Coringa-Herald National Nature Reserve Marine Survey 2007
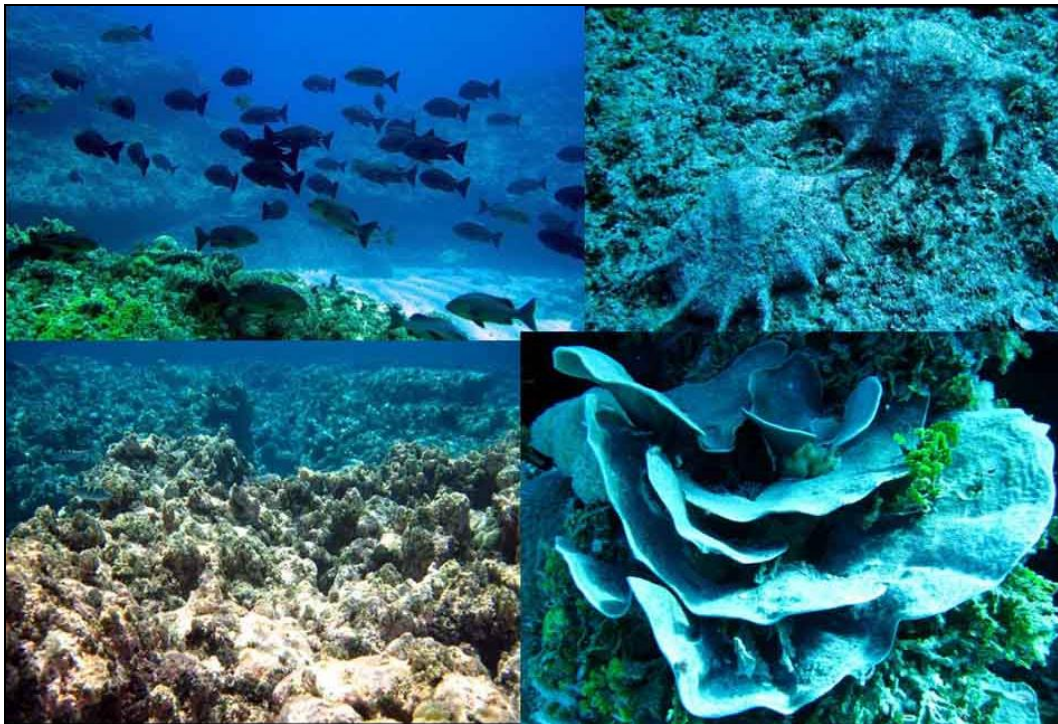
For the Department of the Environment, Water, Heritage and the Arts

By
C&R Consulting and James Cook University

Authors: Dr. Daniela Ceccarelli, Prof. J. Howard Choat, Dr. Tony Ayling, Ms. Zoe Richards, Dr. Lynne van Herwerden, Dr. Avril Ayling, Dr. Glen Ewels, and Mr. J.-P. Hobbs
Mapping: Mr. Ben Cuff

IMPORTANT NOTE

_____

Director, C&R Consulting

Copyright

Disclaimer

1. EXECUTIVE SUMMARY

This report combines the results of two surveys of coral, macroinvertebrate and fish communities in the Coringa-Herald National Nature Reserve (CHNNR or the Reserve). The first survey, conducted by JCU in May 2007, surveyed the Herald Cays (NE and SW Herald). The C&R Consulting survey in October 2007 focused on South East Magdelaine Cay (SE Magdelaine), Chilcott Islet (Chilcott) and South West Coringa Islet (Coringa). Ecological communities were found to be in a similar condition to those described in previous surveys, with very little recovery of hard coral cover.

Reefs in the CHNNR support approximately 7.3% hard coral cover and a relatively species-poor fish community. Coral cover, already historically low, has been slow to recover from disturbances in the last two decades, probably due largely to the small size of the reefs, as well as isolation and exposure. SE Magdelaine supported the highest coral cover, coral and reef fish diversity and the highest general abundance of surveyed reef species, while SW Herald had the largest populations of some large reef fish families. The presence of Pacific Ocean corals lends support to the suggestion that Coral Sea reefs provide stepping-stones for the dispersal of species between the Great Barrier Reef and Pacific Ocean reefs.

Corals of the genus *Acropora* were expected to be diverse and abundant on the clear-water CHNNR reefs, but very few live or dead colonies were encountered during the survey. *Acropora* species are the most vulnerable to disturbance and are also early colonisers of disturbed sites. Along with the small size and sexual immaturity of other hard coral, soft coral and sponge colonies, the low cover of *Acropora* is typical of reefs in the early phase of recovery.

Algal turf, coralline algae and *Halimeda* spp. were the predominant benthic taxa in the CHNNR. Algal turf is an important food source for a range of marine invertebrates and herbivorous fish, and was dominant primarily in sheltered back reef habitats, corresponding with the greatest density of large herbivorous fish. Coralline algae, often indicative of heavy grazing, was abundant on the reef front, and the low abundance of grazing herbivores in these habitats suggests that the high coralline algae cover is another historical feature of the reefs.

Densities of holothurians and tridacnid clams were similar to those found in other surveys of isolated, oceanic reefs. Some holothurians of high commercial value were more abundant in the CHNNR, suggesting successful protection from exploitation. Gastropods valuable for the ornamental shell industry were found in high densities in some areas of the Reserve, indicating that it may be important to include these species in future surveys.

Key fish species were found in low densities, potentially as a result of the low microhabitat complexity, resulting in lower food and habitat availability. Apex predators such as serranids and sharks, along with large keystone invertebrate feeders and herbivores, are economically valuable and globally vulnerable to overexploitation, highlighting the need for their protection and the careful monitoring and safeguarding of their habitat.

By nature of their isolation, oceanic reefs such as those in the CHNNR harbour unique communities. They also have few sources of propagules, and tend to recover slowly from disturbance. Many key species occur in low numbers, making them highly vulnerable to local extinction. Recommendations arising from these surveys focus on the continued protection and effective monitoring of the Reserve. The protection of the hard coral community and of key fish and invertebrate species are crucial to the safeguarding of the resilience of these reefs in the light of expected climate change.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

2.   INTRODUCTION

The Coringa-Herald National Nature Reserve (CHNNR or the Reserve) is a strict Nature Reserve (IUCN category 1a[1]) located in the Coral Sea, on the Queensland Plateau some 400 km east of Cairns (Figure 1). The Reserve is part of the National Representative System of Marine Protected Areas governed by the Department of the Environment, Water, Heritage and the Arts (DEWHA), and is managed as a strict nature reserve, International Union for the Conservation of Nature (IUCN) Category 1a. The aim of the Reserve's Management Plan (Environment Australia 2001), is to preserve the natural state of its habitats, ecosystems and native species. Monitoring programs form a core element of addressing key management objectives.

Reef fish, holothurians and benthic communities were surveyed in the Reserve on behalf of the DEWHA in 1985, 2001, 2003 and 2007 (Ayling and Ayling 1985, Byron et al. 2001, Oxley et al. 2003, Choat et al. 2007). The most recent of these surveys (2003 and 2007) recorded very low hard coral cover (<5%) and diversity in comparison to prior years and to Great Barrier Reef (GBR) sites at similar latitudes. These declines are most probably due to the impacts of successive bleaching events and cyclones in the last decade.

Coral cover has historically been low on small Coral Sea reefs (Bellwood and Hughes 2001, Oxley et al. 2003, Choat et al. 2007), and recovery from cyclone damage and bleaching events has been extremely slow (Wakeford 2002, Oxley et al. 2003). Fish abundance and diversity is correspondingly low, as a lack of microhabitat structure and complexity results in a decreased availability of food and shelter (Bellwood and Hughes 2001). Previous surveys of the CHNNR have found decreased density and diversity of reef fish in comparison to the GBR. However, the unique coral and fish assemblages suggest that these isolated reefs act as stepping stones in the westward movement of larvae from the west Pacific to the GBR.

Ecologically, the remoteness and small size of these reefs typically results in a species poor community with a high potential for self-recruitment (Whittaker 1998). This increases their potential vulnerability for two reasons. Firstly, communities with low diversity are vulnerable to losing whole functional groups, which can compromise ecosystem function and resilience (Bellwood and Hughes 2001). Secondly, the remoteness and potential reliance on self-recruitment makes species inhabiting isolated islands subject to slow recoveries from any significant disturbance. Given the potential vulnerability of the CHNNR reefs, and their biogeographical and historical importance, it is crucial that the ecological status of these reefs is closely monitored.

Commercially valuable benthic invertebrates are not exploited in the CHNNR, but fisheries such as the Coral Sea Fishery exist outside its boundaries (AFMA 2007). Stocks of these invertebrates within the Reserve are therefore of particular management interest, as the CHNNR could serve as a source of propagules for exploited areas. The first assessment of holothurian density within the CHNNR was conducted in 2003 (Oxley et al. 2003).

Climatically, the CHNNR is located in the Southwestern Pacific annual monsoon belt, with most rainfall occurring between December and April, and is periodically affected by tropical cyclones (Environment Australia 2001). At least seven cyclones crossed the Reserve prior to the 2003 survey (Oxley et al. 2003), and five more have crossed the area since 2003

---

[1] Definition: Strict nature reserve/wilderness protection area managed mainly for science or wilderness protection – an area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.

(Australian Severe Weather 2007). Additionally, the Coral Sea is affected by episodes of elevated Sea Surface Temperatures (SST), leading to widespread bleaching and mortality in corals. Severe cyclones and elevated SST are both expected to increase as a result of anthropogenically induced climate change, increasing the vulnerability of reefs worldwide. CHNNR reef communities are relatively isolated from recruitment sources and exposed to a high disturbance regime. These reefs are therefore vulnerable due to their exposure to external agents of disturbance, the potential loss of functional groups resulting from their naturally low species richness, and the reduced speed of recovery from disturbance. Closely monitoring the ecological status of these reefs, and documenting temporal changes in community structure, is therefore a crucial component of managing the Reserve.
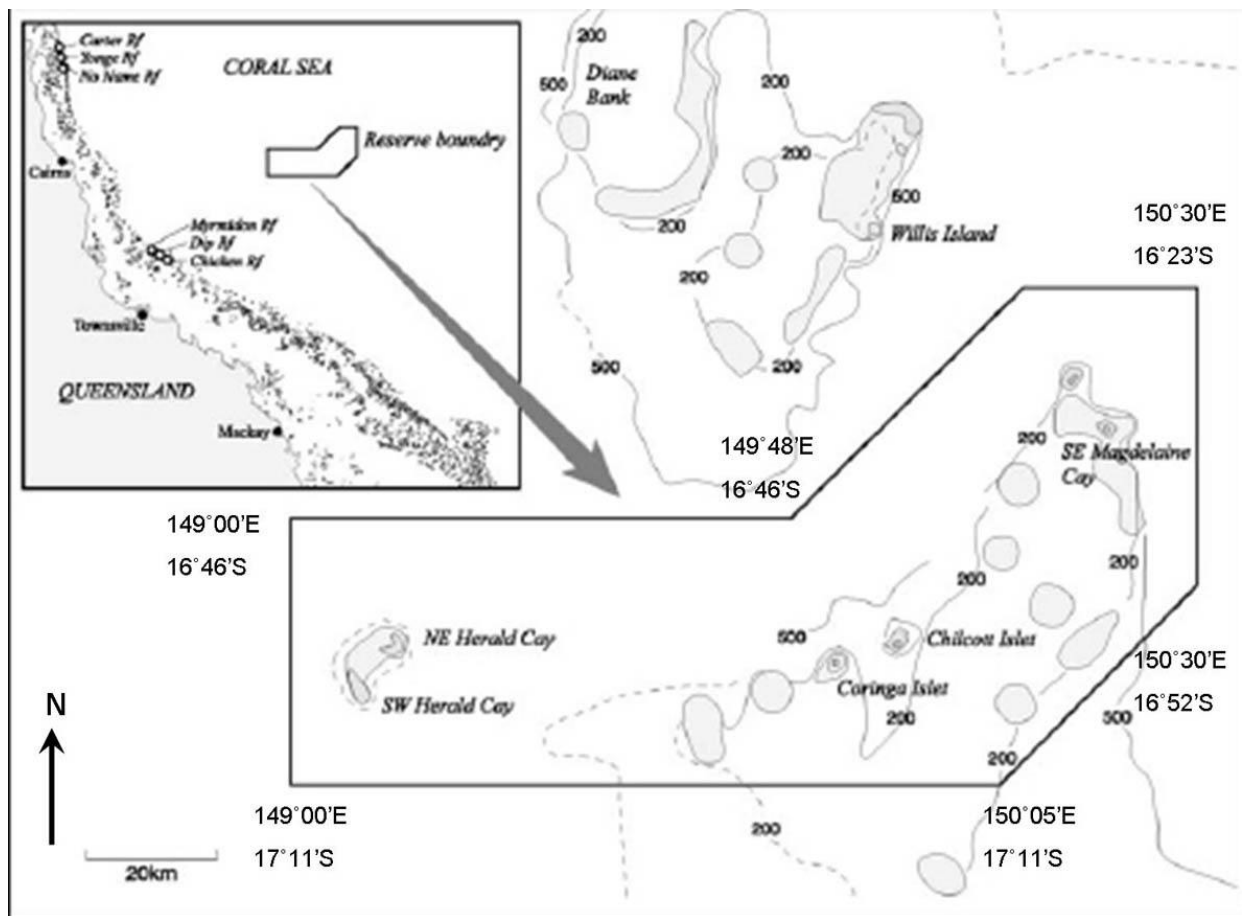
Figure 1. Location of the Coringa-Herald National Nature Reserve in the Coral Sea off the east coast of Australia (after Oxley et al. 2003).

3. OBJECTIVES AND SCOPE

The objectives of this study were to conduct ecological surveys of coral, fish and invertebrate communities in the CHNNR, as part of the ongoing monitoring of the status of the coral reefs. The survey, conducted over two field trips, included the North East and South West Herald Cays (JCU, May 2007), and South East Magdelaine Cay, Chilcott Cay and South West Coringa Islet (C&R Consulting, October 2007). The study serves as a comparison to previous surveys, especially the 2003 survey conducted by the Australian Institute of Marine Science (AIMS).

This report describes the patterns of abundance, species richness and distribution patterns of selected groups of reef fishes and benthic organisms. The sampling protocol for reef fishes was designed to obtain abundance and size-frequency estimates of vulnerable species; and abundance and distributional data on groups of reef fishes of functional importance in the Coral Sea reef ecosystem. Invertebrate surveys included a large range of sessile biota (focusing on scleractinian corals) and mobile invertebrates (holothurians, tridacnid clams, gastropods, echinoids and Crown-of-Thorns starfish *Acanthaster planci*). Management recommendations to the DEWHA are drawn from the results and conclusions of this survey.

4.   METHODS

The present surveys were conducted from the 14th to the 18th of May (JCU) and from the 23rd to the 31st of October 2007 (C&R) aboard the Tusa IV and Australian Customs Vessel (ACV) Botany Bay respectively. The JCU team surveyed North East and South West Herald Cays (NE and SW Herald), and the C&R team focused on the remaining cays: Chilcott Islet (Chilcott), South West Coringa Islet (Coringa), and South East Magdelaine Cay (SE Magdelaine). The C&R team also surveyed shallow water habitats of NE Herald not covered by the JCU team. Winds in the Reserves are typically strong south-easterly trade winds, occasionally changing to northerly winds during summer months, often limiting access to exposed sites.

On each reef, efforts were made to approximate and add to the four sampling locations of the 2003 AIMS survey (Figure 2, Appendix 1). Generally, three locations were in exposed or semi-exposed habitats (West Flank, Reef Front and North East sites of the AIMS survey) and one was in a relatively sheltered habitat (Back Reef). Where sampling sites were added, efforts were made to locate them on exposed sides of the reefs, as these are considered critical to ecological processes on isolated oceanic reefs. Reef flat habitats were surveyed using snorkel swims.

At each SCUBA site, eight belt transects were used to quantify benthic and fish communities, either concentrating on a single depth zone (8-15m, JCU), or with four transects placed in deeper habitats (8-15m) and four transects in shallower habitats closer to the reef crest (4-6m, C&R). A diver (JHC, DC) counted all larger, mobile fish in a 30 x 10 m belt while deploying the transect tape as close to the substratum as possible. The same diver (DC) then counted all non-cryptic, diurnal site-attached fish in a 4m wide belt while returning along the transect tape. The second diver (ZR, LvH, AA) recorded all benthic organisms using the line intersect method (e.g. Baird et al. 2005) along 20 m of the same transect. Benthic communities were categorised in a way that allowed comparisons with previous studies and integration between the two 2007 surveys (Table 1).

Table 1. Benthic categories used in this survey.

HC:	**Hard Coral**	Hard Coral = Scleractinian Corals as described in Veron 2000. *Tubipora musica* (tube coral) and *Millepora* sp. (fire coral) are included in counts for the HC category
SC:	**Soft Coral**	Soft coral = *Xenia* sp., *Lobophytum*, *Sarcophytum*, *Isis hippuris*
SP:	**Sponge**	
CA:	**Coralline Algae**	Coralline algae
HA:	**Halimeda**	Halimeda
OA:	**Other Algae**	Other algae **=** *Caulerpa* sp., other macroalgae
OI:	**Other Invertebrates**	Other invertebrates = *Tridacna* clams, hydroid, ascidian, borrowing urchins, spider conchs (*Lambis* spp.), nudibranch, cone shells (*Conus* sp.) Holothurians (*H. atra, S. chloronotus*)
SD:	**Sand**	Bare sand
DC:	**Dead Coral**	Dead hard coral that has maintained its colony morphology
R/R:	**Bare Rock and Rubble**	Rock or rubble with no visible biota

Additionally, each SCUBA site was the start or finishing point (depending on the direction of the current) for a 500m (400m, JCU) belt transect used to survey densities of larger reef fish (e.g. Maori wrasse, bumphead parrotfish, large predators) and sharks, and invertebrates such as holothurians, tridacnid clams, invasive species (e.g. Crown-of-Thorns starfish, *Drupella*), and other commercially important species (Trochus, ornamental shells). The distance was determined with a GPS and marked with buoys, and the first diver (AMA, DC) swam well above the substratum, counting all large fishes and sharks within a 20m belt, while the second diver (ZR) recorded all invertebrates of interest in a 5m belt. Each 500m swim began at a depth of 15-20m (or as deep as the base of the slope at each site) and ended at 8-10m.

To extensively survey shallower habitats, 500m transects were swum on snorkel over the reef crest, reef flat and shallow back reef habitats (only C&R). The number of these transects at each Cay was determined by the size of the reef and by the weather conditions (Table 2). Two surveyors swam parallel to each other and approximately 10m apart, recording all invertebrates of interest in a 5m belt.

Table 2. Summary of replicates conducted at each reef of the CHNNR by both surveys.

Survey	SW Herald	NE Herald	SE Magdelaine	Chilcott	Coringa
Invertebrate swims – SCUBA (500x5m)			4	4	4
Invertebrate swims – SCUBA (400x5m)	7	11			
Invertebrate swims – snorkel (500x5m)		12	8	10	4
Fish transects (30x10m)	21	46	32	32	32
Benthic transects (20m)*	28	60	32	32	32
Large fish swims (500x10m)			4	4	4
Large fish swims (400x20m)	7	11			

*The May survey benthic transects were also used to record mobile invertebrates along a 5m   belt.
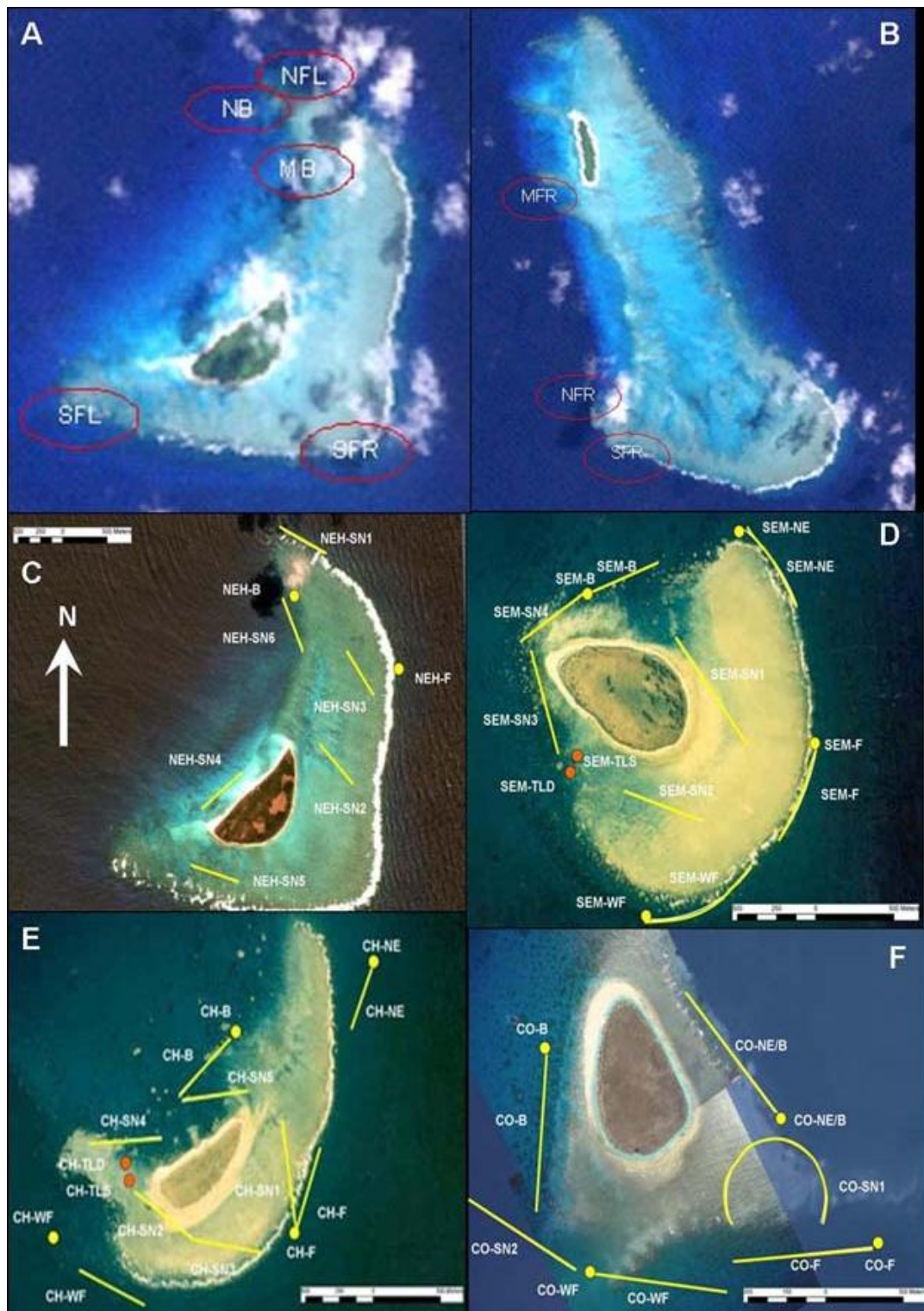
Figure 2. Map of sampling sites A) NE Herald and B) SW Herald, both JCU; C) NE Herald, D) SE Magdelaine, E) Chilcott and F) Coringa (C&R). Locations of major **JCU sites**: SFL=South Flank, SFR=South Front, MB=Mid Back, NFL=North Flank, NB=North Back, MF=Mid Front, NFR=North Front. **C&R sites**: yellow dots: SCUBA sites for fish and benthic transects; yellow lines: snorkels and SCUBA swims (approx 500m long); red dots: Temperature loggers at SE Magdelaine and Chilcott Cays. Note that scale bars and North arrows are not included in subsequent figures using these maps.

An extension to the marine surveys undertaken in this project was the deployment of four temperature loggers and the collection of 4 population samples for zooxanthellae genotyping by Dr. Ray Berkelmans at AIMS (Appendix 2). The diversity of dinoflagellate symbionts present in these corals will be quantified to examine the Coral Sea zooxanthellate community in the context of locating strains that may enhance survival from coral bleaching.

Results from these surveys are presented using the pooled data from both 2007 surveys, except where otherwise stated. Abundance estimates of fish, holothurians, clams and other macroinvertebrates were converted to percent cover or density (individuals per hectare) where appropriate, to enable comparisons with previous studies. The statistical significance of differences between reefs, habitats, exposure and / or depth was tested using Analysis of Variance (ANOVA), with logarithmic transformations used when data did not conform to the assumptions of normality and homogeneity of variances. To detect significant patterns at the level of communities, Multivariate ANOVA (MANOVA) was employed, and followed up with Canonical Discriminant Analysis to illustrate the nature of the separation between groups (e.g. which species were driving the separation between habitats in the fish community).

Multivariate analysis was conducted on the grazing herbivore assemblages to examine whether the structure and composition of this assemblage at the Herald Cays differs to the assemblages found on the GBR and Elizabeth and Middleton Reefs (Figure 3). The analysis was conducted on untransformed data using the Modified Gower (base 10) dissimilarity measure. This measure has been shown to allow a direct weighting of a change in species composition to an order of magnitude change in abundance (Anderson et al. 2006). Non-metric multidimensional scaling (nMDS) was used to visualize multivariate patterns in regional reef fish assemblages. To visualise the maximum difference between regions, a canonical analysis of principle co-ordinates CAP was used (Anderson and Millar 2004). This method searches for the axis that represents the greatest between group differences in multivariate space. In this case, we wanted to visualise the between region differences.

Where possible, comparisons were made with the results of previous surveys in the CHNNR (Ayling and Ayling 1985, Byron et al. 2001, Oxley et al. 2003) and with surveys conducted in other Commonwealth Marine Reserves. Most of these comparisons could not be tested statistically, as the raw data were not available, but trends could be detected easily from the graphical representation of the data.
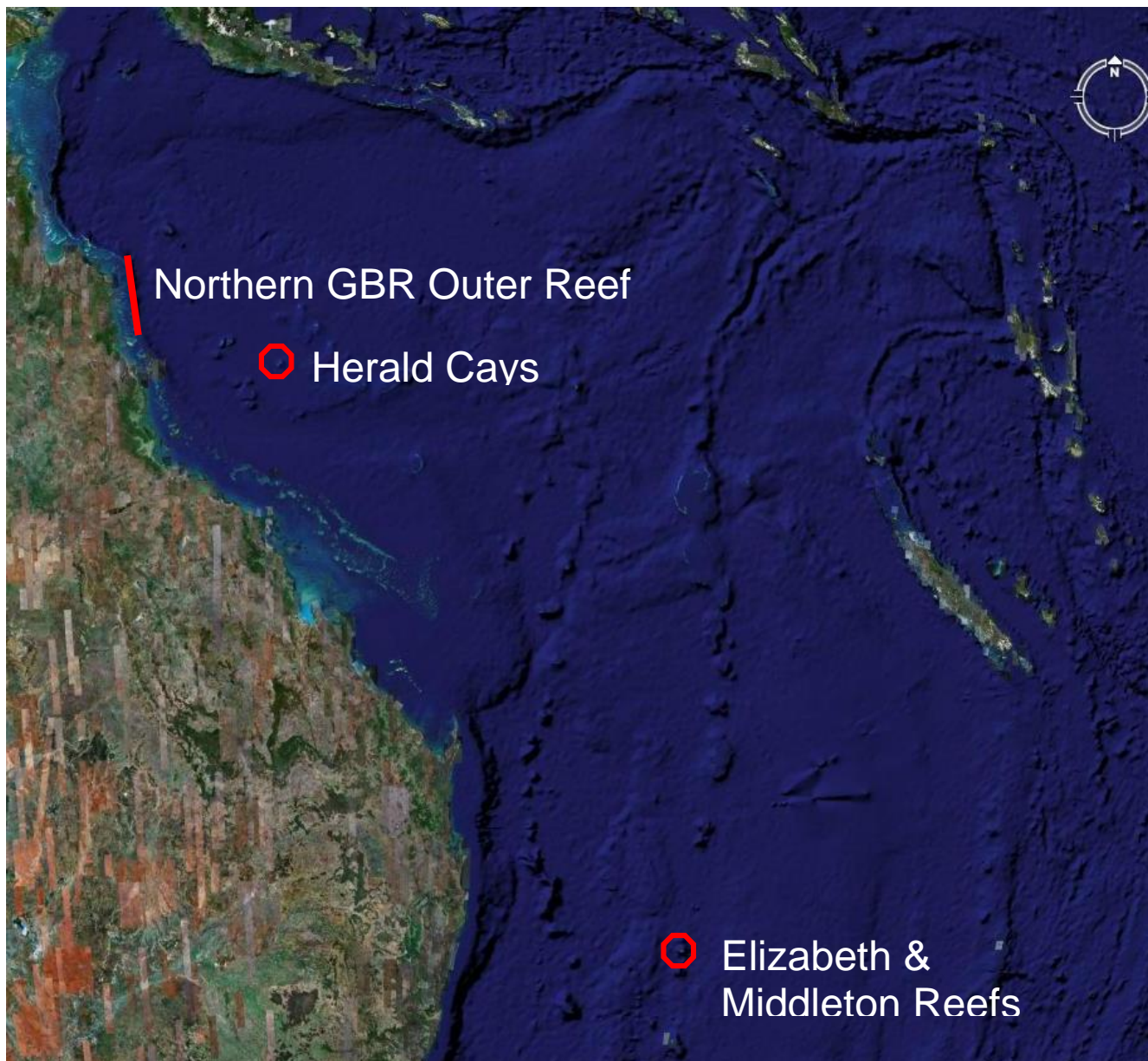
Figure 3. The location of the Herald Cays in the Coral Sea and the positions of comparative coral reef systems (GBR outer reef fronts and Elizabeth and Middleton Reefs).

