

Commonwealth Environment Research Facilities

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A comparative study between fished and protected inter-reefal shoal habitats and their fish communities on the Great Barrier Reef

Report on ongoing monitoring off Townsville and initial surveys near Cardwell and Cairns, North Queensland

Peter Speare and Marcus Stowar



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Supported by the Australian Government's
Marine and Tropical Sciences Research Facility
Project 4.8.2 Effects of the Great Barrier Reef Zoning Plan
on inshore habitats and biodiversity: Shoals

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National Library of Australia Cataloguing-in-Publication entry:

Author: Speare, Peter.
Title: A comparative study between fished and protected inter-reefal shoal habitats and their fish communities on the Great Barrier Reef : report on ongoing monitoring off Townsville and initial surveys near Cardwell and Cairns, North Queensland / Peter Speare, Marcus Stowar.
ISBN: 9781921359040 (pdf)
Notes: Bibliography.
Subjects: Fish surveys—Queensland—Great Barrier Reef.
Fish populations—Queensland—Great Barrier Reef.
Fishes—Habitat—Queensland—Great Barrier Reef.
Other Authors/Contributors: Stowar, Marcus, 1975-
Reef and Rainforest Research Centre.
Dewey Number: 597.009943

This report should be cited as:

Speare, P. and Stowar, M. (2008) *A comparative study between fished and protected inter-reefal shoal habitats and their fish communities on the Great Barrier Reef. Report on ongoing monitoring off Townsville and initial surveys near Cardwell and Cairns, North Queensland.* Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns (60pp.).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's Marine and Tropical Sciences Research Facility.

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Published in April 2008.

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Acronyms Used In This Report

ANOVA	Analysis of variance
BRUVS	Baited Remote Underwater Video Stations
CAP	Canonical analysis of principal coordinates
DISTLM	Distance based multivariate analysis for a linear model
DTM	Digital Terrain Model
EWE	East North-east
GPS	Global Positioning System
IHO	International Hydrographic Office
MPA	Marine Protected Area
MTSRF	Marine and Tropical Sciences Research Facility
NNW	North North-west
NW	North-west
N-S	North to South
PERMANOVA ...	Permutational multivariate analysis of variance
RAP	Representative Areas Program
SBRUVS	Stereo Baited Remote Underwater Video Stations
SE	South-east
SSE	South South-east
TSS DMS	TSS International Dynamic Motion Sensors
WSW	West South-west
WGS	World Geodetic System

Abstract

This report encompasses baseline studies of fish and habitats on shoal ground in the Cardwell and Cairns regions of the Great Barrier Reef, and seasonal monitoring of an established set of contrasting sites (closed and open to fishing) in the vicinity of Townsville. Acoustic mapping techniques were utilised to provide topographical imagery of all study sites for the purposes of directing towed video for habitat classification, and the deployment of Baited Remote Underwater Video Stations (BRUVS) for the acquisition of fish species and their relative abundance in habitats on these shoal areas.

Townsville

All sites in the Townsville region were from unconsolidated sandy sediments supporting marine plants with patches of structurally more complex and diverse epibenthic communities of filter feeders and some hard corals. One site, RAP 4 was centred on the wreck of a wooden trawler.

BRUVS sampled 150 species from 39 Families of fish over four discreet sampling events between July 2006 and March 2007. There was roughly twice the number of species recorded from each set on complex habitat compared to the surrounding habitat (109 versus 71 species overall). Species richness did not vary with the level of protection or throughout the sampling period.

The distribution and relative abundance of fish assemblages varied with protection and location on each of the two principal habitat types. There was an interaction between these two factors which was due to the fish assemblages in the complex habitat on Magnetic Shoal having greater similarity to those on the Mackerel Patch, and the fish assemblages over sand at RAP 4 and RAP 16 being distinct from those in the green zone and Magnetic Shoal.

The distributions and relative abundances of 22 species potentially targeted by fishers were similarly influenced by the level of protection, but possibly because of a confounded site effect. There was believable evidence of an increase in the abundance of *Plectropomus maculatus* and *Choerodon venustus* in the new green zone.

Cardwell

The shoal study sites off Cardwell are founded on rocky substrate with surrounding fine sand sediments. Their inshore and relatively shallow water attributes ensure relatively turbid conditions in response to wind driven wave and tidal movements.

BRUVS sampled 65 species from 27 families with, on average, twelve species from the rocky substrates and six species from the muddy sand bottom surrounding these outcrops. While there was site-associated differences in the fish communities (distribution and relative abundance) the greatest dissimilarity between fish assemblages could be attributed to the two principal habitat divisions (hard rock and soft sediment). *Parupeneus indicus*, *Plectropomas maculatus*, *Choerodon schoenleinii* and *Scarus ghobban* were strongly correlated with hard bottom habitat, whereas *Scomberomorus queenslandicus*, *Carangoides coeruleopinnatus* and *Nemipterus furcosus* were indicative of open bottom habitat. Fish communities were similar across sites on rocky substrate, but there was a site effect in relation to fish assemblages over the soft sediments that was attributed to the more mobile species inhabiting these areas.

Of fourteen targeted species, there was evidence that *Lutjanus erythropterus*, *Epinephelus coioides*, *Scomberomorus queenslandicus*, *Choerodon schoenleinii* and *Lethrinus laticaudis* are more abundant at Brook Shoal, which was protected from fishing in 2004.

The limited extent of rocky habitat at both Brook Shoal and Forty Foot Rock precluded extensive sampling effort, which means that more temporal effort must be employed to resolve any zoning effects.

Cairns

Three paired sites with contrasting zoning were established in the Cairns region on deep-water shoals in the vicinity of emergent coral reefs. In general, all sites offered similar habitats except that the sites adjacent to Green Island lacked marine plants, possibly in response to lower light levels coincident with higher turbidity.

Cairns sites shared 140 fish species from diverse taxonomic and trophic functional groups. Fish assemblages had a strong association with either the sandy open bottom or the structurally and biologically diverse reef habitats, with more than twice the number of species associating with the complex habitat.

The distributions and relative abundances of 24 species of interest to fishers were not discriminated simply on the basis of protection because of interactions between location and habitat effects. *Plectropomus leopardus* and *Lethrinus lentjan* were more abundant at the protected site adjacent to Michaelmas reef and *Argyrops spinifer* at the protected site adjacent to Green Island, but thus far the effects of the rezoning have not had a large impact upon the fish communities of reefs near to Cairns.

1. Introduction

Marine Protected Areas (MPAs) are often established to manage and maintain fisheries and fish biodiversity (Russ 2002, Friedlander and DeMartini 2002, Halpern 2003) and associated habitats (e.g. Ashworth and Ormond 2005). The comparison of long-standing MPAs with adjacent control areas shows that fishing results in the selective removal of species, especially apex predators (Russ and Alcala 1996), which can have indirect effects on fish community structure and other functional groups (Kingsford 1998, Willis and Anderson 2003).

The Great Barrier Reef Marine Park Zoning Plan (2003) came into effect on 1 July 2004 and greatly extended the amount of “no take” zones protected from extractive uses, primarily fishing, especially in non-reef habitats (Cappo *et al.* 2004). This change in zoning provided a rare opportunity to examine the responses of biodiversity (both predators and prey) when released from fishing pressure. The Marine and Tropical Sciences Research Facility (MTSRF) Project 4.8.2 consists of two tasks sharing common goals. This report concerns the impact of the change in zoning upon the biodiversity of submerged shoals. A parallel report by researchers from James Cook University will present the impact of the change in zoning upon the biodiversity of shallow coral reefs.

2. Objectives

The objectives of the shoals project (Project 4.8.2) in the MTSRF Annual Research Plan for Year 1 (ARP1) were:

- Collect baseline data from shoals near Townsville and Cardwell, contrasting shoals protected from fishing since July 2004 (no-take, green zones) with shoals that have remained available for fishing (open, blue zones).
- Repeat the sampling of the Townsville shoals to capture any seasonal changes in the fish assemblages.

Part-way through the year, the Reef and Rainforest Research Centre, which facilitates the MTSRF in North Queensland, issued a letter of variation adding:

- Collect baseline data from other locations nominated by the Great Barrier Reef Marine Park Authority (GBRMPA).

In this report, we cover the off objectives of the original MTSRF project and present the results for one additional area: Cairns.

3. Methods

3.1 Study Sites

Townsville

The shoal grounds of concern off Townsville are referred to as the Magnetic Shoals. We reported previously (Speare and Stowar 2007) that many of the given 'fishing marks' in the area known as the Magnetic Shoals are low relief seabed habitats that have little definition in acoustic maps but can be seen as sparse epibenthic communities with towed video.

Five relatively small areas with epibenthic structure were identified from the new Green Zone created around Palm Islands in Halifax Bay. The close proximity of three (RAP 12, 13 and 14) suggested that they should be pooled and treated as a single unit, hereafter identified as RAP 12 (Figure A1). Three contrasting sites were located in the General Use Area to the North (RAP 16), East (RAP 4) and Southeast (Mackerel Patch) (Speare and Stowar 2007). Acoustic images of these study sites are shown in Appendix 1.

Cardwell

Brook Shoal (MNP-18-1077) was identified by the GBRMPA as an area of interest to local fishers that had been rezoned to a no-take MPA in 2004. Located between the Brook Islands and Hinchinbrook Island, it is a group of three small patches of rocky substrate extending ~300m ENE by WSW (Figure B1). The largest central rock has an extent of ~75m and the outlying rocks are each in the order of a quarter of this size (Appendix 1). The shoal rises to ~11m off a muddy sand bottom at ~15m. The closest known hard bottom habitat is at Brook Islands some 2.5kms to the east.

Sites available to fishers and with similar rocky substrates were located at Eva Island, which is 10km SSE of Brook Shoal, and Woln Garin Island, 20km NNW of Brook Shoal. Eva Rock is a rocky shoal bridging between Eva and Hinchinbrook Islands, a distance of ~1.5km, and extending ~1km N-S. The surrounding unconsolidated bottom is similar muddy sand to Brook Shoal as are the surrounding depths and rise of the rocky bottom. This site differs in that it is in the order of one hundred times more extensive than Brook Shoal and is connected to further rocky habitat on Hinchinbrook and Eva Islands.

The shoal ground referred to as Forty Foot Rock lies ~1km SE of Dunk Island and is more similar to Brook Shoal albeit slightly smaller. It consists of a section of rocky substrate extending ~80m with two very small satellite rocks nearby rising to ~18m off a surrounding muddy sand bottom at ~22m (Figure B1).

Cairns

Shoal features are relatively extensive in the Cairns region and provided a lot more choices of similar physical sites with contrasting zoning. The features chosen were typically comprised of small reef-like structures scattered on a sandy bottom in depths of 25-40m. Three paired sites, representing both Green and Blue Zones, were established between Green Island and Hastings Reefs (Figure C1 and Appendix 1).

3.2 Sampling

Acoustic survey

Bathymetry was recorded with a pole-mounted multibeam echo sounder RESON Seabat 8101 (Stieglitz 2006a). Vessel track and heading were recorded with the vessel's own GPS and gyrocompass. The motion of the vessel was recorded with a TSS DMS dynamic motion sensor mounted at the centre of gravity of the vessel. Dynamic offsets were calculated from a patch test at Wirraway Shoal and Eva Rocks respectively to survey standards of the International Hydrographic Office (IHO).

The Seabat 8101 multibeam echo sounder has 101 beams with an angle of 1.5° athwart ship for each beam. It records bathymetry in a swath of a total width of approximately seven times the water depth. Data was processed with the software SWATHED by the Ocean Mapping Group of the University of New Brunswick, Canada, and visualised with IVS Fledermaus. Sonar ranges measured with the echo sounder were converted to depth by integrating the range, GPS, heading and motion data whereby the acoustic data was corrected for refraction using sound velocity profiles recorded at the start and end of each survey, and tidal water level variation was corrected for using high-resolution tidal predictions or *in situ* recordings.

At each site, the survey consisted of numerous parallel survey tracks. The water depth determined the distance between tracks. In general, tracks were spaced apart such that 100% overlap was achieved, i.e. each point on the seafloor was ensonified twice, which resulted in optimum spatial resolution of the digital terrain model (DTM). The processed xyz data was converted into a DTM with a spatial resolution of 0.5m by weighted gridding, whereby outer-beam data with a larger acoustic footprint was given a smaller weight than high-resolution inner-beam data. Weights were selected proportional to beam number, and data from the outer five beams on both port and starboard side was disregarded. The data available from these surveys were converted to geo-referenced images for the purpose of navigating over the terrain (Plate 1).

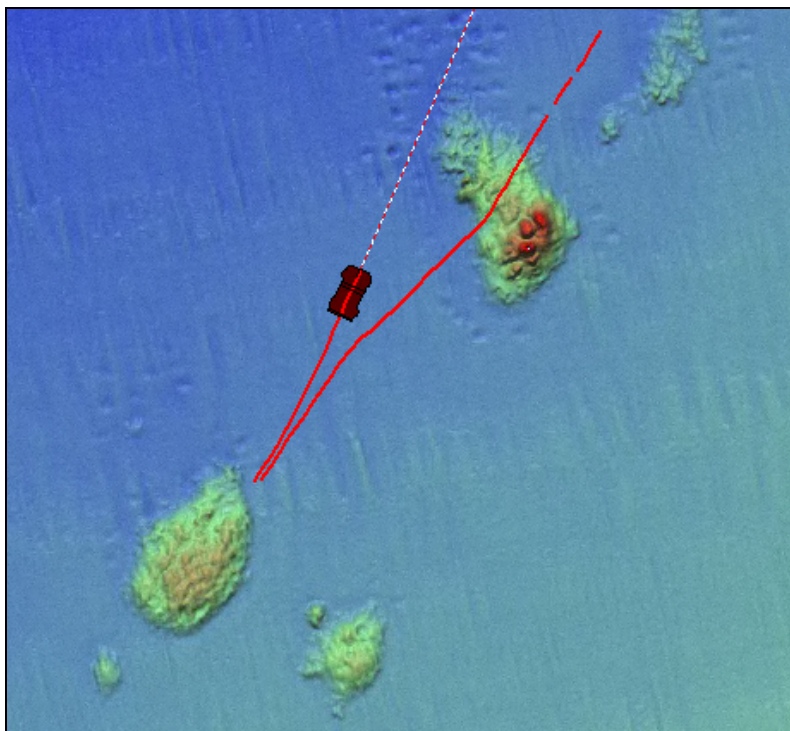


Figure 1: Acoustic data rendered as georeferenced terrain provide accurate navigation control of towed video classification of substrates and benthos and deployment of BRUVS and SBRUVS.

Habitat mapping

Habitat classification was undertaken as per Speare and Cappel (2006) with a low-voltage underwater video system towed behind the vessel. The classification scheme included a schema for the abiotic substrate components and the overlying benthic organisms (Appendix 2). A limited suite of individual organisms of interest could also be recorded as point events. All data records were fixed in four dimensions, viz. latitude, longitude, depth and time, and georeferenced to the World Geodetic System, WGS84, at a resolution typically less than 5m horizontally, 0.5m vertically and three seconds temporally. These data were summarised to provide information on the relative contributions of each class to the habitats on each of the study sites.

Fish abundance

BRUVS baited with ~0.5kg of pilchards as an attractant (Cappel *et al.* 2003) were deployed on the study sites (Appendix 3). Deployment sites were chosen with reference to the towed video footage and acoustic maps to enable precise positioning with respect to habitat type and features (Appendix 1). The small size of habitat patches, specifically in the Townsville and Cardwell areas, and the constraints associated with independent sampling (ideally limiting sets to a minimum separation of 300m, Cappel *et al.* 2004) often restricted BRUVS sets to one on the habitat at any time. BRUVS were nominally soaked for one hour and the fish fauna identified and enumerated over the full period of video capture. Tape reading, the process of extracting numerical information on each species/taxon identified from the BRUVS set, was undertaken to provide an index of relative abundance (MaxN) which is the maximum number of individuals of a species sighted over the sampling period (= soak time). As the gear has a fixed, stationary field of view, fish will move in and out of view such that MaxN is necessarily restricted to a brief period of time, typically seconds. In this way, no fish is counted twice and the relative abundance estimates are invariably conservative (Willis *et al.* 2000).

Fish size

Stereo BRUVS (SBRUVS) offer the opportunity to accurately measure individual fish size (Harvey *et al.* 2003), which is useful since the first impact of fishing is to reduce mean fish size by selective removal of the largest individuals. As the processing time required to recover fish measurements is high, SBRUVS were deployed only on sites where targets of interest were seen in the BRUVS sets. Software designed to enable linear measurements to be obtained from stereo imagery (Vision Metrology Services, Melbourne, Victoria) provided ~5mm accuracy in the measurement of fish length from the recovered footage (e.g. Harvey *et al.* 2001). Note, SBRUVS data are not reported here and were not specified in the MTSRF contract but have been collected as part of the baseline studies and may be used in the future if sites continue to be monitored.

3.3 Data Analysis

Data from each region were analysed separately, rather than pooled, because of regional differences in the habitats and fish assemblages caused by a range of uncontrollable factors. For example, sites in Rockingham Bay are coastal, whereas sites from Cairns are in the reef matrix on the outer shelf. The nominal experimental design was two fixed levels of protection (take and no-take) and three replicates of each; however this option was not available in Rockingham Bay due to the scarcity of suitable habitat. Even in Townsville, we don't believe that all of the sites within a treatment can be considered good replicates of each other, and an unbalanced design was forced on us again by available habitat.

Permutational distance-based analyses were used because of the inherent skewness of census data where many zero counts occur. The species relative abundance matrices were 4th root transformed and row standardised prior to conversion to Bray-Curtis dissimilarity matrices. Where possible (fully balanced ANOVA design), permutational multivariate analysis of variance (PERMANOVA, see Anderson 2001) was undertaken to examine the contributions and interactions of the main effects of protection and site. Each factor was independently tested with the programme DISTLM (distance based multivariate analysis for a linear model, see McArdle and Anderson 2001) that is also capable of analysing an unbalanced experimental design. Canonical analysis of principal coordinates (CAP, see Anderson and Willis 2003) was employed to discriminate fish assemblages at protected and fished sites as this analysis has been demonstrated to produce a more robust multivariate solution where group differences do not align with the direction of overall variation (Anderson and Willis 2003). CAP also calculates the correlation values for each species and identifies those having the greatest influence over the observed differences.

Each species was assigned to one of ten trophic groups and the data subsequently investigated using the multivariate strategies to identify any role of protection status, geographical position and habitat type on the functional profile of associated fish assemblages:

- Algae / invertebrates;
- Corallivore;
- Generalist carnivore;
- Generalist macrocarnivore;
- Herbivore;
- Invertebrate carnivore;
- Macroinvertebrate carnivore;
- Piscivore;
- Sponges / invertebrates; and
- Zooplanktivore.

Univariate analyses were applied to species richness (number of species / BRUVS set). The mean relative abundance (MaxN) of individual species is provided graphically where relevant to analyses supporting the aims of this study.

4. Results

a. *Townsville*

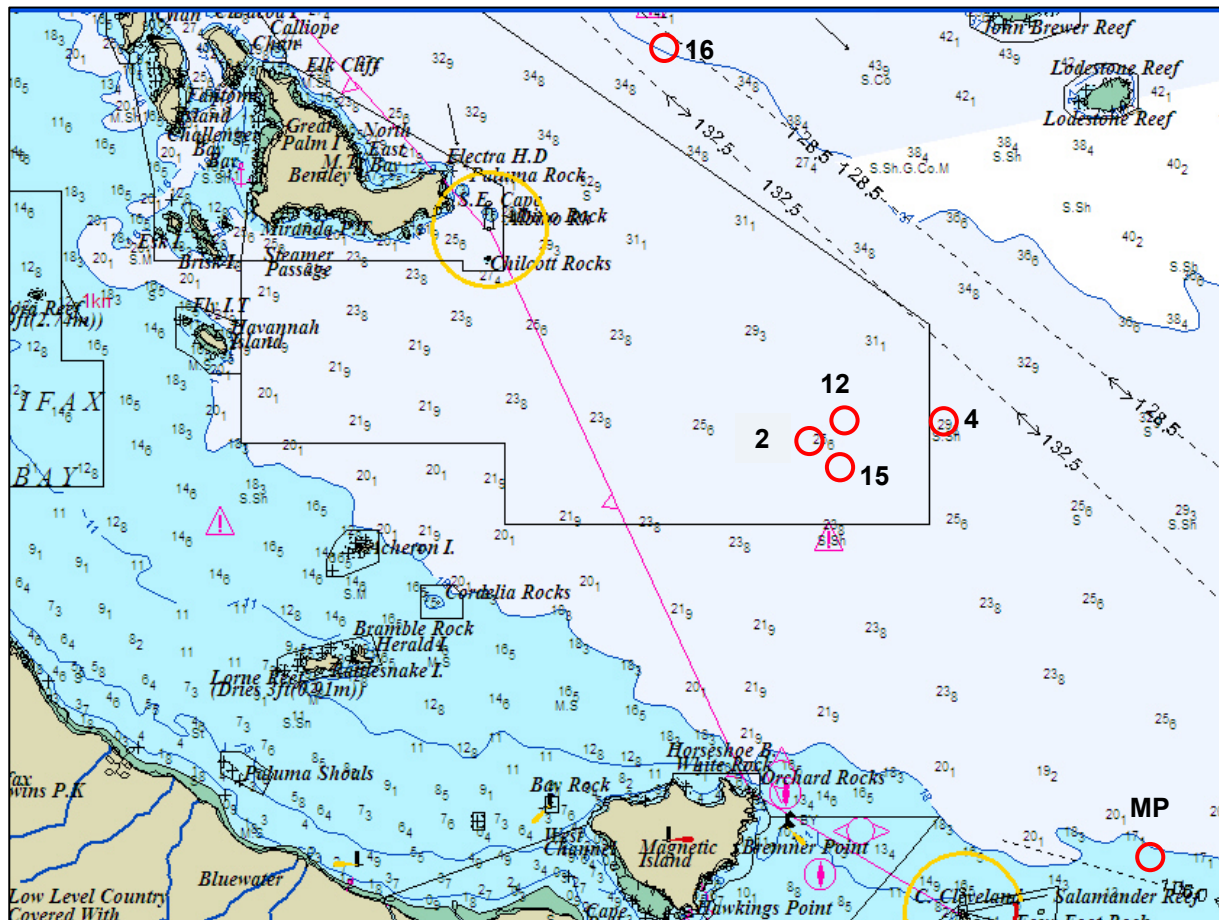


Figure a1: Townsville study sites from Halifax and Bowling Green Bays.

