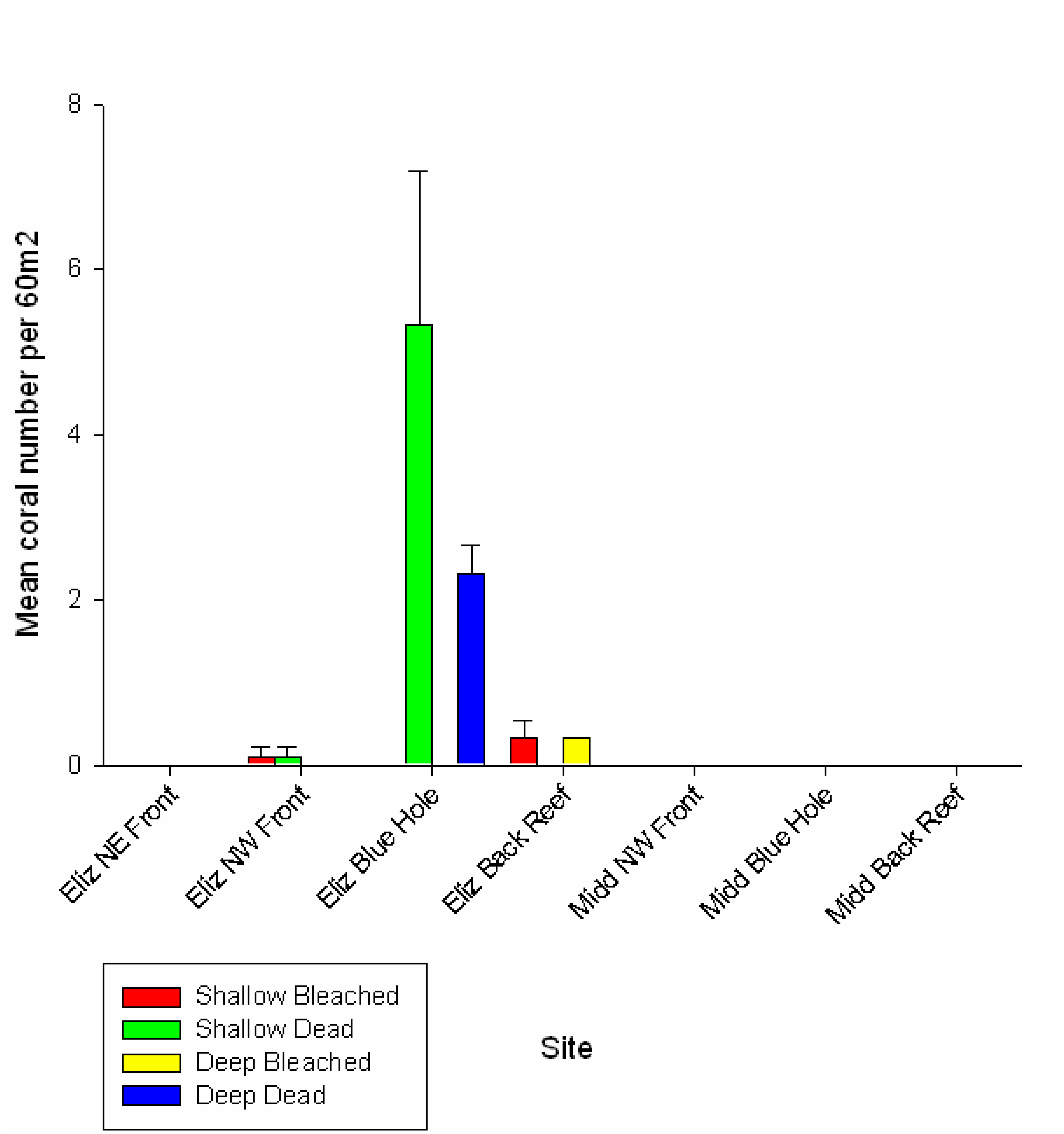


Figure 8: The condition of hard coral observed at two depths across 7 locations at Elizabeth and Middleton Reefs.