5.   RESULTS AND DISCUSSION

5.1   *Benthic communities*

The CHNNR is characterised by low live coral cover, with an average of 7.3% and a range from 6 -14%. The prevailing substrate on all reefs was turf algae, the calcified gree alga *Halimeda* and coralline algae, the latter particularly in exposed habitats. The composition of the sand suggests that *Halimeda* is a major contributor to the local sediment supply. The composition of turf algae was a matrix of mixed algal components depending upon location – for example, algal turf on the reef front of Chilcott consisted of *Halimeda*, coralline algae, green and calcareous algae. Overall, benthic cover estimates in the CHNNR have remained relatively stable since 2003. Hard coral cover appears to be slowly increasing, and patterns of coral cover and community structure are consistent with those expected of an exposed reef with historically low coral cover that is recovering from disturbance.

5.1.1   BENTHIC COVER – OVERALL TRENDS

Between 53 and 61% of the benthos in the CHNNR is comprised of algae; turf algae was the dominant benthic component of all five surveyed reefs (Figure 6). Benthic community structure was significantly different between the five CHNNR reefs (Appendix 3).

Proportionally, the cover of hard coral was highest at SE Magdelaine, and lowest at SW Herald (Figure 4, Appendix 3). Sponges and soft corals, although common at most sites, were generally present as small colonies and therefore did not contribute greatly to cover estimates (e.g. Figure 5). Between 14 and 20% of the reef within the Reserve was abiotic (non-living). Macro-invertebrates including clams, holothurians, gastropods, nudibranchs and hydroids were found in low numbers on transects at all locations except Coringa. Only a very small amount of dead coral was recorded at NE Herald, but it should be noted that coralline and turf algae quickly overgrow dead coral or bare substrate. The presence of bare rock/rubble at NE Herald and SE Magdelaine is indicative of historical mortality and a high level of community turnover and productivity.
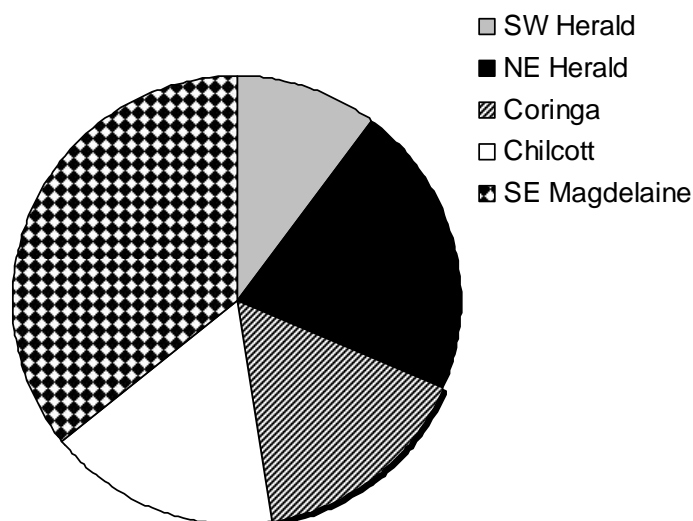
Figure 4. Proportion of hard coral cover at different locations within the CHNNR.

There was no significant difference in the hard coral cover between habitats (Appendix 3), but a general trend was detected (Figure 7). The greatest cover of hard coral was found in the NE Flank (exposed) habitats, followed by the West Flank (exposed), Back Reef (protected) and Reef Front (exposed) habitats. SE Magdelaine had the highest cover of live hard corals in all four surveyed habitats, reaching over 15% in some areas, although the difference was smallest in exposed Reef Front habitats (Figure 8). The NE Flank of NE Herald and the West Flank of Chilcott were the only areas with coral cover comparable to that found on SE Magdelaine. All other habitats and reefs supported coral cover of well below 10%.
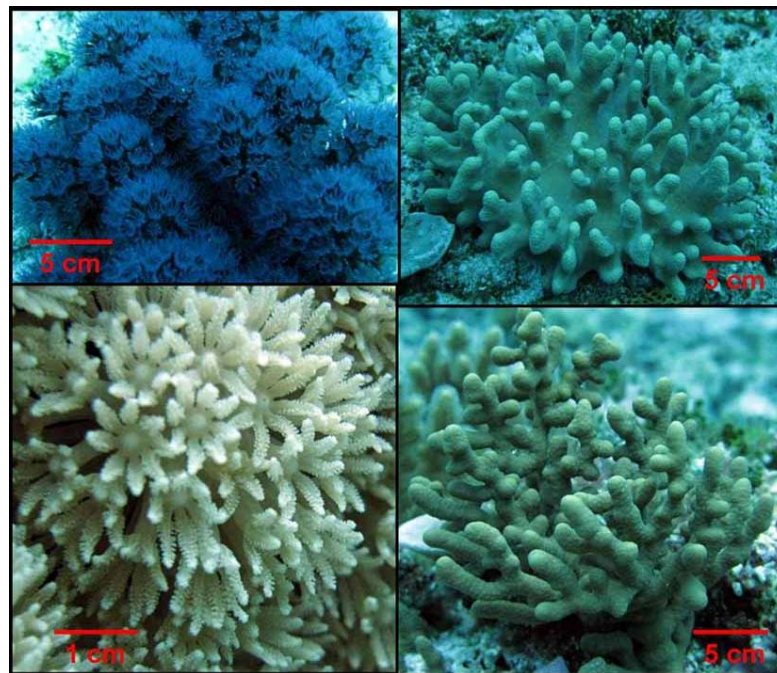
Figure 5. Soft corals at SE Madgelaine, clockwise from top left: *Efflatounaria*, *Lobophytum*, *Xenia*, *Isis hippuris* (Photos: DC)
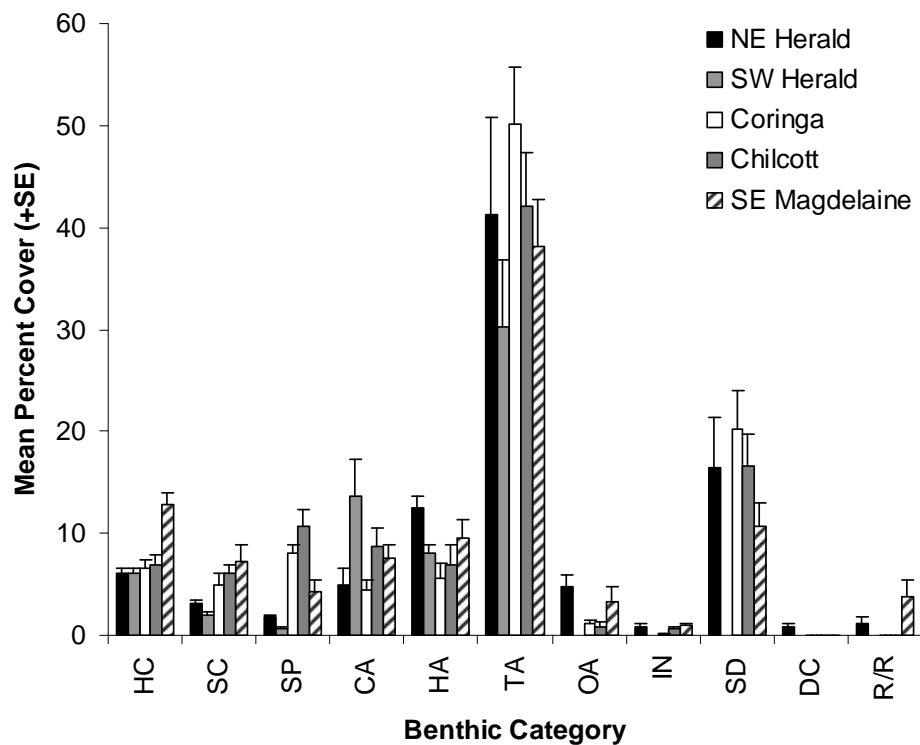
Figure 6. Mean percent cover (+SE) of coarse benthic categories from five locations within the CHNNR. HC = hard coral; SC = soft coral; SP = sponge; CA = Coralline, HA = *Halimeda*, TA = Turf, OA = Other Algae; IN = other invertebrates; SD = sand, DC = dead coral and R/R = bare rock/rubble. Data for the last five categories are presented from the October surveys only.
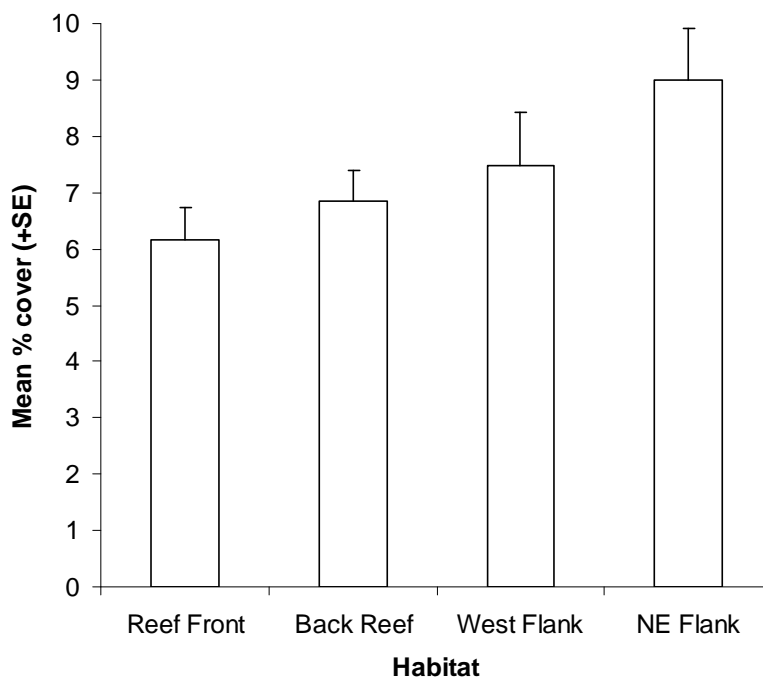
Figure 7. Mean percent cover of hard coral in different habitats within the CHNNR.
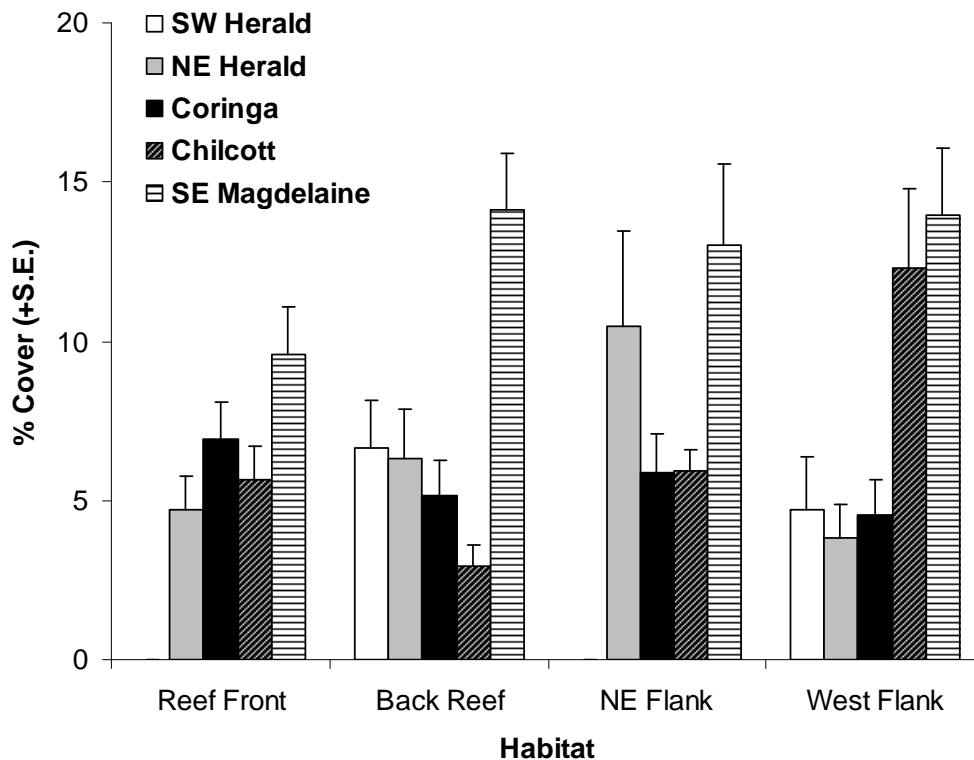
Figure 8. Mean % cover of hard coral across the habitats of each surveyed reef in the CHNNR. Reef Front and NE Flank habitats were not surveyed at SW Herald.

5.1.2   CORAL BIODIVERSITY

A total of 140 species of scleractinian coral were recorded from the four surveyed reefs. This raises the 2003 biodiversity estimate by 41 species - only 99 species were previously known from the Reserve (Oxley et al. 2003). The highest local biodiversity was 77 species recorded from Madgelaine, followed by 74 species at Coringa, 58 species at NE Herald, and 52 species at Chilcott (Figure 9). The coral assemblage within the Reserve spans 31 Genera (Table 3) and 11 Families of scleractinian coral (Figure 10). Notable absentees from the community were members of the genus *Pachyseris, Alveopora, Pectinia* and *Anacropora*. *Pachyseris* is common in all habitats on the GBR and can dominate some sites, particularly lower reef slopes. *Alveopora*, *Pectinia* and *Anacropora* are also usually present on the GBR, but may be absent from the CHNNR because of the lack of appropriate habitats (protected turbid water, Veron 2000). *Porites lichen* and *Coscinarea exesa* were dominant on back reefs, resembling Lihou Reef back reef environments (Oxley et al. 2003). The predominance of these species in Back Reef habitats in Coral Sea Reserves is unusual, and should be taken into account during future monitoring surveys.

Figure 9. Number of scleractinian coral species at each surveyed reef on the CHNNR.

Table 3. Hard coral genera present in the Reserve (species number in brackets).

Acanthastrea (4)	*Echinophyllia* (1)
Acropora (31)	*Halomitra* (1)
Astreopora (4)	*Herpolitha* (1)
Barabattoia (1)	*Hydnophora* (2)
Caulastrea (1)	*Isopora* (1)
Coeloseris (1)	*Lobophyllia* (3)
Coscinarea (2)	*Montastrea* (4)
Cyphastrea (3)	*Montipora* (8)
Diploastrea (1)	*Ouphyllia* (2)
Echinopora (4)	*Pavona* (5)
Euphyllia (1)	*Platygyra* (4)
Favia (8)	*Plerogyra* (1)
Favites (5)	*Pocillopora* (6)
Fungia (2)	*Porites* (7)
Galaxea (1)	*Psammocora* (2)
Gardinoseris (1)	*Seriatopora* (1)
Goniastrea (6)	*Stylophora* (2)
Goniopora (2)	*Symphyllia* (2)
Leptoseris (1)	*Stylocoeniella* (2)
Leptastrea (2)	*Turbinaria* (2)

The presence of *Pocillopora linguata,* previously known only from the Central Pacific, and *Siderastrea savignyana*, usually recorded in the Indo-Pacific region but not in Papua New Guinea or Australia, suggest a range extension for these species. This indicates that there are biogeographic connections between the CHNNR coral community and Pacific Ocean coral assemblages, corroborating the idea that reefs in the Reserve may serve as stepping-stones in the dispersal of species between the GBR and the Pacific Ocean (Choat et al. 2007). A *Pocillopora* colony was observed with narrow branches resembling *Pocillopora indiana*, however this species is known only from the Indian Ocean and must be considered a dubious record. This species is included as cf. *P. indiana* in the species list (Appendix 4) and requires further confirmation during follow-up surveys. Another characteristic of oceanic Pacific coral communities was a large outcrop of *Isopora palifera* growing in the back reef habitat of SE Magdelaine.

5.1.3 CORAL COMMUNITY COMPOSITION

Coral taxonomic composition varied between reefs, with SW Herald supporting a higher proportion of Favids and non-scleractinian (mostly soft) corals than other locations, while *Porites* spp. dominated at Chilcott and *Acropora* spp. were predominant at SE Madgelaine. (Figure 10).
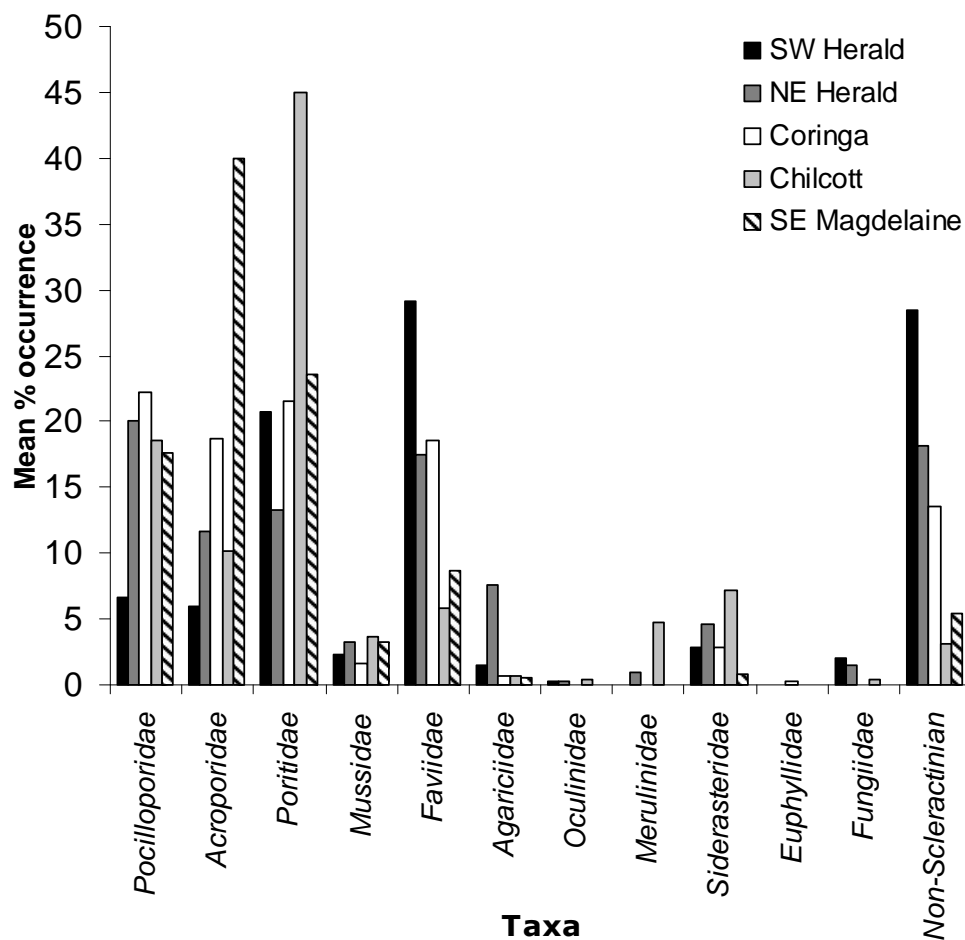
Figure 10. The taxonomic composition (Family level) of hard corals within the CHNNR.

In terms of coral cover and diversity, SE Madgelaine can be considered to be in the best condition of all CHNNR reefs surveyed, with *Acropora*, *Porites* and *Stylophora* representing the most common genera. *Acropora*, *Favia* and *Pavona* were the most common genera observed at NE Herald, and some colonies of the non-scleractinan coral *Tubipora musica* (organ pipe coral) were present. *Pocillopora*, *Acropora* and *Porites* were the most common genera at Chilcott. A unique feature of the Chilcott coral community was the presence of *Hydnophora excesa* and *Echinopora* plates, as these species were not recorded at any other location in the CHNNR. *Pocillopora*, *Porites* and *Favia* were the most common genera at Coringa. Unique species records at Coringa included *Echinophyllia aspera* and *Ouphyllia crispa* (Figure 11)*.* Another interesting feature of this reef was the prevalence of *Isopora* colonies growing only in shaded locations underneath sheltered patch reefs. These are normally found across all microhabitats; hence it is likely that other individuals growing in non-shaded habitats have died. Whole colonies of fossilised favid corals found on the high tide mark of the cays provide evidence of the long history of coral growth in the Reserve (Figure 12).

There was little dead coral evident throughout the surveyed sites, and the more exposed habitats were generally characterised by a lack of structured microhabitats. This may be indicative of historical disturbance predating the 1998 and 2002 bleaching events, which may have had a severe impact on the coral community. The coral community appears to be in a state of recovery, and is composed of a large proportion of juveniles.
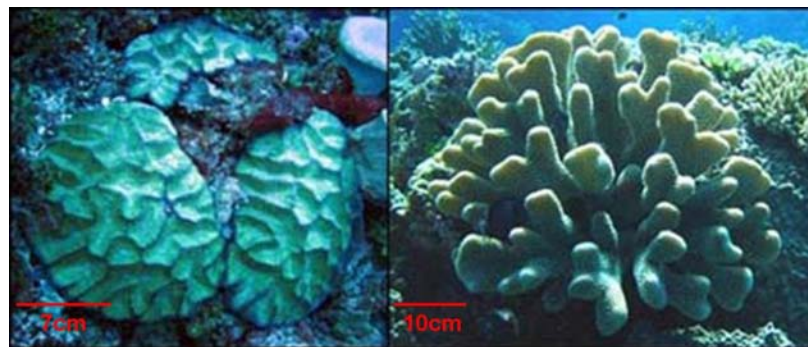
Figure 11. *Oulophyllia crispa* (left) and *Pocillopora eydouxi* (right) at SE Madgelaine. (Photos: DC)
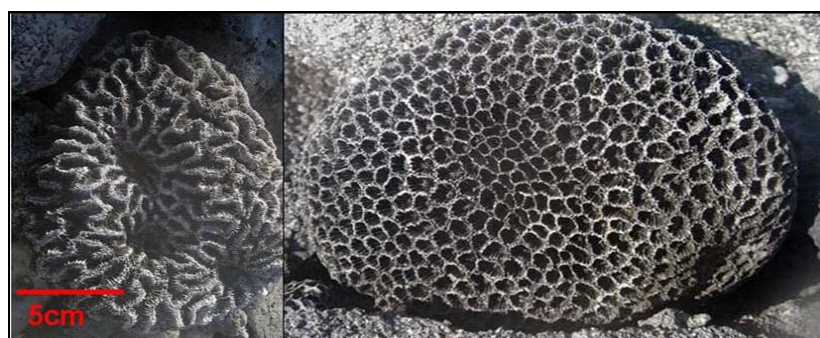
Figure 12. Lithified coral skeletons on the shoreline at Coringa Islet are testimony to the long history of coral growth within the Reserve (Photos: ZR)

5.1.4 CORAL SIZE STRUCTURE

Coral size frequencies in the CHNNR were strongly skewed toward the smaller size ranges (Figure 13; Chi-square=61.22, d.f.=28, p<0.001). The predominance of small colonies was especially evident at SW Herald, while most of the larger colonies occurred at SE Magdelaine. The frequency of small (<5 cm) colonies representing the most recent recruits was similar to that of several of the larger size classes. A predominance of colonies in the 5-10 cm size category suggests a possible high recruitment pulse for the previous cohort
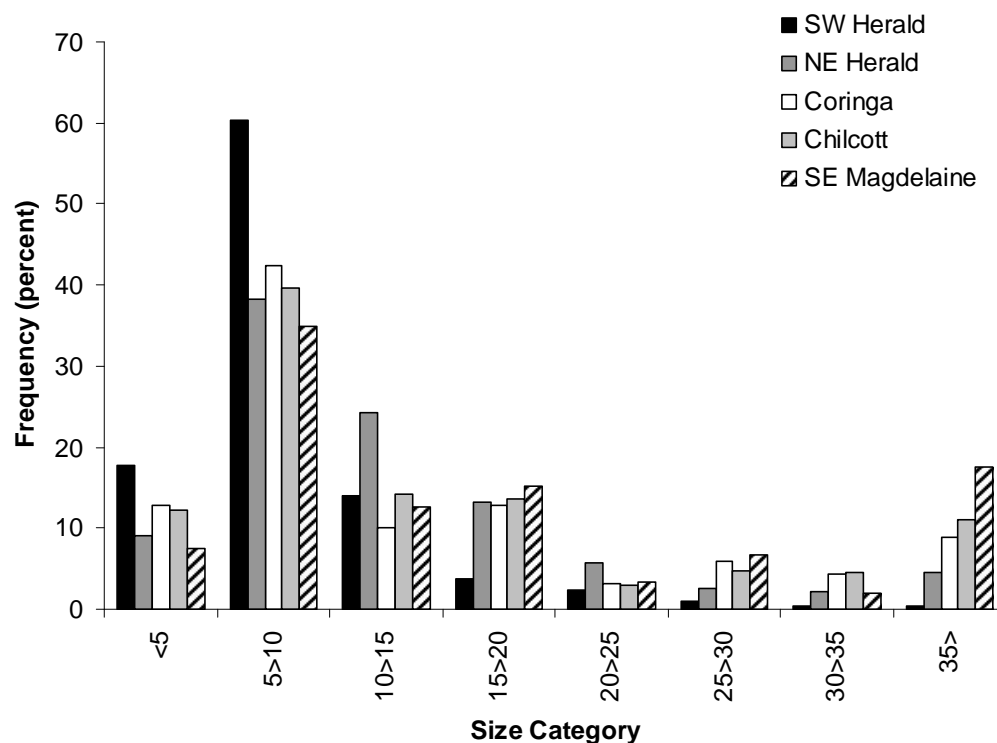
Figure 13. Size frequency distribution of hard coral colonies in the CHNNR.