Habitats

All study sites in the Townsville region comprise unconsolidated sediments of sand, coarse sand and rubble (Figure A2). The underlying topography appears to be low relief sand ridges extending in a general NW-SE orientation (Appendix 1 and Larcombe and Carter 2004). Evidence from sub-bottom profiling indicated exposure of a Pleistocene clay layer that would support the attachment of epibenthos (Stieglitz 2006a).

Benthos at the Magnetic Shoal sites consisted of filter feeding gorgonians, alcyonarians, sponges and bryozoans, which provides important habitat for fishes (Pitcher *et al.* 2005). RAP 2 and RAP 15 included some hard coral isolates that additionally provide for the attachment of other organisms, typically filter feeders. Macroalgae was extensive over the surrounding sediments with some seagrass and burrowing organisms evident in the towed videos.

The sediments at the blue sites (RAP 4, RAP 16 and the Mackerel Patch) were not dissimilar, however RAP 4 and RAP 16 had reasonably extensive areas of sand depressions (sand holes) which provided substantial vertical relief not seen on the other sites. Some

reefal substrate ($\sim 25\text{m}^2$) was observed in a large depression at RAP 16 where there was very little epibenthos other than seagrass on the surrounding sediments. In addition to these features, RAP 4 was centred on a wooden trawler wreck. The Mackerel Patch (MP) was similar to the Magnetic Shoal with filter feeders dispersed over a sand / rubble bottom.

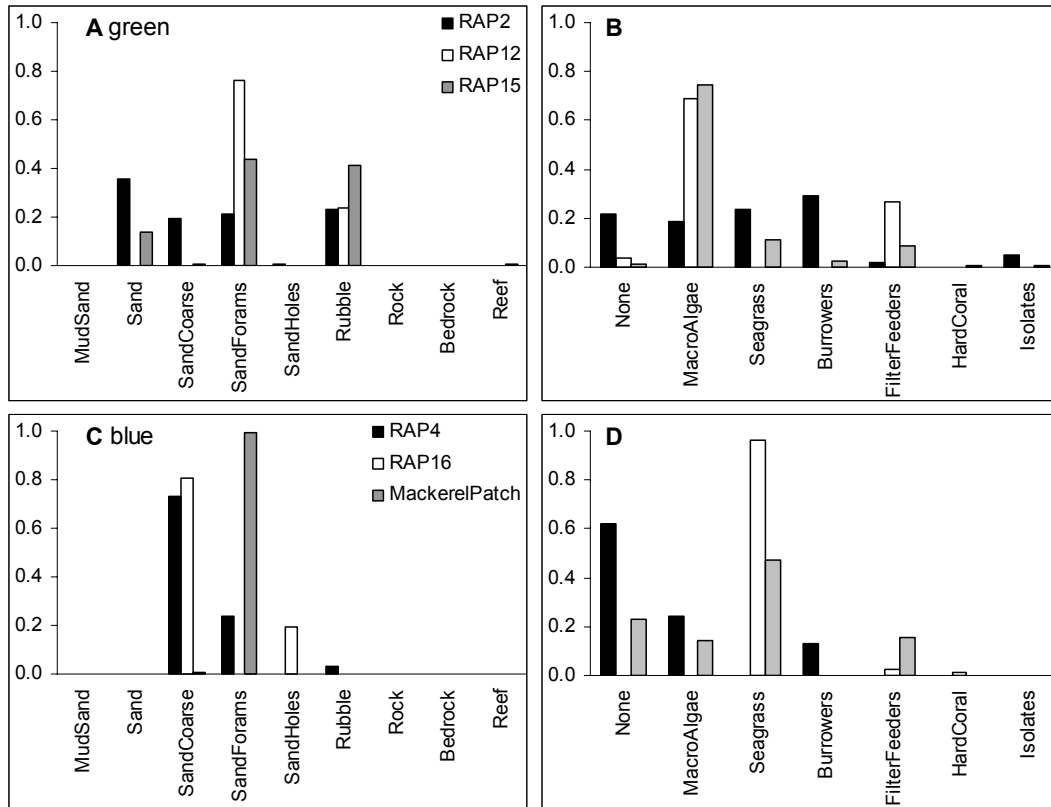


Figure a2: The relative contributions of the primary substrate (A) and epibenthic (B) classes on Magnetic Shoal (A and B) and adjacent blue sites (C and D).

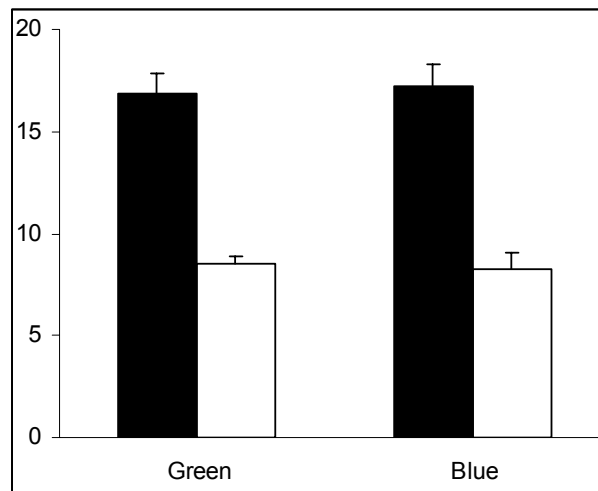
Fish

Ninety-four BRUVS and SBRUVS were deployed over four discreet periods from July 2006 (pilot study, see Speare and Cappel 2006) to March 2007 on three green (Magnetic Shoal) and three blue sites (Table a1 and Appendix 3). Represented in the data were 150 species from 39 families, with six families, carangids (22 species), labrids (16), serranids (12), chaetodontids (8), tetraodontids (8) and nemipterids (8), contributing 49% of species. Sets were made on the more diverse and structurally complex epibenthic habitat patches (32 green / 19 blue) and on sand/rubble sand ($\pm$ marine plants) habitats (24 / 19) surrounding these patches.

Table a1: Summary of BRUVS and SBRUVS sets on study sites between July 2006 and March 2007.

Site	Zone	Jul-06	Sep-06	Nov-06	Mar-06
RAP 2	Gr	4	4	4	4
RAP 12	Gr		11	8	10
RAP 15	Gr		4	3	4
RAP 4	BI	3	4	4	4
RAP 16	BI			8	4
MP	BI		3	4	4

There were approximately twice as many species recorded from complex habitats over the survey period compared with the surrounding areas (Figure a3). Twenty-seven families were better represented (number of species) on habitat patches compared to four families on open bottom. There was no significant difference ($p>0.05$) in species numbers between green and blue sites with respect to the two principal habitat types with an average of $17.3 (\pm 0.73)$ and $8.4 (\pm 0.42)$ on and off structurally complex habitat, respectively (Figure a4). The distributions of *Lutjanus vitta*, *L. sebae*, *L. malabaricus*, *Chaetodontoplus duboulayi*, *Epinephelus areolatus* and *Siganus fuscescens* were correlated with the complex habitat and *Nemipterus furcosus*, *Scomberomorus queenslandicus*, *Echeneis naucrates* and *Pentapodus paradiseus* with the surrounding open bottom habitat (Figure a5).

**Figure a3:** The mean number of species ($\pm 1SE$) recorded from structurally complex (closed bars) and adjacent rubble sand (open bars) habitats in green and blue zones off Townsville.

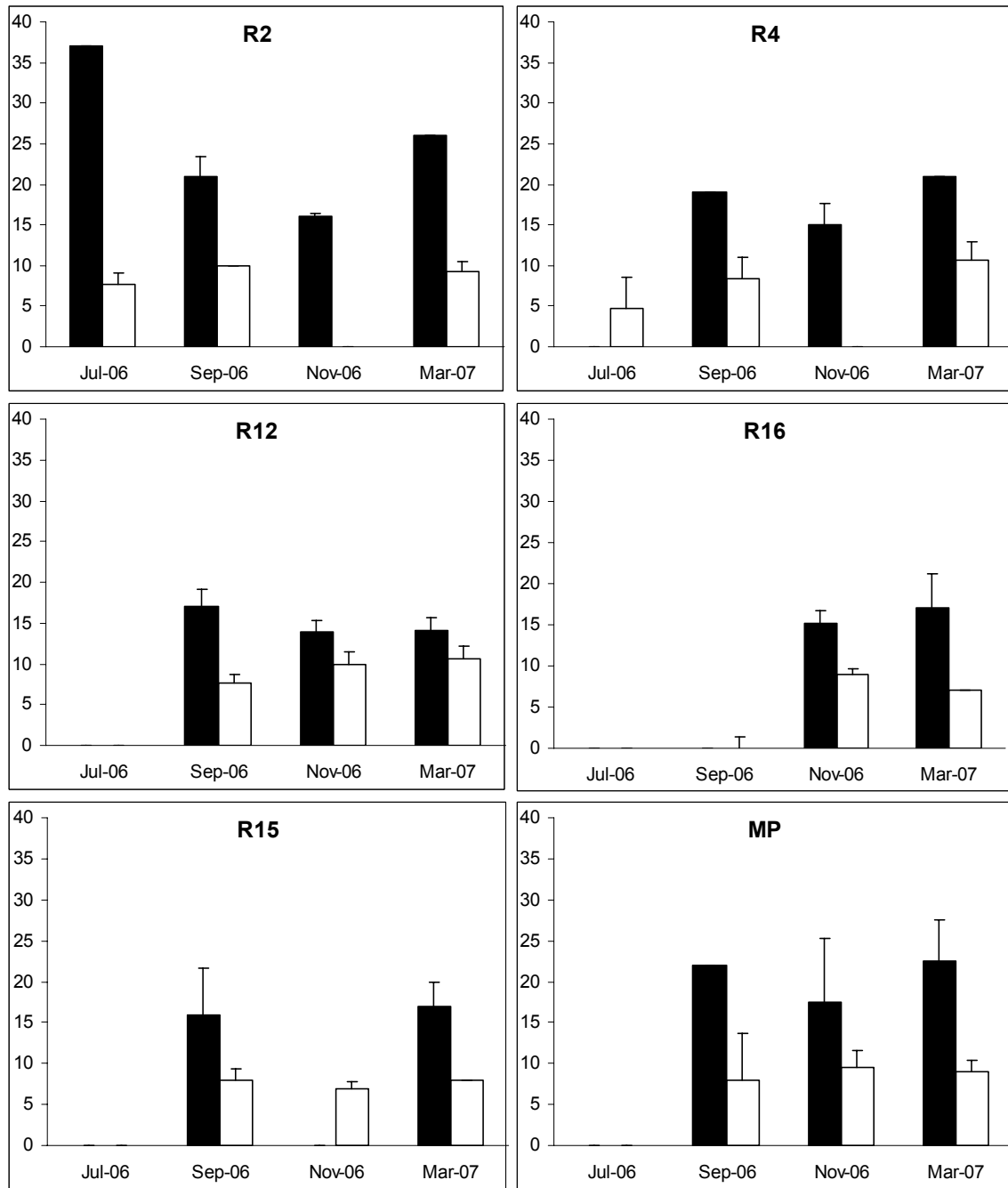


Figure a4: Mean number of species ($\pm 1SE$) on the structurally complex habitats (closed bars) and the surrounding sand / rubble phototrophic habitats (open bars) over the four sampling periods at each of the three green (left-hand side) and three blue (right-hand side) sites.

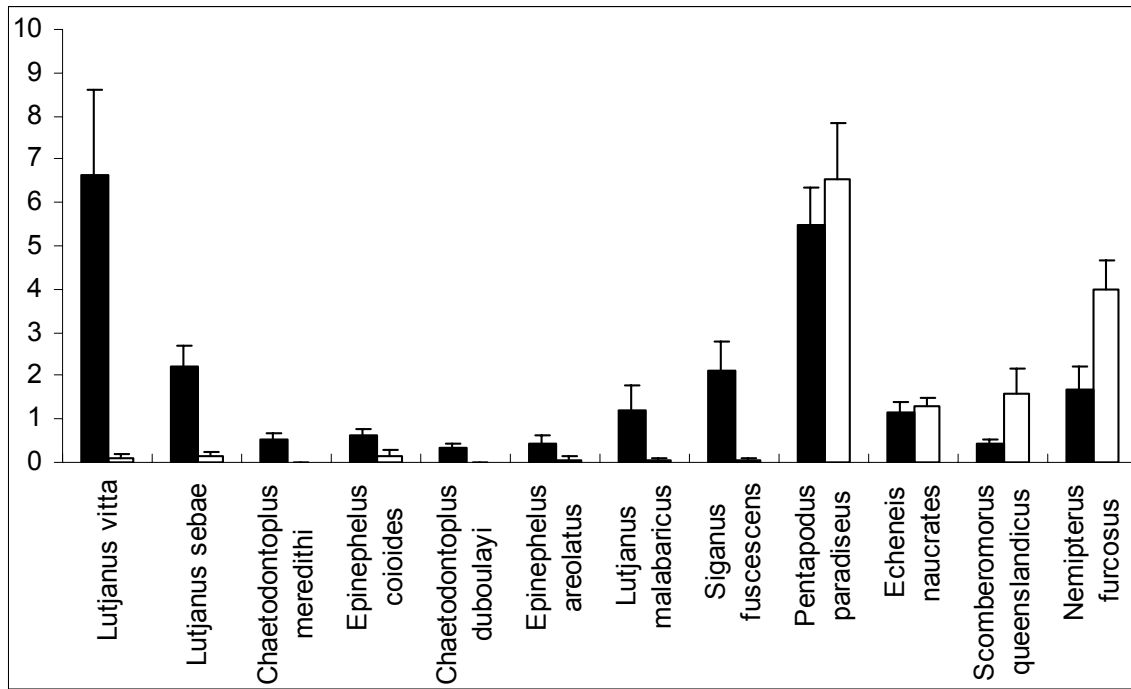


Figure a5: The mean relative abundance (± 1 SE) of species correlated with the two principal habitats on shoal sites in the Townsville region. Closed bars = complex epibenthic filter feeding communities; open bars = low diversity phototrophic epibenthic communities.

Species distributions and relative abundance on the structurally complex habitat and surrounding bottom were influenced by zone and site and with an interaction between these factors persisting over the four discrete sampling periods (Table a2). The fish assemblages over the open bottom in the green zones were distinct from those on the open bottom in the blue zone and, similarly, for the fish assemblages associated with the more complex habitats (Figure a6). The fish assemblages in the complex habitat at the Mackerel Patch site off Cape Cleveland were more similar to those at Magnetic Shoal than the other blue zone sites. Carangids (*Charangoides fulvoguttatus*, *C. chrysophrys* and *Gnathodon speciosus*) and *Diagramma pictum* were associated with the sandy habitats at RAP 4 and RAP 16 (blue), whereas *Nemipterus furcosus*, *Seriolina nigrofasciatus* and *Scomberomorus queenslandicus* were associated with these habitats in the green zone. *Lutjanus sebae* and *Epinephelus coioides* were more prevalent and abundant in the complex habitats of the blue zone sites of RAP 4 and RAP 16.

Table a2: Multivariate analysis of factors influencing the structure of fish assemblages on shoals in the Townsville region.

Factor	df	MS	F	p(perm)
covariable Time	3	5054		
Zone	1	20233	10.28	<0.01
Site	2	5143	2.61	<0.01
Zone*Site	2	8526	4.33	<0.01
residual	45	88524		

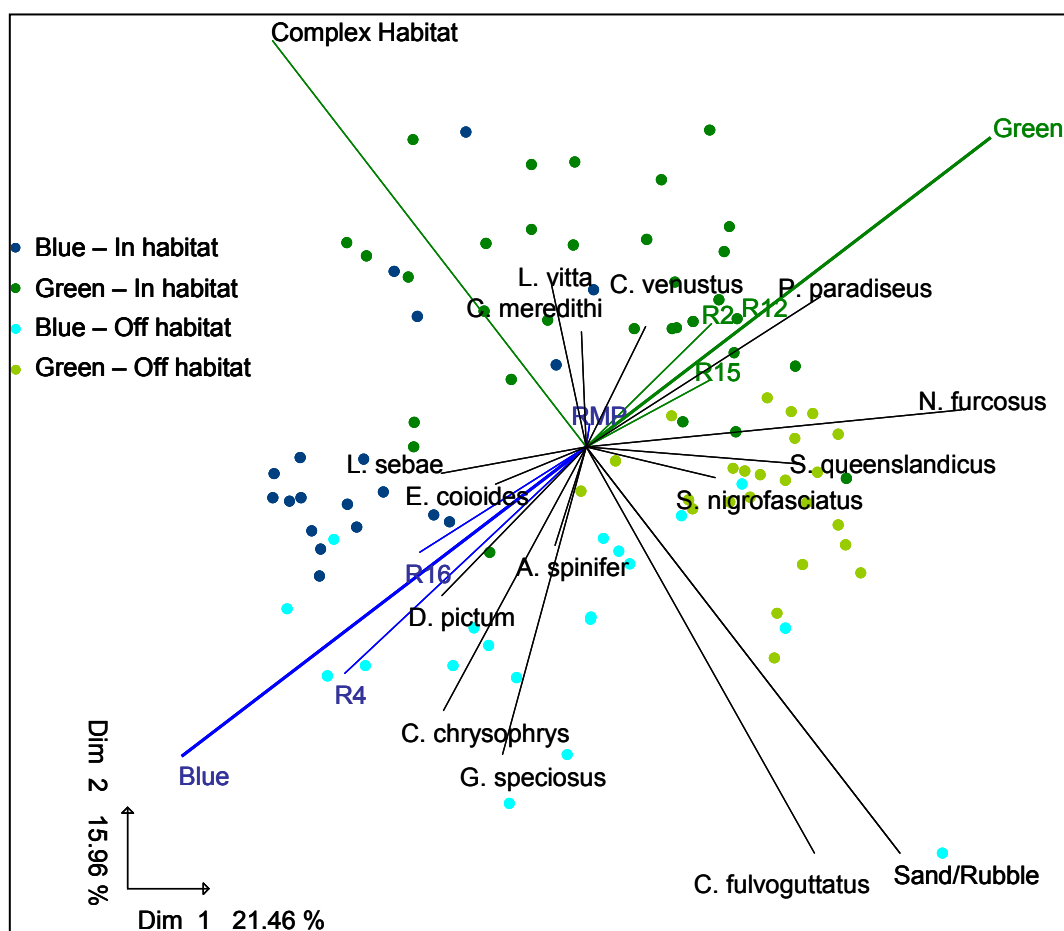


Figure a6: Biplot of transformed (4th root, row standardised) fish relative abundances over all sites and sampling periods. Vectors representing the correlation of species with the primary groupings are displayed along with the relative positions of sites, habitats and zones.

Twenty-two species were identified as potentially targeted by fishers. The distributions and relative abundances of these fish varied between zones and sites (Figure a7). *Charangoides fulvoguttatus*, *C. chrysophrys* and *Gnathodon speciosus* were correlated with the blue zone sites RAP 4 and RAP 16 and, while not significant, there was evidence of increasing numbers of *Plectropomus maculatus* and *Choerodon venustus* on Magnetic Shoal (Figure a8). Multivariate analysis of the non-target species revealed a similar association of the fish assemblages with zone ($p < 0.01$) and site ($p < 0.05$) but no significant change at the community level over time.