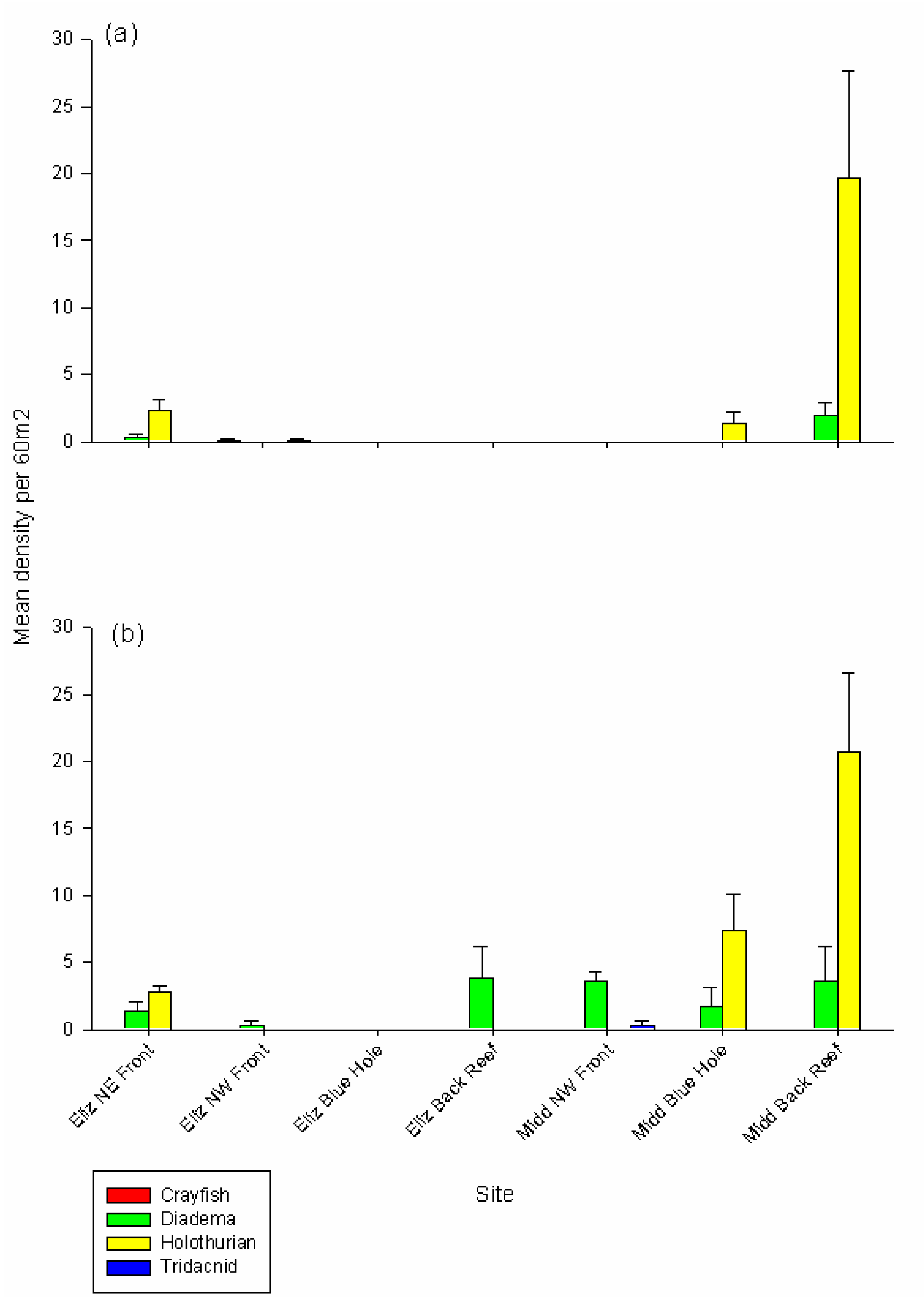


Figure 9: The mean density (per 60 m$^2$ +/-SE) of commercially or ecologically important invertebrates present in (a) shallow (<2 m) and (b) deep (6 – 8 m) surveys undertaken at Elizabeth and Middleton Reefs.