5.1.5 TEMPORAL COMPARISON

The results of five previous surveys of the Herald Cay reefs spanning 23 years were available (Ayling and Ayling 1985, Byron et al. 2001, Oxley et al. 2003, Evans et al. 2007). The cover of hard coral reached a peak of approximately 20% shortly before the 1998 bleaching event (Wilkinson 1998, Byron et al. 2001), when a dramatic decline occurred not just in hard coral cover, but also in the cover of soft coral and sponges (Figure 14). Hard coral cover declined to approximately 3%, while soft corals and sponges all but disappeared. Recovery has been extremely slow, with present records of hard coral cover ranging between 5 and 6%.
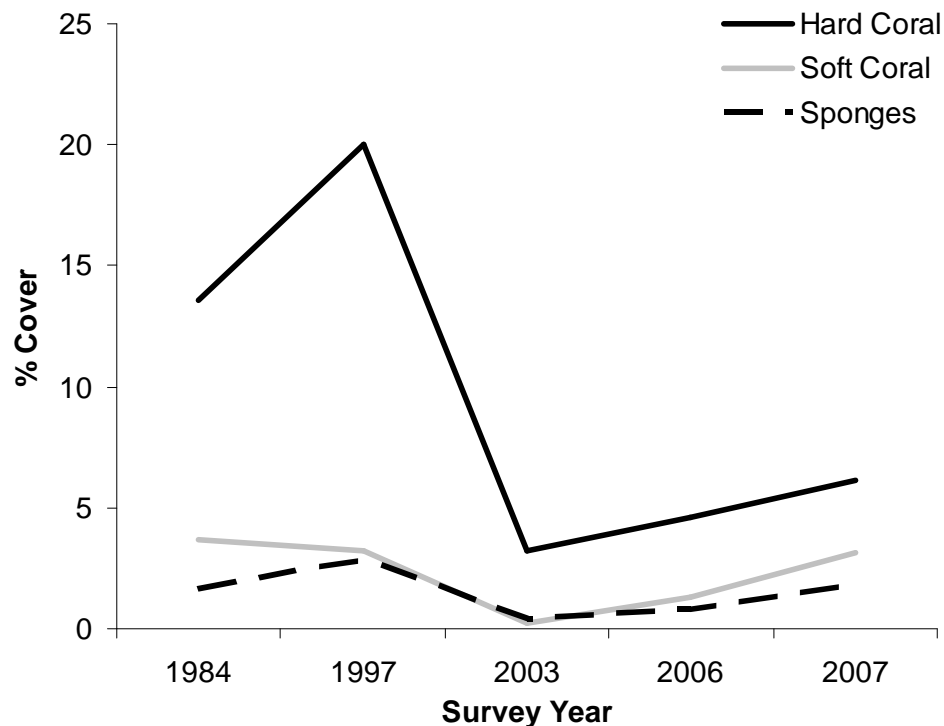
Figure 14. Temporal comparisons of hard coral, soft coral and sponge over 23 years at NE Herald. 1984: Ayling and Ayling (1985); 1997: Byron et al. (2001); 2003: Oxley et al. (2003); 2006: Evans et al (2007); 2007: this report. Note the x-axis is non-linear and the steepness of the lines does not represent the true rate of change. Note also that 1997 data is only from sheltered habitats of the Herald Cays.

5.1.6   REGIONAL COMPARISONS

In comparison to the Great Barrier Reef and Pacific Ocean, coral diversity is low within the Reserve. However, in comparison to other National Nature Reserves (e.g. Ashmore Reef, Lihou Reef, Elizabeth Reef) diversity is relatively high (Table 4). Low diversity is not atypical for isolated oceanic reefs.

Low coral cover is also a consistent feature of other isolated reefs. However, often these reefs are larger and support higher coral cover than the CHNNR reefs (e.g. Choat et al. 2006). West Australian, Tasman Sea and other Coral Sea oceanic reefs were similar in terms of their hard coral cover (Figure 15), while outer GBR reefs have had a minimum of 10% and an average of approximately 35% over the last 15 years (AIMS, pers.comm.).

Table 4. Species richness of scleractinian coral at different locations.

Location	Sp. Richness	Source
Milne Bay, PNG	442	(Fenner 2003)
New Caledonia	342	(Pichon 2006)
Northern Great Barrier Reef	324	(Veron 1993)
Marshall Islands	284	(Richards and Wallace submitted)
Rowley Shoals, WA	188	(Veron 1986)
Osprey Reef, Coral Sea	180	(Fenner 2007)
Ashmore Reef, WA	156	(Kospartov et al. 2006)
Coringa-Herald National Nature Reserve	**140**	**This Survey**
Elizabeth Reef, SE Australia	114	(Oxley et al. 2004a)
Cartier Reef, WA	103	(Kospartov et al. 2006)
Lihou Reef, Coral Sea	100	(Oxley et al. 2004b)
Cocos (Keeling) Islands, Indian Ocean	99	(Woodroffe and Berry 1994)
Christmas Island, Indian Ocean	92	(Berry and Wells 2000)
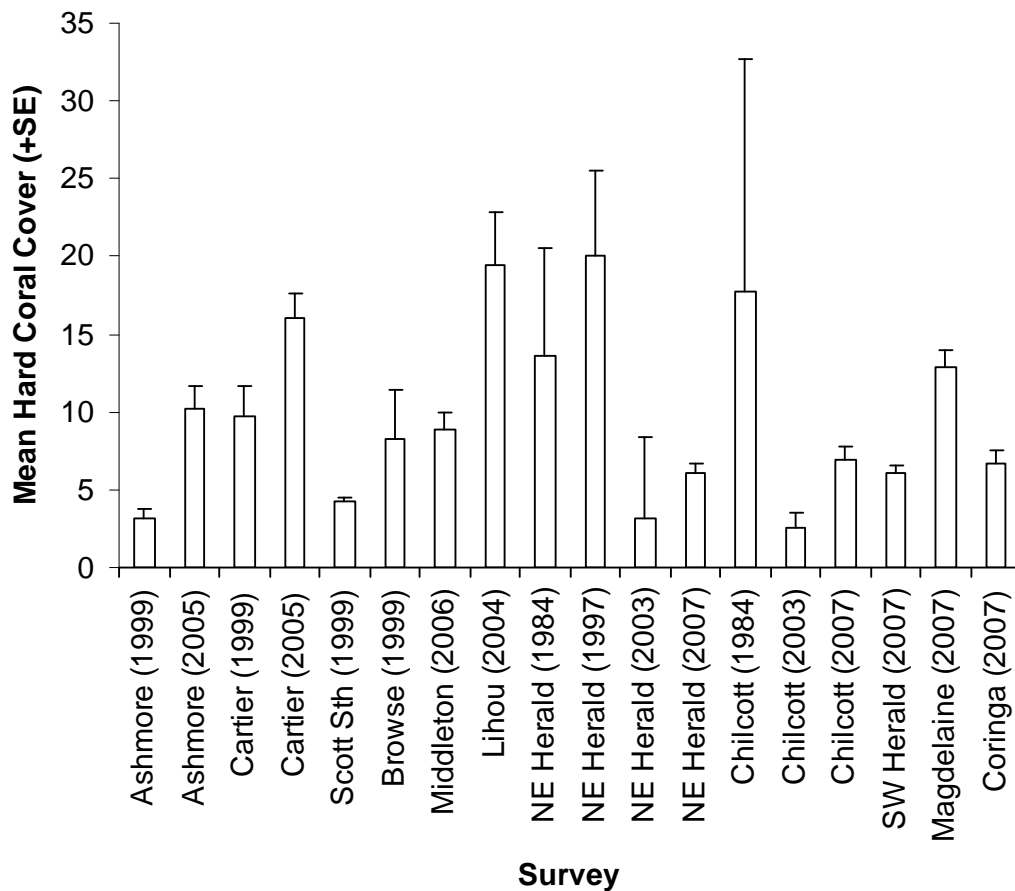
Figure 15. Mean hard coral cover recorded since 1984 across West Australian (Ashmore, Cartier, Scott and Browse Reefs), Tasman (Middleton Reef) and Coral Sea (Lihou, NE Herald, Chilcott, SW Herald, SE Magdelaine and Coringa) regions.

5.1.7 CORAL HEALTH

Crown-of-Thorns (COT) starfish were a primary target transects and long swims, a reflection of the potential impact of this species on the sparse coral cover of the Herald Cays. No COTs were recorded from NE Herald, Chilcott or Coringa. They were observed only at SW Herald, where nine individuals were found, and on SE Magdelaine, where two coral colonies carried COT feeding scars and two COTs were recorded. The low numbers recorded by the two survey methods suggests that the smaller-scale transects were revealing individuals that may have been cryptic to the observers engaged in long swims. There was no evidence of larger aggregations or feeding scars over broad areas, indicating that COTs are not currently a significant source of coral mortality in the CHNNR.

There were no instances of coral disease apart from pigmentation response on a small number of *Astreopora* and *Porites* colonies. Pigmentation response may be a chemical reaction to stimulus (e.g. algae rubbing on the colony surface) and may not indicate any pathogens or cause for concern. Fish feeding scars were apparent on numerous large massive *Porites* colonies on the reef crest, and on small corymbose *Acropora* colonies on the reef fronts. The only records of dead coral were obtained from NE Herald and some overturned plates were found at SE Magdelaine. At other locations within the Reserve there was no evidence of recent coral mortality events, unless all dead coral had already been removed by storm surges. At the time of these surveys no incidences of coral bleaching were recorded.

5.1.8 CONNECTIVITY

Reefs with disturbance-induced low coral cover may have increased chances of recovery if they are within dispersal distance of other reefs, and therefore have the potential of being carried there by ocean currents (Harrison et al. 1984, Richmond 1987, Baird 1998). The Australian Connectivity Interface (Condie et al. 2005) is a web-based tool for environmental scientists and managers to investigate the large-scale patterns of ocean connectivity in Australian waters. The model estimates the probability that any two regions are connected by modelling ocean circulation over a specified dispersion period. Coral larvae have poor swimming abilities (Fadlallah 1983, Chia et al. 1984) and fit the model's assumption of passive dispersal. The probability of a particle reaching a chosen sink location (e.g. the CHNNR) from other locations is plotted in a raster-based map. Twenty days after spawning, 20-50% of spawned coral larvae are expected to still be alive and competent to settle (Baird 2001), so a length of 20 days was used to model connectivity for the CHNNR in October, the major spawning period in Australia. The model output (Figure 16) suggests that while good connectivity exists for parts of the Coral Sea (e.g. Marion Reef), the Reserves have a low probability of receiving larvae from reefs in surrounding areas at this scale. The reefs within the CHNNR may be connected by smaller-scale currents and eddies, and local hydrodynamics may prove more important in the recovery of these reefs from disturbance than larger-scale patterns (Arthur et al. 2006).
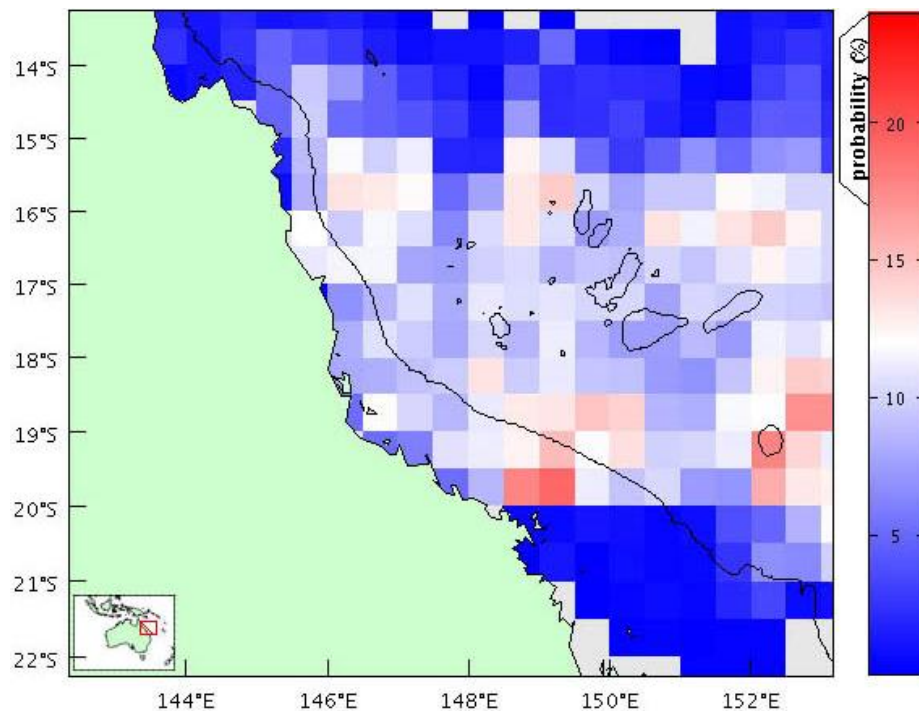
Figure 16. Models of the dispersal connectivity probability of the CHNNR (from 149° to 150°30'E, from 17°11' to 16°23'S) and surrounding locations, using the Australian Connectivity Interface (Condie et al. 2005). The connectivity probabilities imply the probability that larvae arrive at the CHNNR in a pelagic larval duration time of 20 days. Marion Reef is the southernmost Coral Sea reef shown on this map.

5.2 *Invertebrates*

5.2.1 HOLOTHURIANS

Across the CHNNR, a total of 65 snorkels and long SCUBA swims were completed by both surveys to estimate current densities of holothurians, amounting to 15.35 hectares across a range of habitats and depths. A total of 6,703 holothurians of 10 species were recorded across all surveyed sites, of which *Holothuria atra* (lollyfish)*, H. leucospilota* (chocolatefish)and *Stichopus chloronotus* (greenfish) together made up 98.7% (77.6%, 11.6% and 9.5% respectively). The other seven species were recorded in low numbers in most habitats.

The highest holothurian densities were found on the back reefs of Chilcott and SE Magdelaine. The Herald Cays and Coringa supported significantly smaller populations (Figure 17, Appendix 5). NE Herald, SW Herald and SE Magdelaine showed a clear trend of higher holothurian densities on the back reef, in both deep and shallow habitats, while Chilcott had high densities in all habitats. The high-density aggregation of *H. atra* recorded at Chilcott in 2003 was also found during this survey.

H. atra was the dominant species in the CHNNR, followed by *H. leucospilota* (most individuals were recorded among the high-density *H. atra* aggregation on the Chilcott back reef in 2007) and *S. chloronotus* (Figure 18). *H. nobilis* (black teatfish), the species of highest commercial value recorded, was represented by 93 individuals across the CHNNR in 2007, and 25 in 2003, indicating a possible Reserve-wide increase. The species composition of holothurians varied significantly between reefs in 2007 (Appendix 5).
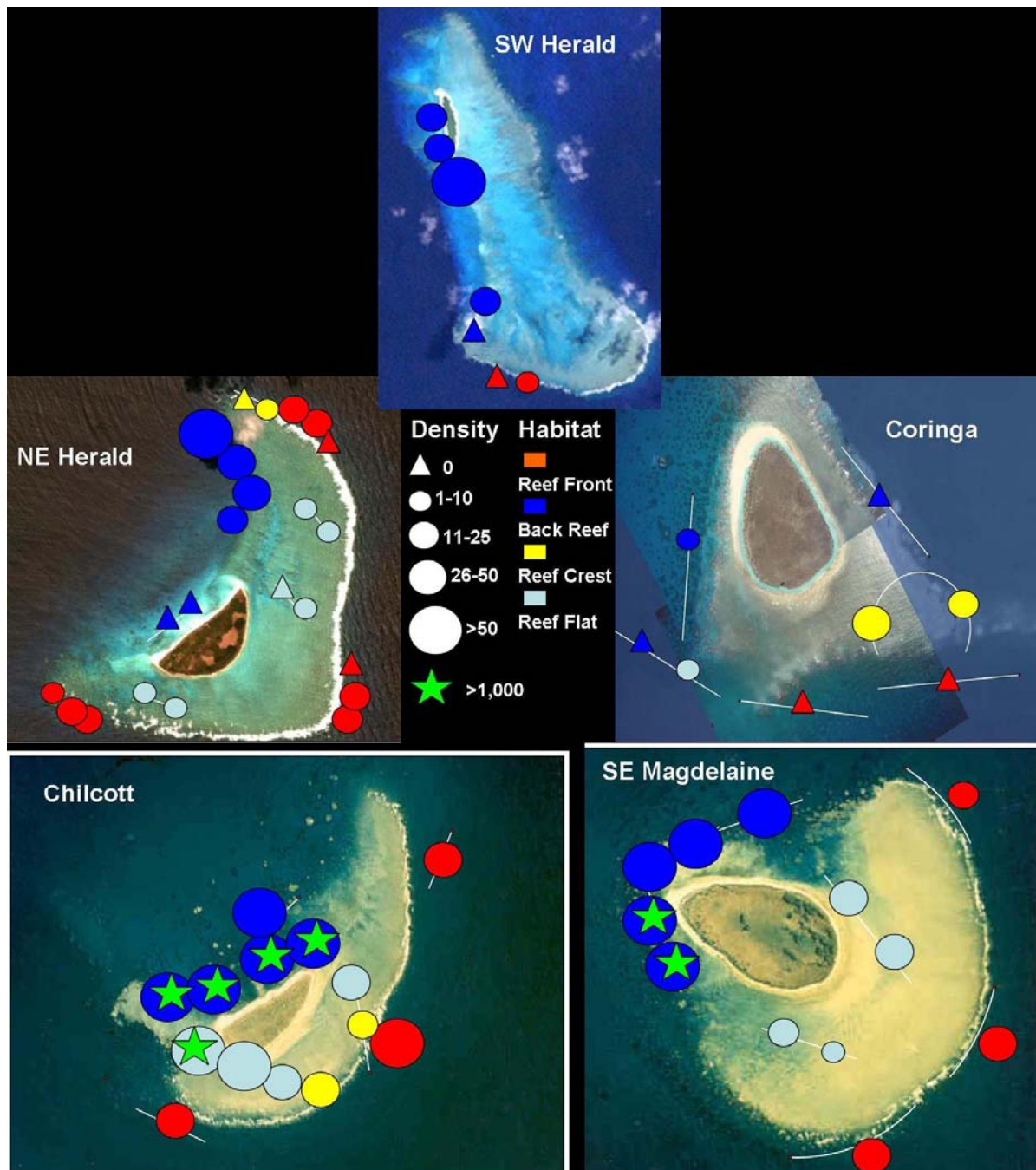
Figure 17. Holothurian density (individuals per hectare) at the five surveyed cays. Stars represent high-density aggregations.
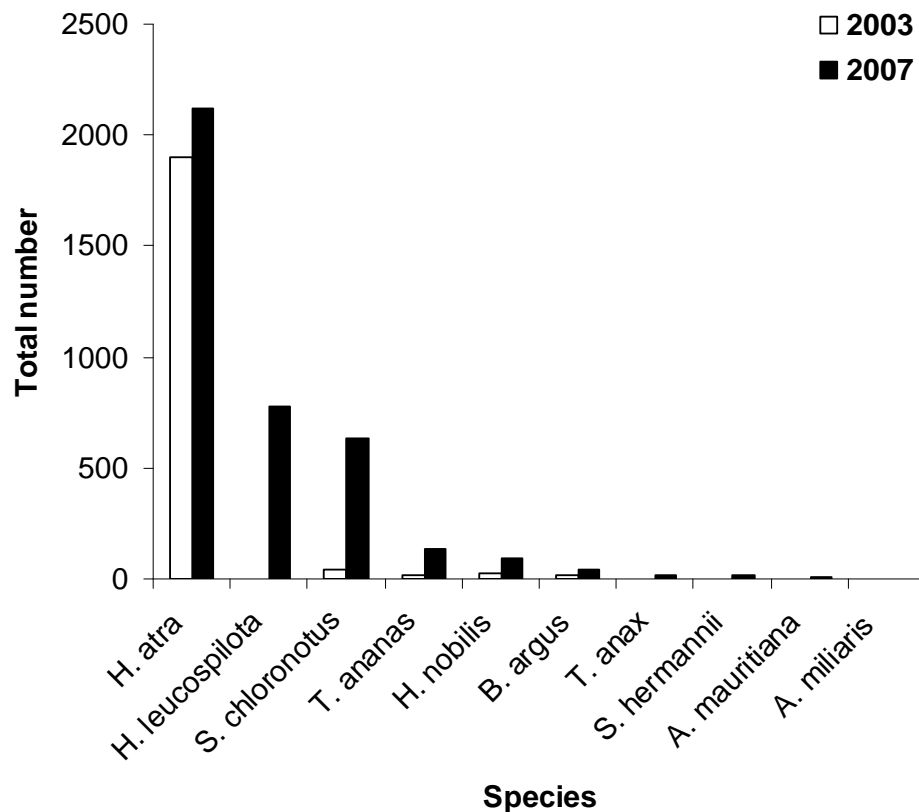
Figure 18. Total number of individuals of each species recorded in the CHNNR in 2003 and 2007. This figure excludes the high-density aggregation of *H. atra* on the Chilcott back reef.

There was no significant difference in reef-wide densities of all species combined between 2003 and 2007 (Figure 19). When comparing holothurian densities in reef flat habitats, most commercially valuable species occurred in higher densities, and across a larger number of reefs, in 2007 than in 2003 (Figure 20). *H. nobilis* was found in similar densities on the Chilcott reef flat, where it was recorded in 2003. This species was also found on the reef flats of the other three reefs in 2007, but not in 2003. *Bohadschia argus* (leopardfish) was only found at NE Herald Cay during both surveys, with no significant changes in density.

In back reef habitats, there was a general trend of holothurian density decline from 2003 to 2007. The most striking differences between the two surveys were the decline of *H. nobilis* on the Coringa back reef, The increase in *S. chloronotus* at SE Magdelaine, and the absence of *B. argus* and *Actinopyga mauritiana* (surf redfish) at Chilcott and Coringa in 2007 (Figure 21).
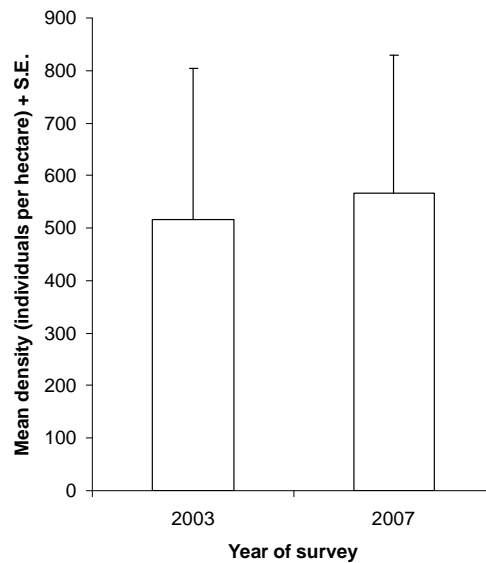
Figure 19. Total holothurian density in 2003 and 2007.
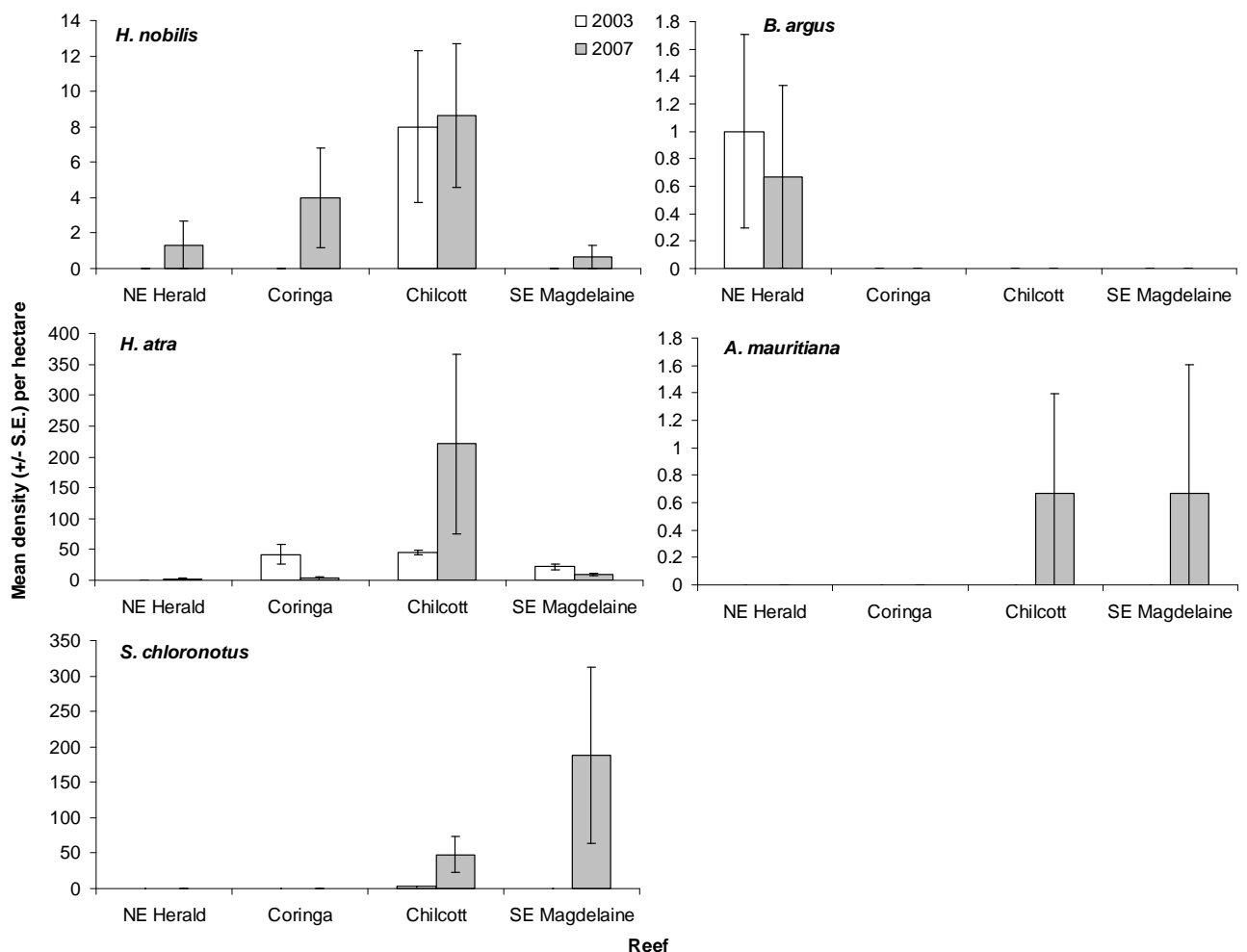
Figure 20. Mean density per hectare of commercially valuable species of holothurians in reef flat habitats of CHNNR reefs in 2003 and 2007. SW Herald is not included, as no reef flat habitats were surveyed there. Note the different scales on the y-axes.
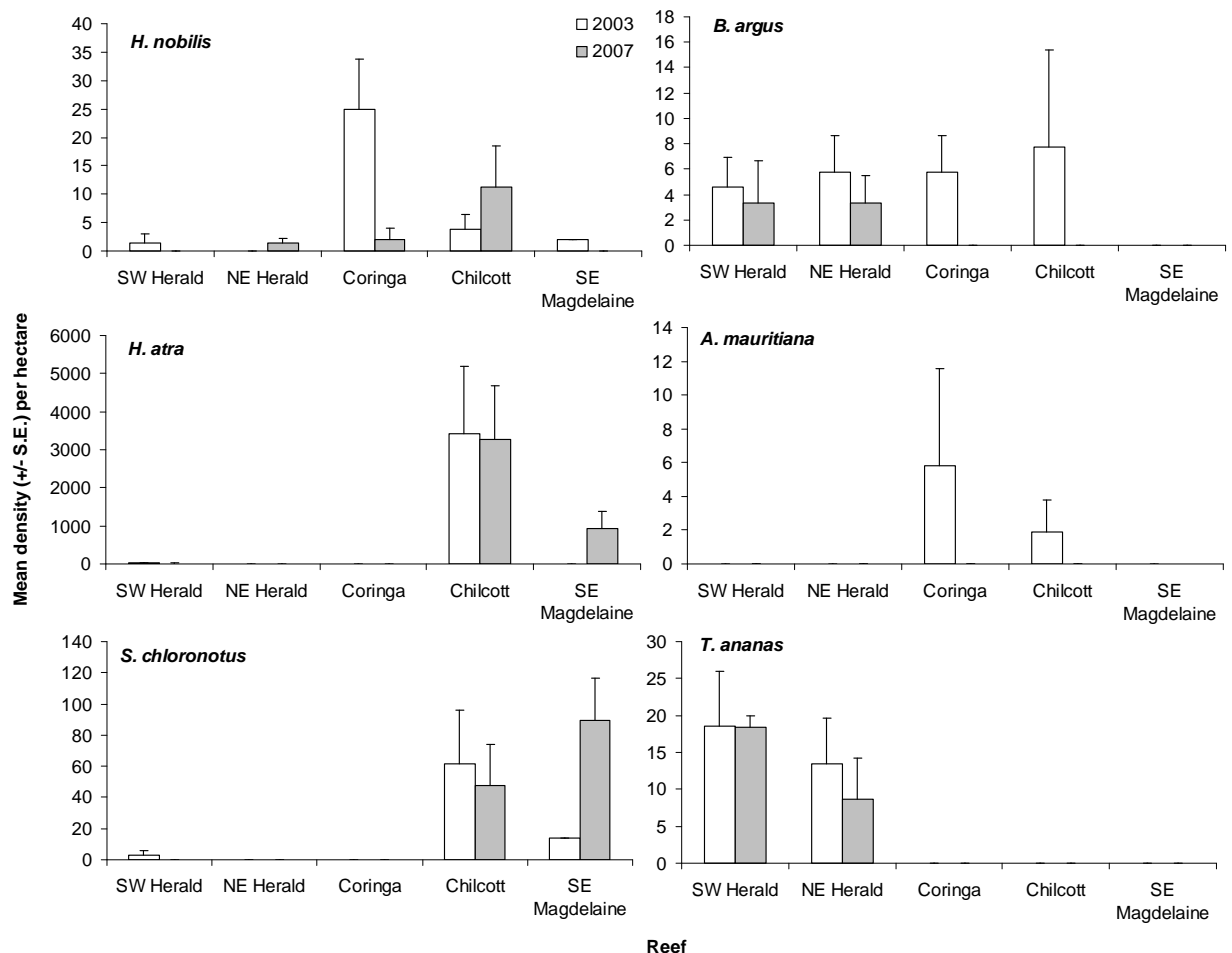
Figure 21. Mean density per hectare of commercially valuable species of holothurians in back reef habitats of CHNNR reefs in 2003 and 2007. SW Herald estimates do not include shallow reef flat habitats. Note the different scales on the y-axes.