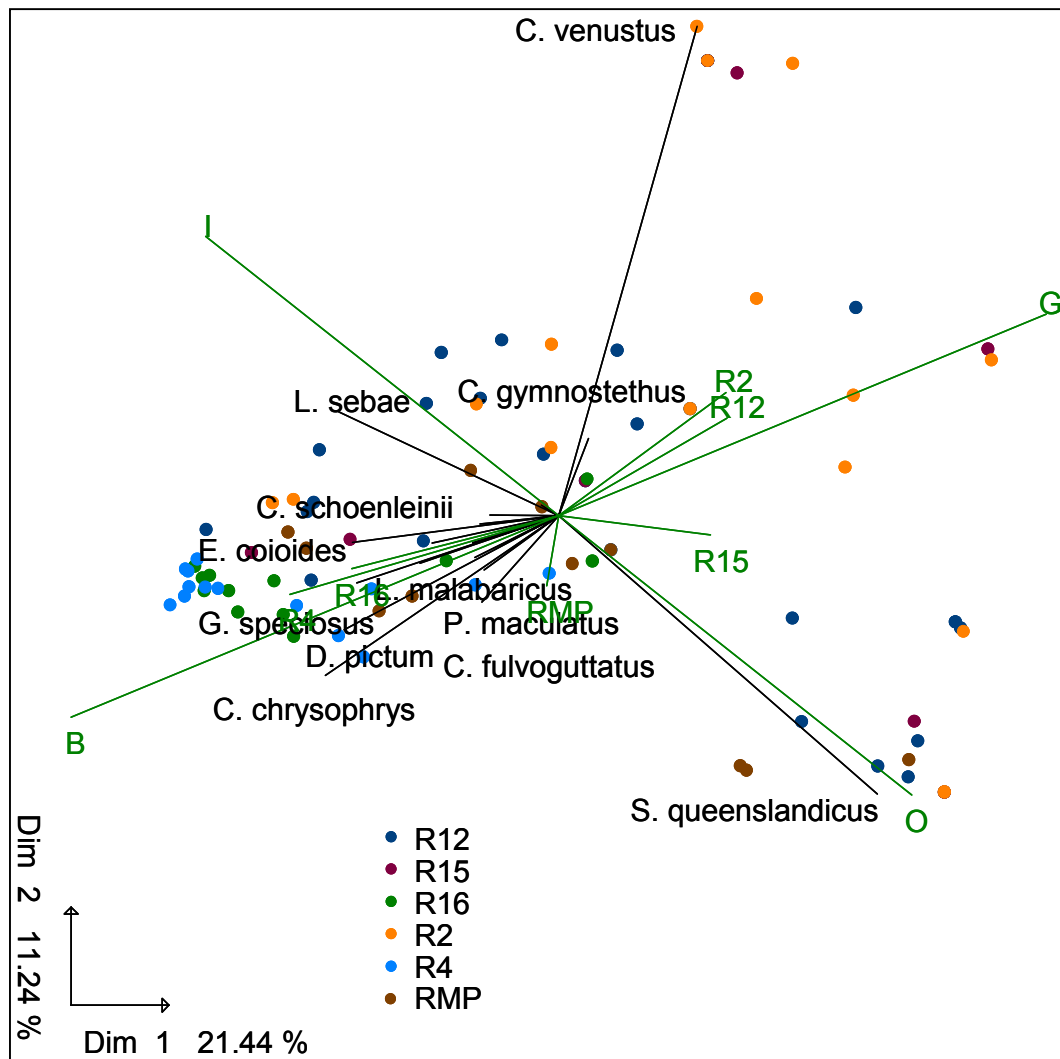


Figure a7: Biplot of transformed (4th root, row standardised) targeted fish relative abundances over all sites and sampling periods. Vectors representing the correlation of species with the primary groupings are displayed along with the relative positions of sites, habitats and zones.

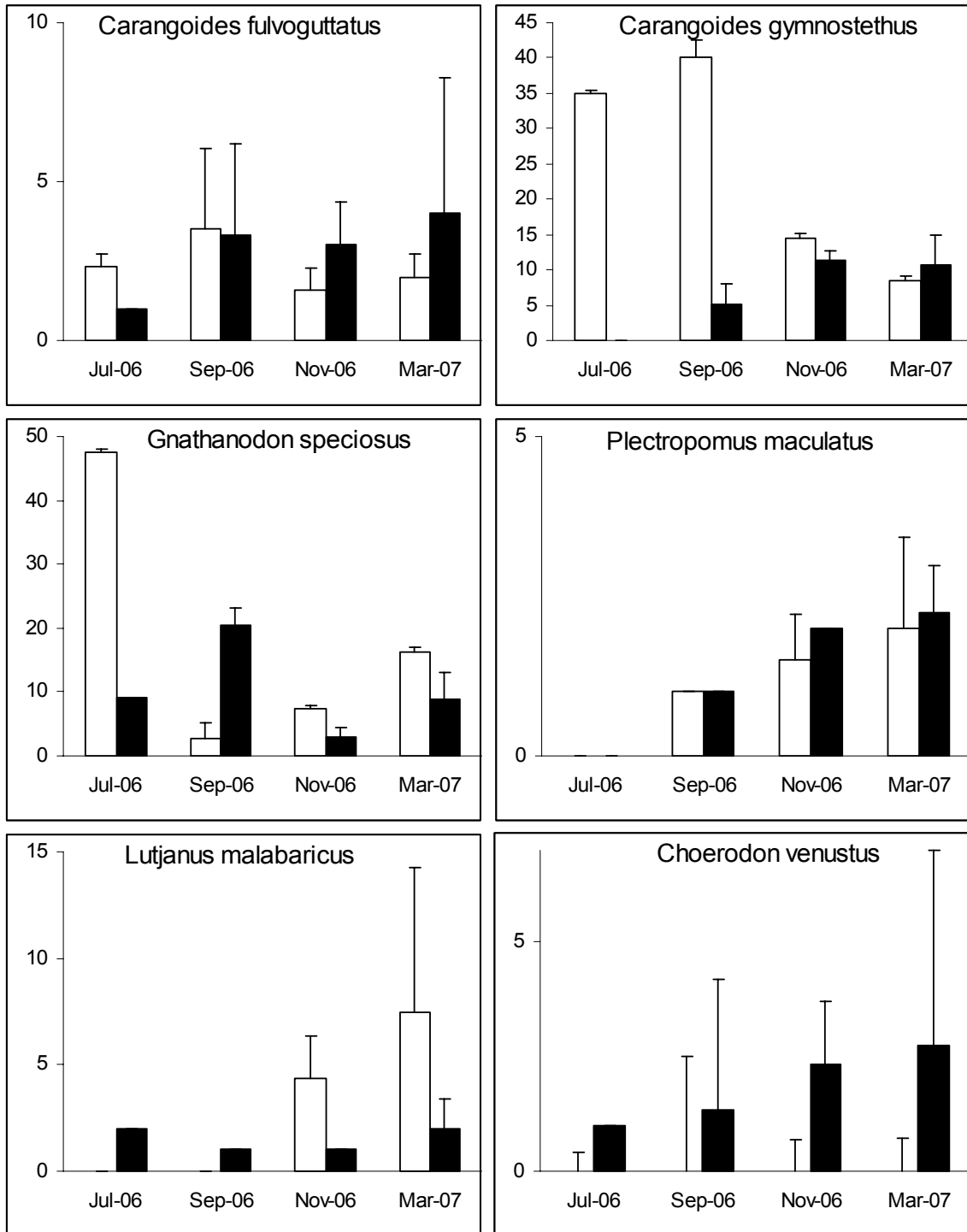


Figure a8: Mean relative abundance ($\pm 1SE$) of species displaying temporal changes over the sampling period between July 2006 and March 2007 in the green zone at Magnetic Shoals (closed bars) and adjacent blue zones (open bars).

Discussion

The fish assemblages on the study sites in the Townsville region displayed an affinity with habitat type, with generally twice as many species in the scattered and diverse structurally complex habitats as the surrounding macroalgae and / or seagrass areas. The species richness on these shoals compares with the study sites from the Cairns region where the main structural component was calcareous reef structures.

Invertebrate carnivores and piscivores were associated with the open bottom habitats, and herbivores and invertebrate carnivores with the small patches of diverse habitat. These differences across trophodynamic functional groups, the differential availability of shelter with habitat as well as predator-prey interactions and ontogenic movements are likely to explain this contrast between habitats (e.g. Polunin 1996, St John 1999).

The Magnetic Shoal sites were more similar to each other with respect to their topography, sediments and epibenthic community structure. These similarities in the habitat features were reflected in the similarity of the fish assemblages across these sites. The Mackerel Patch (MP), offshore from Cape Cleveland, was most similar to the green zone sites in terms of both habitats and associated fish assemblages, whereas RAP 4 and RAP 16 were distinct from the other sites. The latter two blue sites share a greater topographical complexity with respect to the extensive sand depressions occurring in these areas, and these features may be responsible for the greater number of carangids on these sites. It is also worth noting the contribution of mobile schooling species such as the carangids to the open bottom assemblages with the inherent greater variability in their relative abundance (see Figure a8).

The distribution patterns of the targeted species and the non-targeted species were not dissimilar and consequently tended to reflect the pattern of association with habitats identified above. This general pattern in the fish assemblages was sustained over time but with discreet changes in the abundance of a few species of interest to fishers, some indicative of incremental improvement in their relative abundance.

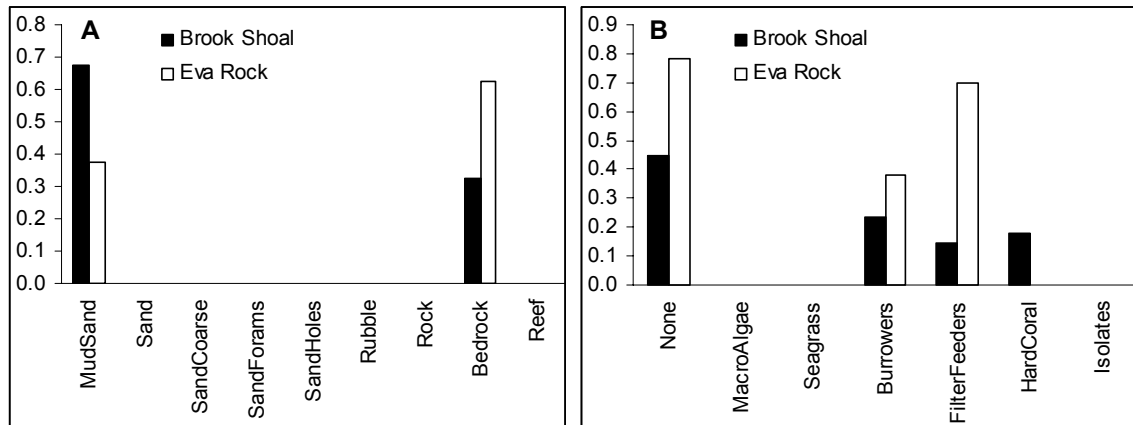


Figure b2: The relative contributions of the primary substrate (A) and epibenthic (B) classes on the sites at Brook Shoal and Eva Rock. Note, Forty Foot Rock was not surveyed.

Fish

Twenty BRUVS and SBRUVS sets were deployed in September and December 2006 on Brook Shoal (four sets in September / four sets in December), Eva Rock (5/4) and Forty Foot Rock (0/3) (Appendix 3). Overall, ten sets were made directly on the rocky substrate associated with these shoals and another ten on the surrounding muddy sand floor (Appendix 1). Sixty-five species from 27 families were seen with a predominance of Carangids (13spp), Lutjanids (7), Labrids (5) and Pomacanthids (4). CAP analysis did not discriminate between the two sampling periods ($p < 0.05$), which implied there was no significant change in the fish communities over the three-month interval and thereby enabled combining of all records for subsequent analyses.

Overall and habitat related species richness was not significantly different among the three sites (Kruskal-Wallis $p > 0.05$) with an average of $8.3(\pm 1.0)$ species recorded from each set but with approximately twice as many species recorded from rocky habitat (11.8 ± 1.25) as from the surrounding muddy sand bottom (5.6 ± 0.45) (Figure b3). The fish assemblages recorded over both types of habitat at each site varied sufficiently to distinguish sets made on each shoal (CAP $p < 0.05$, misclassification rate BS – 22%, FF – 0%, ER – 25%). Forty-three species (66%) were restricted to one of the three sites (Brook Shoal (BS) – 11spp/17%, ER – 26/40%, FF – 6/9%), which may reflect the small size of the available habitat at two out of the three sites.

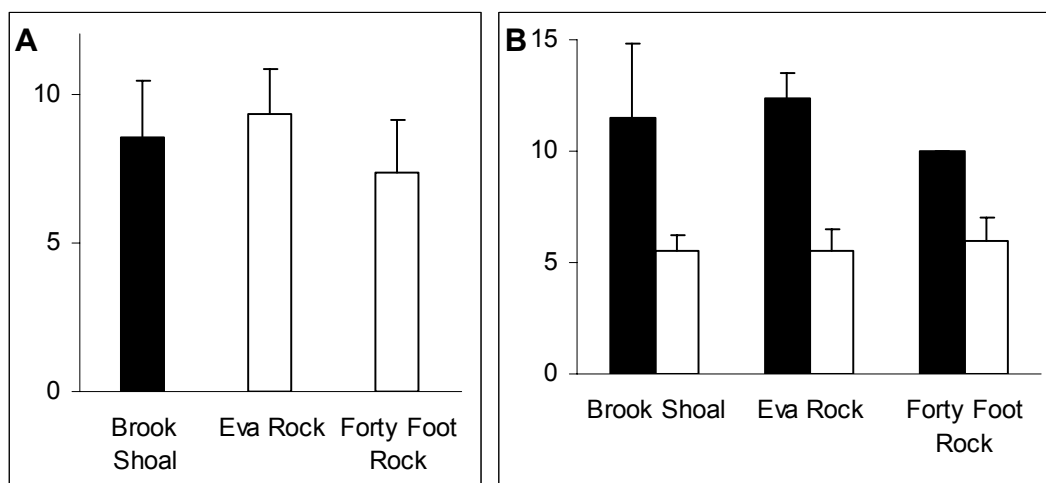


Figure b3: The mean number of species ($\pm 1SE$) recorded from BRUVS sets on Brook Shoal, Eva Rock and Forty Foot Rock. (a) Muddy sand and rocky habitats combined; (b) closed bars = hard bottom; open bars = soft bottom.

The differences between sites were particularly evident in the ordination from CAP analysis where fish assemblages on the open muddy sand bottoms were substantially more variable than those on the rocky substrate (Figure b4) but remained distinct (misclassification rate – 0%). The distributions of several species (*Parupeneus indicus*, *Plectropomas maculatus*, *Choerodon schoenleinii* and *Scarus ghobban*) were strongly correlated ($|r| > 0.5$) with hard bottom habitat whereas *Scomberomorus queenslandicus*, *Carangoides coeruleopinnatus* and *Nemipterus furcosus* were indicative of open bottom habitat. The mean relative abundance of each of these species, and also *Pomacanthus sexstriatus*, *Lutjanus russelli* and *L. vitta* varied between habitats ($p < 0.05$) (Figure b5). DISTLM analysis of sets made on rocky substrate revealed no effect of zone ($p > 0.05$) or site ($p > 0.05$) based on the distributions and relative abundance of the 47 species recorded from this habitat (Table b1).

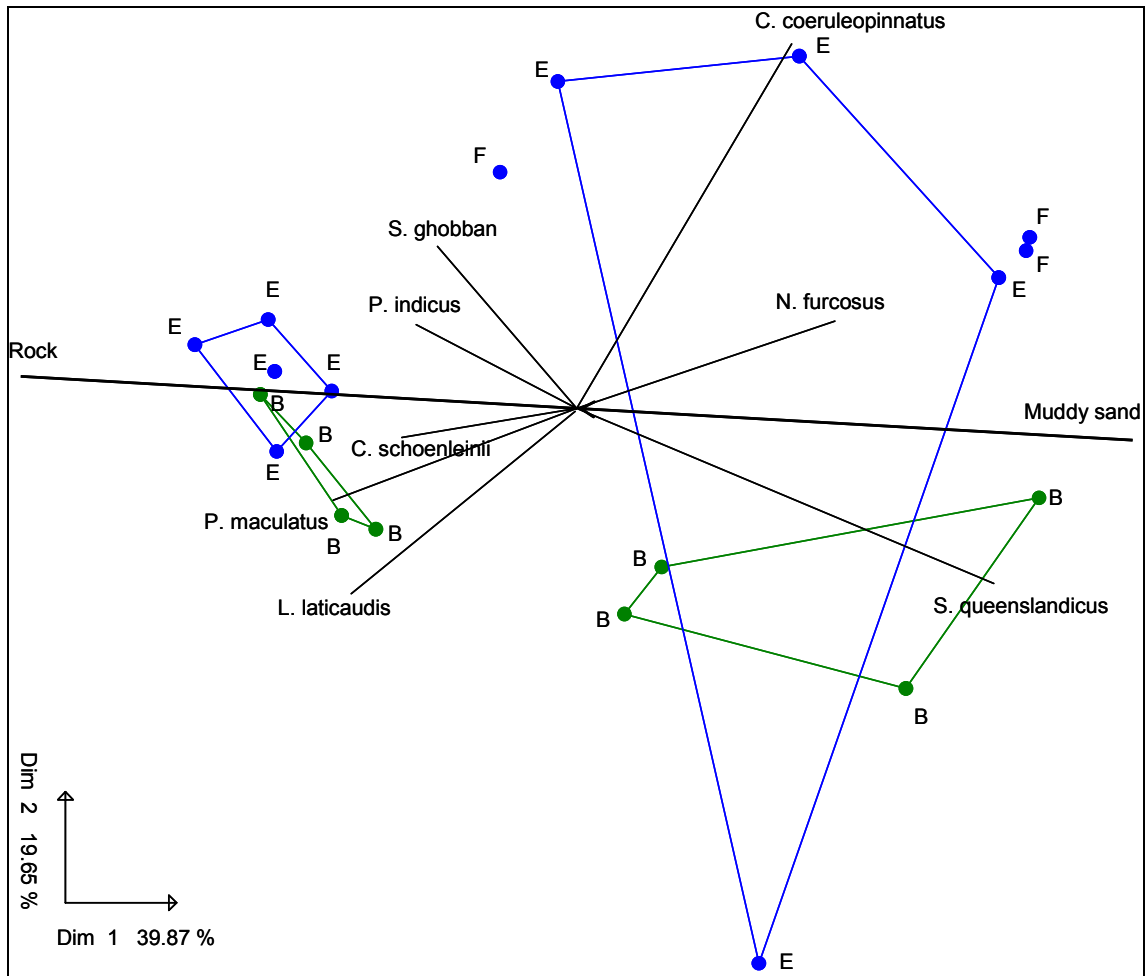


Figure b4: Canonical analysis of BRUVS sets made on rocky (left-hand side) and muddy sand (right-hand side) substrates at Brook Shoal (B), Eva Rock (E) and Forty Foot Rock (F) clearly distinguished ($p < 0.05$) fish assemblages associated with the two habitat types. This analysis also highlighted the more variable fish assemblages associated with the muddy sand bottom.

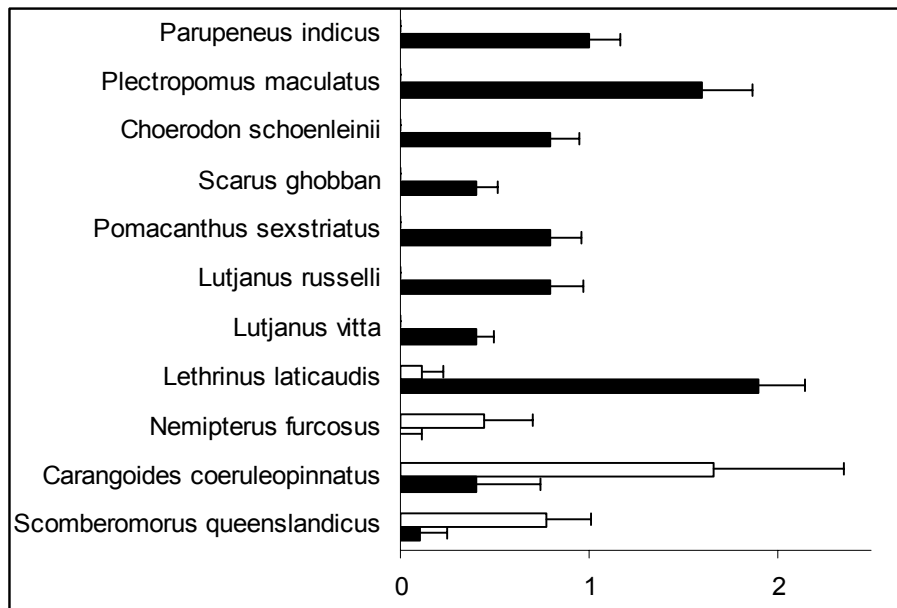


Figure b5: The mean relative abundance ($\pm 1SE$) of species correlated with the muddy sand (open bars) and rocky (closed bars) substrates occurring on the study sites.

Table b1: DISTLM of the relative abundances of 47 species from rocky and 34 from muddy sand habitats occurring on the study sites in response to zone and site and their interactions.

Rock	df	Rocky habitat			Muddy sand		
		MS	F	p(perm)	MS	F	p(perm)
Zone	1	2549	1.05	0.25	5643	1.65	<0.05
Site	2	2207	0.91	0.17	5245	1.63	<0.05
Zone*Site	2	1509	0.62	0.20	3091	0.81	<0.05
residual	4	2432			3412		

These associations of fish assemblages with habitat type were also explained in terms of their trophic functional attributes. Invertebrate and generalist carnivores and coralivores were associated with the rocky habitat and zooplanktivores and piscivores with the muddy sand areas (Figure b6).

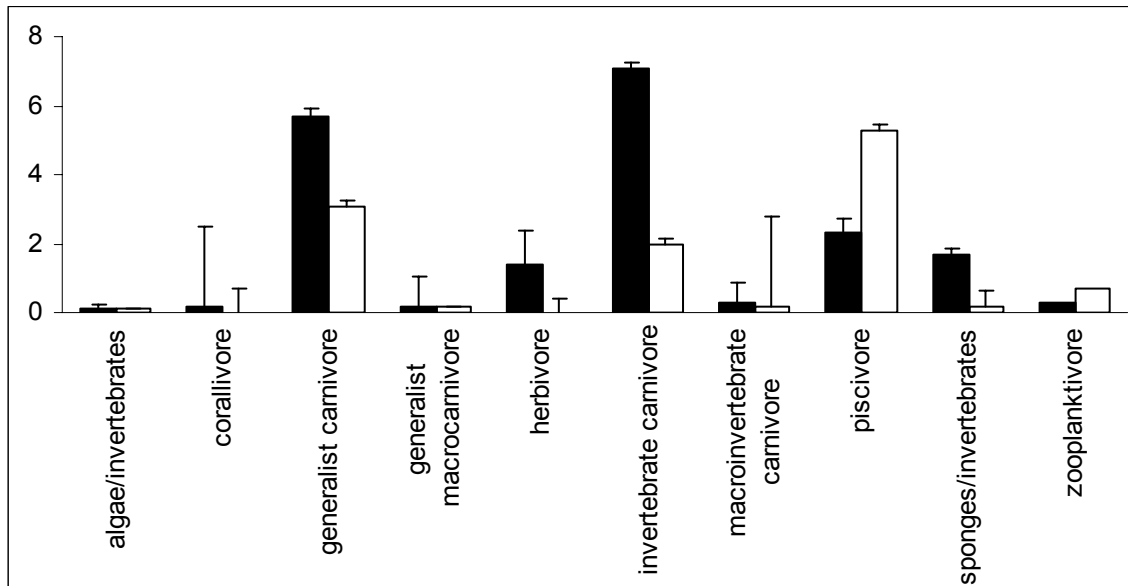


Figure b6: The number of functional units (fish) occurring on muddy sand (open bars) and rocky (closed bars) habitats at the three sites off Cardwell.