**DISCUSSION**

Elizabeth and Middleton Reefs are the southernmost open ocean platform reefs in the world. Their isolation and location has resulted in a unique and biologically diverse community, comprised of tropical, temperate and endemic species. Effective monitoring of these reefs is required to maintain their outstanding natural heritage values. As part of the ongoing monitoring process, both Reefs were visited from the 18th to the 21st of February, 2007. All the research monitoring objectives designated by the Department of the Environment and Water Resources were achieved in the short time frame available:

1. Four existing data loggers were retrieved, and 8 new data loggers deployed.
2. Twenty black cod samples were collected utilising underwater probes and line fishing techniques and sent to CSIRO for genetic analyses
3. A rapid visual assessment (surveys) of reef health was conducted at 12 sites across both Reefs. The rapid surveys provided the opportunity to develop a representative picture of the local abundance patterns of the key organisms identified in the terms of reference. The rapid visual surveys included estimations of hard coral cover and condition, abundances of coral predators (primarily *Acanthaster planci*), commercially and ecologically important invertebrates (e.g. holothurians, *Diadema*), large vulnerable species (e.g. black cod and the Galapagos shark) and endemic fishes. To examine if there were any substantial changes in the abundance of these species, we compared the results of the present study to previous work. Previous work included the detailed studies of Oxley *et al* (2004), conducted at Elizabeth Reef in 2003, and Choat *et al* (2006), undertaken predominately at Middleton Reef in 2006. For some fish species, Oxley *et al* 2004 estimated abundances using 45 swims, which equated to a survey area of 2000-4000 $m^2$. Where data was available, we also used the findings from earlier surveys, including the observations made by Kelly in 2002 (Whitting 2002) and the surveys summarised by the Australian Museum (1992).

Benthic composition

When comparing with earlier surveys of both reefs, the present study has shown that benthic composition has not changed considerably in recent years. As in 1994 and 2006 surveys (Choat *et al*, 2006), the benthic substratum at both Elizabeth and Middleton Reefs were dominated by turfing algae, although encrusting forms and hard coral were present.

The percentage of live coral cover was moderately high at both Reefs within the present study, with a mean cover of 49% at Elizabeth Reef and 27% at Middleton Reef. Hard coral was more predominant in this present study than in previous surveys by Oxley *et al* (2004) or Choat *et al* (2006). Choat *et al* (2006), reported that hard coral made up < 10% of benthic cover in transects throughout reef front habitats at both Elizabeth and Middleton Reefs, while Oxley *et al* (2004), reported that average coral cover was 25% at Elizabeth Reef. However, caution must be made when comparing past surveys with the present work, as the number of replicate transects used in this present survey were much lower. In addition, we mainly surveyed sites that were previously found to have high coral cover and were unable to survey the southern locations where low coral cover had been recorded previously (Oxley *et al*, 2004; Choat *et al*, 2006). More extensive sampling covering all sides of the Reefs is required to determine if coral cover is increasing at Elizabeth and Middleton Reefs.

The morphotype composition of the hard coral substrata was dominated by both branching and digitate morphotypes in the shallow transects, although the deeper transects held a much more balanced array of morphotypes. The shallow transects in the Blue Hole locations were distinct in having extremely high predominance of branching corals, with little other morphotype present, a pattern apparent in previous studies of the Reefs (Oxley *et al*, 2004, Choat *et al*, 2006).

Middleton Reef had a much lower diversity of coral morphotypes than Elizabeth Reef, with only branching, digitate and encrusting morphotypes present. However, such a low diversity of coral morphotypes at Middleton Reef may be an artefact of lower sampling intensity. At Middleton Reef, due to time and weather constraints, surveys were undertaken at only 4 sites covering 3 major locations (or habitats), the NW Front, within the lagoon (Blue Hole location) and in the Back Reef locations. In comparison, 8 sites covering 4 major locations, namely the NE and NW Front, the lagoon habitat (Blue Hole location) and the Back Reef location were surveyed at Elizabeth Reef.

Large vulnerable fauna

For the present study, surveys predominantly focused on the abundance of the black cod (*Epinephelus daemelii*) and the Galapagos shark (*Carcharhinus galapagensis*). Both species were found throughout the locations, reaching their highest densities in the Blue Holes.

The abundance of the Galapagos shark recorded in this present survey was higher than the densities recorded in 2003 and 2006 (Oxley *et al*, 2004; Choat *et al*, 2006). However, the higher values calculated in this present study are not likely to represent an increase in abundance, but rather reflect differences in sampling protocol. In this present rapid survey we were restricted to 100 x 10m transects, which were smaller than the previous surveys, and these smaller transects tend to overestimate the abundance of Galapagos sharks (Choat *et al*, 2006). The Blue Holes at both Reefs contained an extremely high number of Galapagos sharks, a pattern that is consistent with previous surveys (21 per 45 minute swim in Elizabeth Blue Holes and 12.1 per hectare at Middleton Blue Holes) (Oxley *et al*, 2004; Choat *et al*, 2006). The abundance of sharks within the Blue Hole location is a feature of sink holes on isolated reefs and may be due to their higher productivity and warmer water, forming suitable nursery habitat for these species (Choat *et al*, 2006).