Regional comparisons for the most common species, *H. atra*, reveal that population densities in the Reserve are among the highest recorded over the last two decades in the Timor Sea and West Australian Reserves (Ashmore, Mermaid, Scott and Seringapatam and Hibernia Reefs, Cartier and Browse Islands), on the GBR (outer shelf and midshelf reefs) and the Coral Sea (Elizabeth and Lihou Reefs, Coringa-Herald Reserve). The only comparable densities were recorded on Elizabeth Reef in 2004 and on GBR outer shelf reefs in 2003 (Figure 22).

Densities of the commercially valuable *H. nobilis*, on the other hand, appear universally low since surveys began in 1985. High densities (85.6 individuals per hectare) have been recorded only on Elizabeth Reef in 2004. CHNNR population densities of approximately 3.8 individuals per hectare, reported from both 2003 and 2007, are higher than densities recorded at Ashmore Reef over two decades of surveys, but two to three times lower than GBR and Mermaid Reef densities (Figure 22).
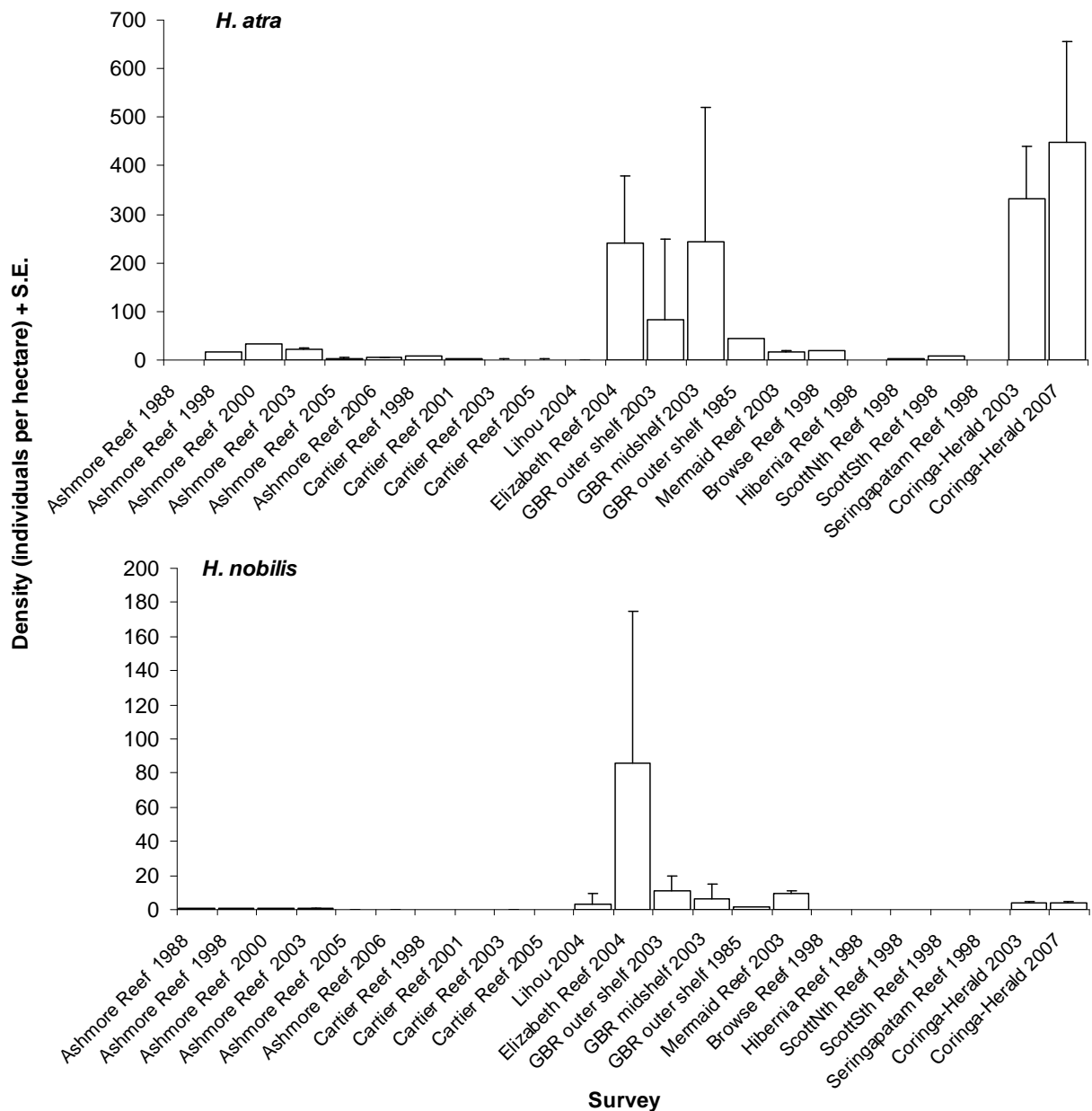
Figure 22. Regional comparison between surveys over two decades for densities of *H. atra* (top) and *H. nobilis* (bottom). These figures exclude May 2007 estimates. Note the different scales on the y-axes.

In the most recent reviews on the commercial value of holothurians, the commercially important species included all the species found in this survey (Toral-Granda 2006, 2007). There are regional and temporal variations in the value of sea cucumbers, which often determine which species are most likely to be harvested and therefore in need of management or protection. The value of several species in the CHNNR (the prickly redfish *Thelenota ananas*, black teatfish *H. nobilis*, greenfish *Stichopus chloronotus* and curryfish *Stichopus hermanii*) have varied from high to medium commercial value over time (Kospartov et al. 2006, Toral-Granda 2006). *H. nobilis* and *T. ananas* are of high conservation concern globally, while *Actinopyga miliaris*, *A. mauritiana*, *S. chloronotus* and *S. hermanii* are overexploited over parts of their distribution range (Toral-Granda 2006).

5.2.2 *TRIDACNID CLAMS*

The densities of tridacnid clams were recorded along the same transects used to estimate holothurian densities during the October survey (Section 5.2.1.); these density estimates do not include May 2007 data. An overall density of 55.6 (+/- 10.26) individuals per hectare was found across all surveyed sites of the CHNNR. Clams were found in all habitats and the community was dominated by the horseshoe clam *Hippopus hippopus* in shallow reef flat and back reef habitats, and by *Tridacna maxima / squamosa* in more exposed and deeper habitats.

Unlike holothurian densities, the highest clam densities were found at NE Herald and SE Magdelaine, and the difference between these and the lower-density populations at Coringa and Chilcott was smaller (and statistically non-significant, Appendix 5, Figure 23). Back Reef, Reef Crest and Reef Flat habitats tended to support larger clam populations than deeper areas of the Reef Fronts. As with holothurians, the highest overall densities were found in Back Reef habitats. The combined populations of *T. maxima* and *T. squamosa* dominated the clam community overall with over 450 individuals, followed by over 150 individuals of *H. hippopus*. Very low numbers of the giant clam *T. gigas* and the smaller *T. derasa* were found (Figure 24).

There was considerable variability in the clam communities between different habitats on each reef. *T. maxima / squamosa* was present in similar densities across all habitats on most reefs, with the highest density on the Back Reef of NE Herald. *T. gigas* and *T. derasa* were both absent from Coringa, and were otherwise found consistently only on the Back Reef (and the Reef Flat in the case of *T. derasa*). *H. hippopus*, the second most abundant species, was recorded in high densities only on the Back Reef and Reef Flat of SE Magdelaine (see Appendix 5, Figure 25).
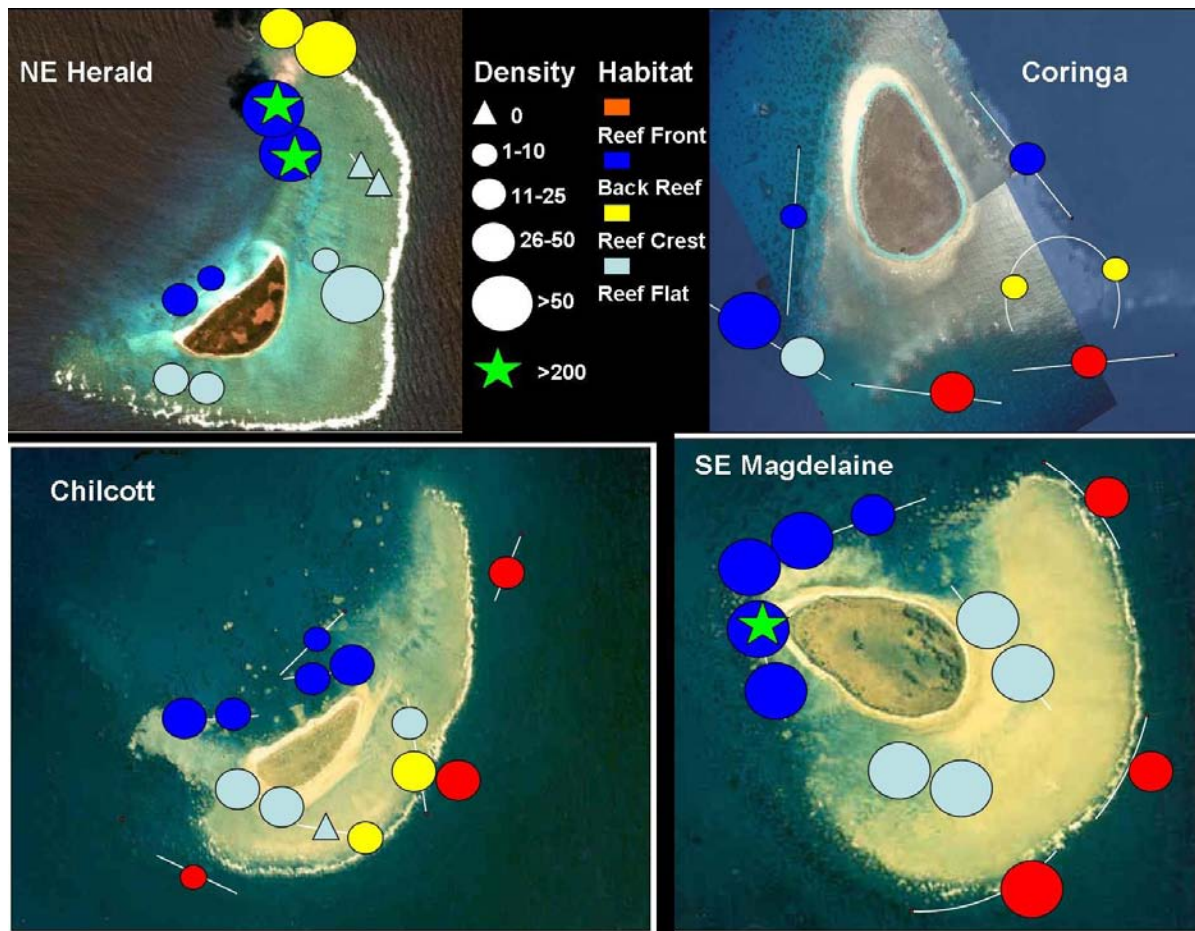
Figure 23. Densities (individuals per hectare) of tridacnid clams at the four CHNNR cays. The star indicates areas with the highest densities of clams (> 200 individuals per hectare).
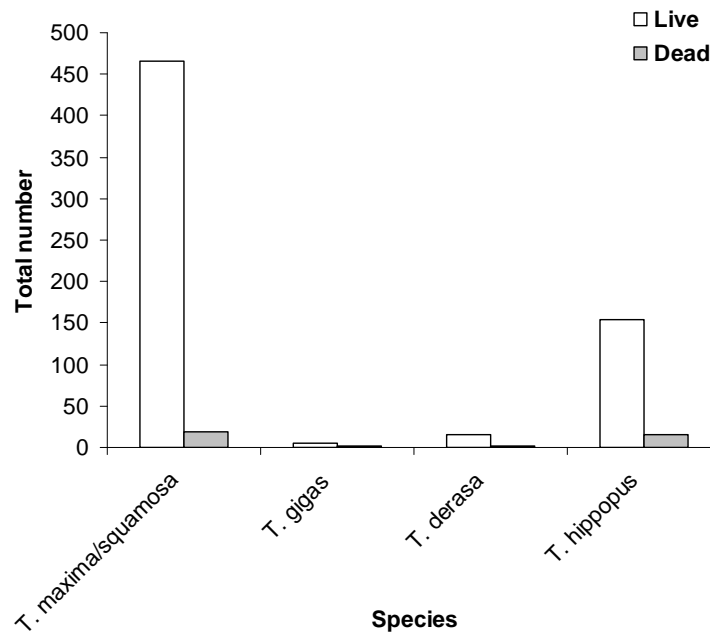
Figure 24. Total number of living and dead individuals of the four species of tridacnid clams in the CHNNR.
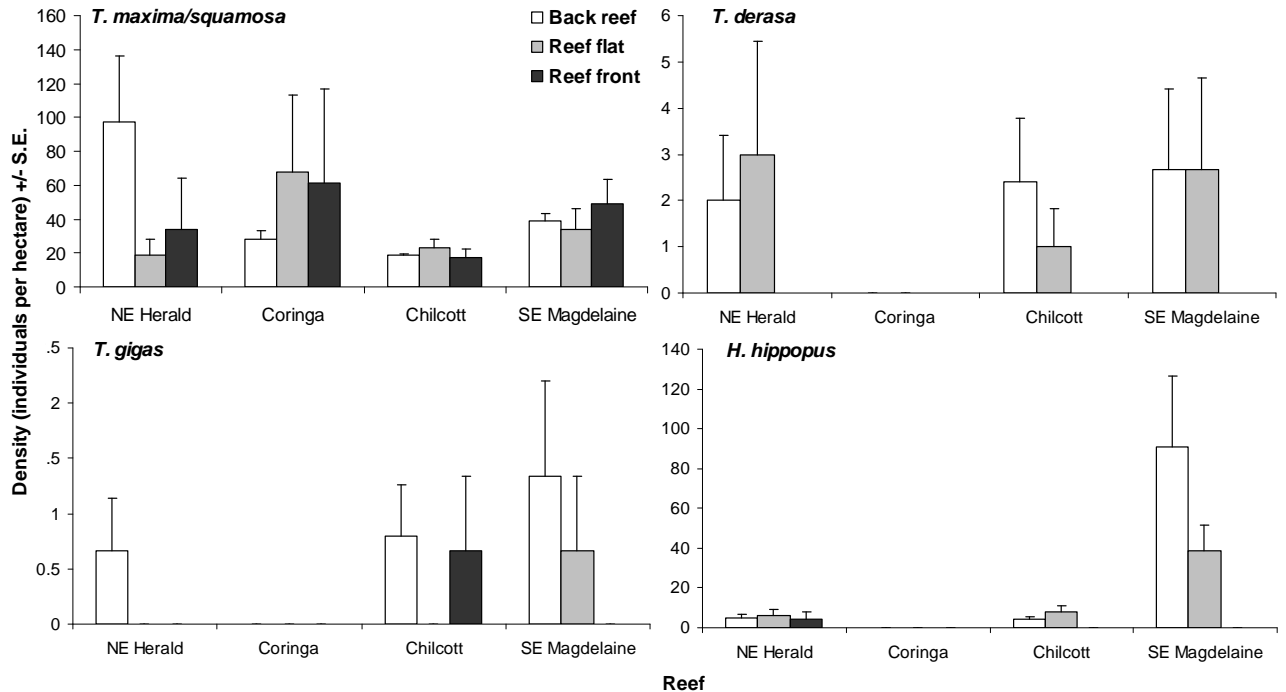
Figure 25. Densities of the four species of tridacnid clams across habitats and reefs of the CHNNR. Note the different scales on the y-axes.

Data for regional comparisons are available for *T. maxima*, *T. gigas* and *H. hippopus*. The clam densities found in the CHNNR appear to be comparable to those of Western Australian reefs and islands for *T. maxima / squamosa* and slightly lower for *T. gigas* and *H. hippopus*, although the decline in clam densities at Ashmore Reef in recent years brings about a reversal of this trend. Compared to Rose Atoll (near Samoa) and the Arnarvon Islands in the Solomons, densities of *T. gigas* and *H. hippopus* in the CHNNR are higher, but densities of *T. maxima / squamosa* are similar or much lower (Figure 26). Clam populations on these Pacific reefs have been subject to overexploitation, presumably much more so than in the Coral Sea.
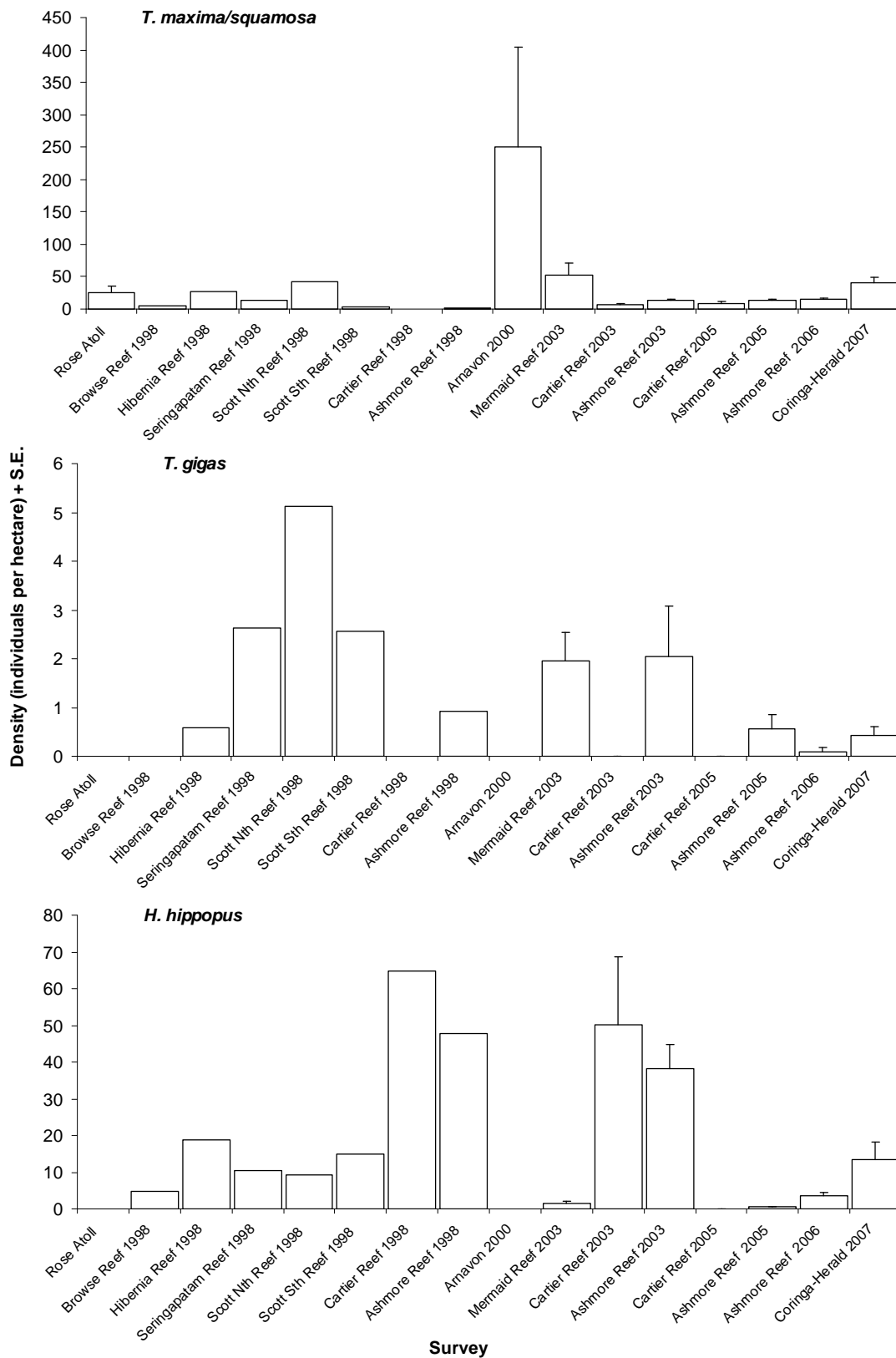
Figure 26. Densities of *T. maxima/squamosa*, *T. gigas* and *H. hippopus* across surveys. Note the different scales on the y-axes.

5.2.3 OTHER INVERTEBRATES

Invertebrates of commercial value (e.g. Trochus and ornamental shells) were also recorded during the present survey. Despite the extent of habitat potentially suitable for Trochus (Kospartov et al. 2006, Ceccarelli et al. 2007), only five individuals of varying sizes were found. Other gastropods that are valuable for the ornamental shell trade (spider conchs *Lambis* spp., baler shells *Cymbium* sp., cone snails *Conus* spp. and cowries *Cypraea* spp.) were present in higher abundances; 119 individual gastropods were recorded. Of particular note was the deep northeastern reef front of SE Magdelaine, where spider conchs were present at a density of 132 individuals per hectare. This family is generally found in shallow reef lagoons, and tends to occur in low densities (McClanahan 2002).

These shells are collected and exported whole for their decorative value, and rare or unusual shells are sought by shell collectors and conchologists. More recently, it has also been recognised that some gastropods (e.g. cone snails) are pharmacologically valuable, prompting scientists to call for their protection (Harvard Medical School 2003). The population status of many species is poorly known and the trade itself largely unregulated. As the value of these species to science is increasingly recognised, it may be important to include them in future surveys as a component of the monitoring of commercially valuable invertebrates.

Much of the sand in the back reef habitats of the CHNNR is made up of foraminiferans. The composition of the foraminiferan community is increasingly used as an indicator of water quality (Hallock et al. 2003). This index could be useful in the CHNNR, both in the context of nutrients, as potentially contributed through bird droppings / guano, and dissolved CO_2, as an indicator of the effects of climate change on ocean water chemistry.

5.3 Fish communities

5.3.1 SPECIES RICHNESS

Species richness estimates are presented only from the October data, although incidental sightings from both surveys were added to species lists from previous surveys (Table 5), bringing the total number of recorded fish species for the CHNNR up to 372. Belt transects and incidental records revealed 326 species of non-cryptic, diurnal reef fish, a similar number to that reported by Oxley et al. (2003). Counting only species surveyed along the 30 x 10m belt transects, there were an average of 55.2 (+/- 2.6) species per habitat, with no consistent patterns among different sides of each reef. The areas of highest species richness were the exposed West Flank and Reef Front sites of SE Magdelaine (Figure 27).

Table 5. List of species not previously recorded in the CHNNR found during the present surveys. Common names are from Allen et al. (2003), where available.

Family	Species	Common Name
Acanthuridae	*Acanthurus bariene*	Roundspot surgeonfish
	Acanthurus leucocheilus	Pale-lipped surgeonfish
	Ctenochaetus binotatus	Twospot bristletooth
	Ctenochaetus cyanocheilus	Bluelipped bristletooth
	Naso tonganus	Bulbnose unicornfish
	Paracanthurus hepatus	Palette surgeonfish
Balistidae	*Melichthys vidua*	Pinktail triggerfish
	Odonus niger	Redtooth triggerfish
Carangidae	*Caranx lugubris*	Black jack
Chaetodontidae	*Heniochus acuminatus*	Longfin bannerfish
Cirrhitidae	*Cirrhitichthys oxycephalus*	Pixy hawkfish
Ephippidae	*Platax teira*	Longfin spadefish
Labridae	*Bodianus axillaris*	Axilspot hogfish
	Iniistius celebicus	Celebes razorfish
	Halichoeres chloropterus	Pastel-green wrasse
	Pteragogus enneacanthus	Cockerel wrasse
Lutjanidae	*Paracaesio xanthura*	Yellowtail false fusilier
Pomacentridae	*Amphiprion perideraion*	Pink anemonefish
	Amphiprion chrysopterus	Orange-finned anemonefish
	Chrysiptera rollandi	Rolland's demoiselle
	Dascyllus aruanus	Humbug dascyllus
	Stegastes lividus	Bluntsnout Gregory
Scaridae	*Chlorurus bleekeri*	Bleeker's parrotfish
	Scarus globiceps	Violet-lined parrotfish
	Scarus spinus	Greensnout parrotfish
Serranidae	*Pseudanthias kashiwae*	Silver-streak goldie
	Pseudanthias pleurotaenia	Squarespot anthias
	Pseudanthias dispar	Redfin anthias
Siganidae	*Siganus lineatus*	Lined rabbitfish
	Siganus woodlandi	not available
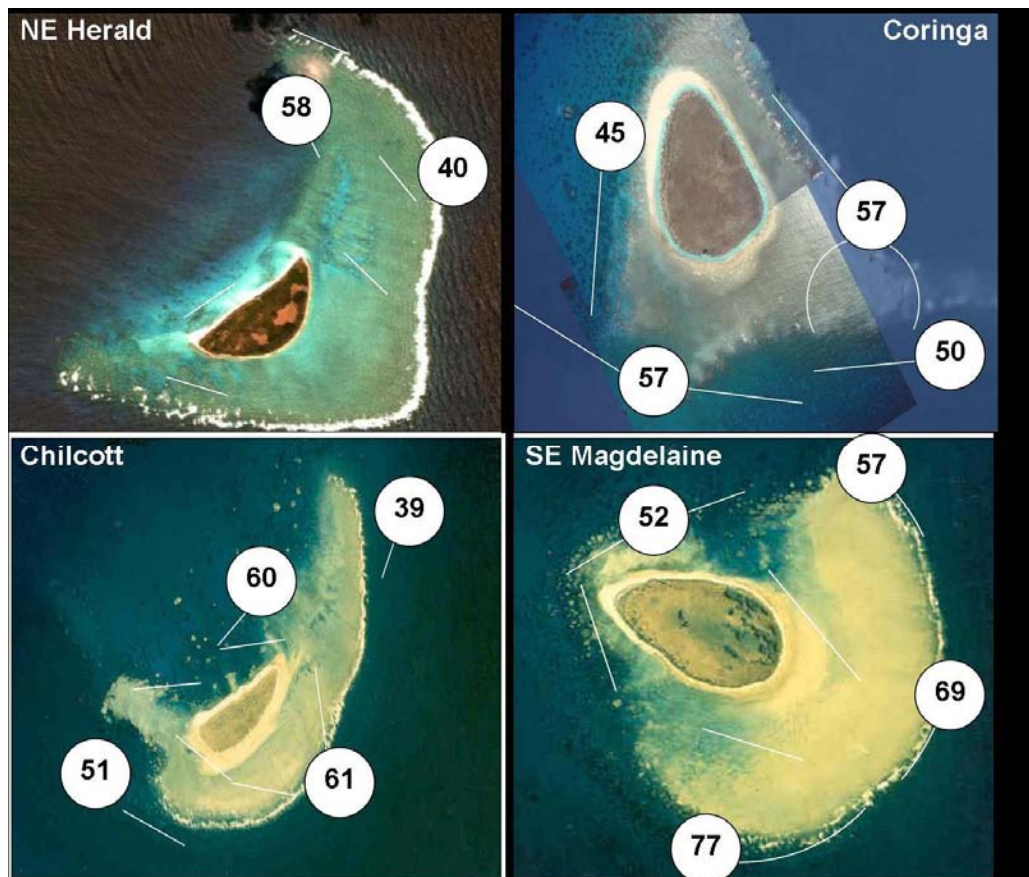
Figure 27. Numbers of reef fish species at each surveyed site, including both shallow and deep transects at each site.