Fourteen species were recognised as target species or likely to be taken by fishers. Analyses restricted to this group of fish did not show any statistically significant difference in their distribution and relative abundance ($p > 0.05$) in relation to protection, however eight benthic species were more abundant at the only protected site (Brook Shoal) and none showed the opposite pattern of greater abundance in the areas open to fishing (Figure b7). The 51 non-target species were unevenly distributed ($p < 0.05$) between zones with *Chaetodontoplus duboulayi*, *Labroides dimidiatus* and *Lutjanus russelli* correlated with the protected area of Brook Shoal, and *Carangoides coeruleopinnatus*, *Atule mate*, *Abalistes stellatus* and *Caranx tille* correlated with sites open to fishing.

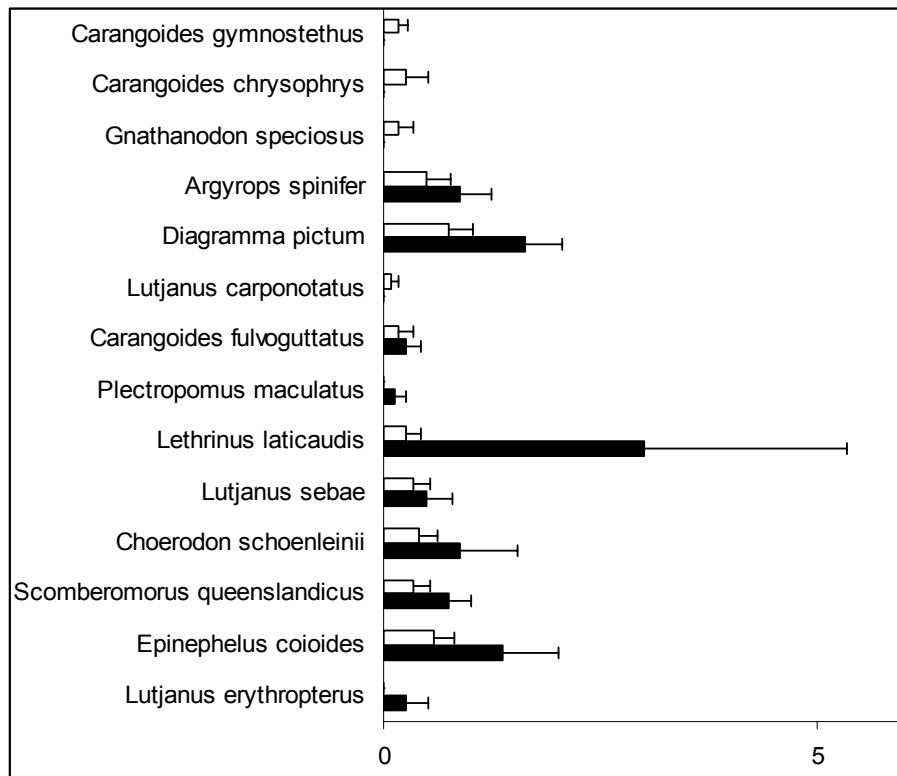


Figure b7: The mean relative abundance ($\pm 1SE$) of targeted species which correlated with the level of protection. Green zone = closed bars; blue zones = open bars.

Discussion

The shoals included in this study were each centred on small rocky outcrops ranging in size from tens to hundreds of metres in extent. The species richness associated with this habitat from each of the three study sites tended to reflect their relative sizes. The species richness on the shoal sites in the Cardwell area was relative low in comparison to that recorded from the other two regional survey areas off Cairns and Townsville (Figure b8).

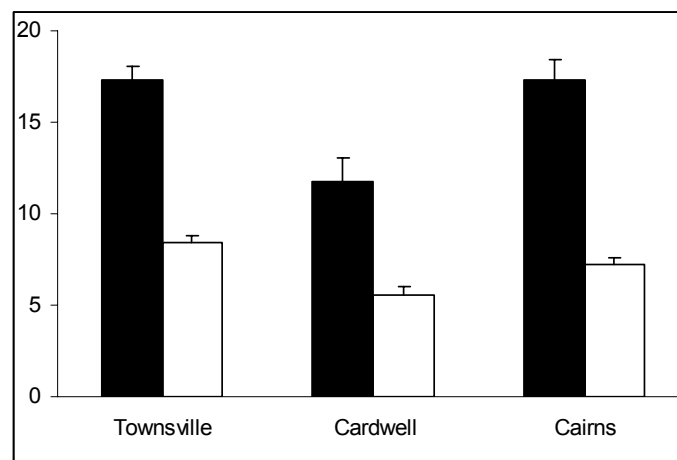


Figure b8: The mean number of species ($\pm 1SE$) on (closed bars) and off (open bars) the primary habitats recorded from three regional areas.

The two distinct habitats on the study sites in the Cardwell region had the greatest influence on the species richness and fish assemblages. Species richness did not vary with protection or location but was measurably greater on the rocky features targeted by fishers than on the surrounding sedimentary environments. Similarly, in terms of trophic functional groups, there were significant differences between habitats that transcended protection and location.

The extremely small rocky features, in particular at Brook Shoal and Forty Foot Rock, make it difficult to ensure independent sampling with BRUVS and SBRUVS. Our preferred procedure of limiting sets to a minimum 300m separation is not possible at these two study sites which may mean that some individuals were resampled.

Many of the target group of fish were associated with the rocky habitats and while there was no evidence for an overall greater representation in the protected site of Brook Shoal, there were indications of greater abundance among several of these species. Further confirmation of a zone effect for individual species may be represented in the data relating to fish size, which will be available when the SBRUVS footage has been processed.

c. Cairns

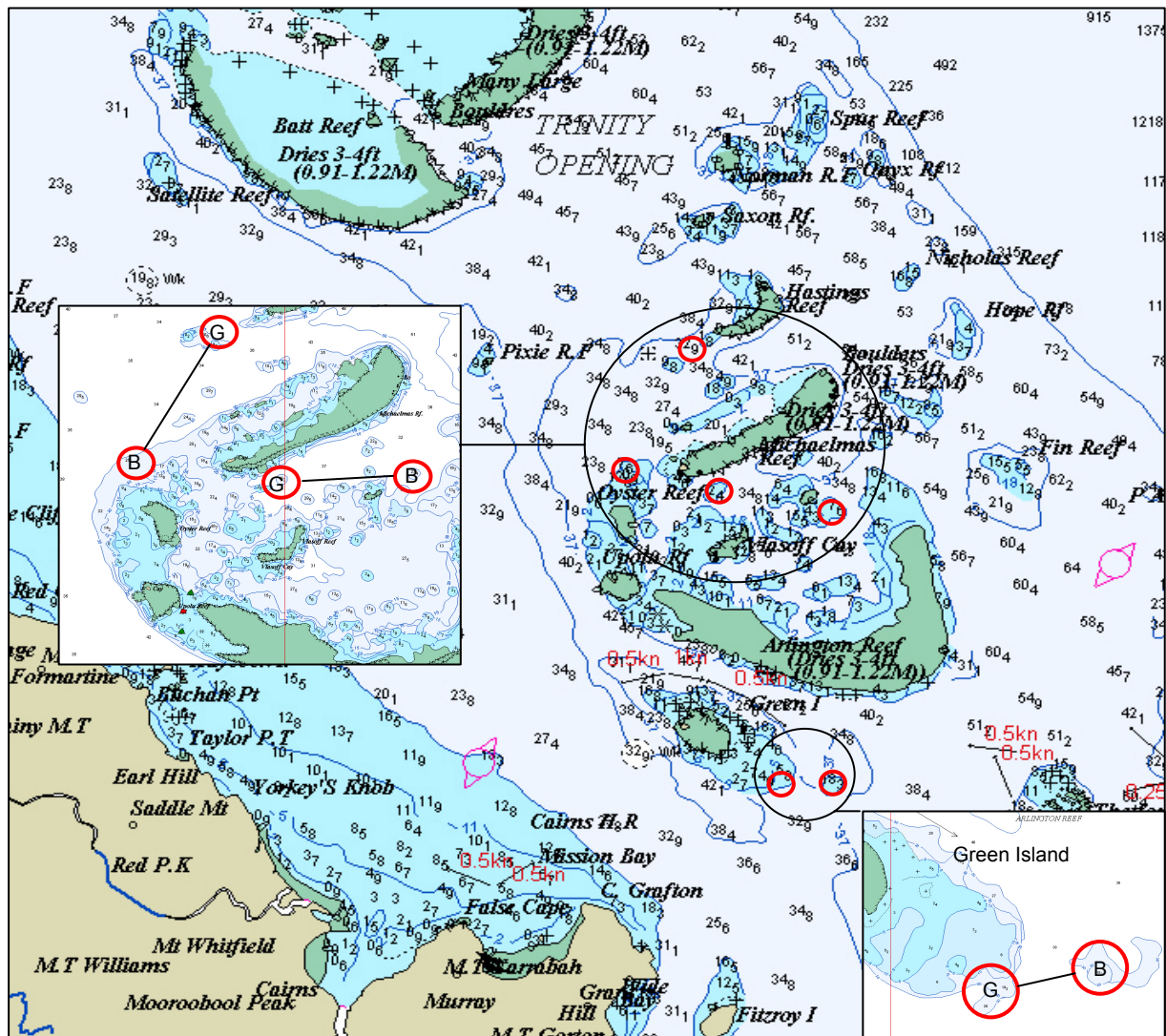


Figure c1: Cairns study sites.

Habitats

The pairs of green and blue sites in the Cairns region included substrates of sand, rubble and reef including scattered submerged bommies (Figure c2). Extensive rubble fields were located off the southeast edge of the reef surrounding Green Island with isolated bommies scattered in the deeper water. These structures were predominantly occupied by hard coral in the blue zone but included both filter feeding gorgonians and hard corals in the adjacent green zone. Marine plants were not evident on the sandy substrate in the green zone. Overall, the structural complexity and extent of habitats were similar at each site. The average water depth in the green zone site was 30m and 33m in the blue zone and the deeper waters were quite turbid presumably related to tidal flushing through Grafton Passage which would tend to account for the presence of abundant filter feeders.

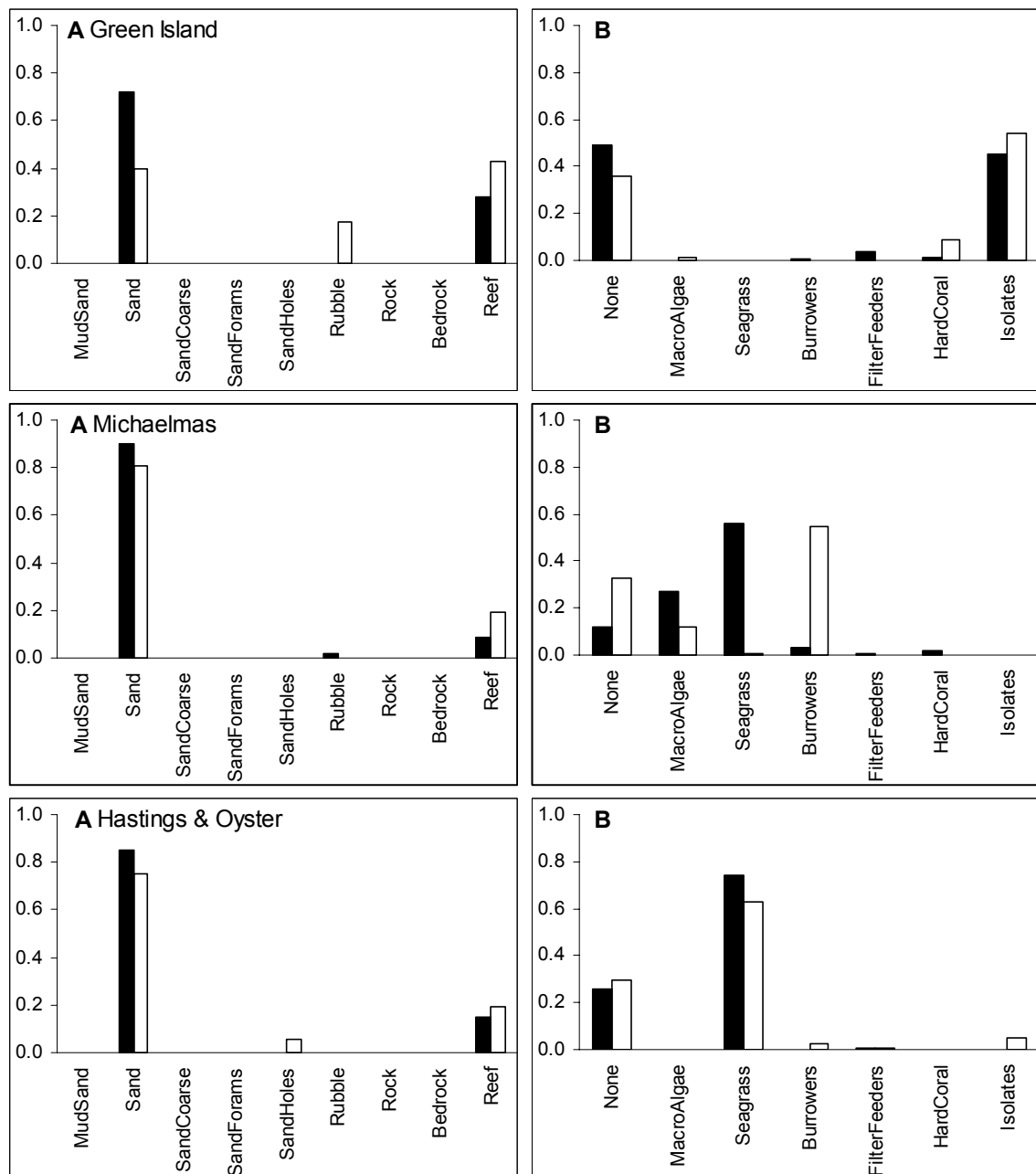


Figure c2: Substrate and epibenthic cover on the six study sites off Cairns. Green sites = closed bars.

The Michaelmas Reef sites had an average depth of 32m and 36m in the green and blue zones, respectively. Both sites were predominantly sand with scattered bommies. Much of the reefal structures were covered in silt and supported an algal mat with few hard corals and filter feeders. Marine plants were more abundant over the sand at the green site and the presence of burrowing organisms in the blue site tended to indicate finer sediments in this area. Overall, the structural complexity and extent of habitats were similar at each site (Figure c2 and Appendix 1). Depressions in the sand (sand holes) nearby several bommies were particularly evident in the blue zone but also present in the green site (Stieglitz 2006b). These features were up to 10m across and 1-2m in depth and contributed to the structural complexity of these unconsolidated habitats. They occurred at most of the study sites and were very extensive at the leeward margin of the Oyster Reef site.

The shoal site running off the southern extension of Hastings reef presented as a ridge of rubble and sand bridging to a large submerged bommie to the southwest. Depths varied between 34m on the rise and 37m to the east and west. There were many small patches of reefal substrate, few hard corals and sparse filter feeding gorgonians. There was extensive seagrass over the sandy bottom at both Hastings and Oyster reef sites. The Oyster Reef shoal site had an extensive area of reefal substrate along the western margin that gave way to an extensive area of sand holes in the deeper water at 30m. There was little epibenthos evident on the hard structure (Figure c2 and Appendix 1).

Fish

Sixty-one BRUVS and SBRUVS sets (Appendix 3) returned 140 species from 31 families with Labrids (18 species), Carangids (13), Serranids (10), Lutjanids (10) and Lethrinids (10) predominating. The species richness in all protected areas was not significantly different to areas outside the green zones (Figure c3A) whereas on complex structural habitats there was a significantly greater number of species compared with unconsolidated sandy bottoms (Figure c3B). CAP analysis of the distributions and relative abundances of the 140 species confirmed a robust distinction between fish assemblages on consolidated reefal substrate and the surrounding sandy bottom ($p < 0.01$, misclassification rate 3.3%). *Choerodon fasciatus*, *Cheilinus fasciatus*, *Cantherines dumerilii*, *Lutjanus quinquelineatus*, *L. vitta* and *Plectropomus leopardus* were correlated with the reefal substrates whereas *Nemipterus furcosus*, *Carangoides coeruleopinnatus* and *Pentapodus paradiseus* were indicative of the sandy habitats (Figure c4).

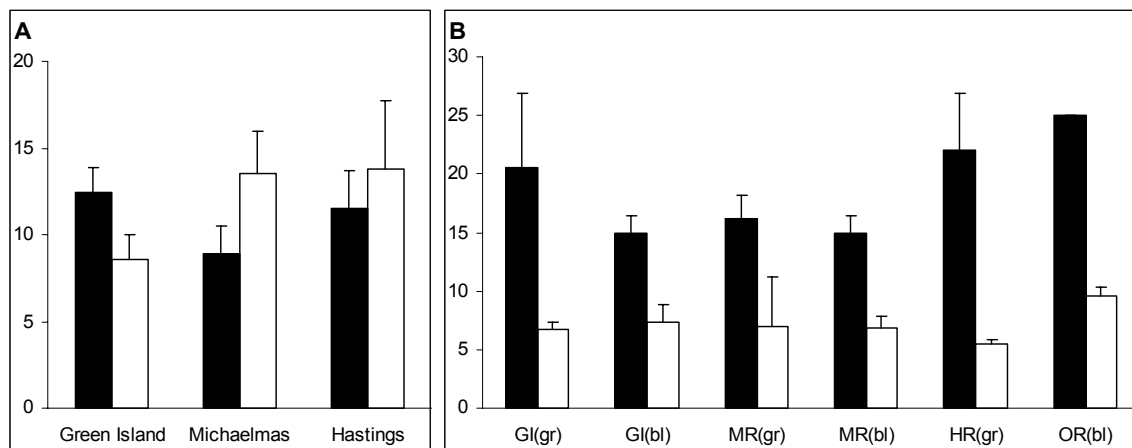


Figure c3: The mean number of species ($\pm 1SE$) recorded from BRUVS sets on Green Island, Michaelmas and Hastings reef sites. (a) Green (closed bars) and non-green (open bars) sites; (b) reefal substrates (closed bars), sandy bottom (open bars).

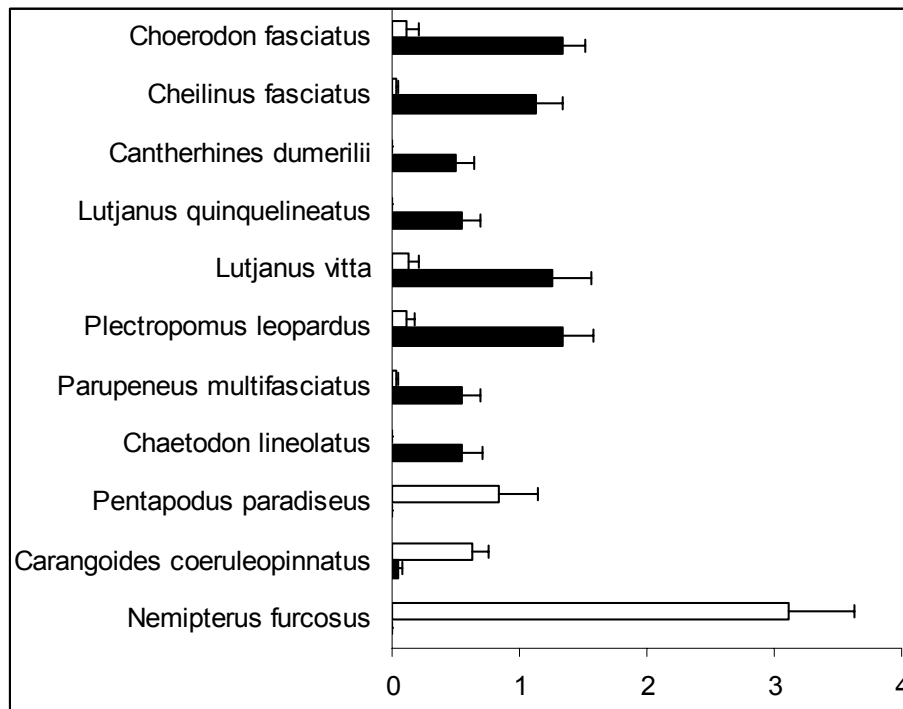


Figure c4: The mean relative abundance (± 1 SE) of species correlated with the sand (open bars) and reefal (closed bars) substrates on the shoal sites at Green Island and Michaelmas, Hastings and Oysters reefs.

Given the clear distinction between fish assemblages on consolidated and unconsolidated substrates, the data were analysed separately for each habitat type. Overall there were 109 species on the reefal habitats and 71 on the open sandy bottoms. Fish assemblages on reefal substrates did not vary across green and blue zones but there were dissimilarities between sites ($p < 0.01$, DISTLM analysis with unbalanced ANOVA) (Table c1). There was a zone effect associated with the site discrimination which was largely related to the greater similarities of the fish assemblages at Green Island and Michaelmas reef compared to Hastings and Oyster Reefs, the more inshore pair of sites (Figure c5). The prevalence and relative distributions of *Choerodon fasciatus*, *Cheilinus fasciatus*, *Chaetodon rainfordi* and *Lethrinus laticaudis* correlated with Green Island and Michaelmas Reefs, and *Labroides dimidiatus*, *Choerodon venustus*, *Pentapodus aureofasciatus*, *Sufflamen fraenatum* and *Lethrinus ravus* were more abundant at Hastings and Oyster Reefs.