No other shark species were observed in this survey, and only two other species of sharks have been observed (in low numbers) previously at the Reefs (Choat *et al*, 2006). Both *Dasyatis* sp. and the green turtle (*Chelonia mydas*) were identified in formal transects, albeit in extremely low numbers. Previous surveys have shown that such large fauna can be extremely rare at both Reefs (Choat *et al*, 2006).

Surveys of black cod showed that individuals are relatively abundant throughout both Reefs (1 per 1000 $m^2$). The density estimates of black cod in this present survey were higher than that recorded in 2003 and 2006 surveys (mean densities of 2-5 per hectare

Oxley *et al*, 2004; Choat *et al*, 2006). As with the Galapagos sharks, the higher density estimates obtained in this present study are probably an overestimate due to the use of smaller transects (Choat *et al*, 2006), and not related to an increase in abundance. The NW Front and Blue Hole locations exhibited the highest abundances of individuals, which is similar to the spatial distribution patterns recorded in previous surveys (Choat *et al*, 2006). Overall, the abundance of Galapagos sharks and black cod remains high at both Reefs.

<u>Endemic fishes</u>

The doubleheader wrasse (*Coris bulbifrons*) was one of the most abundant large wrasses present at both Reefs and exhibited a mean density across all sites of 1.17 per 300 $m^2$ (equates to 3.9 per 1000 $m^2$), attaining greatest densities at Middleton back reef and lagoon. This is a similar result to Choat *et al* (2006), who recorded densities of 2-5 per 1000 $m^2$ (mean 3.3) at Middleton Reef, with greatest densities observed in the lagoon and back reef. *Coris bulbifrons* was also common at Elizabeth Reef during 2003 surveys, and was recorded at 9 out of the 10 sites in densities of 1-25 per 45 minute dive (Oxley *et al*, 2004). Overall the *C. bulbifrons* populations appear to very healthy at the Reefs, however given the vulnerability of other large wrasses to overfishing (Choat *et al*, 2006b) these populations could quickly decline with minimal fishing effort, and the isolation of the Reefs would make recovery slow.

The conspicuous angelfish, *Chaetodontoplus conspicillatus*, is a sought after species for the aquarium trade and was seen at both Reefs, but not in formal transects. This species appears to have a low abundance at the Reefs, only being recorded in 3 of the 10 sites (in densities of 2-6 per 45 min dive) at Elizabeth Reef in 2003 (Oxley *et al*, 2004), and at 2 of the 6 Middleton locations in 2006 with an overall mean of less than 1 individual per 120 $m^2$ (Choat *et al*, 2006). This low abundance could be a natural phenomenon at the Reefs and this species may have larger populations in other parts of its range (Table 2). However, monitoring of this rare species at the Reefs should continue.

The three striped butterflyfish (*Chaetodon tricinctus*) was one of the most abundant butterflyfish at the Reefs (mean of 1.38 per 300 $m^2$ across all sites and depth) and the greatest densities of this species were observed in Middleton lagoon (mean of 5.25 per 300 $m^2$). Choat *et al*, (2006) recorded mean densities of 0-2.75 (adjusted to per 300 $m^2$) at most Middleton sites, with the greatest abundance of individuals at the SE front (6 per 300 $m^2$) and moderately high densities in the lagoon. In the 2003 surveys of Elizabeth Reef, Oxley *et al*, (2004) observed *C. tricinctus* in 8 of their 10 sites in densities between 6 and 125 individuals per 45 minute dive. The greatest densities were observed at the exposed southern sites. Due to unfavourable weather conditions, formal surveys were unable to encompass the southern exposed sides of the Reefs, where past work has revealed highest densities of *C. tricinctus*. Overall, the abundance of *C. tricinctus* remains high at both Reefs.