Overall, reef fish species richness did not vary significantly across the four reefs, or between exposed and sheltered sides. However, the variation between sheltered and exposed sites was different from reef to reef (Appendix 6). The exposed sites (West Flank, NE Flank and Reef Front) supported higher species richness than sheltered back reefs at Coringa and SE Magdelaine, but this pattern was reversed at NE Herald and Chilcott (Figure 28). Exposure to wave action plays an important role in shaping the species composition of reef fish communities (Meija and Garzon-Ferreira 2000, Dominici-Arosemena and Wolff 2005, Pais et al. 2007). Fish diversity can also be affected by habitat area complexity, and the interaction between habitat complexity and exposure (Donaldson 2002). Habitat complexity is often more pronounced in exposed areas of coral reefs, as strong wave action created a wider variety of microhabitats (Friedlander et al. 2003, Dominici-Arosemena and Wolff 2005). However, the interesting feature of the CHNNR reefs is the lack of complexity in these habitats, which could partly explain why NE Herald and Chilcott reef front habitats (which are less structurally complex) are less diverse than expected, or observed at Coringa and SE Magdelaine (which have more complex reef fronts).

Fish density was significantly higher on the sheltered back reefs of all four reefs than in the exposed habitats (Figure 29). Interestingly, the highest fish densities were found on Coringa Islet in both habitats, despite this reef being the most depauperate in terms of coral and invertebrates.
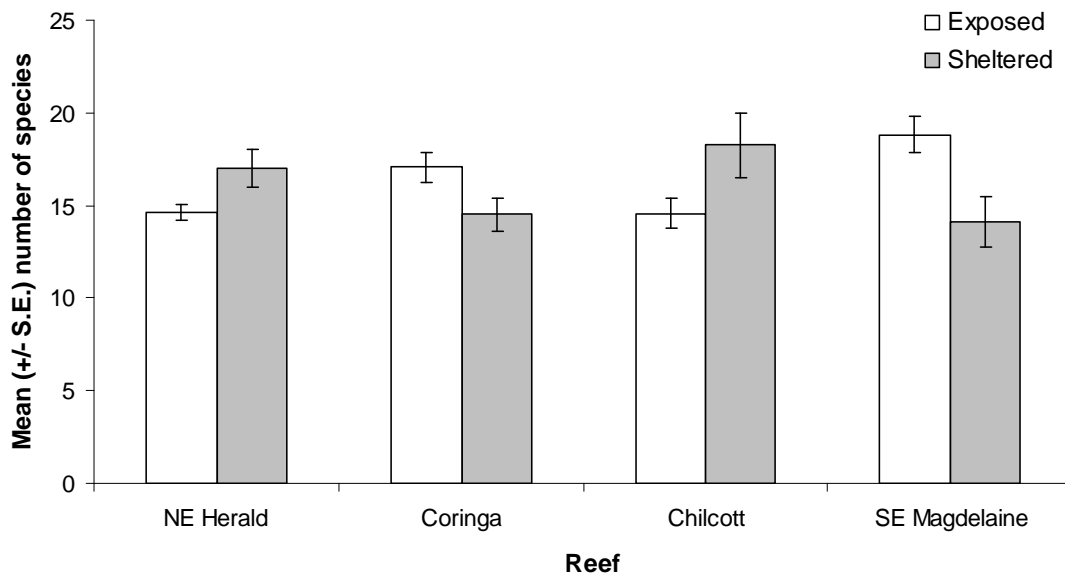
Figure 28. Mean species richness found on the exposed and sheltered sides of the CHNNR reefs. Only the Back Reef sites were classed as 'Sheltered', and all other sites (Reef Front, West Flank and North East) were classed as 'Exposed'.
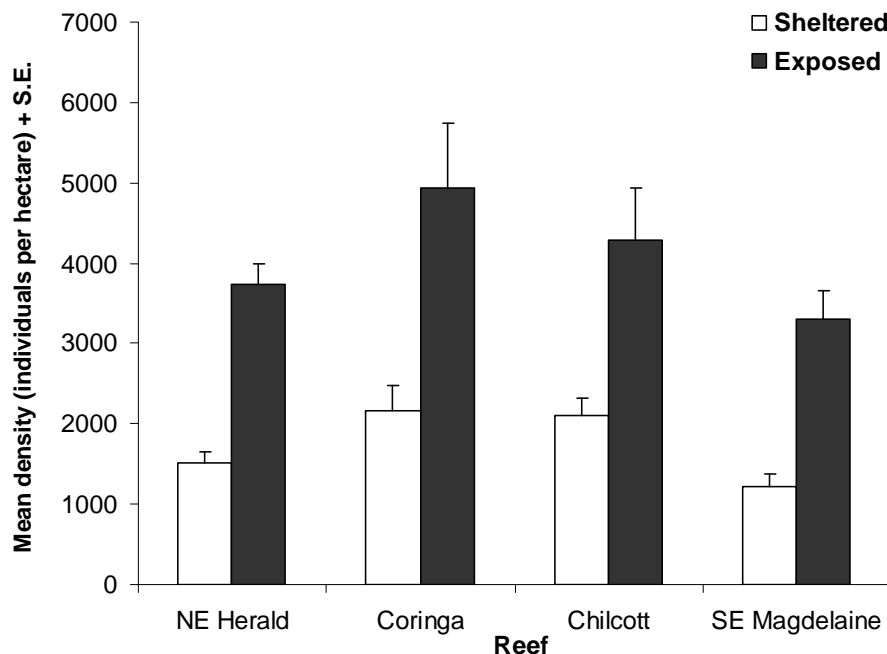
Figure 29. Mean fish density in exposed (Reef Front, West Flank and NE Flank) and sheltered (Back Reef) habitats of the four cays.

By far the most abundant was the damselfish family, dominating significantly on all four reefs and in most habitats (except the Back Reef). It was followed by the wrasse and surgeonfish family, and there was significant variation in the abundance of different families across reef and habitats (Appendix 6). Damselfish were primarily dominant on Coringa and Chilcott, and in Reef Front habitats (Figure 30). Wrasses were most abundant at NE Herald, but both wrasses and surgeonfish displayed a relatively even distribution across reefs and habitats. Back reefs were characterised by the lowest abundance of damselfish, which resulted in a relatively even abundance structure between the six families.

Exposure, habitat, depth and reef were all factors in determining the species composition of the CHNNR reef fish community (Appendix 6). Each reef supported a slightly different assemblage, which was further differentiated between distinct species groups in deep, shallow, exposed and sheltered habitats of each reef. The most distinct differences in species composition occurred between exposed and sheltered habitats. Exposed habitats were characterised by larger abundances of small wrasses and planktivorous damselfishes, while sheltered sites hosted more parrotfish and surgeonfish, and a different host of planktivorous and omnivorous damselfish species (Figure 31). This pattern is corroborated by repeating the CDA on fish families that combine all species within each family. Reef front habitats support primarily wrasses and damselfish, while the larger roving herbivores (see also Figure 35) are concentrated in back reef habitats (Figure 32).
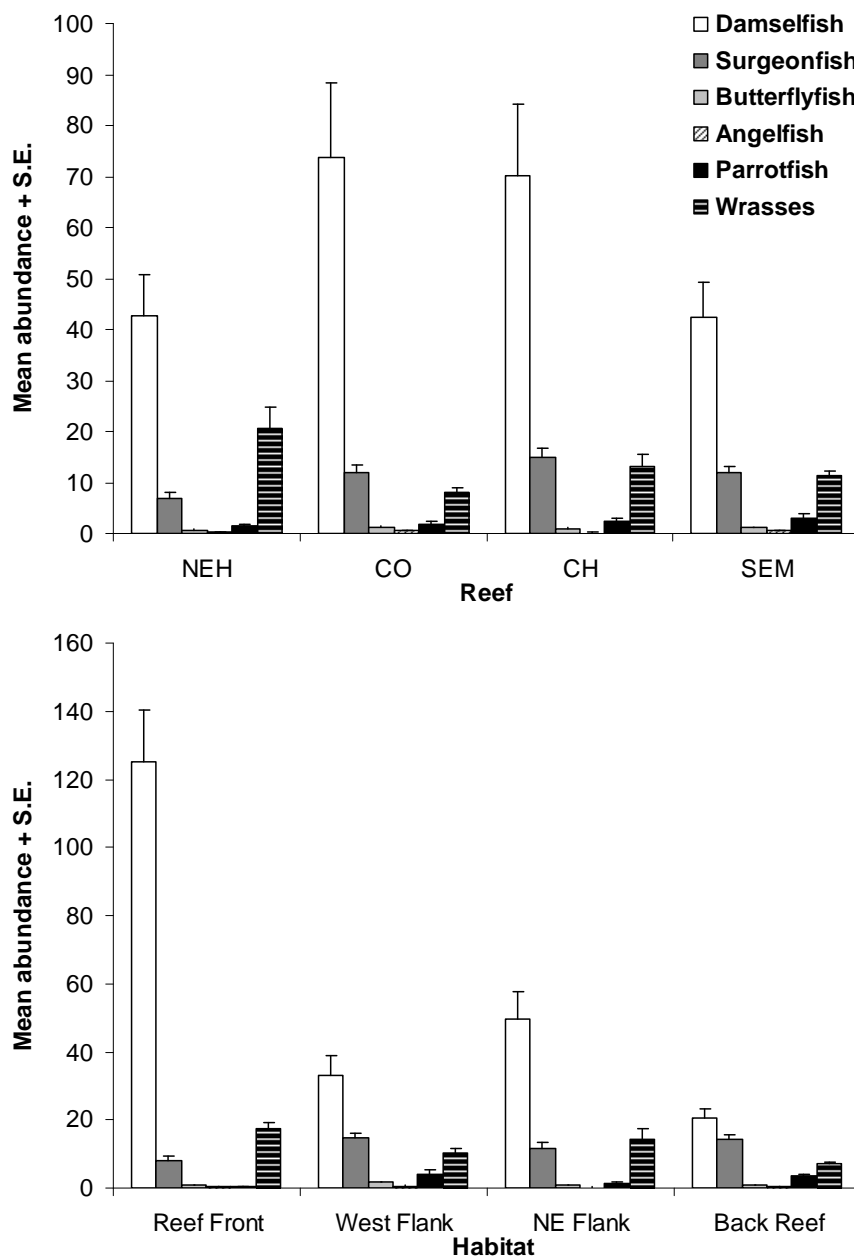
Figure 30. Mean abundance of the six major fish families on each reef (top) and in each habitat (bottom). NEH = NE Herald; CO = Coringa; CH = Chilcott; SEM = SE Magdelaine. Note that only shallow habitats were sampled at NE Herald cay.
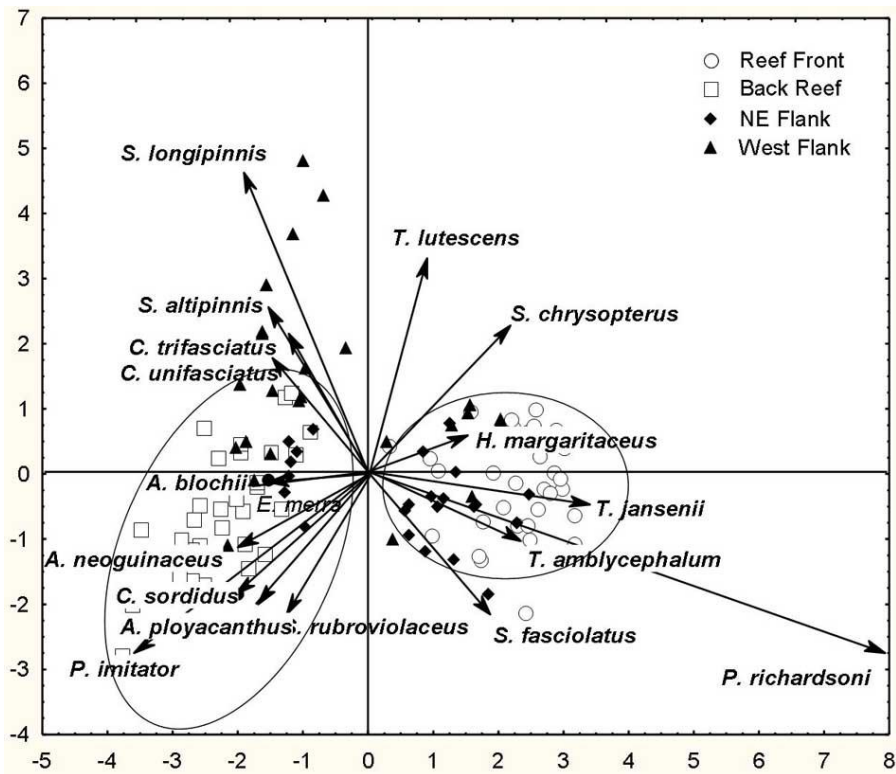
Figure 31. Canonical Discriminant Analysis (CDA) of selected fish species separated by habitat. The two circles encompass the two main data groups. The main separation is between Reef Front (right circle) and Back Reef (left circle) habitats.
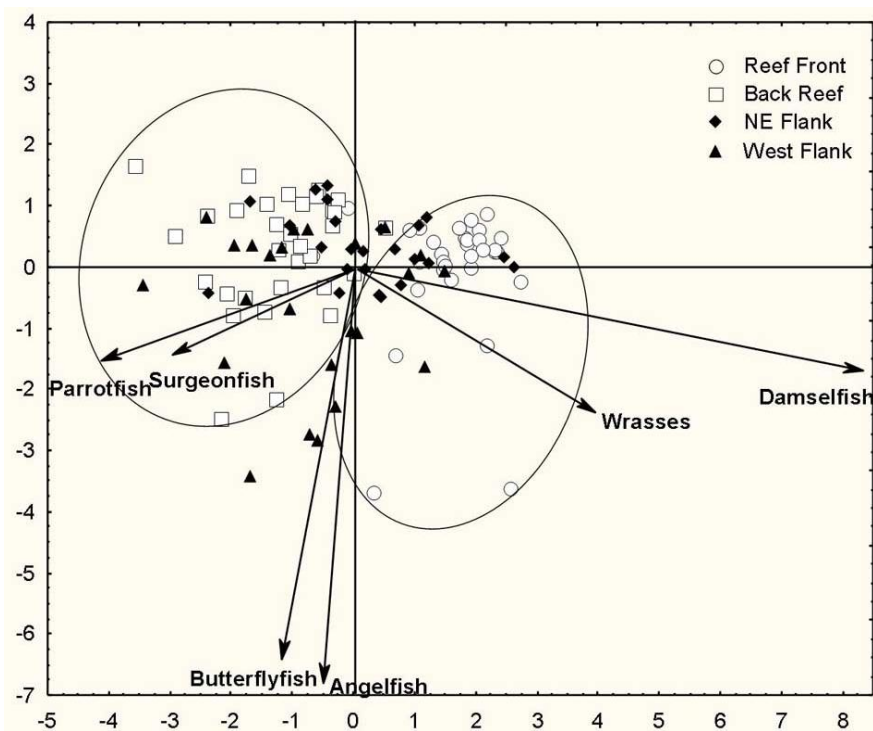
Figure 32. Canonical Discriminant Analysis (CDA) of the dominant fish families, separated by habitat. The two circles encompass the two main data groups. The main separation is between Reef Front (right circle) and Back Reef (left circle) habitats.

5.3.2 APEX PREDATORS: SERRANIDS

The principal representatives of apex predators on coral reefs include large serranids (groupers) and sharks. In the CHNNR, large serranids were relatively rare, and included only the blacksaddle coral trout *Plectropomus laevis* and the yellow-edged lyretail *Variola louti*, with a single individual of the camouflage grouper *Epinephelus polyphekadion* and a number of peacock grouper *Cephalopholis argus* recorded in May 2007 in the Herald Cays. Smaller serranids encountered more frequently, and recorded during the 30 x 10m transects in October, included the groupers *E. merra*, *E. hexagonatus* and *C. urodeta*.

Estimates of large serranids were approximately five individuals per hectare for all surveyed locations except SW Herald, where densities were significantly higher than at the other four cays with an average of 9.4 individuals per hectare. Serranid density at SE Magdelaine was comparable to those at NE Herald, while Chilcott and Coringa both had densities of below 2 individuals per hectare (Figure 33a). *P. laevis* density was highest at SW Herald, were the overall structure of the reef was very different from the other surveyed reefs. The more elongated shape along a slightly northwesterly axis may have offered more sheltered and complex habitats. Average *P. laevis* densities at NE Herald and SE Magdelaine were only half of those found at SW Herald, and Coringa and Chilcott had very low densities of less than one individual per hectare, respectively (Figure 33b).

Large Serranids

Plectropomus laevis
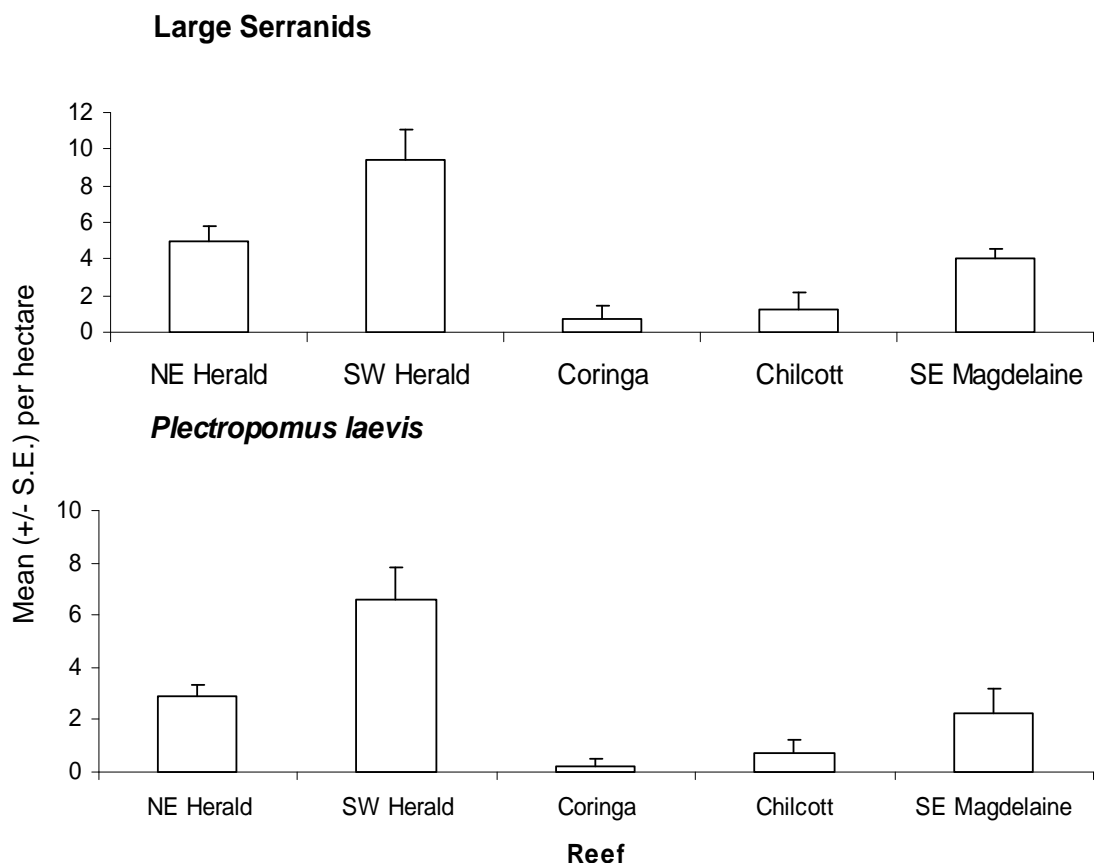
Figure 33. Mean abundance per hectare of large serranids and *P. laevis* in the CHNNR. Note that NE and SW Herald estimates are those obtained in May, while all others were obtained in October. The large serranids include *P. laevis* and *Variola louti* only to ensure consistency between studies.

5.3.3 APEX PREDATORS: REEF SHARKS

Only three species of shark were recorded in the CHNNR, one of which is a benthic feeder (tawny nurse shark *Nebrius ferrugineus*). The density of the other two species combined, *Carcharhinus amblyrhynchos* (grey reef shark) and *Triaenodon obesus* (whitetip reef shark) was highest at SE Magdelaine (Appendix 6), followed by SW Herald. Densities of sharks at NE Herald, Chilcott and Coringa were much lower (Figure 34).
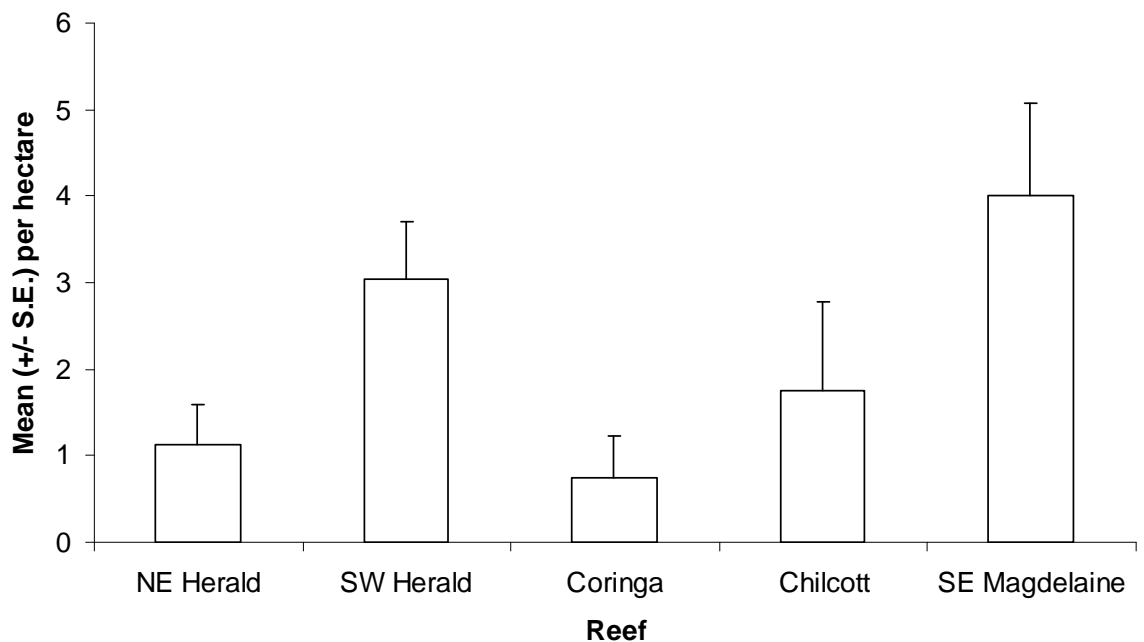
Figure 34. Abundance per hectare of reef sharks *Carcharhinus amblyrhynchos* and *Triaenodon obesus* combined.

5.3.4 ROVING HERBIVORES AND MAORI WRASSE

Roving herbivores are strong determinants of benthic community structure on many reefs, reducing algal biomass, maintaining the balance of reef benthos in favour of live coral (Smith et al. 2001) and playing an integral role in coral recovery from disturbance (Arthur et al. 2006). They include large scarids (parrotfish), acanthurids (surgeonfish) and siganids (rabbitfish). Among these, the large excavating scarids form an important functional group in that they contribute most to reef bioerosion (Bellwood and Choat 1990), and are represented in the CHNNR by the species *Bolbometapon muricatum* (bumphead parrotfish), *Chlorurus microrhinus* (steephead parrotfish) and *Cetoscarus bicolour* (bicolour parrotfish). There is a tendency for herbivores to be most abundant in zones of medium to high wave exposure (Meija and Garzon-Ferreira 2000). In the CHNNR, roving herbivores were characterised by small species, were most abundant in sheltered Back Reef habitats. The exceptions were NE Herald and SE Magdelaine, where there were more herbivores at exposed sites (Figure 35).

Excavating scarid density ranged from 0.9 to 3.3 individuals per 1,000m^2 among the five reefs, with the lowest density recorded at Coringa (Figure 36a). This is relatively low compared with the outer GBR and Elizabeth and Middleton Reefs. Their distribution was atypical in that the highest densities were found in Back Reef areas, especially at Chilcott

and Coringa. The four reefs were significantly different in the pattern of distribution of excavating scarid densities between exposed and sheltered sites. Densities of *Chlorurus microrhinus* were highest at SW Herald and Chilcott, but reached maximum densities of only 1.6 individuals per 1,000m^2 (Figure 36b).