Table c1: DISTLM analysis of the relative abundances of 109 species from reefal, and 71 species from sand habitats, occurring on the study sites in response to zone and site and their interactions.

Habitat	Reefal				Sand			
	df	MS	F	p(perm)	df	MS	F	p(perm)
Zone	1	3088	1.21	0.19	1	5414	1.76	0.06
Site	2	4440	1.73	<0.01	2	7043	2.29	<0.01
Zone*Site	2	3113	1.21	<0.05	2	4009	1.31	0.09
residual	18	2559			31	3080		

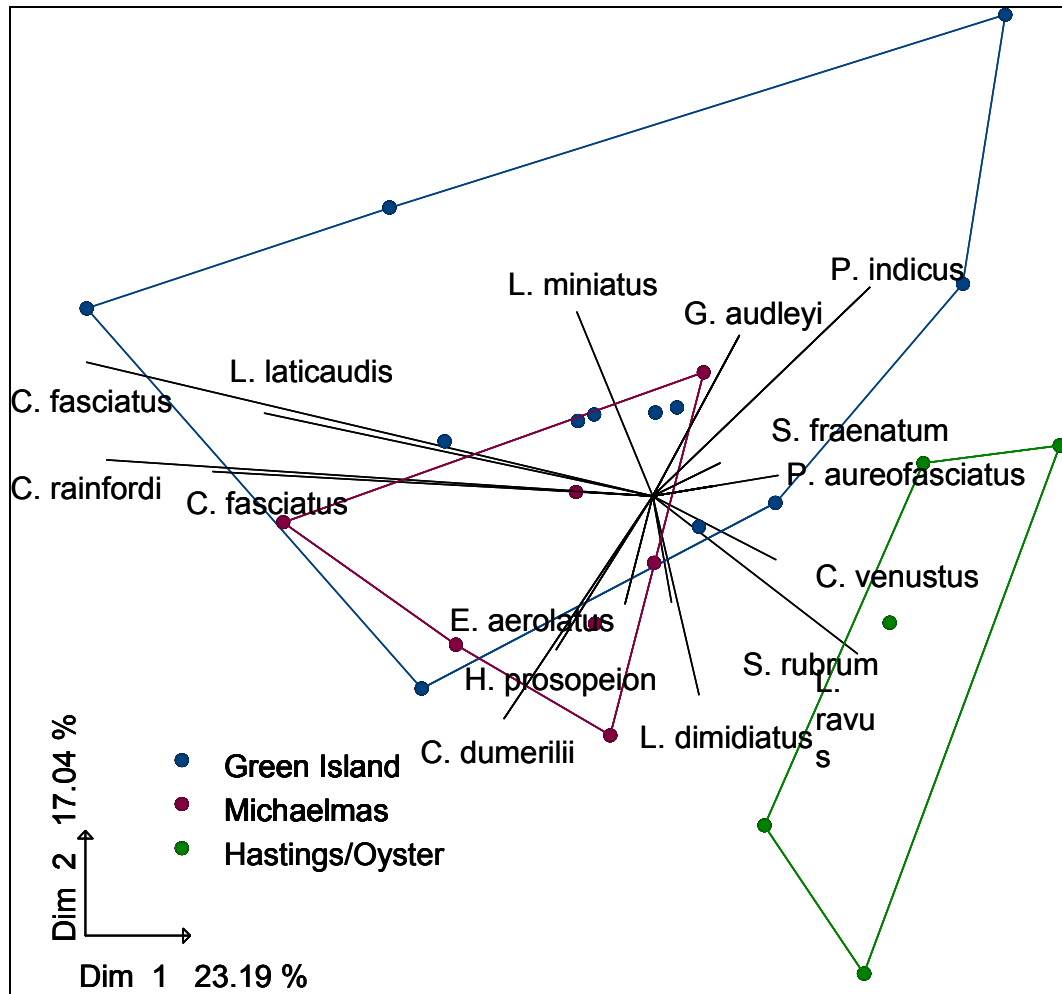


Figure c5: Biplot of principal coordinates ordination from CAP analysis and species vectors for BRUVS sets on reefal habitat at the three paired sites.

Fish assemblages on the open sandy bottoms did not vary between zones ($p > 0.05$) but there was a significant site effect ($p < 0.05$, DISTLM analysis with unbalanced ANOVA) due to the fish assemblages on the more inshore sites at Hastings and Oyster reefs being sufficiently distinct from those on the more offshore sites (Figure c6).

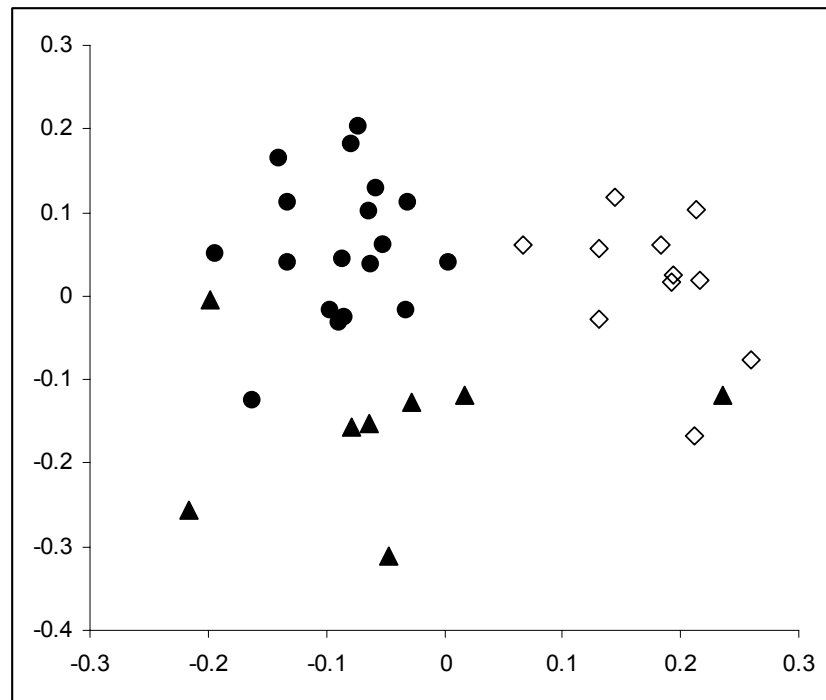


Figure c6: Canonical analysis of principal coordinates (CAP) of fish assemblages on open sandy bottoms from Green Island (closed circles), Michaelmas (closed triangles) and Hastings / Oysters reefs (open diamonds).

The distributions of *Abalistes stellatus*, *Pentapodus paradiseus*, *Carangoides gymnostethus*, *C. coeruleopinnatus* and *Lethrinus ravus* had the greatest variation between sites.

With each species assigned to a functional trophic group, habitat alone discriminated among the fish assemblages (CAP, $p < 0.01$; misclassification rate 5%). Algae and invertebrate feeders, herbivores and corallivores were correlated with the reefal substrates, while invertebrate, macroinvertebrate and, to some extent, generalist macrocarnivores correlated with the sandy habitats. Zooplanktivores, piscivores and generalist carnivores were not restricted to either habitat.

Twenty-four species were identified as targeted by fishers. Their overall distributions did not vary between blue and green zones but both site and habitat influenced their distributions. *Plectropomus leopardus*, *Lethrinus lentjan*, *L. laticaudis*, *L. miniatus* and *Lutjanus carponatus* correlated with reefal substrates and *Argyropis spinifer* and four carangids (*Carangoides chrysophrys*, *Carangoides fulvoguttatus*, *Carangoides gymnostethus* and *Gnathanodon speciosus*) were correlated with sandy substrates. An interaction between site and habitat was due to *Plectropomus leopardus* and *Lethrinus lentjan* being more abundant at the green site adjacent to Michaelmas reef, *Lethrinus ravus* at Oyster reef and *Argyropis spinifer* at the Green Island green site (Figure c7).

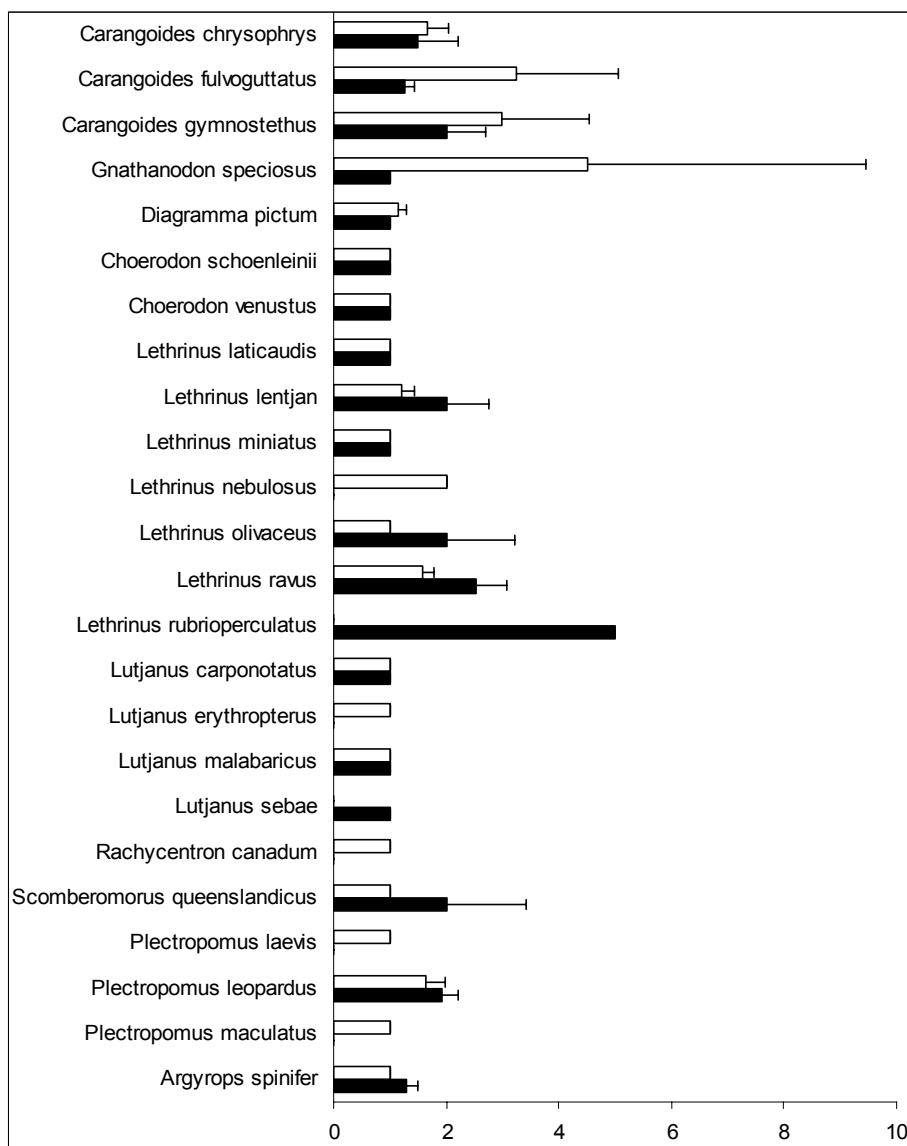


Figure c7: The mean relative abundance (± 1 SE) of targeted species in the three green (closed bars) and three blue (open bars) areas off Cairns.

Discussion

Two distinct habitats were evident on the study sites off Cairns – scattered reef substrates with filter feeders and corals, and unconsolidated sandy sediments with variable cover of marine plants. Species richness on these habitats was similar to that recorded on the Townsville shoals with roughly twice the number of species recorded from sets in the complex habitat as on the surrounding sandy sediments.

Marine reserves have been shown to impact on the trophodynamics of fish communities. Graham *et al.* 2003 showed that an increase in coral trout was accompanied by a reduction in the abundance of their prey. There was no evidence of site or zone based variation in the trophic structure of fish assemblages on shoals off Cairns and any difference in the trophic structure was assigned to variations between habitats.

Of the 24 fish identified as targeted species, the majority were recorded in very low numbers from each BRUVS set. As a group, they represented 14% of recorded fishes and their

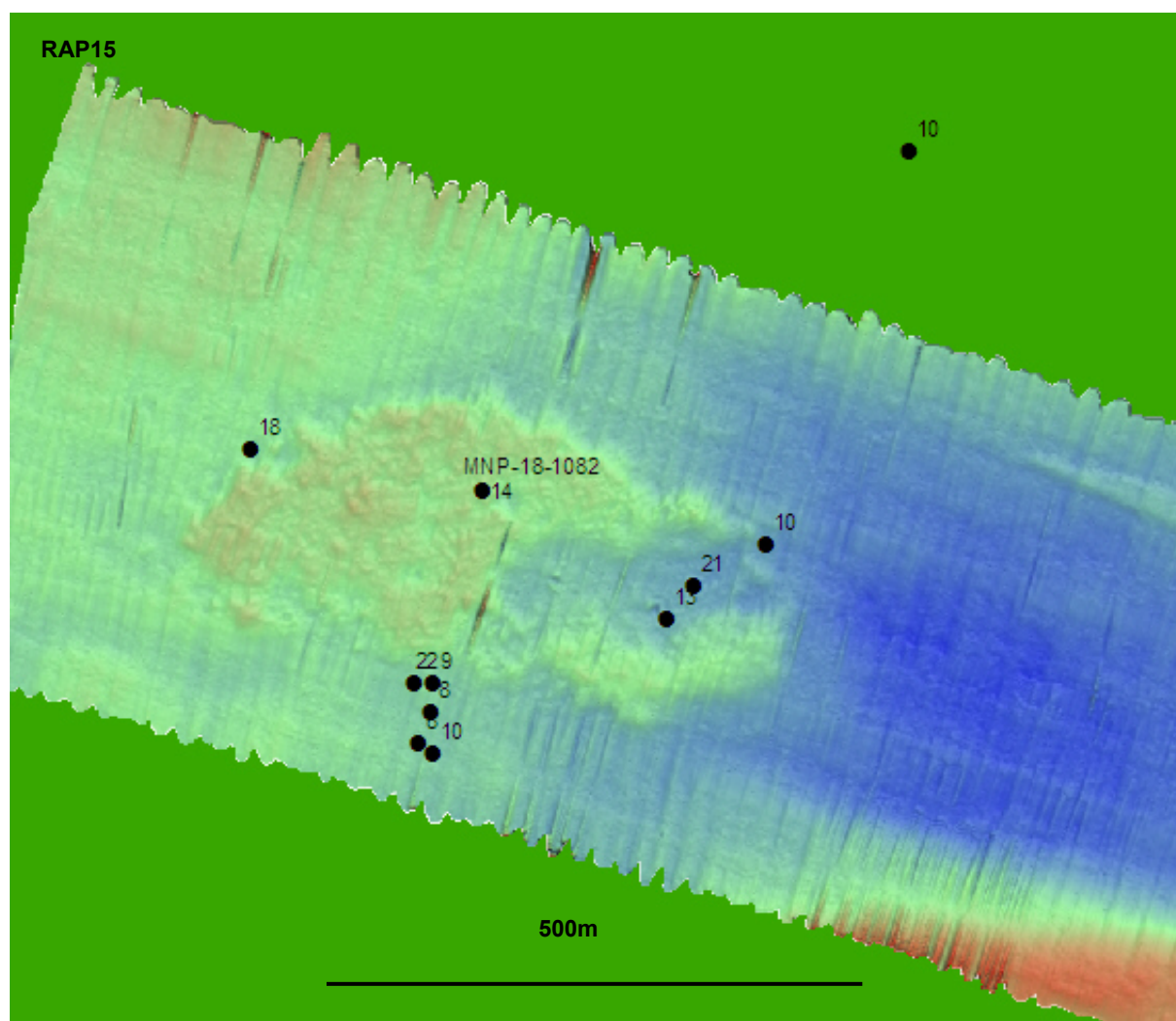
distribution varied in a similar manner to the overall fish assemblages. It is curious that three species of carangid were more abundant in blue sites. While they are considered very mobile and show greater variation in recorded numbers, it is probable that they should have been equally abundant in the green zones.

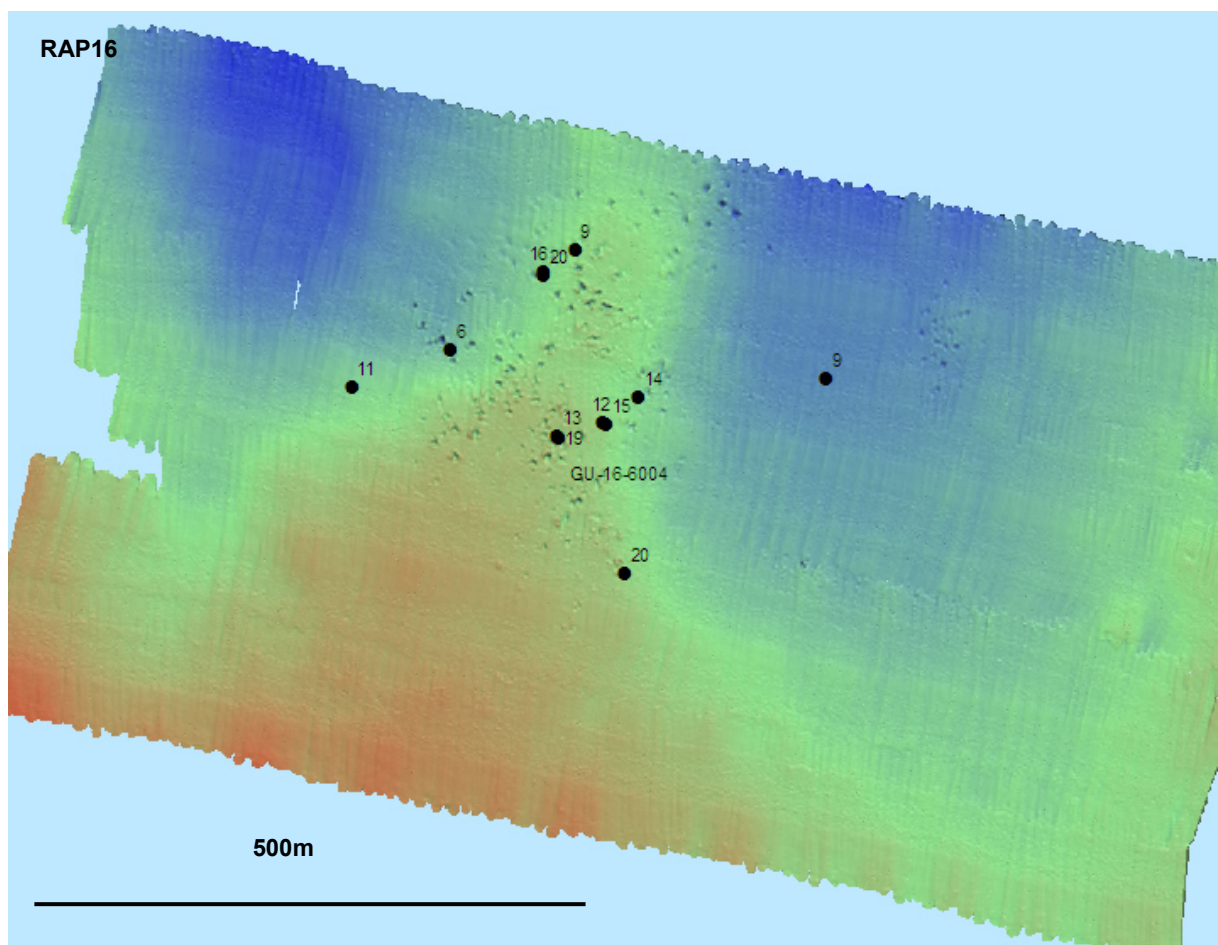
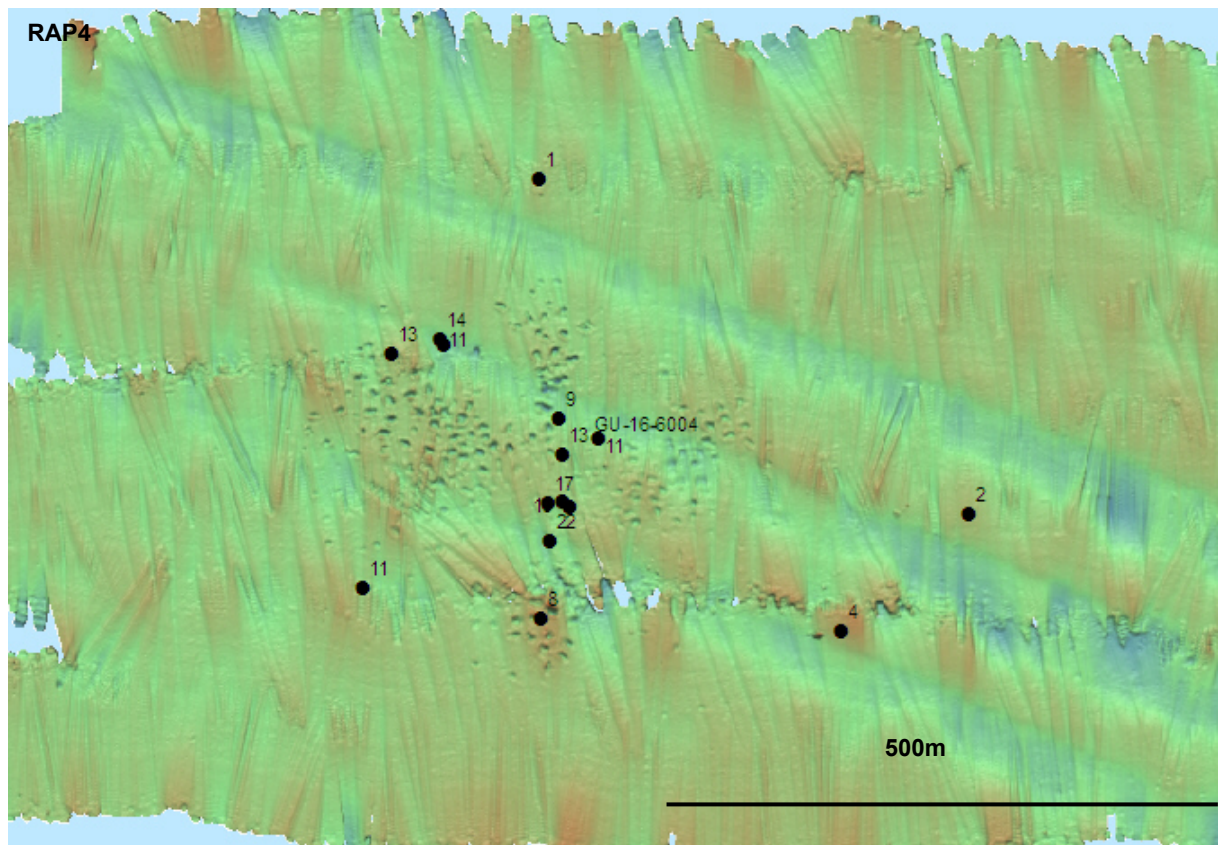
Overall, the main differences in the fish assemblages were in relation to habitat type, which was equally represented in blue and green zones. There was an interaction between site and location that was most likely to be a consequence of the relative cross-shelf position of the paired study sites (Williams 1982, 1991). This baseline includes a broad suite of species from wide ranging functional groups and a similar broad range of targeted species that might be expected to respond to the release of fishing pressure in the new green zones.