The low abundance of the white snout or McCulloch's anemonefish (*Amphiprion mccullochi*) at the Reefs is of particular concern. Only 5 individuals, (mostly in Middleton lagoon), were recorded in all formal surveys. A similar result was detected by Choat *et al* 2006 (fish present at 2 of 6 Middleton locations at a mean of less than 1 individual per 120 $m^2$) and Oxley *et al* 2004 (fish present at 3 of 10 Elizabeth sites in low abundances of 2-6 individuals per 45 min dive). Although a significant population of the white snout anemonefish may exist at Lord Howe Island, it is likely that due to the isolation of Elizabeth and Middleton Reefs, the anemonefish populations are largely (or entirely) reliant on self-recruitment (Jones *et al*, 2005). Anemonefishes are habitat specialists and are directly reliant on the distribution and abundance of their host anemone. Changes in the abundance of the host anemone (e.g. through mortality due to bleaching) will directly affect the abundance of resident anemonefishes. *Amphiprion mccullochi* is a habitat specialist with a small geographic range and low abundance, characteristics that increase a species' risk of extinction (Munday, 2004). This anemonefish is a valuable species in the aquarium trade and should not be collected from the Reefs. We recommend that future surveys of the Reefs should closely monitor the abundance of anemonefish populations.

Commercially important invertebrates

Holothurians were found in very high abundances, throughout both Reefs, particularly in sandy sheltered habitats. The highest densities of holothurians were apparent at back reef habitats at Middleton Reef (mean density of 20.17 per 60 $m^2$, equating to 3361 per hectare). Although this density is higher than other coral reef locations (see Oxley *et al*, 2004), caution must be made as our estimates are for all holothurian species combined. The 2 main species found at the Reefs were *Holothuria atra*, and the commercially valuable *H. whitmaei (nobilis)*. In comparison, the 2003 survey at Elizabeth Reef also revealed very high densities of holothurians, suggesting that these populations are virgin stocks that have not been harvested (Oxley *et al*, 2004). The isolation of the Reefs has provided a refuge from harvesting, however poachers may be tempted by high densities of the valuable *H. whitmaei (nobilis).*

The low abundance of tridacnid clams recorded in this survey is typical of previous surveys that have recorded low numbers (Australian Museum, 1992, Oxley *et al*, 2004). Trochus were not recorded in our surveys and previous work has found this mollusc to be in low abundance at the Reefs (Whitting, 2002). Only 1 crayfish (*Panulirus longipes)* was recorded in formal transects, while 3 were observed outside transects. Choat *et al* (2006) also found crayfish to be in low abundance at Middleton Reef. It is unlikely that tridacnid clams, trochus or crayfish have been overfished at the Reefs, but rather they may occur naturally at low abundances at the Reefs or in habitats that have not been adequately surveyed.

Coral condition and threats

Overall, the coral communities appeared healthy, with little evidence of bleaching, disease or predation. Crown-of-thorns starfish have caused substantial coral mortality at the Reefs in the past and were common at both Reefs during the 1987 survey (Australian Museum, 1992). In the 1994 survey at Middleton Reef, low numbers were encountered at most sites, except the western lagoon, which had densities of 12.2 per 2000 $m^2$ (see Choat *et al*, 2006). In 2002, Kelly noted COTS were common at some Middleton locations (including some of the sites censused in this survey), but were not seen at Elizabeth Reef (Whitting, 2002). In 2003, only 3 individuals were observed over 3 days of surveys at Elizabeth Reef (Oxley *et al*, 2004). In 2006, Choat *et al* (2006) found low densities (0-2 per 2000 $m^2$) at most Middleton sites, although 1 site (SE front) had a mean density of 23.2 per 2000 $m^2$. COTS do not seem to be a major threat to the Reefs at present, as they were not recorded at either Reef during this survey. However, we were unable to survey the southern exposed sides of both Reefs. The corallivorous mollusc, *Drupella*, do not appear to be a threat to the Reefs given that no individuals were recorded in the present survey or in 2003 (Oxley *et al*, 2004) and only a small number were observed at Middleton Reef in 2006 (Choat *et al*, 2006).

*Diadema* can play an important role as herbivores on reefs, regulating algae abundance, thereby allowing corals to settle and grow. However, *Diadema* were not observed in significant numbers in this study, and are unlikely to play a major role at either Elizabeth or Middleton Reefs. This survey recorded *Diadema* densities of 0-3.83 per 60 $m^2$ (all sites and both Reefs) while Choat *et al* (2006) observed similar densities of 0-5 per 60 $m^2$ at Middleton Reef. The major herbivores at Middleton and Elizabeth Reefs appear to be the numerically dominant, temperature herbivorous fishes (Choat *et al*, 2006).