The presence of the humphead (or Maori) wrasse *Cheilinus undulatus* is often used as a 'reef health' indicator in reef dynamics as one of the few predators of large, mobile invertebrates (Chateau and Wantiez 2007). Solitary or paired individuals were generally found on the reef front in the CHNNR, and both surveys found low densities of this species as compared with other regions. For example, a study in New Caledonia reported nine individuals per hectare (Chateau and Wantiez 2007), while generally less than one individual per hectare was recorded in the CHNNR (Figure 37).
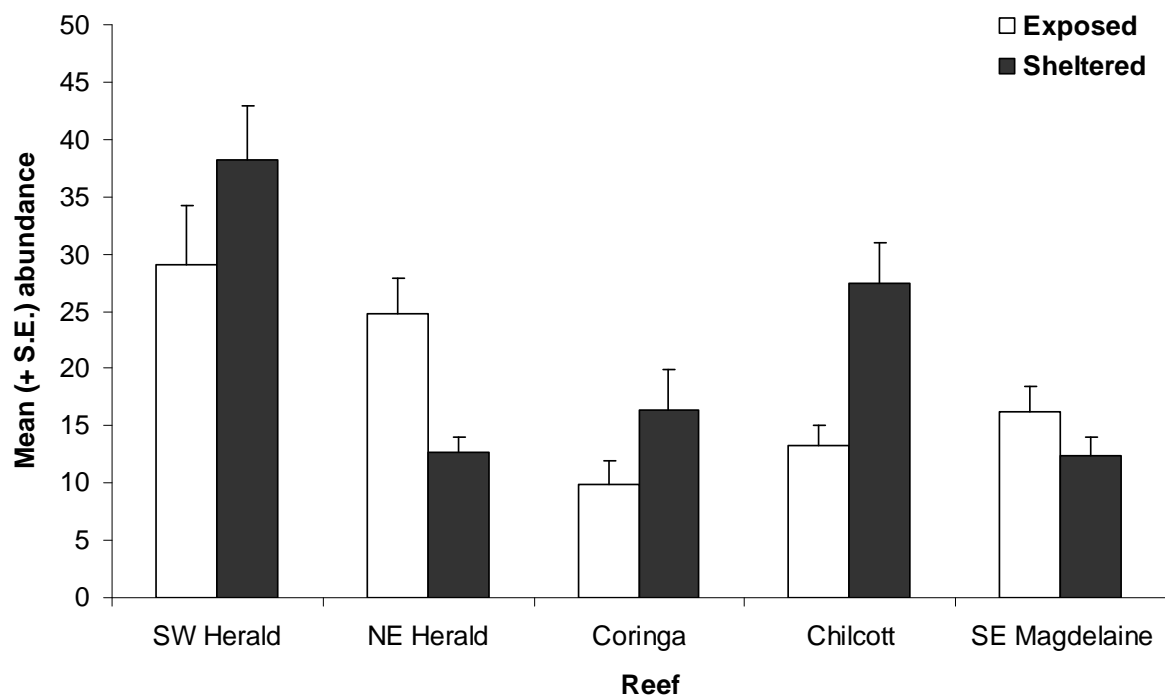
Figure 35. Mean abundance of roving herbivores on exposed and sheltered sites of CHNNR reefs.
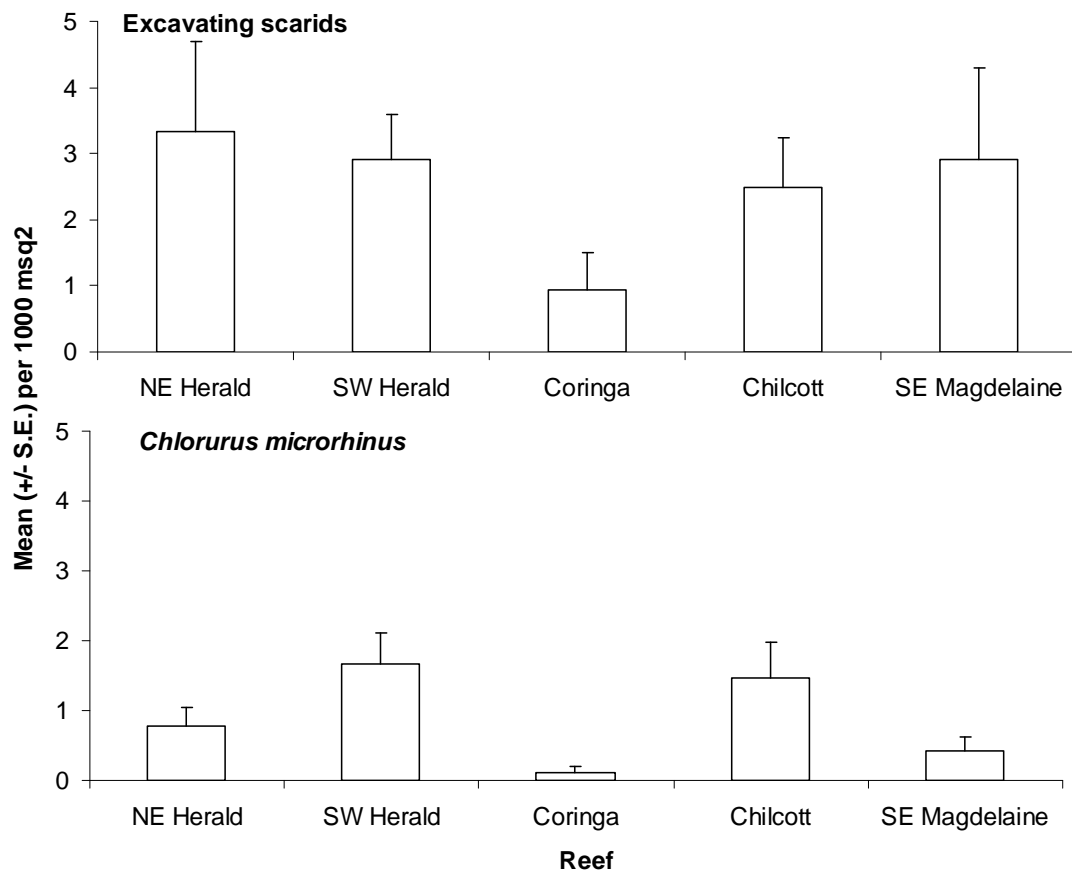
Figure 36. Mean abundance per 1,000 m^2 of all excavating scarids and *C. microrhinus*.
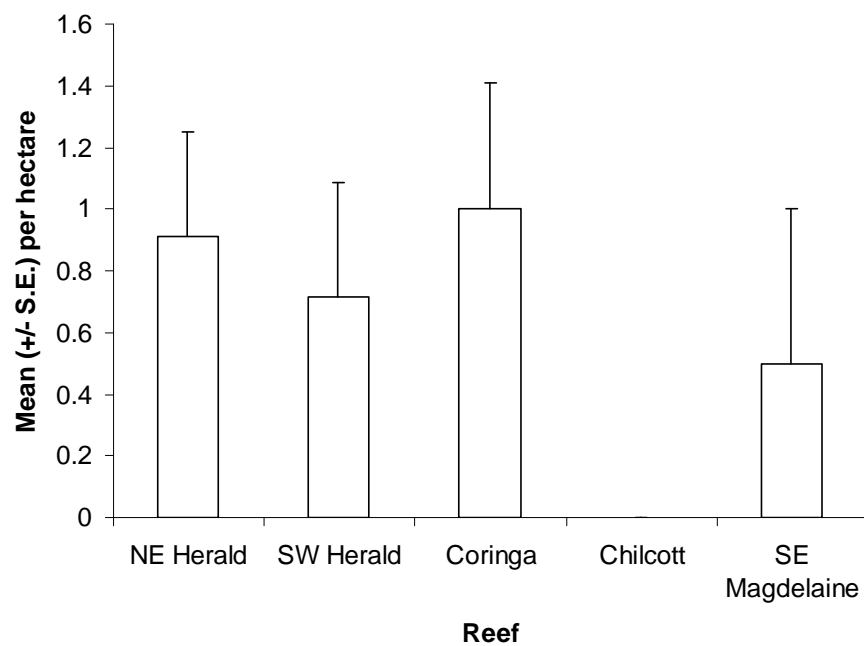
Figure 37. Mean abundance per hectare of Maori wrasse *Cheilinus undulatus* in the CHNNR.

5.3.5 MULTIVARIATE AND REGIONAL COMPARISONS

Multivariate analyses were used to distinguish between the grazing reef fish assemblages from different regions and locations. nMDS revealed that assemblages tended to group together based on the 3 regions (Figure 38). The differences between assemblages from the 3 regions were highlighted by using a canonical analysis of principle co-ordinates (CAP).
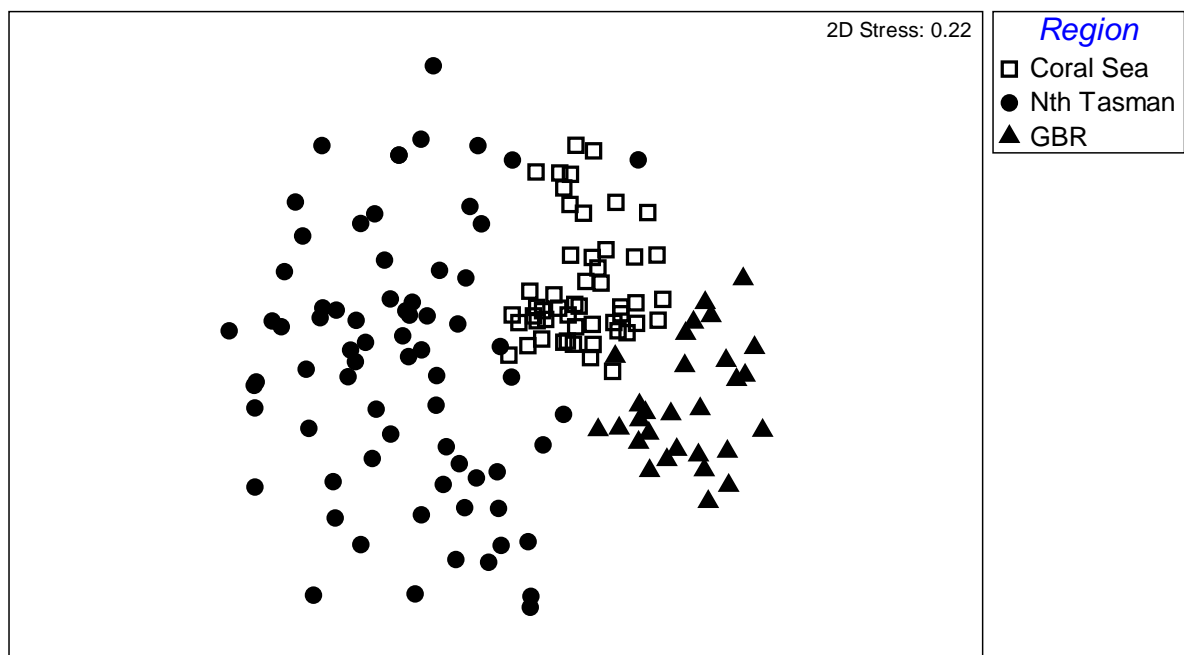
Figure 38. Multidimensional scaling analysis of grazing reef fishes from 3 regions. Abundance estimates derived from 30 x10 m belt transects in reef front habitats in the northern Tasman Sea, (Elizabeth and Middleton Reefs), the Coral Sea (NE and SW Herald Cays) and the northern GBR outer reefs (Hicks, Day, and Carter Reefs) and mid shelf reefs (Lizard Island, North Direction Island, MacGillivaries Reefs). Data are from the Herald Cays only.

Compared to the other two regions, the Herald Cays assemblages were characterized by their relatively high abundance of the surgeonfish *Acanthurus nigrofuscus*, *Naso lituratus* and the parrotfish *Scarus longipinnis* and relatively low abundances of *S. altipinnis, S. psittacus,* the chub *Kyphosus pacificus* and surgeonfish *A. nigroris* (Figure 39b). The CAP analysis of locations revealed a less clear pattern, with some overlap between assemblages from different locations (Figure 39a).
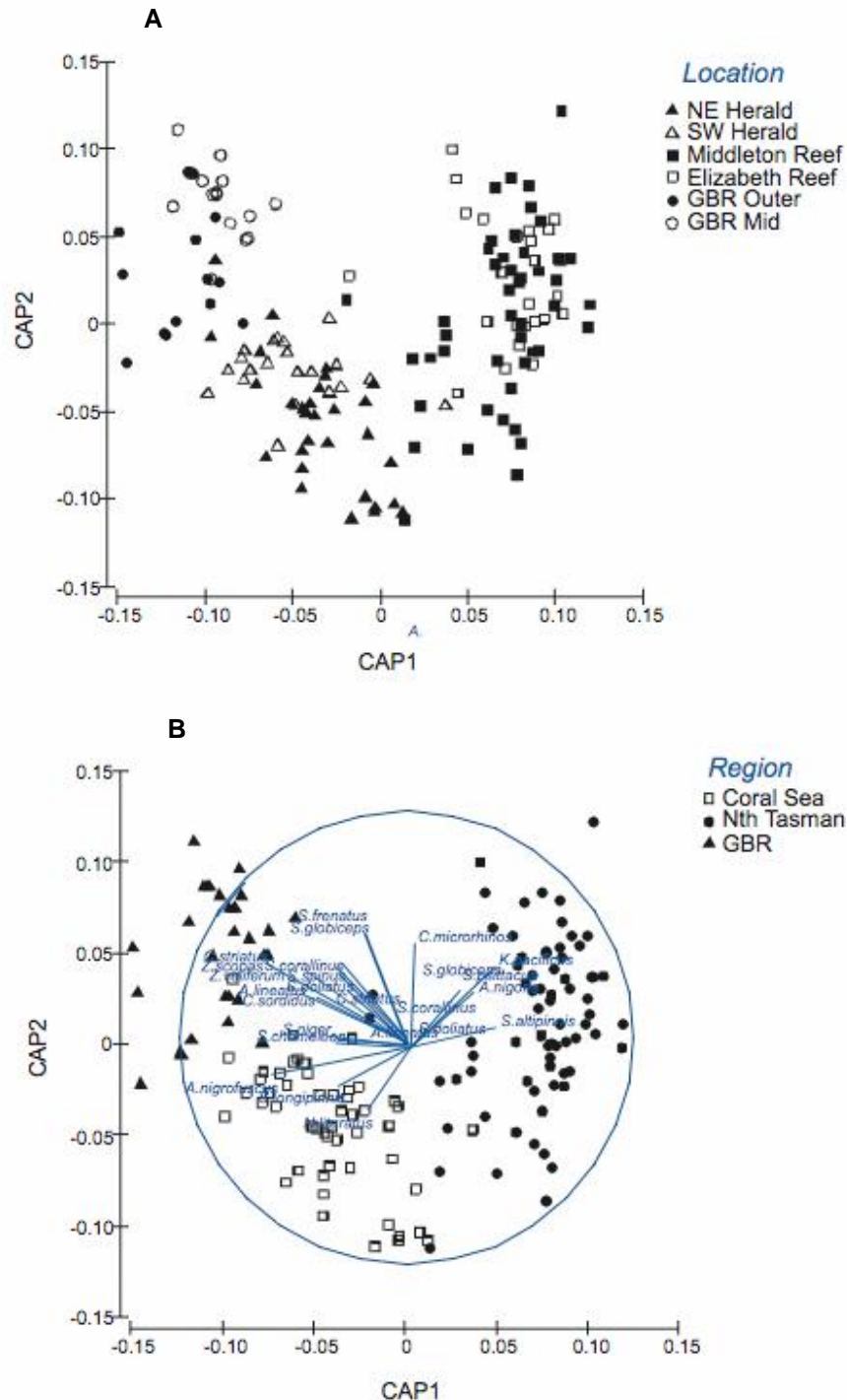
Figure 39. A canonical analysis of principle co-ordinates (CAP) of grazing reef fishes from (A) 6 locations and (B) 3 regions. Vectors indicate species whose abundances are positively correlated with particular locations or regions and are therefore useful in distinguishing between assemblages from different locations or regions. Data are from the Herald Cays only.

Large serranids are usually heavily targeted by commercial and recreational fishers. Regionally, it appears that serranid populations in the CHNNR compare favourable with North Tasman reefs, but are low compared with the northern GBR (Figure 40). *Plectropomus laevis* is a relatively widespread species that appears to be rare at most localities (less than 1 adult per $1000m^2$). The exception to this rarity is the outer reefs of the northern GBR where abundances of 1.7 per $1000m^2$ were recorded (Pears 2006). However the common coral trout *P. leopardus* was found to be 4-5 times more abundant on most GBR mid and outer reefs. In the CHNNR, mean abundances of *P. laevis* per hectare were over twice as high as on the outer GBR reefs (Figure 40). These abundance estimates represent the greatest densities recorded for this species, and its population appears to have remained stable over the last four years.
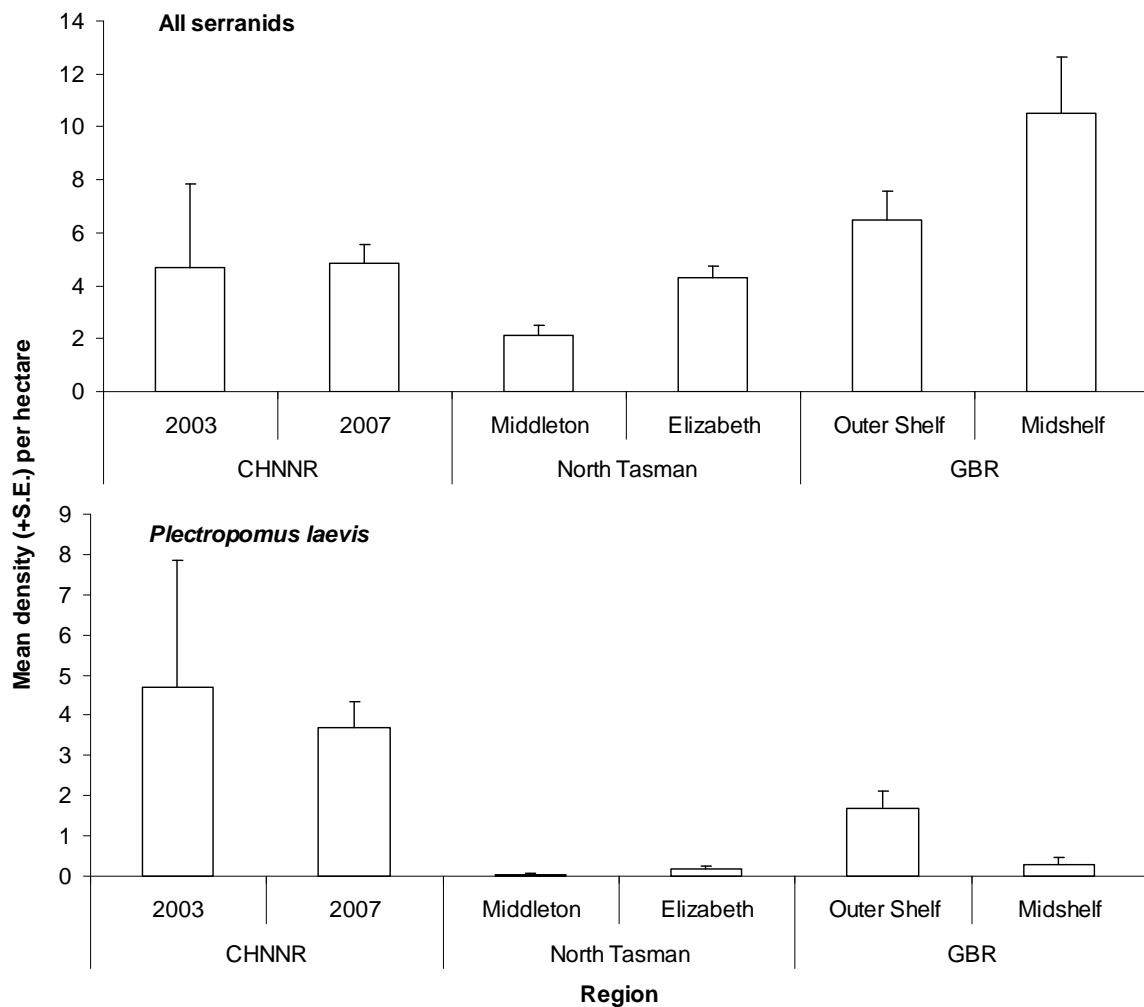
Figure 40. Density of all serranids and *P. laevis* across three regions. Note that the 2003 estimates of all serranids include only *P. laevis*; no other large serranids were included in that dataset.

The mean abundance of sharks (1.9 individuals per hectare) across all CHNNR reefs was higher than Middleton Reef in the North Tasman, but considerably lower than Preservation Zones on the northern GBR (Figure 41).
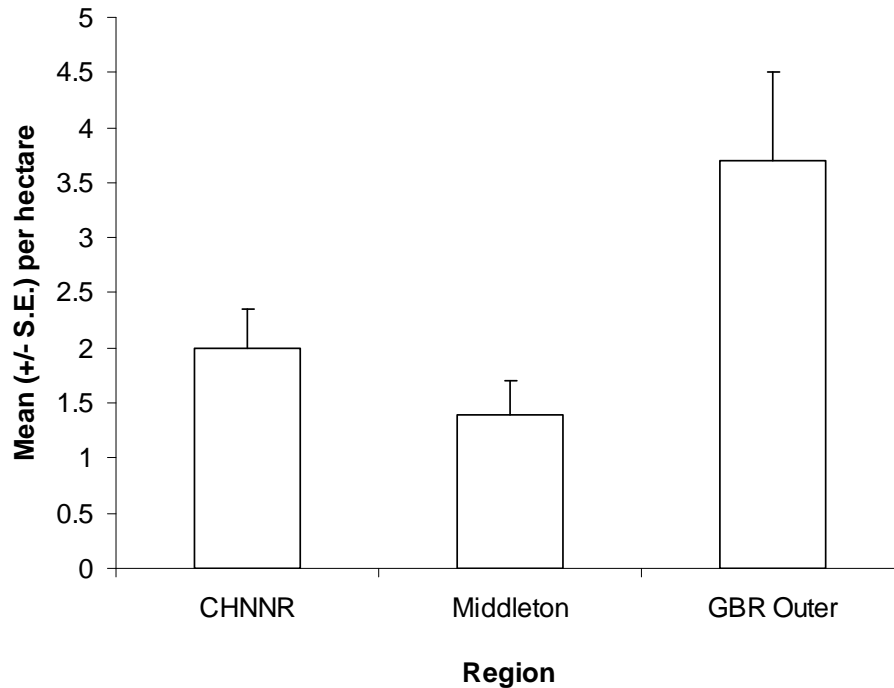
Figure 41. The mean abundance of reef sharks (combined for grey reef shark *Carcharhinus amblyrhynchos* and whitetip reef shark *Triaenodon obesus*) per hectare from 3 regions.

Excavating parrotfishes had relatively low abundances in the CHNNR. For all excavating parrotfish species combined, the Reserves had a mean density of 2.3 individuals per 1000m^2. In comparison, the abundance of excavating parrotfishes was more than 3 times greater on reefs in the northern Tasman Sea and more than 7 times greater on northern GBR reefs (Figure 42). A similar result was found for one of the major reef excavating parrotfish *Chlorurus microrhinos*. This species was recorded in densities of 1.6 individuals per 1000m^2 across CHNNR reefs. This species is at least twice as abundant on northern Tasman Sea reefs and 6 times more abundant on northern GBR reefs (Figure 42). The combined excavators and *C. microrhinus* experienced a decline from the 2003 survey (Oxley et al. 2003).
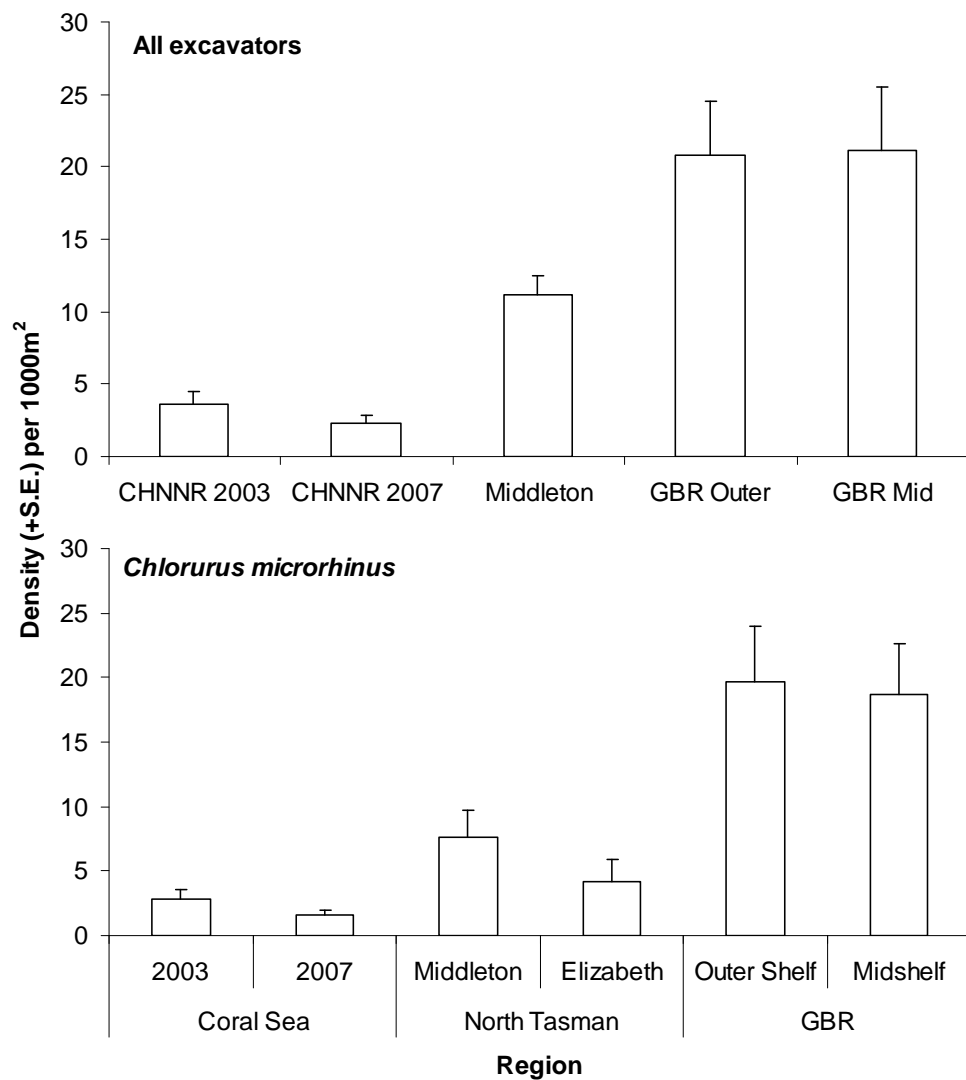
Figure 42. Mean abundance per 1,000 m^2 of all excavating scarids and *C. microrhinus* from three regions, and two Coral Sea surveys.

There was no significant change in Maori wrasse *Cheilinus undulatus* populations in the CHNNR between 2003 and 2007. However, regional comparisons showed that CHNNR populations are very low; this species was twice as abundant on mid shelf reefs and at least 6 times more abundant on outer reefs of the northern GBR (Figure 43).
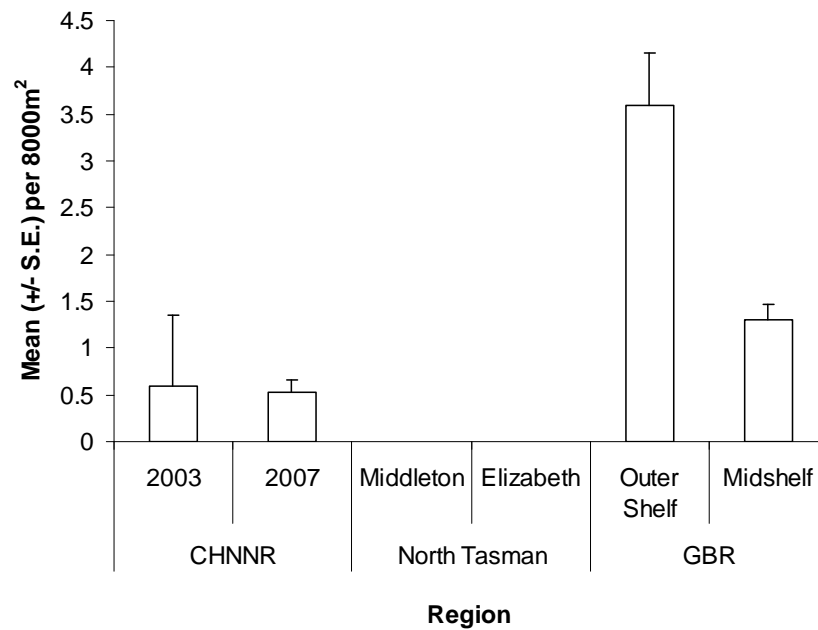
Figure 43. The mean abundance per 8000m^2 of Maori wrasse (*Cheilinus undulatus*) from 3 regions.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 *Conclusions*

The CHNNR encompasses a series of small, isolated oceanic reef systems with unique fish and benthic communities. Their remoteness and high level of exposure to physical disturbance makes it difficult to access them, and they have therefore not been well studied. Ecological processes that apply to larger reef systems, such as the GBR, appear to function differently in the CHNNR. The management of oceanic reef reserves may need to be adapted as further research begins to reveal what these differences are.