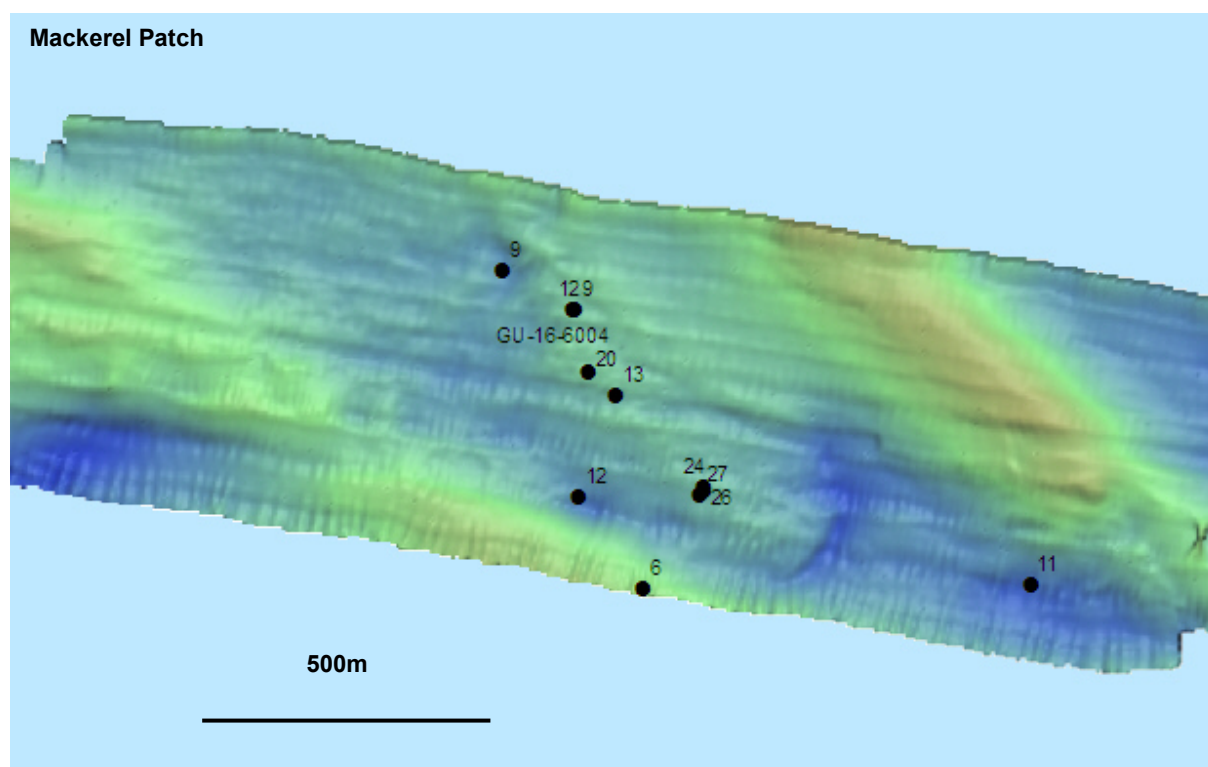
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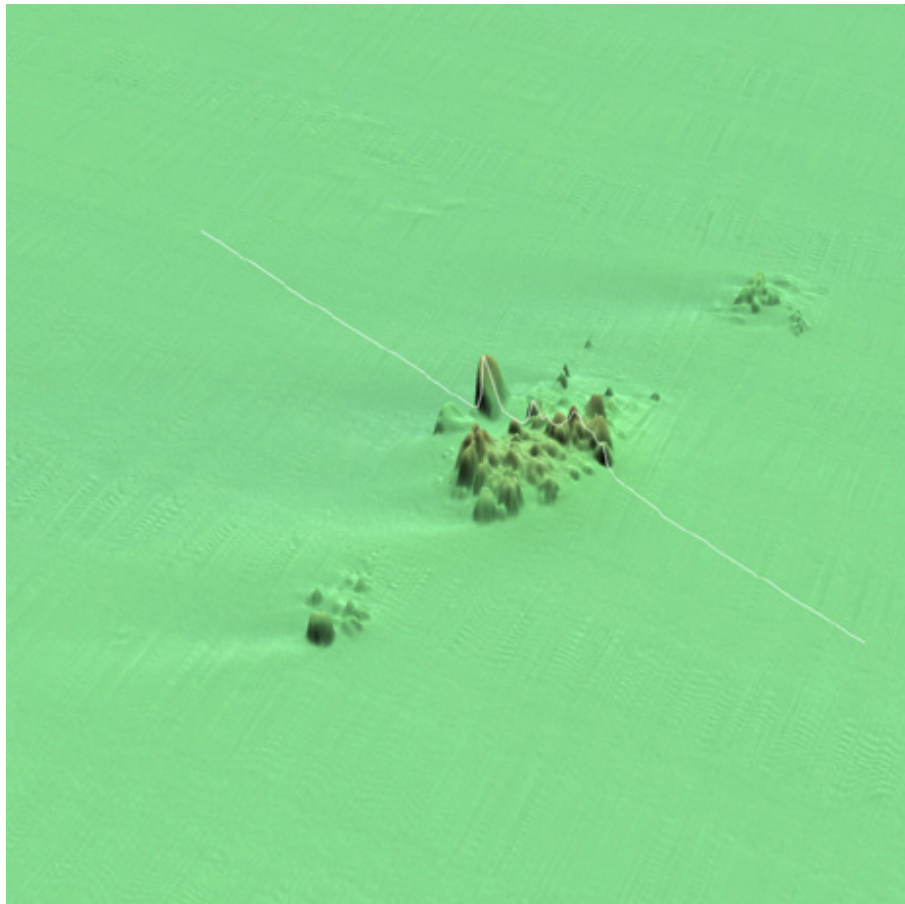
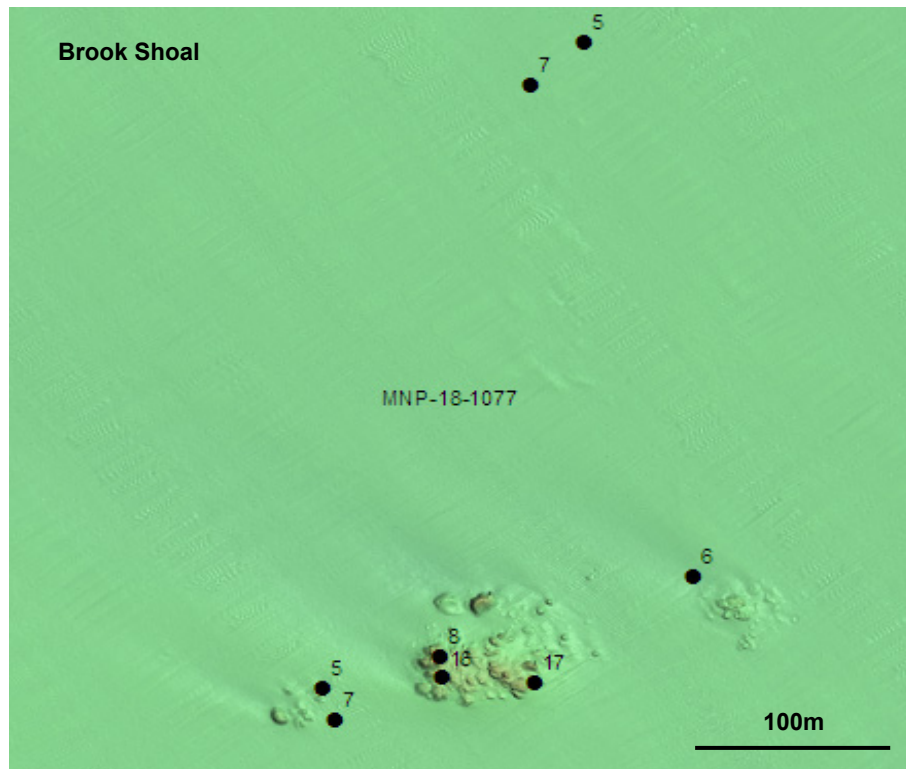
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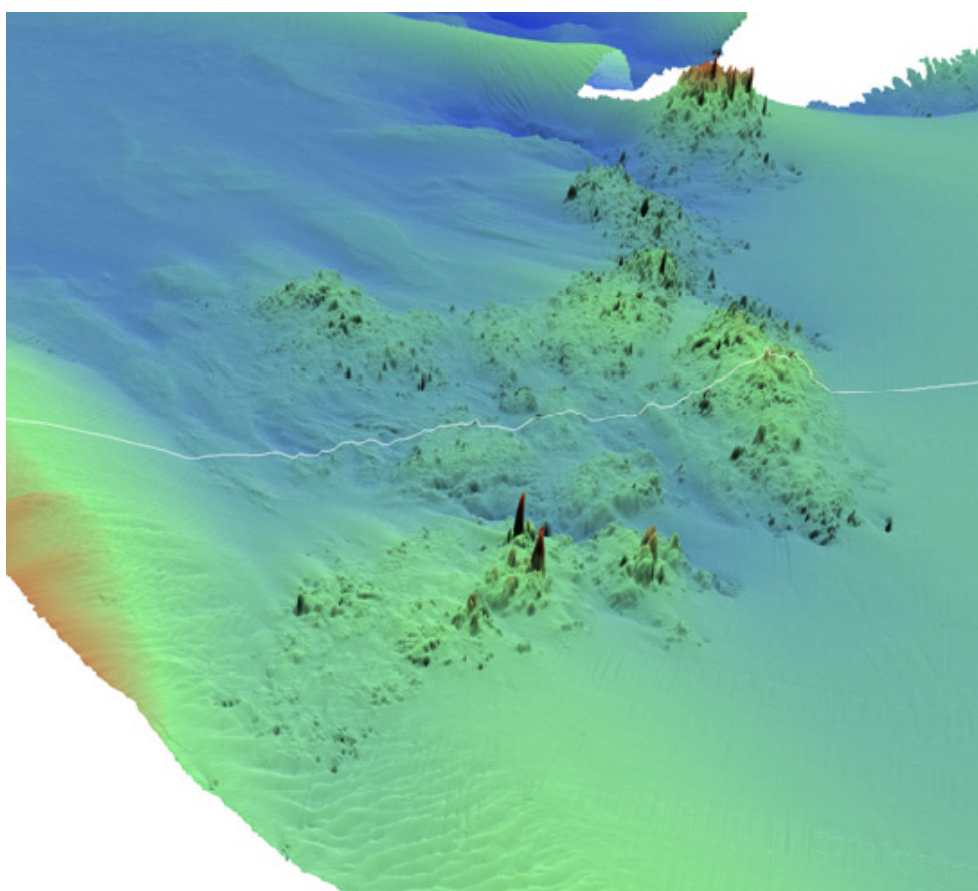
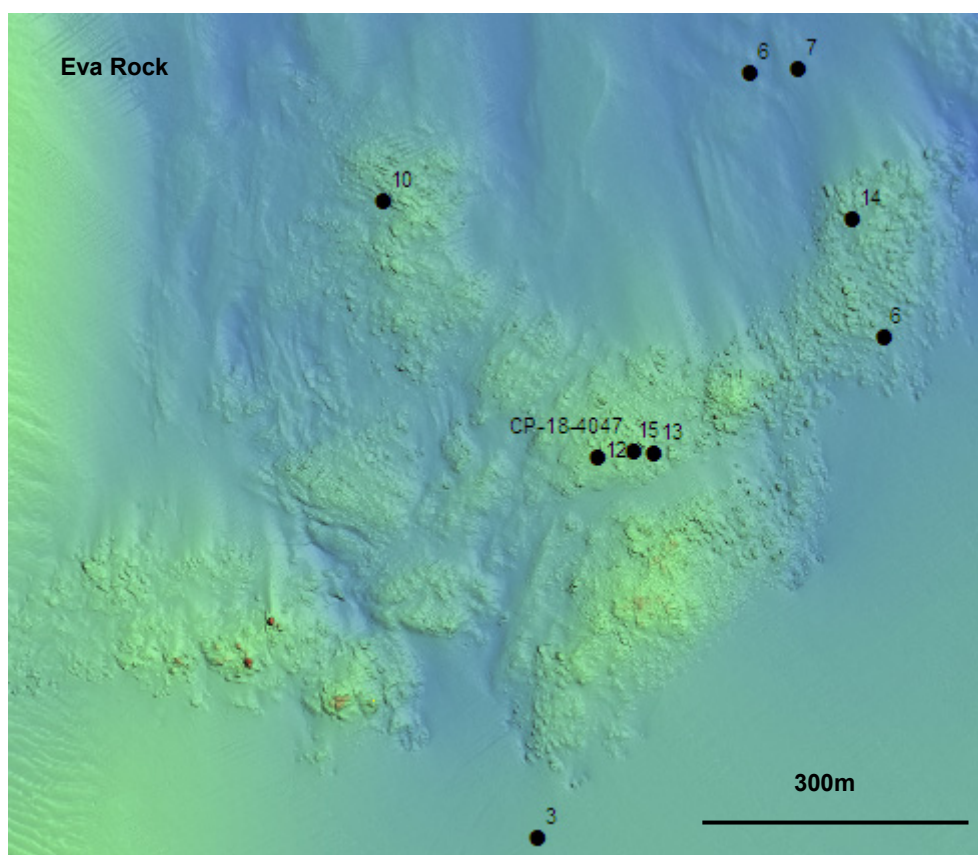


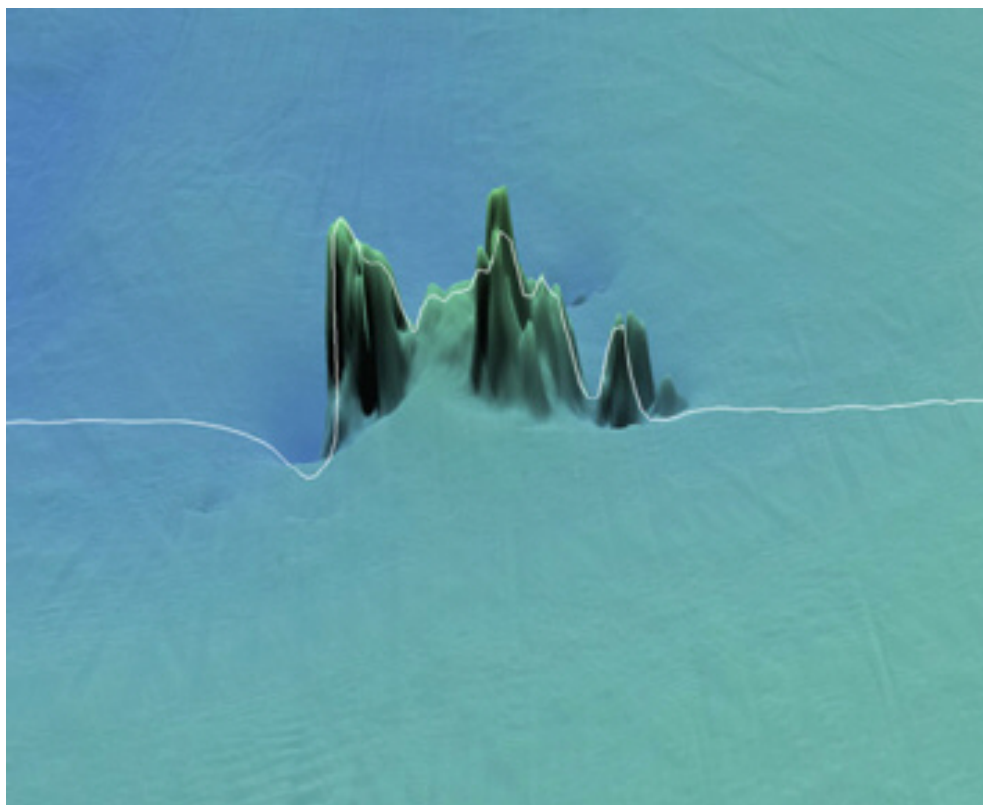
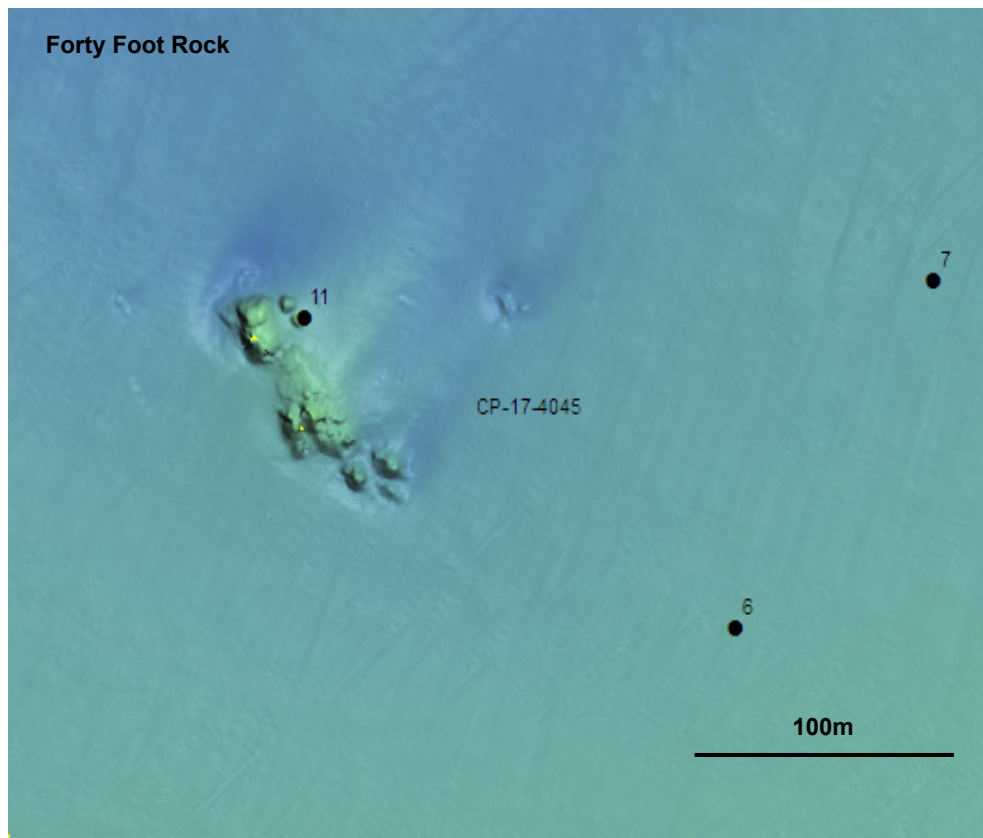