Coral bleaching is associated with elevated water temperatures and has caused widespread coral mortality throughout the tropics in the last decade. The 2003 survey of Elizabeth Reef did not record any evidence of bleaching (Oxley *et al*, 2004). Only 5 coral colonies were observed to be recently bleached in this current survey. There was also some recent coral mortality in the lagoon habitat (Blue Holes) at Elizabeth Reef, which may have been due to bleaching. Water temperature in the Blue Holes should be monitored closely, as these areas have high coral cover and are likely to experience higher water temperatures than the surrounding reef due to reduced water flow.

Coral disease is another serious threat to coral reef health, however no obvious signs of disease were observed during this survey or the 2003 survey at Elizabeth Reef (Oxley e*t al*, 2004). Disease and bleaching have not caused obvious damage to Elizabeth or Middleton Reefs in recent years, however given the wide-scale destruction of coral communities globally, these disturbances should be considered a potential future threat and warrant ongoing monitoring of the Reefs.

Marine debris, fishing gear and anchor damage can also degrade reefs, but there was no evidence of these threats during the present survey or the 2003 survey at Elizabeth Reef (Oxley *et al*, 2004).

Lagoon habitat

Both Reefs have a distinct lagoonal area or "blue holes" that deserve attention because of their unique habitat and associated assemblages. The physical properties of the blue holes differ to other areas of the reef in that there is less water flow, less wave action, reduced visibility and the potential for higher water temperatures. The blue holes have the greatest percentage of live coral cover, particular branching *Acropora* species, that form important shelter for a range of coral reef organisms by providing extensive 3-dimensional habitat structure.

The blue holes provide a unique environment that is used by a particular suite of species. The authors' personal observations from 2006 and the present surveys revealed that many species of fish and other organisms are only found within this habitat at both Reefs. The highest abundances of anemonefish, Galapagos sharks and black cod occurred in the blue holes, a pattern seen in previous surveys (Oxley *et al*, 2003; Choat *et al*, 2006). The relatively high abundance of juvenile sharks and black cod indicate that these areas may form important nursery habitats for these species. This important lagoonal habitat is relatively small in comparison to the other habitats present at the Reefs (e.g. back reef, reef front, reef flat), and is potentially vulnerable to a range of disturbances. Large stands of live branching *Acropora* dominated the blue holes, and these corals are one of the most vulnerable to bleaching (Marshall and Baird, 2000) and predation by COTS (Pratchett, 2001). A bleaching event, COTS outbreak or severe storm could potentially cause significant damage to the *Acropora* corals, thereby affecting this important habitat and the species relying on this habitat.

## Conclusion and recommendations

Overall, the Reefs appear to have a moderate cover of live coral, with 49% recorded at Elizabeth Reef and 27% at Middleton Reef. There was minimal evidence of threats such as coral bleaching, COTS, *Drupella*, or marine debris at the Reefs. There has been no noticeable change in the abundances of habitat forming species, important invertebrates, large fauna or endemic fishes. The abundance of holothurians, black cod, Galapagos shark and doubleheader wrasse remains high, however stocks of these valuable species can be easily decimated by overfishing and recovery would be slow due to the isolation of the Reefs. The abundance of the endemic white snout anemonefish and conspicuous angelfish is low, warranting continued monitoring and protection from collection.

Monitoring in the form of a rapid reef health survey should continue on a regular (e.g. yearly) basis. These regular monitoring trips should focus on conducting rapid visual assessment of key species and threats, such as those covered in this survey. Surveys that are more detailed should occur every 3-5 years. Monitoring should always include the blue holes (lagoon) habitat because of their uniqueness and importance.

Monitoring of water temperature using data loggers should continue. We recommend that data loggers also be placed in the blue holes to monitor the threat of increased water temperature on the sensitive, but highly abundant, *Acropora* species that form an integral part of this lagoonal habitat.

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**APPENDIX**

Photos of endemic and potentially vulnerable fishes surveyed at Elizabeth and Middleton Reef. (a) Black cod (*Epinephelus daemelii*) (b) Galapagos shark (*Carcharhinus galapagensis*) (c) Three striped butterflyfish (*Chaetodon tricinctus*) (d) White snout anemonefish (*Amphiprion mccullochi*) (e) Doubleheader wrasse (*Coris bulbifrons*) (f) Conspicuous angelfish (*Chaetodontoplus conspicillatus*). Photo (b) courtesy of Will Robbins all other photos courtesy of Tony Ayling.