Reefs in the CHNNR are dominated by algae and support a relatively species-poor fish community. The low coral cover can be considered a historical feature of these reefs, which has been compounded in the last two decades by disturbance and a lack of recovery due largely to isolation and exposure. Severe sea surface temperature (SST) anomalies in 1998 and 2002 (Oxley et al. 2003) led to coral bleaching that reduced live coral cover from 20% to less than 5%. In March 2004, a severe bleaching event was recorded at nearby Lihou Reef, affecting an estimated that 65% of the hard coral cover (Oxley et al. 2004b). The short-term impact of this bleaching event on reefs in the CHNNR was not examined.

The presence of coral populations characteristic of Pacific Ocean reefs lends support to the suggestion that reefs of the CHNNR and surrounding Coral Sea reefs provide stepping-stones for the dispersal of species between the GBR and the greater Pacific Ocean region (see also Treml et al. 2008). Maintaining the overall integrity and resilience of these reefs is therefore necessary to ensure that they can function effectively at stepping-stone habitats. Connectivity between the CHNNR and other reef systems or regions should be examined, both to inform management of the Reserve itself, and to assist in integrating the planned marine reserve network of the East Marine Region with areas, such as the Reserve, that have a history of protection (DEWHA 2008).

At least five cyclones crossed the Reserve between 1985 and 2006 (Oxley et al. 2003, Choat et al. 2007), but the extent of local destruction from these storms was not recorded. The lack of *Acropora* corals at all sites other than SE Madgelaine is informative because *Acropora* species are more sensitive than most other corals to many kinds of disturbance (Hughes and Connell 1999, Marshall and Baird 2000). *Acropora* are also early colonisers of disturbed sites (Wallace 1985). Given few *Acropora* were recorded from the Reserve, it appears that coral communities in the Reserve are still in the early phase of recovery.

Hard coral provides both the structure and food source for other reef organisms. The absence of juvenile corals and mature breeding individuals is a cause for concern for the maintenance and recovery of coral community structure in the Reserve. An important observation is that despite the timing of the present survey during the October full moon, when many corals in the Southern Hemisphere are reproductively gravid and preparing for spawning or brooding, only one in six *Acropora* corals sampled were found to be gravid. While non-quantitative, this observation indicates that recovery is likely to be slow in the Reserve due to a lack of mature reproductive individuals. Maturation of an *Acropora* colony takes 3-8 years; given *Acropora* corals grow approximately 3-5cm per year it is likely that, in the absence of further disturbance, the largest cohort of corals within the Reserve (5-10 cm) are approximately 2 years old and not expected to reproduce for 1-7 years.

Algae were the dominant form of substratum cover in the CHNNR, but did not include the frondose macroalgae that are usually associated with degraded coral reefs (Hughes 1994,

McCook 1999). The algal community consisted of algal turf, a closely cropped 'lawn' of barely visible algae, coralline algae, resembling calcareous rocks, and *Halimeda*, a genus of heavily calcified green algae. The CHNNR cays are important nesting sites for a diversity of tropical sea birds, which contribute nutrients to the ecosystem. This has presumably been so for thousands of years and these nutrient levels have not been altered by human activities, as is the case for coral reef environments impacted by human populations and their activities on land (e.g. Jones et al. 2004, Munday 2004). Algal turf, the predominant benthic component of the CHNNR, is an important food source for a range of marine invertebrates and herbivorous fish (Hackney et al. 1989). Coralline algae, also a large component of the Reserve benthos, often indicates heavy grazing. However, the low abundance of grazing herbivores on reef front habitats during the survey suggests that the high coralline algae cover is another historical feature of the reefs. *Halimeda spp.* can be a keystone species because it is the primary contributor to local sediment loads (Heyward et al. 1997). Back reef sediments of the CHNNR revealed a high proportion of *Halimeda* - derived sand.

Densities of macroinvertebrates such as holothurians, tridacnid clams, sea urchins and ornamental shells appear similar to those found in other surveys of isolated, oceanic reef. Some holothurians of high commercial value were more abundant in the CHNNR, suggesting that protection from exploitation has been successful. Gastropod species with high value for the ornamental shell industry were found in high densities in some areas of the Reserve, indicating that it may be important to include these species in future surveys of Commonwealth Reserves, to establish a baseline against which to measure potential changes due to commercial and / or illegal exploitation. Incidental observations at Ashmore Reef in 2006 suggest that in the absence of other high-value invertebrates, ornamental shell gastropods may be targeted next, but a lack of baseline density data there and in other Reserves precluded a definitive assessment of potential decline.

The principal herbivore groups in the CHNNR are the roving herbivores (parrotfish, surgeonfish and rabbitfish), territorial damselfish and surgeonfish (primarily *Acanthurus lineatus*) and to a smaller extent, sea urchins. Large herbivores appear largely confined to the more sheltered back reef habitats. The combination of higher microhabitat complexity and higher herbivore density may contribute to the higher coral cover (Diaz-Pulido and McCook 2003, Feary et al. 2007) and may promote faster recovery from disturbance in this habitat. Even though most active reef growth occurs on the exposed reef front (Nakamura and Nakamori 2007), the back reefs may provide refugia for populations that act as sources of propagules for the replenishment of the rest of the reef (Kospartov et al. 2006), and may therefore play a major role in reef resilience. However, the relationship between algae, corals and grazing fishes is very poorly understood on isolated oceanic reefs, and needs urgent attention to inform their management.

In low diversity systems such as the CHNNR, resilience is compromised because each functional group (e.g. herbivores, apex predators, detritivores, etc.) is represented by only a few species, and the loss of individual species can easily result in the loss of whole functional groups – a situation described by the term 'limited functional redundancy' (Bellwood and Hughes 2001). The loss of functional groups impacts on ecosystem function and stability (Bellwood and Hughes 2001). Limited functional redundancy was most notably identified amongst the large apex predators in the CHNNR, with only 5 species encountered during the survey period. Apex coral reef predators, such as large serranids and sharks, were found in low densities. This is likely to be a result of the low microhabitat complexity across large extents of the exposed reef fronts, resulting in lower overall prey density for these predators. These species, along with large keystone invertebrate feeders and herbivores, are economically valuable and globally vulnerable to overexploitation (Pears 2006, Robbins et al. 2006), highlighting the need for their protection and the careful monitoring and safeguarding of their habitat. Surprisingly, the blacksaddle coral trout *P. laevis*, an exploited predatory species that was recently listed as vulnerable by IUCN, has

the highest density of any surveyed location in the world and Australia therefore has a responsibility to protect this stronghold.

Large, interconnected reef systems such as the GBR are expected to recover rapidly after disturbance events (Halford et al. 2004) because some patches always survive to seed degraded sites. Their large size and higher levels of connectivity also ensure higher abundance and diversity of corals and fishes. By nature of their isolation, oceanic reefs such as those in the CHNNR have few source reefs, tend to recover slowly from disturbance events (Graham et al. 2006). Furthermore, nearby reefs such as Lihou are in a similar state, which further slows recovery. Most coral species within the Reserve are rare and occur in low numbers, making them highly vulnerable to local extinction. Ultimately, it is the hard coral community that provides the habitat structure that feeds and shelters the rest of the reef community, and its recovery from disturbance is a key element in the overall resilience of the reef system. The onset of unprecedented climate change brings the focus of coral reef protection to promoting this resilience. These surveys clearly indicate that these reefs require a different management approach, based on an improved understanding of their unique community composition and ecological processes.

6.2 *Recommendations*

The CHNNR is ecologically unique and biogeographically important as a link between GBR and Pacific Ocean reef communities, and maintaining their closure from exploitation is important for their protection.

- Effective protection and enforcement measures should continue to be developed to limit illegal exploitation within the Reserves.
- Monitoring must be continued at regular intervals (at least every 3 years) to detect changes in the reef community. It is advisable to attempt the use of the same monitoring team, or new teams that can liaise with previous teams, for the consistency of methods. Despite the inevitable refining of survey methods that will occur from one survey to the next, efforts must made to:
- enable temporal comparisons for key species and species groups, to adequately detect change in response to climate change; and
- enable spatial comparisons to similar reef systems worldwide as new data emerge.
- Monitoring and protection efforts must continue to include key species and species groups, such as large keystone predators and herbivores, commercially important organisms (adding ornamental shell gastropods) and habitat-forming communities.
- Future monitoring would greatly benefit from including water and sediment quality, to compare water quality between cays with/without breeding bird colonies, to help evaluate the effects of guano in providing an important source of the usually limiting nutrient phosphorus. The increased phosphorus may favour algal growth (including coralline algae) over coral growth, which may be supressed by phosphorus (Kinsey and Davies 1979, McCook 1999, Diaz-Pulido and McCook 2003). Most current research in this area has focused on nutrients from terrestrial run-off, whereas the CHNNR is an oligotrophic (low-nutrient) system. Despite this, it has obviously been receiving nutrient input (specifically phosphorus) from the large bird populations for extensive periods of time. It is important to test the possibility that this may explain, in part, why these reefs have historically been relatively depauperate.
- The value of monitoring would be greatly enhanced by adding sites open to exploitation (e.g. the Willis Island group), as this will provide a real measure of the effectiveness of closures.

- The level of habitat complexity appears to play a major role in driving the species richness and cover or density of fish and coral within the Reserve. Future monitoring surveys should consider adding targeted habitat complexity measures.
- It is recommended that connectivity modelling be undertaken to determine possible source and sink reefs for the CHNNR.
- It is recommended that the DEWHA continue collaborations with the Australian Customs Service to monitor the Reserve for visible signs of coral bleaching during their routine fly-overs.
- Managers should build capacity for adaptive management of the Reserve by deploying reactive resource surveys in response to evidence of bleaching or disturbance events such as cyclones.

7.   ACKNOWLEDGEMENTS

8. REFERENCES

AFMA (2007) Coral Sea Fishery at a glance. accessed 03.12.07, last updated 01.06.07, http://www.afma.gov.au/fisheries/ext_territories/coral_sea/at_a_glance.htm

Allen GR, Steene R, Humann P, Deloach N (2003) Reef Fish Identification. Tropical Pacific. New World Publications, Inc., Jacksonville FL

Anderson MJ, Millar MB (2004) Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. Journal of Experimental Marine Biology and Ecology 305: 191-221

Anderson MJ, Ellingsen KE, McArdle BH (2006) Multivariate dispersion as a measure of beta diversity. Ecology Letters 9: 683-693

Arthur R, Done TJ, Marsh H, Harriott V (2006) Local processes strongly influence post-bleaching benthic recovery in the Lakshadweep Islands. Coral Reefs 25: 427-440

Australian Severe Weather (2007) Southern hemisphere tropical cyclones: historical season maps. accessed 18.12.07, last updated 16.03.07, http://www.australiansevereweather.com.au/cyclones/history.htm

Ayling AM, Ayling AL (1985) Coral Sea Surveys. Unpublished Report to Australian National Parks and Wildlife Service, Canberra

Baird A, Campbell S, Anggoro A, Ardiwijaya R, Fadli N, Herdiana Y, Kartawijaya T, Mahyiddin D, Mukminin A, Pardede S (2005) Achenese Reefs in the Wake of the Asian Tsunami. Current Biology 15: 1926-1930

Baird AH (1998) The length of the larval phase in corals: new insights into patterns of reef connectivity. Australian Coral Reef Society Newsletter 27: 6-7

Baird AH (2001) The ecology of coral larvae: settlement patterns, habitat selection and the length of the larval phase. PhD Thesis, James Cook University of North Queensland

Bellwood DR, Choat JH (1990) A functional analysis of grazing in parrotfishes (family Scaridae): the ecological implications. Environmental Biology of Fishes 28: 189-214

Bellwood DR, Hughes TP (2001) Regional-scale assembly rules and biodiversity of coral reefs. Science 292: 1532-1534

Berry PF, Wells FE (2000) Survey of the marine fauna of the Montebello Islands, Western Australia, and Christmas Island, Indian Ocean. Records of the Western Australian Museum Supplement 59: 1-127

Byron G, Malcolm H, Thompson AA (2001) The benthic communities and associated fish faunal assemblages of North East Cay, Herald Cays, Coral Sea. In: Herald Cays Scientific Study Report. Geography Monograph Series No 6. The Royal Geographic Society of Queensland Inc., Brisbane

Ceccarelli D, Kospartov M, Beger M, Richards Z, Birrell C (2007) An assessment of the impacts of illegal fishing on invertebrate stocks at Ashmore Reef National Nature Reserve, 2006. C & R Consulting Report for the Department of Environment and Water Resources, Canberra

Chateau O, Wantiez L (2007) Site fidelity and activity patterns of a humphead wrasse, *Cheilinus undulatus* (Labridae), as detemined by acoustic telemetry. Environmental Biology of Fishes 80: 503-508

Chia FS, Buckland-Nicks J, Young CM (1984) Locomotion of marine invertebrate larvae: a review. Canadian Journal of Zoology 62: 1205-1222

Choat JH, van Herwerden L, Robbins WD, Hobbs JP, Ayling AM (2006) A report on the ecological surveys conducted at Middleton and Elizabeth Reefs, February 2006. Report by JCU to the Australian Government Department of Environment and Heritage, Canberra

Choat JH, van Herwerden L, Hobbs JP, Ayling AM, Ayling AL, Ewels G (2007) Ecological surveys of the marine environment at the Herald Cays, Coral Sea, May 2007. Draft Report produced by James Cook University for the Department of the Environment and Water Resources, Canberra

Condie SA, Waring J, Mansbridge JV, Cahill ML (2005) Marine connectivity patterns around the Australian continent. Environmental Modelling & Software 20: 1149-1157

DEWHA (2008) Marine Bioregional Planning in the East. accessed 04.03.08, http://www.environment.gov.au/coasts/mbp/east/index.html

Diaz-Pulido G, McCook LJ (2003) Relative roles of herbivory and nutrients in the recruitment of coral-reef seaweeds. Ecology 84: 2026-2033

Dominici-Arosemena A, Wolff M (2005) Reef fish community structure in Bocas del Toro (Caribbean, Panama): Gradients in habitat complexity and exposure. Caribbean Journal of Science 41: 613-637

Donaldson TJ (2002) High islands versus low islands: a comparison of fish faunal composition of the Palau Islands. Environmental Biology of Fishes 65: 241-248

Environment Australia (2001) Coringa-Herald National Nature Reserve and Lihou Reef National Nature Reserve Management Plan. Environment Australia, Canberra

Evans RD, Robbins WD, Ewels G, van Herwerden L (2007) Rapid benthic assessment of North East Herald Reef, Coringa-Herald National Nature Reserve, Coral Sea (28 November to 7 December, 2006). Report by JCU for the Department of the Environment and Water Resources, Canberra

Fadlallah YH (1983) Sexual reproduction, development and larval biology in scleractinian corals: A review. Coral Reefs 2: 129-150

Feary DA, Almany GR, McCormick MI, Jones GP (2007) Habitat choice, recruitment and the response of coral reef fishes to coral degradation. Oecologia 153: 727-737

Fenner D (2003) Corals of Milne Bay Province, Papua New Guinea. In: Allen GR, Kinch JP, McKenna SA, Seeto P (eds.) A rapid marine biodiversity assessment of Milne Bay Province, Papua New Guinea - Survey II (2000) RAP. Bulletin of Biological Assessment 29. Conservation International, Washington, DC (pp 20-26)

Fenner D (2007) Scleractinian corals of Osprey Reef, Coral Sea. Report in preparation for WWF

Friedlander AM, Brown EK, Jokiel PL, Smith WR, Rodgers KS (2003) Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaii archipelago. Coral Reefs 22: 291-305

Graham NAJ, Wilson SK, Jennings S, Polunin NVC, Bijoux JP, Robinson J (2006) Dynamic fragility of oceanic coral reef ecosystems. Proceedings of the National Academy of Sciences 103: 8425-8429

Hackney J, Carpenter RC, Adey WH (1989) Characteristic adaptations to grazing among algal turfs on a Caribbean coral reef. Phycologia 28: 109-119

Halford A, Cheal AJ, Ryan D, Williams DM (2004) Resilience to large-scale disturbance in coral and fish assemblages on the Great Barrier Reef. Ecology 85: 1892-1905

Hallock P, Lidz BH, Cockey-Burkhard EM, Donnelly KB (2003) Foraminifera as bioindicators in coral reef assessment and monitoring: the Foram Index. Environmental Monitoring and Assessment 81: 221-238

Harrison PL, Babcock RC, Bull GD, Oliver JK, Wallace CC, Willis BL (1984) Mass spawning in tropical reef corals. Science 223: 1186-1189

Harvard Medical School (2003) New medicines at risk from biodiversity loss. Science Daily October 17, 2003

Heyward A, Pincratto E, Smith L (1997) Big Bank Shoals of the Timor Sea. An environmental resource atlas. Australian Institute of Marine Science, Townsville

Hughes TP (1994) Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265: 1547-1551

Hughes TP, Connell J (1999) Multiple stressors on coral reefs: A long-term perspective. Limnology and Oceanography 44: 932-940

Jones GP, McCormick MI, Srinivasan M, Eagle JV (2004) Coral decline threatens fish biodiversity in marine reserves. Proceedings of the National Academy of Science USA 101: 8251-8253

Kinsey DW, Davies PJ (1979) Effects of elevated nitrogen and phosphorus on coral reef growth. Limnology and Oceanography 24: 935-940

Kospartov M, Beger M, Ceccarelli D, Richards Z (2006) An assessment of the distribution and abundance of sea cucumbers, trochus, giant clams, coral, fish and invasive marine species at Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve: 2005. Report prepared by UniQuest Pty Ltd for the Department of the Environment and Heritage, Canberra

Marshall PA, Baird AH (2000) Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. Coral Reefs 19: 155-163

McClanahan TR (2002) The effects of time, habitat, and fisheries management on Kenyan coral-reef-associated gastropods. Ecological Applications 12: 1484-1495

McCook LJ (1999) Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. Coral Reefs 18: 357-367

Meija LS, Garzon-Ferreira J (2000) Reef fish community structure in four atolls of the San Andres Providencia archipelago (southwestern Caribbean). Revista de Biologia Tropical 48: 883-896

Munday PL (2004) Habitat loss, resource specialization, and extinction on coral reefs. Global Change Biology 10: 1642-1647

Nakamura T, Nakamori T (2007) A geochemical model for coral reef formation. Coral Reefs 26: 741-755

Oxley WG, Ayling AM, Cheal AJ, Thompson AA (2003) Marine surveys undertaken in the Coringa-Herald National Nature Reserve, March-April 2003. Report produced for CRC Reef for Environment Australia, Canberra

Oxley WG, Ayling AM, Cheal AJ, Osborne K (2004a) Marine surveys undertaken in the Elizabeth Middleton Reefs Marine National Nature Reserve, December 2003. Report to the Australian Government Department of Environment and Heritage, Canberra

Oxley WG, Emslie M, Muir P, Thompson AA (2004b) Marine surveys undertaken in the Lihou Reef National Nature Reserve, March 2004. Report undertaken for the Department of the Environment and Heritage, Canberra

Pais A, Azzurro E, Guidetti P (2007) Spatial variability of fish fauna in sheltered and exposed shallow rocky reefs from a recently established Mediterranean Marine Protected Area. Italian Journal of Zoology 74: 277-287

Pears RJ (2006) Comparative demography and assemblage structure of serranid fishes: implications for conservation and fisheries management. PhD thesis, James Cook University

Pichon M (2006) Scleractinia of New Caledonia: check list of reef dwelling species. In: Payri CE, Richer de Forges B (eds.) Compendium of marine species form New Caledonia. Documents Scientifiques et Techniques II 7. Institut de Recherche pour le Developpment, Noumea (pp 147-155)

Richards ZT, Wallace CC (submitted) Rarity in the Genus *Acropora*. Coral Reefs

Richmond RH (1987) Energetics, competency and long-distance dispersal of planula larvae of the coral *Pocillopora damicornis.* Marine Biology 93: 527-533

Robbins WD, Hisano M, Connolly SR, Choat HJ (2006) Ongoing Collapse of Coral-reef shark populations. Current Biology 16: 2314-2319

Smith JE, Smith CM, Hunter CL (2001) An experimental analysis of the effects of herbivory and nutrient enrichment on benthic community dynamics on a Hawaiian reef. Coral Reefs 19: 332-342

Toral-Granda MV (2006) Fact sheets and identification guide for commercial sea cucumber species. SPC Beche-de-mer Information Bulletin 24: 49-52

Toral-Granda MV (2007) Facts on sea cucumber fisheries worldwide. SPC Beche-de-mer Information Bulletin 25: 39-41

Treml EA, Halpin PN, Urban DL, Pratson LF (2008) Modeling population connectivity by ocean currents, a graph-theoretic approach for marine conservation. Landscape Ecology 23: 19-36

Veron JEN (1986) A biogeographic database of hermatypic coral species of the Central Indo-Pacific. Australian Institute of Marine Science, Townsville

Veron JEN (1993) A biogeographic database of hermatypic corals. AIMS monograph Series. Australian Institute of Marine Science, Townsville

Veron JEN (2000) Corals of the World. Australian Institute of Marine Science, Townsville

Wakeford M (2002) Assessment of bleaching at Flinders Reef, Coral Sea. Australian Institute of Marine Science, Townsville

Wallace CC (1985) Reproduction, recruitment and fragmentation in nine sympatric species of the coral genus *Acropora*. Marine Biology 88: 217-233

Whittaker RJ (1998) Island Biogeography: Ecology, Evolution and Conservation. Oxford University Press, New York

Wilkinson CR (1998) Status of the coral reefs of the world. Australian Institute of Marine Science, Townsville

Woodroffe CD, Berry PF (1994) Scientific studies of the Cocos (Keeling) Islands: An introduction. Atoll Research Bulletin 406

APPENDIX 1: SITE LOCATIONS

Grid: Lat/Long (note different units used for May and October			
Datum: WGS 84			
'B' and 'E' at the end of a site name symbolise 'Beginning' and 'End'			
Name	Latitude	Longitude	Date/Time
May			
NE Herald			
South Flank 1	S16.94991	E149.18600	14-May-07 9:30:00 AM
South Flank 2	S16.94699	E149.18216	14-May-07 12:05:00 PM
South Flank 3	S16.94950	E149.18350	14-May-07 14:10:00 PM
NE Flank 1	S16.92002	E149.19983	15-May-07 08:30:00 AM
NE Flank 2	S16.91837	E149.20116	15-May-07 10:55:00 AM
NE Flank 3	S16.91975	E149.20404	15-May-07 13:30:00 PM
NE Back	S16.92254	E149.19901	15-May-07 15:00:00 PM
Mid Back	S16.93509	E149.20078	16-May-07 08:20:00 AM
South Front 1	S16.95230	E149.19513	16-May-07 10:20:00 AM
South Front 2	S16.95178	E149.19099	16-May-07 13:10:00 PM
South Front 3	S16.95299	E149.19913	16-May-07 15:10:00 PM
SW Herald			
Mid Back 1	S16.98782	E149.12822	17-May-07 09:00:00 AM
Mid Back 2	S16.98934	E149.12949	17-May-07 10:40:00 AM
Mid Back 3	S16.99199	E149.13051	17-May-07 14:30:00 PM
South Flank 1	S17.01565	E149.13533	18-May-07 08:45:00 AM
South Flank 2	S17.01962	E149.13704	18-May-07 10:15:00 AM
NE Flank 1	S16.96852	E149.13597	18-May-07 12:55:00 PM
NE Flank 2	S16.97097	E149.13054	18-May-07 14:05:00 PM
October			
NEH-F	S16 55 53.7	E149 12 49.1	23-OCT-07 2:42:24PM
NEH-B	S16 55 30.8	E149 12 08.1	23-OCT-07 2:52:52PM
NEH-SN1B	S16 55 17.6	E149 12 21.5	23-OCT-07 7:39:09AM
NEH-SN1E	S16 55 10.2	E149 12 06.1	23-OCT-07 7:41:54AM
NEH-SN2B	S16 56 28.0	E149 12 30.7	23-OCT-07 6:03:19AM
NEH-SN2E	S16 56 15.8	E149 12 19.1	23-OCT-07 8:18:43AM
NEH-SN3B	S16 56 00.8	E149 12 39.2	23-OCT-07 8:42:32AM
NEH-SN3E	S16 55 47.7	E149 12 29.4	23-OCT-07 8:48:19AM
NEH-SN4B	S16 56 24.2	E149 11 48.3	23-OCT-07 9:20:49AM
NEH-SN4E	S16 56 33.7	E149 11 34.1	23-OCT-07 9:26:15AM
NEH-SN5B	S16 56 56.8	E149 11 45.5	23-OCT-07 9:49:34AM
NEH-SN5E	S16 56 51.1	E149 11 28.8	23-OCT-07 9:56:16AM
NEH-SN6B	S16 55 47.4	E149 12 12.6	23-OCT-07 10:19:37AM
NEH-SN6E	S16 55 31.0	E149 12 05.1	23-OCT-07 10:26:31AM
CO-WF	S16 58 30.0	E149 54 31.7	29-OCT-07 2:37:36PM
CO-WFE	S16 58 29.2	E149 54 48.9	29-OCT-07 3:51:24PM
CO-F	S16 58 24.2	E149 55 00.9	20-OCT-07 3:07:38PM
CO-FE	S16 58 25.4	E149 54 42.3	30-OCT-07 9:43:34AM