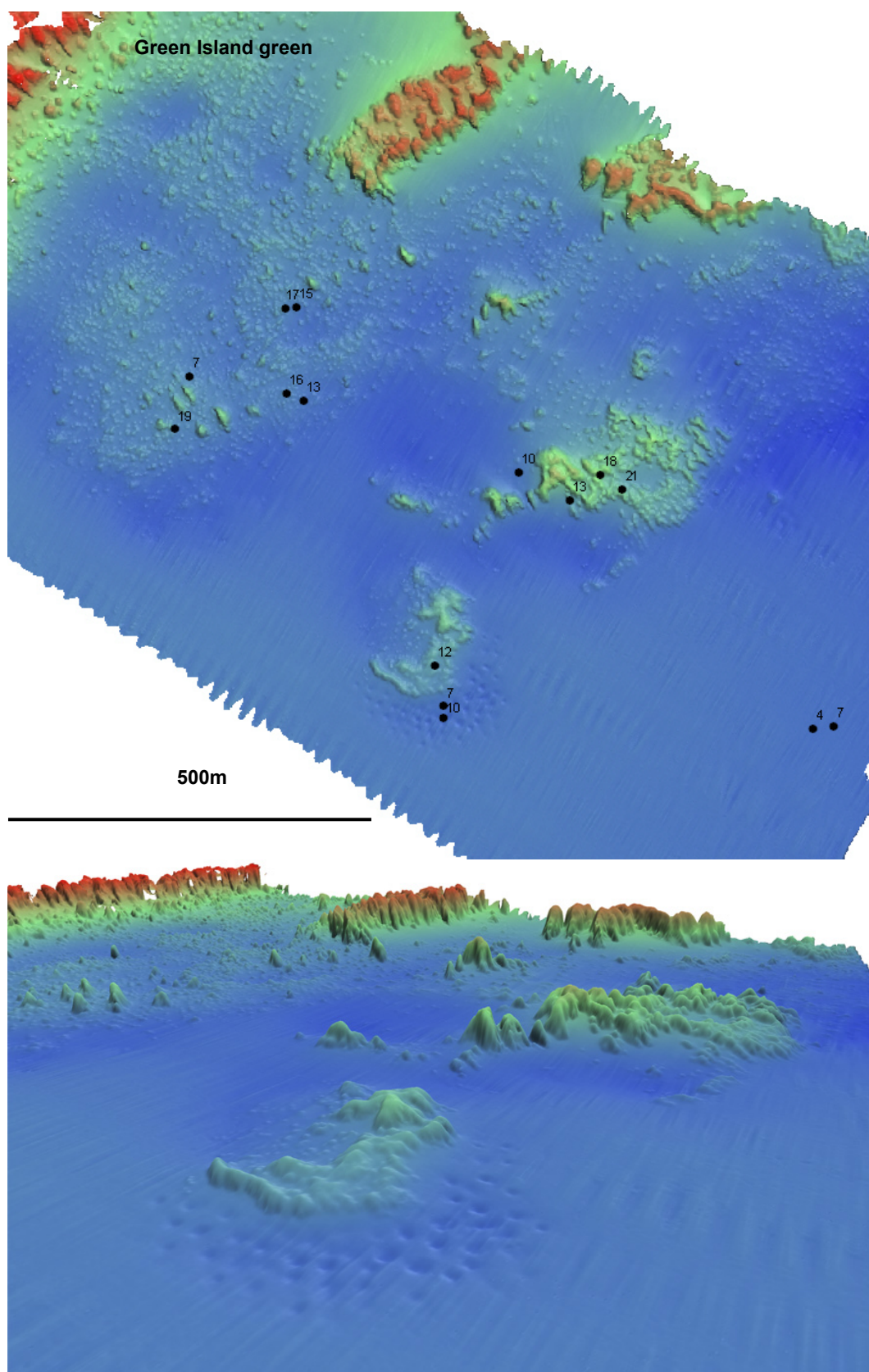
Cardwell

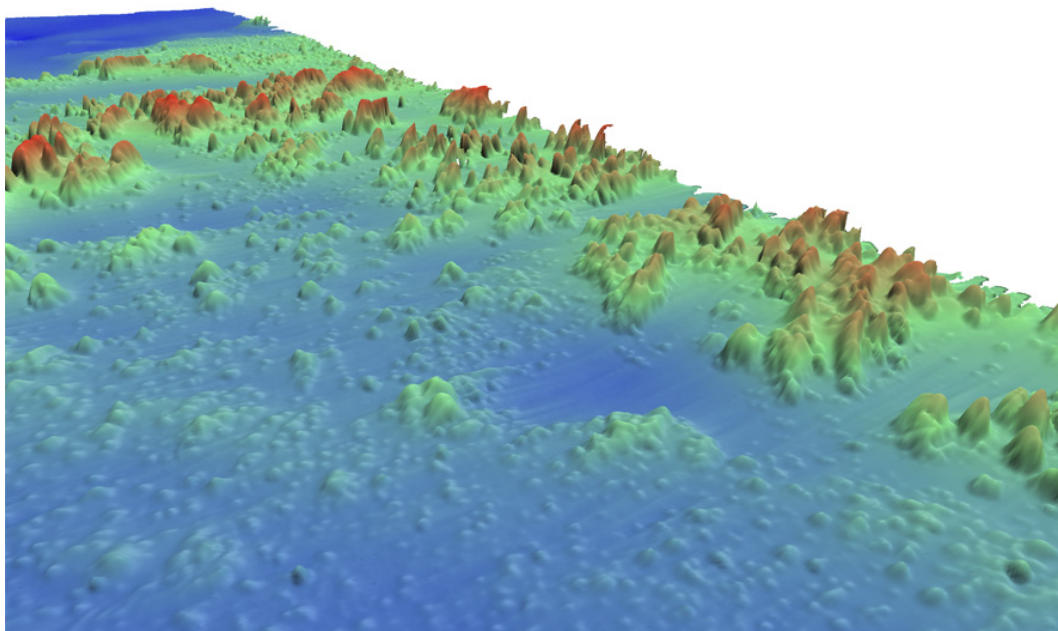
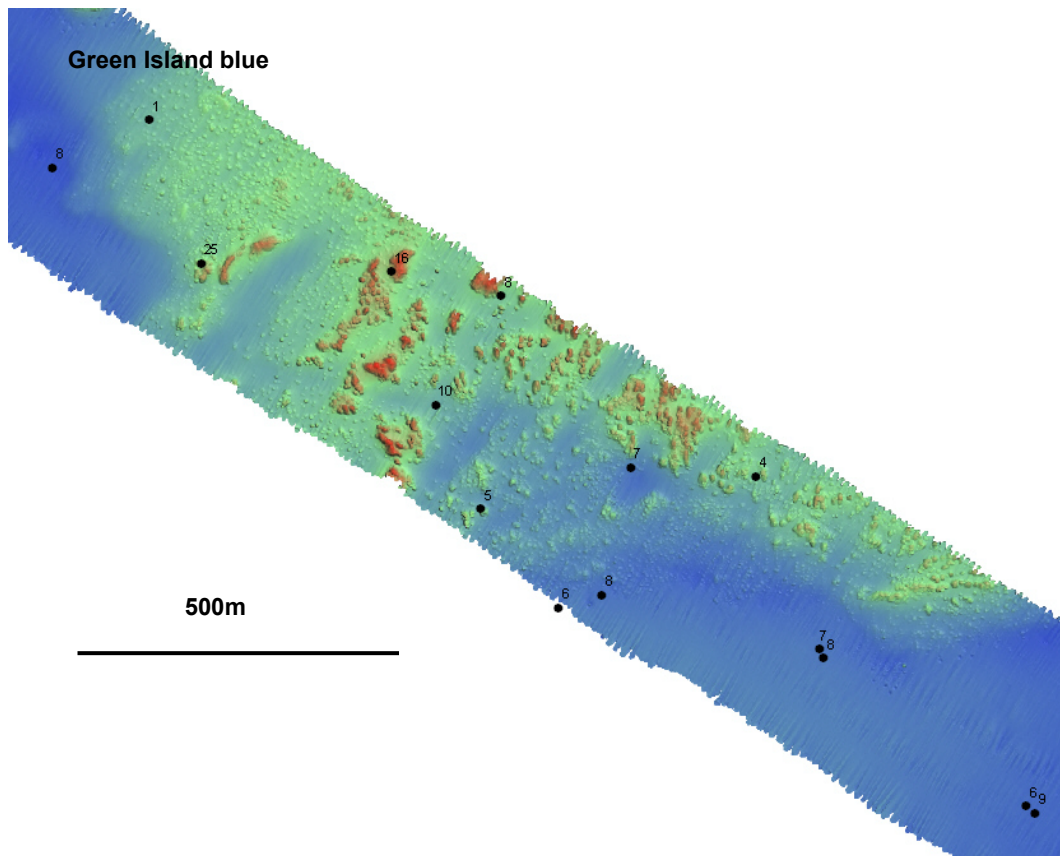


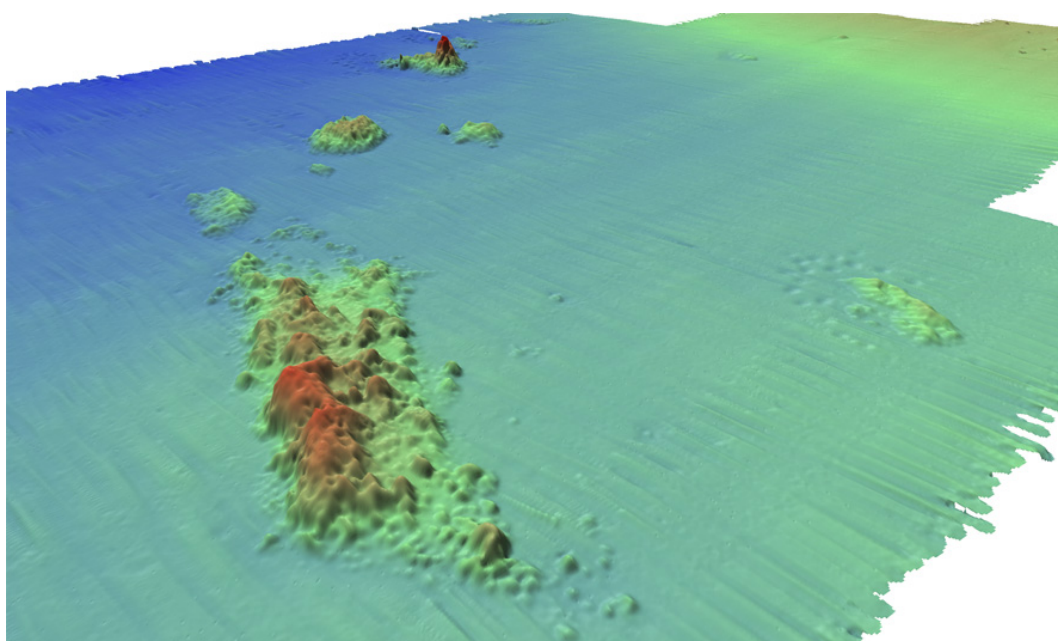
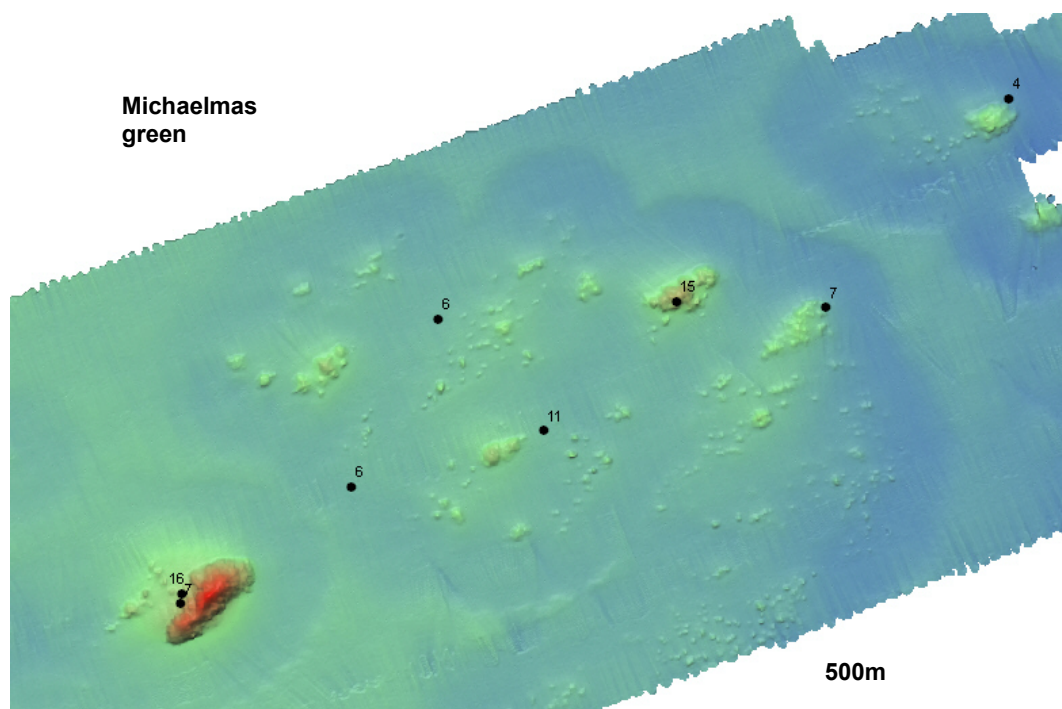


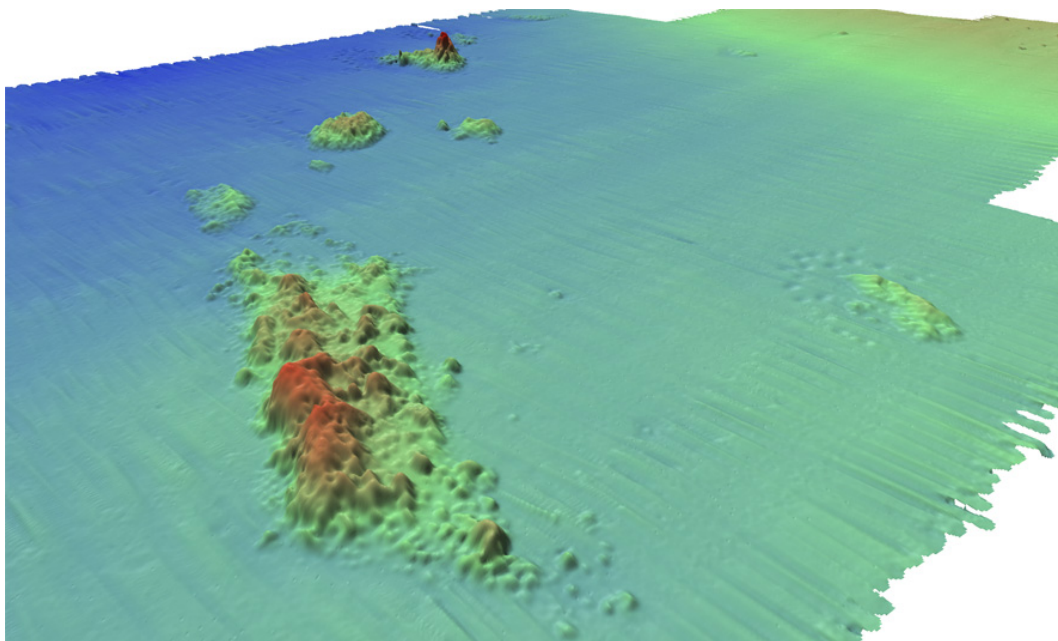
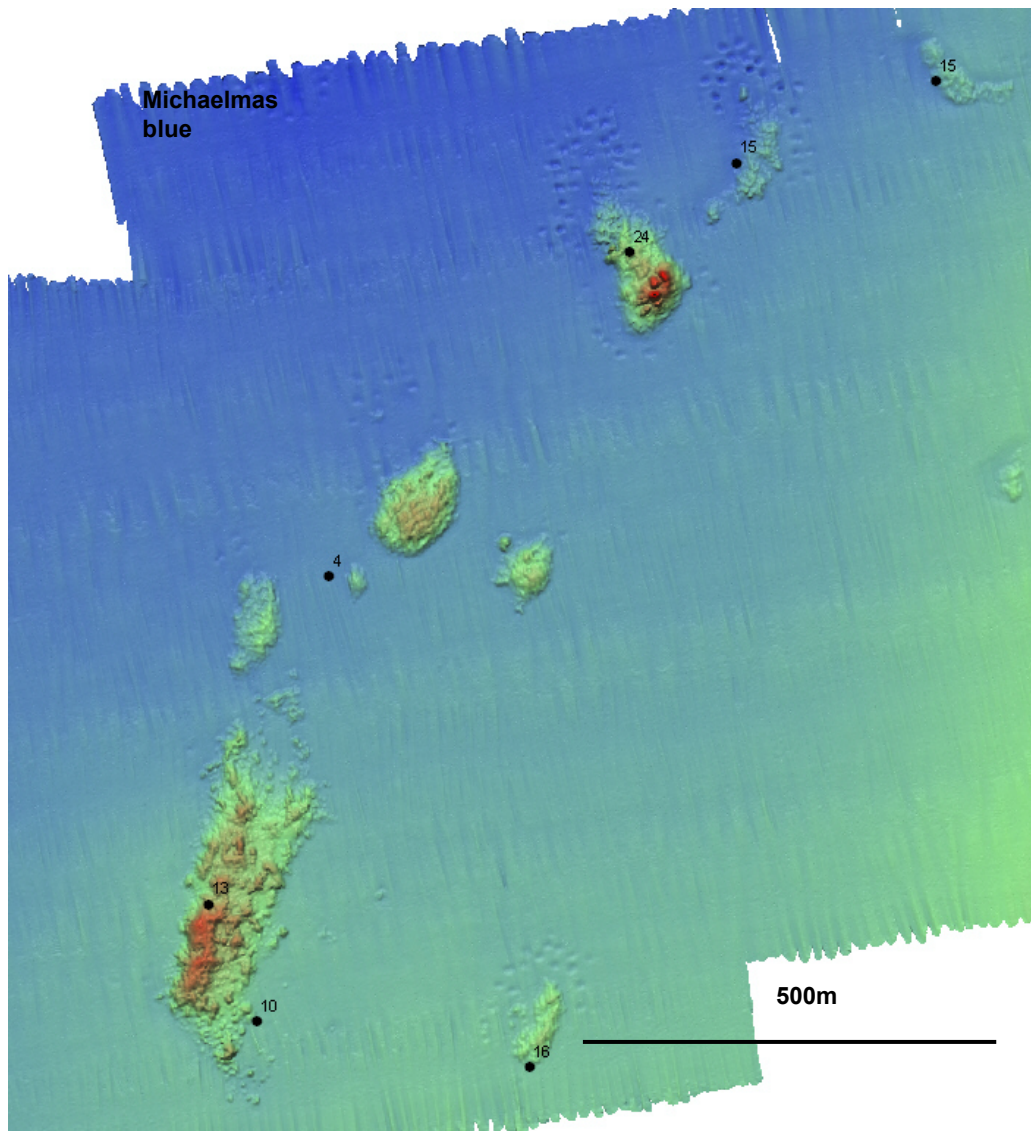