CO-NE	S16 58 10.8	E149 54 49.3	30-OCT-07 1:04:56PM
CO-NEE	S16 57 58.4	E149 54 38.0	30-OCT-07 3:03:05PM
CO-B	S16 58 03.4	E149 54 18.3	31-OCT-07 7:37:59AM
CO-SN1B	S16 58 21.4	E149 54 53.7	30-OCT-07 8:40:15AM
CO-SN1E	S16 58 22.4	E149 54 42.6	20-OCT-07 3:18:35PM
CO-SN2B	S16 58 26.0	E149 54 21.5	30-OCT-07 9:52:25AM
CO-SN2E	S16 58 18.1	E149 54 07.2	30-OCT-07 10:09:12AM
CH-F	S16 56 25.3	E150 00 37.1	20-OCT-07 2:51:21PM
CH-WF	S16 56 25.4	E149 59 35.9	20-OCT-07 2:56:09PM
CH-WFB	S16 56 39.1	E149 59 58.7	28-OCT-07 9:56:07AM
CH-WFE	S16 56 32.1	E149 59 42.9	28-OCT-07 9:49:24AM
CH-NE	S16 55 35.4	E150 00 57.0	20-OCT-07 2:53:42PM
CH-NEE	S16 55 47.2	E150 00 51.5	28-OCT-07 4:23:33PM
CH-B	S16 55 48.8	E150 00 21.3	29-OCT-07 7:43:21AM
CH-BE	S16 55 59.9	E150 00 08.2	29-OCT-07 10:04:13AM
CH-SN1B = CH-F			
CH-SN1E	S16 56 04.5	E150 00 31.8	20-OCT-07 3:01:08PM
CH-SN2B	S16 56 26.4	E150 00 11.1	28-OCT-07 9:13:32AM
CH-SN2E	S16 56 17.5	E149 59 57.0	28-OCT-07 9:38:08AM
CH-SN3B	S16 56 29.8	E150 00 28.5	28-OCT-07 10:48:31AM
CH-SN3E	S16 56 27.0	E150 00 11.4	28-OCT-07 11:09:39AM
CH-SN4B	S16 56 07.3	E150 00 03.6	28-OCT-07 2:52:21PM
CH-SN4E	S16 56 08.2	E149 59 45.9	28-OCT-07 3:34:43PM
CH-SN5B = CH-BE			
CH-SN5E	S16 56 00.7	E150 00 08.8	29-OCT-07 9:23:29AM
CH-TLD	S16 56 12.5	E149 59 54.0	29-OCT-07 11:15:13AM
CH-TLS	S16 56 15.2	E149 59 54.9	29-OCT-07 11:29:05AM
SEM-NE	S16 35 38.0	E150 20 35.4	24-OCT-07 2:30:32PM
SEM-WF	S16 36 45.0	E150 20 14.2	25-OCT-07 7:39:44AM
SEM-F	S16 36 16.1	E150 20 50.8	25-OCT-07 9:44:26AM
SEM-B	S16 35 48.8	E150 20 01.2	26-OCT-07 9:21:12AM
SEM-SN1B	S16 36 15.1	E150 20 36.0	20-OCT-07 10:21:23AM
SEM-SN1E	S16 35 56.6	E150 20 21.0	20-OCT-07 10:24:53AM
SEM-SN2B	S16 36 28.2	E150 20 26.2	25-OCT-07 9:07:36AM
SEM-SN2E	S16 36 22.7	E150 20 09.6	25-OCT-07 9:29:31AM
SEM-SN3B	S16 36 16.1	E150 19 55.2	26-OCT-07 8:41:33AM
SEM-SN3E	S16 35 58.6	E150 19 49.6	26-OCT-07 9:12:26AM
SEM-SN4B	S16 35 56.7	E150 19 47.2	26-OCT-07 2:46:30PM
SEM-SN4E	S16 35 47.8	E150 20 02.4	26-OCT-07 3:14:20PM
SEM-TLS	S16 36 17.1	E150 19 59.6	25-OCT-07 3:10:52PM
SEM-TLD	S16 36 18.8	E150 19 57.8	25-OCT-07 3:56:01PM

APPENDIX 2: CORAL COLLECTIONS

Population Genetic Samples collected from the Reserve

No. samples	Species	Collection Site	Depth Range	Date collected	Collector	Reef Type	Reef Condition
20	*Porites lichen*	SE Magdeleine Cay	3-12m	26-Oct-2007	Zoe Richards	Backreef	12-14% cover
20	*Acropora tenuis*	SE Magdeleine Cay	3-12m	26-Oct-2007	Zoe Richards	West Flank	12-14% cover
20	*Stylophora pistillata*	SE Magdeleine Cay	3-12m	26-Oct-2007	Zoe Richards	Backreef	12-14% cover
20	*Isopora palifera*	Coringa Islet	6-10m	31-Oct-2007	Zoe Richards	NE Flank	5-8% cover

APPENDIX 3: BENTHIC COMMUNITY ANALYSES

MANOVA of coarse benthic categories by Reef

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.933	402.113[a]	6.000	174.000	.000
	Wilks' Lambda	.067	402.113[a]	6.000	174.000	.000
	Hotelling's Trace	13.866	402.113[a]	6.000	174.000	.000
	Roy's Largest Root	13.866	402.113[a]	6.000	174.000	.000
Reef_n	Pillai's Trace	.881	8.328	24.000	708.000	.000
	Wilks' Lambda	.332	9.411	24.000	608.224	.000
	Hotelling's Trace	1.412	10.151	24.000	690.000	.000
	Roy's Largest Root	.751	22.160[b]	6.000	177.000	.000

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept+Reef_n

Combined ANOVA of % hard coral cover between habitats and reefs

Tests of Between-Subjects Effects

Dependent Variable: %hard coral

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2012.234(a)	17	118.367	7.877	.000
Intercept	9028.348	1	9028.348	600.779	.000
Reef	1130.803	4	282.701	18.812	.000
Habitat	98.313	3	32.771	2.181	.092
Reef * Habitat	730.706	10	73.071	4.862	.000
Error	2494.606	166	15.028		
Total	14208.088	184			
Corrected Total	4506.840	183			

APPENDIX 4: HARD CORAL SPECIES LIST

Scleractinian coral Family	*Genus*	*Species*	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
Family Astrocoeniidae Koby, 1890							
	Genus Stylocoeniella Yabe and Sugiyama, 1935						
		Stylocoeniella armata (Ehrenberg, 1834)		X			**X**
		Stylocoeniella guentheri Bassett-Smith, 1890			X		**X**
Family Pocilloporidae Gray, 1842							
	Genus Pocillopora Lamarck, 1816						
		Pocillopora damicornis (Linnaeus, 1758)		X	X		**X**
		Pocillopora eydouxi Milne Edwards and Haime, 1860	X	X	X	X	**X**
		Pocillopora indiania Veron, 2000				X cf.	**X**
		Pocillopora ligulata Dana, 1846			X	X	**X**
		Pocillopora meandrina Dana, 1846	X	X		X	**X**
		Pocillopora verrucosa (Ellis and Solander, 1786)	X	X	X		**X**
	Genus Seriatopora Lamarck, 1816						
		Seriatopora caliendrum Ehrenberg, 1834		X	X		**X**
	Genus Stylophora Schweigger, 1819						**X**
		Stylophora pistillata Esper, 1797	X	X	X	X	**X**
		Stylophora subseriata (Ehrenberg, 1834)		X			**X**
Family Acroporidae Verrill, 1902							
	Genus Montipora Blainville, 1830						

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
		Montipora crassituberculata Bernard, 1897		X			**X**
		Montipora foliosa (Pallas, 1766)				X	**X**
		Montipora foveolata (Dana, 1846)	X	X			**X**
		Montipora grisea Bernard, 1897				X	**X**
		Montipora incrassata (Dana, 1846)			X	X	**X**
		Montipora tuberculosa (Lamarck, 1816)		X			**X**
		Montipora turgescens Bernard, 1897	X			X	**X**
		Montipora verrucosa (Lamarck, 1816)			X		**X**
	Genus Acropora Oken, 1815						
		Acropora abrotanoides (Lamarck, 1816)		X			**X**
		Acropora aculeus (Dana, 1846)		X	X		**X**
		Acropora acuminata (Verrill, 1864)		X			**X**
		Acropora austera (Dana, 1846)		X		X	**X**
		Acropora cerealis (Dana, 1846)		X			**X**
		Acropora crateriformis (Gardiner, 1898)	X	X		X	**X**
		Acropora cytherea (Dana, 1846)		X			**X**
		Acropora digitifera (Dana, 1846)	X			X	**X**
		Acropora divaricata (Dana, 1846)		X			**X**
		Acropora florida (Dana, 1846)				X	**X**
		Acropora gemmifera (Brook, 1892)	X		X	X	**X**
		Acropora humilis (Dana, 1846)	X		X		**X**
		Acropora hyacinthus (Dana, 1846)		X		X	**X**
		Acropora latistella (Brook, 1891)	X				**X**
		Acropora loripes (Brook, 1892)		X		X	**X**
		Acropora lutkeni Crossland, 1952		X			**X**
		Acropora millepora (Ehrenberg, 1834)		X	X	X	**X**
		Acropora monticulosa (Brüggemann, 1879)		X			**X**
		Acropora nasuta (Dana, 1846)		X	X	X	**X**
		Acropora nobilis (Dana, 1846) - INTERMEDIA		X			**X**
		Acropora palifera (Lamarck, 1816)	X	X	X		**X**
		Acropora palmerae Wells, 1954		X			**X**

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
		Acropora polystoma (Brook, 1891)				X	**X**
		Acropora robusta (Dana, 1846)		X		X	**X**
		Acropora samoensis (Brook, 1891)		X			**X**
		Acropora secale (Studer, 1878)		X	X		**X**
		Acropora selago (Studer, 1878)	X	X			**X**
		Acropora subulata (Dana, 1846)		X			**X**
		Acropora tenuis (Dana, 1846)	X	X		X	**X**
		Acropora vaughaniWells, 1954		X	X		**X**
		Acropora verweyi Veron and Wallace, 1984		X			**X**
	Genus Astreopora Blainville, 1830						
		Astreopora gracilis Bernard, 1896				X	**X**
		Astreopora listeri Bernard, 1896		X	X	X	**X**
		Astreopora macrostoma Veron and Wallace, 1984		X			**X**
		Astreopora myriophthalma (Lamarck, 1816)	X	X	X	X	**X**
Family Euphyllidae Veron, 2000							
	Genus Euphyllia Dana, 1846						
		Euphyllia glabrescens (Chamisso and Eysenhardt, 1821)		X	X		**X**
	Genus Plerogyra Milne Edwards and Haime, 1848						
		Plerogyra sinuosa (Dana, 1846)		X			**X**
Family Oculinidae Gray, 1847							
	Genus Galaxea Oken, 1815						
		Galaxea fascicularis (Linnaeus, 1767)	X		X		**X**
Family Siderasteridae Vaughan and Wells, 1943							
	Genus Siderastrea Blainville, 1830						
		Siderastrea savignyana Milne Edwards and Haime, 1850		X			**X**
	Genus						

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
	Psammocora Dana, 1846						
		Psammocora digitata Milne Edwards and Haime, 1851	X				**X**
		Psammocora nierstraszi Horst, 1921		X			**X**
	Genus Coscinaraea Milne Edwards and Haime, 1848						
		Coscinaraea columna (Dana, 1846)	X	X	X		**X**
		Coscinaraea exesa (Dana, 1846)		X	X		**X**
Family Agariciidae Gray, 1847							
	Genus Pavona Lamarck, 1801						
		Pavona duerdeni Vaughan, 1907		X		X	**X**
		Pavona explanulata (Lamarck, 1816)			X		**X**
		Pavona maldivensis (Gardiner, 1905)		X	X	X	**X**
		Pavona varians Verrill, 1864	X		X	X	**X**
		Pavona venosa (Ehrenberg, 1834)	X				**X**
	Genus Leptoseris Milne Edwards and Haime, 1849						
		Leptoseris explanata Yabe and Sugiyama, 1941		X			**X**
	Genus Coeloseris Vaughan, 1918						
		Coeloseris mayeri Vaughan, 1918				X	**X**
	Genus Gardineroseris Scheer and Pillai, 1974						
		Gardineroseris planulata Dana, 1846				X	**X**
Family Fungiidae Dana, 1846							
	Genus Fungia Lamarck, 1801						
		Fungia paumotensis Stutchbury, 1833		X			**X**
		Fungia repanda Dana, 1846			X		**X**

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
	Genus Herpolitha Eschscholtz, 1825						
		Herpolitha limax (Houttuyn, 1772)	X		X	X	**X**
	Genus Halomitra Dana, 1846						
		Halomitra pileus (Linnaeus, 1758)		X			**X**
Family Pectiniidae Vaughan and Wells, 1943							
	Genus Echinophyllia Klunzinger, 1879						
		Echinophyllia aspera (Ellis and Solander, 1788)				X	**X**
Family Merulinidae Verrill, 1866							
	Genus Hydnophora Fischer de Waldheim, 1807						
		Hydnophora exesa (Pallas, 1766)	X	X	X	X	**X**
		Hydnophora microconos (Lamarck, 1816)		X	X	X	**X**
Family Dendrophylliidae Gray, 1847							
	Genus Turbinaria Oken, 1815						
		Turbinaria mesenterina (Lamarck, 1816)				x	**X**
		Turbinaria peltata (Esper, 1794)		X			**X**
Family Mussidae Ortmann, 1890							
	Genus Acanthastrea Milne Edwards and Haime, 1848						
		Acanthastrea brevis Milne Edwards and Haime, 1849	X				**X**
		Acanthastrea echinata (Dana, 1846)	X	X	X	X	**X**
		Acanthastrea hemprichii (Ehrenberg, 1834)	X		X	X	**X**
		Acanthastrea regularis Veron, 2000				X cf	**X**
	Genus Lobophyllia Blainville, 1830						
		Lobophyllia corymbosa (Forskål, 1775)				X	**X**

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
		Lobophyllia hemprichii (Ehrenberg, 1834)	X		X	X	**X**
		Lobophyllia robusta Yabe and Sugiyama, 1936				X	**X**
	Genus Symphyllia Milne Edwards and Haime, 1848						
		Symphyllia recta (Dana, 1846)	X	X	X	X	**X**
		Symphyllia valenciennesii Milne Edwards and Haime, 1849				X	**X**
Family Faviidae Gregory, 1900							
	Genus Caulastrea Dana, 1846						
		Caulastrea furcata Dana, 1846	X				X
	Genus Favia Oken, 1815						
		Favia laxa (Klunzinger, 1879)	X	X		X	**X**
		Favia matthaii Vaughan, 1918	X			X	**X**
		Favia pallida (Dana, 1846)	X	X	X		**X**
		Favia rotumana (Gardiner, 1899)	X			X	**X**
		Favia rotundata Veron, Pichon & Wijsman-Best, 1972		X	X	X	**X**
		Favia speciosa Dana, 1846	X	X	X	X	**X**
		Favia stelligera (Dana, 1846)	X				**X**
		Favia veroni Moll and Borel-Best, 1984	X			X	**X**
	Genus Barabattoia Yabe and Sugiyama, 1941						
		Barabattoia laddi (Wells, 1954)			X		**X**
	Genus Favites Link, 1807						
		Favites abdita (Ellis and Solander, 1786)	X				**X**
		Favites chinensis (Verrill, 1866)	X				**X**
		Favites complanata (Ehrenberg, 1834)	X			X	**X**
		Favites flexuosa (Dana, 1846)			X		**X**
		Favites halicora (Ehrenberg, 1834)		X		X	**X**

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
	Genus Goniastrea Milne Edwards and Haime, 1848						
		Goniastrea australensis (Milne Edwards and Haime, 1857)	X		X	X	**X**
		Goniastrea edwardsi Chevalier, 1971	X				**X**
		Goniastrea favulus (Dana, 1846)	X		X		**X**
		Goniastrea palauensis (Yabe and Sugiyama, 1936)		X cf.			**X**
		Goniastrea pectinata (Ehrenberg, 1834)	X	X	X	X	**X**
		Goniastrea retiformis (Lamarck, 1816)				X	**X**
	Genus Platygyra Ehrenberg, 1834						
		Platygyra lamellina (Ehrenberg, 1834)	X	X	X	X	**X**
		Platygyra pini Chevalier, 1975		X			**X**
		Platygyra ryukyuensis Yabe and Sugiyama, 1936	X			X	**X**
		Platygyra sinensis (Milne Edwards and Haime, 1849)	X		X	X	**X**
	Genus Oulophyllia Milne Edwards and Haime, 1848						
		Oulophyllia bennettae (Veron & Pichon, 1977)	X				**X**
		Oulophyllia crispa (Lamarck, 1816)				X	**X**
	Genus Leptoria Milne Edwards and Haime, 1848						
		Leptoria phrygia (Ellis and Solander, 1786)		X		X	**X**
	Genus Montastrea Blainville, 1830						
		Montastrea curta (Dana, 1846)	X			X	**X**
		Montastrea magnistellata Chevalier, 1971				X	**X**
		Montastrea salebrosa (Nemenzo, 1959)			X	X	**X**
		Montastrea valenciennesi (Milne Edwards and Haime, 1848)	X	X		X	**X**

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
	Genus Diploastrea Matthai, 1914						
		Diploastrea heliopora (Lamarck, 1816)		X		X	**X**
	Genus Leptastrea Milne Edwards and Haime, 1848						
		Leptastrea inaequalis Klunzinger, 1879				X	**X**
		Leptastrea purpurea (Dana, 1846)				X	**X**
	Genus Cyphastrea Milne Edwards and Haime, 1848						
		Cyphastrea chalcidium (Forskål, 1775)	X				**X**
		Cyphastrea microphthalma (Lamarck, 1816)			X		**X**
		Cyphastrea serailia (Forskål, 1775)	X		X	X	**X**
	Genus Echinopora Lamarck, 1816						
		Echinopora gemmacea Lamarck, 1816	X	X			**X**
		Echinopora horrida Dana, 1846		X			**X**
		Echinopora lamellosa (Esper, 1795)				X	**X**
		Echinopora mammiformis (Nemenzo, 1959)	X				**X**
	Genus Moseleya Quelch, 1884						
		Moseleya latistellata Quelch, 1884	X			X	**X**
Family Poritidae Gray, 1842							
	Genus Porites Link, 1807						
		Porites australiensis Vaughan, 1918	X	X		X	**X**
		Porites cylindrica Dana, 1846		X	X		**X**
		Porites horizontalata Hoffmeister, 1925		X	X	X	**X**
		Porites lichen Dana, 1846	X	X	X	X	**X**
		Porites lobata Dana, 1846	X			X	**X**
		Porites lutea Milne Edwards & Haime, 1851	X	X	X	X	**X**
		Porites nigrescens Dana, 1846		X	X		**X**
	Genus Goniopora Blainville, 1830						

Scleractinian coral Family	Genus	Species	NE Herald Island	SE Madgelaine Cay	Chilcott Islet	Coringa Islet	Reserve Total
		Goniopora lobata Milne Edwards and Haime, 1860		X	X	X	**X**
		Goniopora tenuidens (Quelch, 1886)	X	X			**X**
			58	**77**	**52**	**74**	**140**

APPENDIX 5: INVERTEBRATE ANALYSES

ANOVA of holothurians (log-transformed) by Reef and Habitat

Tests of Between-Subjects Effects

Dependent Variable: log_allcukes

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	41.471(a)	13	3.190	7.043	.000
Intercept	89.324	1	89.324	197.197	.000
Reef	29.493	4	7.373	16.278	.000
Habitat	4.052	2	2.026	4.473	.016
Reef x Habitat	7.291	7	1.042	2.299	.041
Error	22.648	50	.453		
Total	184.435	64			
Corrected Total	64.119	63			

a R Squared = .647 (Adjusted R Squared = .555)

Multiple Comparisons

(I) Reef	(J) Reef	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Upper Bound	Lower Bound
NE Herald	SE Magdelaine	-1.1015(*)	.23967	.000	-1.7797	-.4233
	Chilcott	-1.5812(*)	.22814	.000	-2.2268	-.9356
	Coringa	.0380	.27625	1.000	-.7438	.8197
	SW Herald	-.1579	.29052	.982	-.9800	.6643
SE Magdelaine	NE Herald	1.1015(*)	.23967	.000	.4233	1.7797
	Chilcott	-.4797	.26477	.378	-1.2290	.2695
	Coringa	1.1395(*)	.30719	.005	.2702	2.0088
	SW Herald	.9436(*)	.32009	.037	.0378	1.8494
Chilcott	NE Herald	1.5812(*)	.22814	.000	.9356	2.2268
	SE Magdelaine	.4797	.26477	.378	-.2695	1.2290
	Coringa	1.6192(*)	.29829	.000	.7751	2.4633
	SW Herald	1.4234(*)	.31155	.000	.5417	2.3050
Coringa	NE Herald	-.0380	.27625	1.000	-.8197	.7438
	SE Magdelaine	-1.1395(*)	.30719	.005	-2.0088	-.2702
	Chilcott	-1.6192(*)	.29829	.000	-2.4633	-.7751
	SW Herald	-.1958	.34833	.980	-1.1815	.7898
SW Herald	NE Herald	.1579	.29052	.982	-.6643	.9800
	SE Magdelaine	-.9436(*)	.32009	.037	-1.8494	-.0378
	Chilcott	-1.4234(*)	.31155	.000	-2.3050	-.5417
	Coringa	.1958	.34833	.980	-.7898	1.1815

Based on observed means.
* The mean difference is significant at the .05 level.

MANOVA of holothurians by reef and habitat

Multivariate Tests^c

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.431	3.104^a	10.000	41.000	.005
	Wilks' Lambda	.569	3.104^a	10.000	41.000	.005
	Hotelling's Trace	.757	3.104^a	10.000	41.000	.005
	Roy's Largest Root	.757	3.104^a	10.000	41.000	.005
Reef_n	Pillai's Trace	1.083	1.633	40.000	176.000	.017
	Wilks' Lambda	.256	1.701	40.000	157.323	.012
	Hotelling's Trace	1.781	1.758	40.000	158.000	.008
	Roy's Largest Root	1.024	4.505^b	10.000	44.000	.000
Habitat_n	Pillai's Trace	.518	1.466	20.000	84.000	.116
	Wilks' Lambda	.523	1.569^a	20.000	82.000	.081
	Hotelling's Trace	.834	1.669	20.000	80.000	.057
	Roy's Largest Root	.728	3.056^b	10.000	42.000	.005
Reef_n * Habitat_n	Pillai's Trace	1.191	.964	70.000	329.000	.563
	Wilks' Lambda	.219	1.044	70.000	245.886	.396
	Hotelling's Trace	2.045	1.148	70.000	275.000	.219
	Roy's Largest Root	1.259	5.918^b	10.000	47.000	.000

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept+Reef_n+Habitat_n+Reef_n * Habitat_n

ANOVA of log transformed total Clams by reef and habitat

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.855	11	.441	1.247	.296
Intercept	79.210	1	79.210	223.737	.000
Reef	2.704	3	.901	2.546	.072
Habitat	.524	2	.262	.740	.485
Reef x Habitat	.982	6	.164	.462	.831
Error	12.037	34	.354		
Total	110.109	46			
Corrected Total	16.892	45			

MANOVA of log transformed clam species by Reef and Habitat

Multivariate Tests(c)

Effect		Value	F	Hypothesis df	Error df	Sig.
Reef	Pillai's Trace	.316	.972	12.000	99.000	.481
	Wilks' Lambda	.704	.975	12.000	82.310	.480
	Hotelling's Trace	.393	.972	12.000	89.000	.481
	Roy's Largest Root	.306	2.523	4.000	33.000	.060

Habitat	Pillai's Trace	.191	.844	8.000	64.000	.568
	Wilks' Lambda	.816	.828	8.000	62.000	.581
	Hotelling's Trace	.216	.812	8.000	60.000	.595
	Roy's Largest Root	.163	1.306	4.000	32.000	.289
Reef x Habitat	Pillai's Trace	.345	.534	24.000	136.000	.962
	Wilks' Lambda	.688	.516	24.000	109.356	.968
	Hotelling's Trace	.408	.502	24.000	118.000	.973
	Roy's Largest Root	.245	1.389	6.000	34.000	.247

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	log_maxsqua	1.074	3	.358	.959	.423
	log_gigas	.056	3	.019	.446	.722
	log_derasa	.170	3	.057	.414	.744
	log_hip	3.294	3	1.098	3.121	.039
Habitat	log_maxsqua	.319	2	.159	.427	.656
	log_gigas	.054	2	.027	.641	.533
	log_derasa	.260	2	.130	.952	.396
	log_hip	1.907	2	.953	2.710	.081
Reef x Habitat	log_maxsqua	.945	6	.157	.422	.859
	log_gigas	.070	6	.012	.277	.944
	log_derasa	.122	6	.020	.149	.988
	log_hip	2.544	6	.424	1.205	.327
Error	log_maxsqua	12.690	34	.373		
	log_gigas	1.426	34	.042		
	log_derasa	4.647	34	.137		
	log_hip	11.961	34	.352		

APPENDIX 6: FISH ANALYSES

ANOVA of Number of species by Reef and Exposure

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	10.393	3	3.464	.220	.883
Exposure	2.133	1	2.133	.135	.714
Reef x Exposure	**276.372**	**3**	**92.124**	**5.841**	**.001**
Error	1640.354	104	15.773		

ANOVA of fish density by Reef and Exposure

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	**.526**	**3**	**.175**	**3.436**	**.020**
Exposure	**2.694**	**1**	**2.694**	**52.783**	**.000**
Reef x Exposure	.139	3	.046	.908	.440
Error	5.307	104	.051		

ANOVA of all serranids by reef (big fish)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	271.257	4	67.814	8.253	.000
Error	205.429	25	8.217		

ANOVA of *P. laevis* by reef (big fish)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	2.673	4	.668	11.737	.000
Error	1.423	25	.057		

ANOVA of all sharks by reef (big fish)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	38.211	4	9.553	3.359	.025
Error	71.099	25	2.844		

ANOVA of roving herbivores by reef and exposure (transects)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	**2.311**	**4**	**.578**	**4.546**	**.002**
Exposure	.285	1	.285	2.244	.136
Reef * Exposure	1.175	4	.294	2.310	.060
Error	19.448	153	.127		

Multiple Comparisons

(I) Reef	(J) Reef	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Upper Bound	Lower Bound
NEH	SEM	.0899	.08207	.809	-.1367	.3164
	CH	.0878	.08207	.822	-.1388	.3144
	CO	.1567	.08207	.316	-.0698	.3833
	SWH	-.3035(*)	.09389	.013	-.5627	-.0443
SEM	NEH	-.0899	.08207	.809	-.3164	.1367
	CH	-.0021	.08913	1.000	-.2481	.2440
	CO	.0669	.08913	.944	-.1792	.3129
	SWH	-.3933(*)	.10013	.001	-.6698	-.1169
CH	NEH	-.0878	.08207	.822	-.3144	.1388
	SEM	.0021	.08913	1.000	-.2440	.2481
	CO	.0689	.08913	.938	-.1771	.3150
	SWH	-.3913(*)	.10013	.001	-.6677	-.1149
CO	NEH	-.1567	.08207	.316	-.3833	.0698
	SEM	-.0669	.08913	.944	-.3129	.1792
	CH	-.0689	.08913	.938	-.3150	.1771
	SWH	-.4602(*)	.10013	.000	-.7366	-.1838
SWH	NEH	.3035(*)	.09389	.013	.0443	.5627
	SEM	.3933(*)	.10013	.001	.1169	.6698
	CH	.3913(*)	.10013	.001	.1149	.6677
	CO	.4602(*)	.10013	.000	.1838	.7366

ANOVA of *C. microrhinus* by reef (transects)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	2.897	3	.966	3.389	.021
Error	30.781	108	.285		

ANOVA of *C. undulatus* by reef (big fish)

Tests of Between-Subjects Effects

Dependent Variable: che_undulatus

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Reef	3.112	4	.778	.956	.448
Error	20.338	25	.814		

Fish Family MANOVA

Multivariate Tests(c)

Effect		Value	F	Hypothesis df	Error df	Sig.
Reef	**Pillai's Trace**	**.566**	**3.685**	**18.000**	**285.000**	**.000**
	Wilks' Lambda	.518	3.838	18.000	263.529	.000
	Hotelling's Trace	.776	3.950	18.000	275.000	.000
	Roy's Largest Root	.495	7.842(b)	6.000	95.000	.000
Habitat	**Pillai's Trace**	**.924**	**7.042**	**18.000**	**285.000**	**.000**
	Wilks' Lambda	.246	9.391	18.000	263.529	.000
	Hotelling's Trace	2.410	12.271	18.000	275.000	.000
	Roy's Largest Root	2.128	33.701(b)	6.000	95.000	.000
Reef xHabitat	**Pillai's Trace**	**.970**	**2.701**	**42.000**	**588.000**	**.000**
	Wilks' Lambda	.309	2.974	42.000	439.661	.000
	Hotelling's Trace	1.460	3.176	42.000	548.000	.000
	Roy's Largest Root	.835	11.687(b)	7.000	98.000	.000