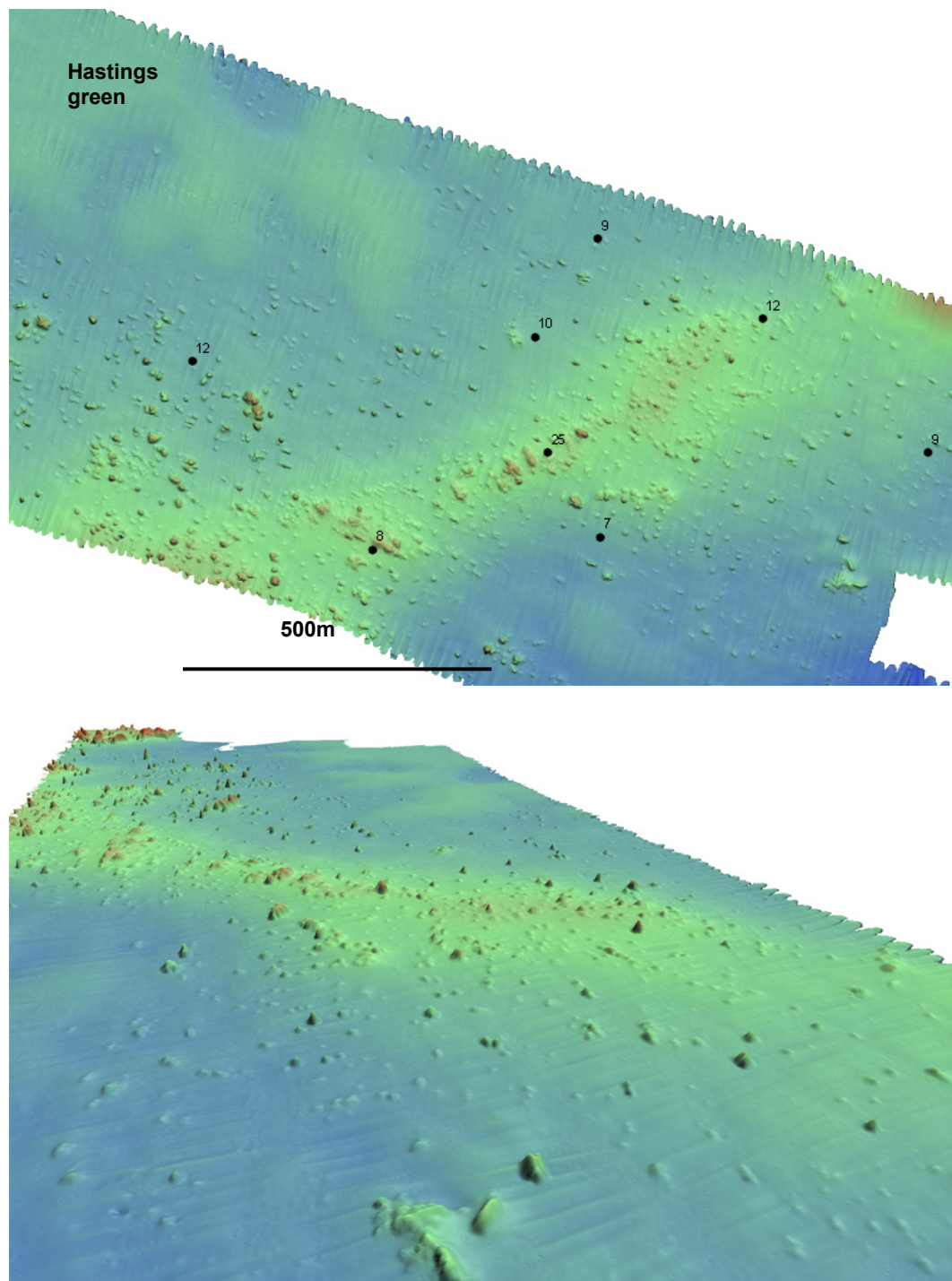
Cairns

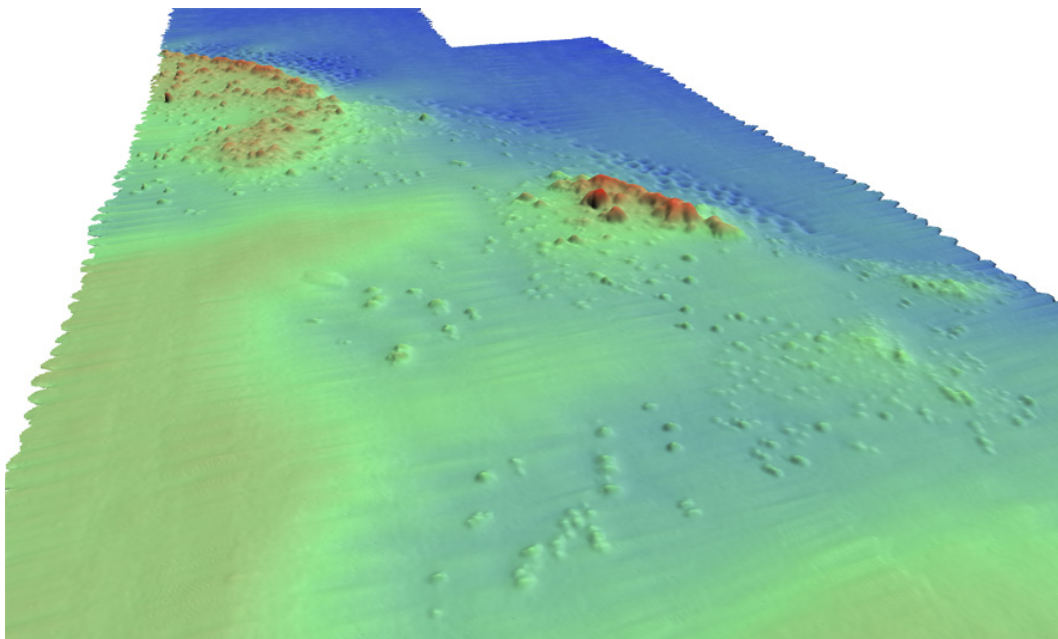
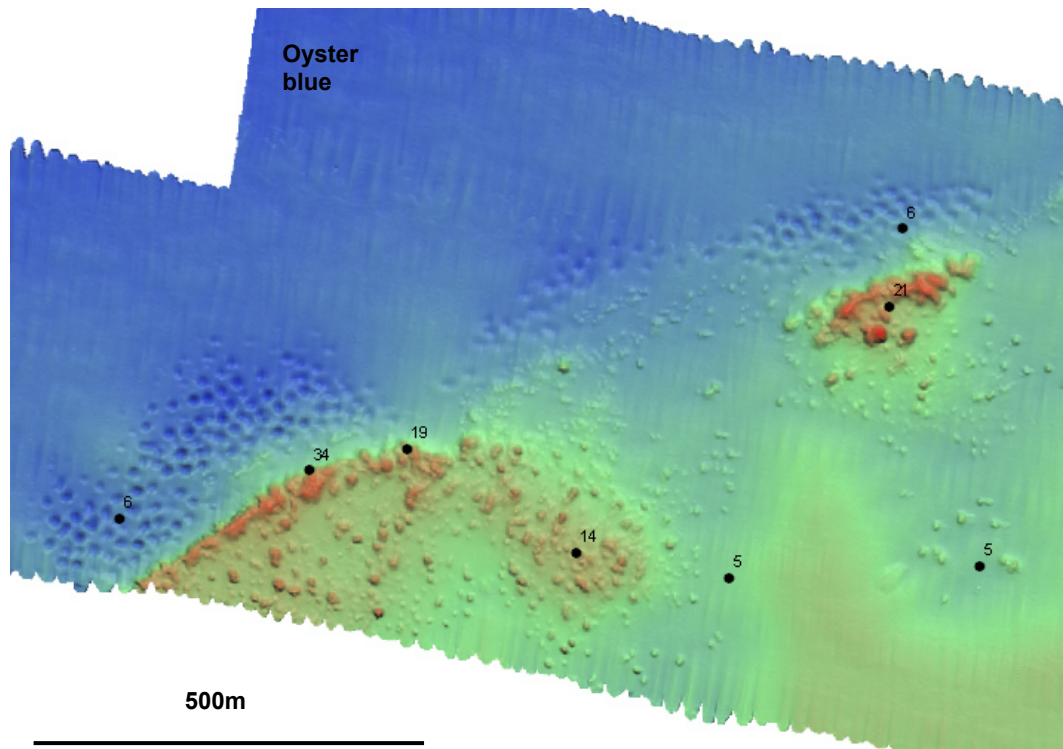












Appendix 2: Classification Information

- a. Classification schedule employed for habitat mapping using towed underwater video. O = Individual organism / point event; S = Substrate class; B = Benthic class.

Category	Key Type
Solitary Hard Coral	O
Solitary Soft Coral	O
Hydroid	O
Crinoid	O
Urchin	O
Starfish	O
Bryozoan	O
Holothurian	O
Gastropod	O
Ascidian	O
Anemone	O
Icelet	O
No Sediment	S
Soft Mud	S
Silt (Sandy mud)	S
Sand	S
Coarse Sand	S
Sand Rubble Forams	S
Rubble (5-50mm)	S
Stones (50-250mm)	S
Rocks (> 250mm)	S
Reef	S
Seagrass – Sparse	B
Seagrass – Medium	B
Seagrass – Dense	B
Algae – Sparse	B
Algae – Medium	B
Algae – Dense	B
Whip Garden – Sparse	B
Whip Garden – Medium	B
Whip Garden – Dense	B
Gorgonian Garden – Sparse	B
Gorgonian Garden – Medium	B
Gorgonian Garden – Dense	B
Porifera (Sponge) Garden – Sparse	B
Porifera (Sponge) Garden – Medium	B
Porifera (Sponge) Garden – Dense	B

Category	Key Type
Hard Coral Garden (Flowerpots) – Sparse	B
Hard Coral Garden (Flowerpots) – Medium	B
Hard Coral Garden (Flowerpots) – Dense	B
Live Reef Corals	B
Caulerpa	B
Halimeda	B
Bivalve Shell Beds	B
Tube Polychaete Beds	B
Burrowing Animals (Bioturbated Mud)	B
Flora	B
null	B

b. Operational data for towed video surveys of study sites off Townsville, Cardwell and Cairns.

Location	Zone	Site	Vessel	DistTravelled(km)	NoRecords	Resolution(m)	Depth Range (m)
Townsville	Green	RAP2	Apollo	20.847	5180	4.0	21.3 - 27.6
	Green	RAP12	Apollo	3.952	950	4.2	26.4 - 28.5
	Green	RAP15	Lady Basten	4.015	1153	3.5	25.1 - 28.4
	Blue	RAP4	Apollo	8.072	2277	3.5	27.7 - 32.7
	Blue	RAP16	Apollo	4.171	1656	2.5	38.8 - 41.7
	Blue	MackerelPatch	Apollo	19.501	5448	3.6	18.4 - 22.0
Cardwell	Green	Brook Shoal	Lady Basten	0.139	50	2.8	14.2 - 17.0
	Blue	Eva Rock	Lady Basten	0.510	196	2.6	18.2 - 24.2
Cairns	Green	GreenIsGreen	Lady Basten	2.760	1532	1.8	22.9 - 33.9
	Green	MichaelmasGreen	Lady Basten	7.124	3679	1.9	26.9 - 37.0
	Green	HastingsReef	Lady Basten	5.039	2661	1.9	30.5 - 40.5
	Blue	GreenIsBlue	Lady Basten	2.783	1471	1.9	20.7 - 36.8
	Blue	MichaelmasBlue	Lady Basten	1.150	733	1.6	31.3 - 38.5
	Blue	OysterReef	Lady Basten	3.409	1806	1.9	25.6 - 32.4

c. Substrate classes and their contributions (metres) to habitats surveyed with towed underwater video at study sites off Townsville, Cardwell and Cairns.

Location	Zone	Site	MudSand	Sand	SandCoarse	SandForams	SandHoles	Rubble	Rock	Bedrock	Reef
Townsville	Green	RAP2		7399	4076	4427	144	4782	13		6
	Green	RAP12				3025		927			
	Green	RAP15		563	36	1753		1649			14
	Blue	RAP4			5919	1894		259			
	Blue	RAP16			3369		798				4
	Blue	MackerelPatch			134	19367					
Cardwell	Green	Brook Shoal		94							45
	Blue	Eva Rock		192							318
Cairns	Green	GreenIsGreen		1989							771
	Green	MichaelmasGreen		6394				114			614
	Green	HastingsReef		4274			8	12			745
	Blue	GreenIsBlue		1108				476			1199
	Blue	MichaelmasBlue		932							218
	Blue	OysterReef		2567			190				652

- d. Epibenthos classes and their contributions (metres) to habitats surveyed with towed underwater video at study sites off Townsville, Cardwell and Cairns.

Location	Zone	Site	None	MacroAlgae	Seagrass	Burrowers	FilterFeeders	HardCoral	Isolates
Townsville	Green	RAP2	4586	3850	4957	6025	389	0	1040
	Green	RAP12	158	2733	0		1061	0	0
	Green	RAP15	49	3003	460	93	360	27	23
	Blue	RAP4	4992	1970	25	1077	8	0	0
	Blue	RAP16		0	4028		91	52	0
	Blue	MackerelPatch	4461	2745	9202		3082	11	0
Cardwell	Green	Brook Shoal	62	0	0	32	20	25	0
	Blue	Eva Rock	4	0	0	195	311	0	0
Cairns	Green	GreenIsGreen	1358	0	0	20	106	29	1247
	Green	MichaelmasGreen	831	1943	3973	204	41	132	0
	Green	HastingsReef	1284	0	3730		25	0	0
	Blue	GreenIsBlue	993	38	0		0	242	1510
	Blue	MichaelmasBlue	379	140	4	627	0	0	0
	Blue	OysterReef	1015	0	2143	77	12	0	162

Appendix 3: BRUVS Operational Data

Location	Zone	Set	Deployment	Longitude	Latitude	Depth(m)
CAIRNS						
Green Island	BI	GlbA_1	13/12/2006 11:21:24	146.0706	-16.80147	37.0
	BI	GlbA_2	13/12/2006 11:58:18	146.06278	-16.79758	36.5
	BI	GlbA_25	13/12/2006 11:26:48	146.06198	-16.79782	36.8
	BI	GlbA_3	13/12/2006 12:03:22	146.05892	-16.79163	27.4
	BI	GlbB_1	13/12/2006 15:53:53	146.07077	-16.8016	38.0
	BI	GlbB_2	13/12/2006 15:59:04	146.0668	-16.79858	36.4
	BI	GlbB_25	13/12/2006 16:02:35	146.06687	-16.79875	36.2
	BI	GlbB_3	13/12/2006 16:07:26	146.06092	-16.79208	32.2
	BI	GlbC_2	17/12/2006 11:30:02	146.06055	-16.796	34.3
	BI	GlbC_25	17/12/2006 11:21:38	146.05445	-16.78884	31.7
	BI	GlbC_3	17/12/2006 11:33:11	146.06331	-16.79524	34.7
	BI	GlbD_1	17/12/2006 13:54:27	146.05267	-16.78972	37.6
	BI	GlbD_2	17/12/2006 13:57:11	146.0554	-16.79148	27.8
	BI	GlbD_25	17/12/2006 14:09:50	146.06562	-16.7954	30.1
	BI	GlbD_3	17/12/2006 14:00:45	146.05972	-16.79409	32.9
	Gr	GlgA_1	13/12/2006 14:41:32	146.03397	-16.80158	32.1
	Gr	GlgA_15	13/12/2006 15:07:51	146.02935	-16.80145	32.3
	Gr	GlgA_2	13/12/2006 14:54:56	146.03158	-16.79858	27.7
	Gr	GlgA_3	13/12/2006 14:59:40	146.0276	-16.79747	31.5
	Gr	GlgB_1	13/12/2006 17:09:38	146.03423	-16.80155	32.6
	Gr	GlgB_15	13/12/2006 17:01:33	146.0313	-16.7984	27.7
	Gr	GlgB_2	13/12/2006 17:56:00	146.02935	-16.8013	32.3
	Gr	GlgB_3	13/12/2006 17:01:12	146.02738	-16.79738	30.1
	Gr	GlgC_1	17/12/2006 9:24:58	146.02736	-16.79632	29.1
	Gr	GlgC_15	17/12/2006 9:19:48	146.03029	-16.79837	31.2
	Gr	GlgC_2	17/12/2006 9:29:07	146.02598	-16.79783	29.7
	Gr	GlgC_3	17/12/2006 9:32:46	146.02924	-16.80079	28.2
	Gr	GlgD_1	17/12/2006 12:31:47	146.03092	-16.79872	26.4
	Gr	GlgD_15	17/12/2006 12:36:07	146.02751	-16.7963	29.5
	Gr	GlgD_2	17/12/2006 12:37:58	146.02617	-16.79717	28.7
Michaelmas	BI	MbA_1	18/12/2006 10:33:56	146.07039	-16.60466	37.5
	BI	MbA_2	18/12/2006 10:36:49	146.06716	-16.60645	33.8
	BI	MbA_25	18/12/2006 10:23:50	146.06323	-16.61453	36.3
	BI	MbA_3	18/12/2006 10:39:43	146.06399	-16.60986	37.7
	BI	MbB_1	18/12/2006 12:59:43	146.06828	-16.60552	38.2
	BI	MbB_25	18/12/2006 13:10:35	146.06271	-16.6133	32.6
	BI	MbB_3	18/12/2006 13:05:47	146.06611	-16.61501	36.1
	Gr	MgA_1	18/12/2006 9:49:30	145.99857	-16.61682	26.4
	Gr	MgA_15	18/12/2006 9:54:01	146.00237	-16.615	33.8
	Gr	MgA_2	18/12/2006 9:57:10	146.00532	-16.61371	34.7
	Gr	MgA_3	18/12/2006 10:00:02	146.00723	-16.61152	35.4
	Gr	MgB_1	18/12/2006 11:34:20	146.00375	-16.61365	28.5
	Gr	MgB_15	18/12/2006 11:50:49	146.00035	-16.61559	33.5

Location	Zone	Set	Deployment	Longitude	Latitude	Depth(m)
	Gr	MgB_2	18/12/2006 11:37:10	146.00126	-16.61383	33.0
	Gr	MgB_3	18/12/2006 11:40:37	145.99858	-16.61671	28.8
Saxon	Bl	SbA_1	16/12/2006 15:25:44	145.92197	-16.6094	28.3
	Bl	SbA_15	16/12/2006 15:39:59	145.9234	-16.6065	30.3
	Bl	SbA_2	16/12/2006 15:31:05	145.91691	-16.60891	31.1
	Bl	SbA_3	16/12/2006 15:35:53	145.91929	-16.60833	28.1
	Bl	SbB_1	18/12/2006 16:16:27	145.92404	-16.6093	28.7
	Bl	SbB_15	18/12/2006 16:19:26	145.9207	-16.60919	25.7
	Bl	SbB_2	18/12/2006 16:21:30	145.91848	-16.60851	28.6
	Bl	SbB_3	18/12/2006 16:26:34	145.9233	-16.60715	26.9
Hastings	Gr	SgA_1	16/12/2006 11:08:44	145.96827	-16.53989	36.7
	Gr	SgA_15	16/12/2006 11:23:30	145.974	-16.54236	37.1
	Gr	SgA_2	16/12/2006 11:14:03	145.97308	-16.53955	35.6
	Gr	SgA_3	16/12/2006 11:17:31	145.97629	-16.53929	35.3
	Gr	SgB_1	16/12/2006 13:05:00	145.97397	-16.53817	34.7
	Gr	SgB_15	16/12/2006 13:14:32	145.97326	-16.54118	33.8
	Gr	SgB_2	16/12/2006 13:23:52	145.9786	-16.54118	36.6
	Gr	SgB_3	16/12/2006 13:31:52	145.9708	-16.54254	33.8
CARDWELL						
Brook Shoal	Gr	BS_1	11/09/2006 15:03:43	146.26279	-18.16265	15.1
	Gr	BS_2	11/09/2006 15:07:40	146.26324	-18.16245	13.2
	Gr	BS_3	11/09/2006 15:10:58	146.2643	-18.16198	15.9
	Gr	BS_4	11/09/2006 15:16:22	146.26362	-18.15968	15.8
	Gr	BSB_1	19/12/2006 15:51:32	146.26384	-18.15948	15.1
	Gr	BSB_15	19/12/2006 16:05:55	146.26363	-18.16247	14.5
	Gr	BSB_2	19/12/2006 15:54:22	146.26323	-18.16235	12.9
	Gr	BSB_3	19/12/2006 16:09:22	146.26274	-18.1625	14.5
Eva Rock	Bl	ER_1	11/09/2006 12:51:37	146.31543	-18.23478	27.6
	Bl	ER_2	11/09/2006 12:54:36	146.31412	-18.23826	18.2
	Bl	ER_3	11/09/2006 12:57:52	146.31308	-18.24176	22.4
	Bl	ER_4	11/09/2006 17:06:45	146.31362	-18.2383	22.6
	Bl	ER_5	11/09/2006 17:10:42	146.31621	-18.23721	15.7
	Bl	ERB_1	19/12/2006 16:45:24	146.315	-18.2348	27.7
	Bl	ERB_2	19/12/2006 16:48:56	146.31592	-18.23614	21.1
	Bl	ERB_25	19/12/2006 16:51:50	146.31395	-18.23825	16.5
	Bl	ERB_3	19/12/2006 16:54:01	146.31168	-18.23598	21.7
40' Rock	Bl	FFA_1	18/12/2006 13:24:58	146.18618	-17.97184	23.1
	Bl	FFA_15	18/12/2006 13:22:22	146.18424	-17.97195	19.0
	Bl	FFA_2	18/12/2006 13:27:40	146.18557	-17.97285	21.9
TOWNSVILLE						
RAP12	Gr	12_1	09/09/2006 11:38:43	146.93497	-18.909	26.8
	Gr	12_2	09/09/2006 11:42:57	146.9373	-18.90815	26.6
	Gr	12B_3	10/09/2006 11:08:56	146.93462	-18.90871	27.8
	Gr	12C_3	29/10/2006 11:12:22	146.93506	-18.90896	27.8
	Gr	12D_3	29/10/2006 12:43:43	146.93522	-18.9089	28.2
	Gr	12E_1	30/03/2007 12:11:30	146.935283	-18.909017	27.6

Location	Zone	Set	Deployment	Longitude	Latitude	Depth(m)
	Gr	12E_25	30/03/2007 12:08:13	146.934417	-18.90845	27.2
	Gr	13_3	09/09/2006 11:49:54	146.93917	-18.90328	27.1
	Gr	13_4	09/09/2006 11:59:30	146.94123	-18.9008	27.4
	Gr	13B_1	10/09/2006 10:59:18	146.93956	-18.90026	27.7
	Gr	13B_2	10/09/2006 11:06:29	146.93746	-18.90674	27.1
	Gr	13C_2	29/10/2006 11:03:51	146.93995	-18.90516	28.2
	Gr	13D_2	29/10/2006 12:29:41	146.93993	-18.9055	28.4
	Gr	13E_1	30/03/2007 13:38:08	146.94115	-18.900883	28.0
	Gr	13E_15	07/11/2006 12:01:55	146.93965	-18.9003	27.7
	Gr	13E_2	30/03/2007 13:42:41	146.939917	-18.905217	27.6
	Gr	13E_25	30/03/2007 13:35:12	146.939483	-18.9004	27.8
	Gr	13E_3	30/03/2007 13:45:56	146.936167	-18.90245	27.8
	Gr	14_1	09/09/2006 13:31:58	146.95001	-18.89913	25.5
	Gr	14_2	09/09/2006 13:38:04	146.94826	-18.90068	26.3
	Gr	14B_3	09/09/2006 15:34:03	146.94661	-18.90178	25.6
	Gr	14B_4	09/09/2006 15:40:12	146.94881	-18.90036	25.7
	Gr	14C_1	29/10/2006 10:54:07	146.94903	-18.90516	28.4
	Gr	14D_1	29/10/2006 12:13:22	146.94915	-18.90466	28.7
	Gr	14E_25	07/11/2006 12:12:39	146.94886	-18.90033	28.4
	Gr	14F_1	30/03/2007 15:13:38	146.94825	-18.90165	27.6
	Gr	14F_2	30/03/2007 15:17:42	146.947567	-18.901017	27.8
	Gr	14F_25	30/03/2007 15:09:29	146.9488	-18.900183	27.9
	Gr	14F_3	30/03/2007 15:20:17	146.946933	-18.89865	27.7
RAP15	Gr	15_3	09/09/2006 13:52:37	146.93985	-18.92495	23.3
	Gr	15_4	09/09/2006 14:04:44	146.9384	-18.92775	24.4
	Gr	15B_1	09/09/2006 15:17:28	146.939	-18.9273	24.3
	Gr	15B_2	09/09/2006 15:20:02	146.93689	-18.92813	24.0
	Gr	15C_4	29/10/2006 11:27:12	146.936985	-18.9283	27.2
	Gr	15D_4	29/10/2006 13:00:34	146.936998	-18.92855	27.6
	Gr	15E_25	07/11/2006 10:06:55	146.93692	-18.92849	27.2
	Gr	15F_1	29/03/2007 15:20:18	146.938567	-18.92755	26.9
	Gr	15F_2	29/03/2007 15:22:15	146.9373	-18.926983	26.5
	Gr	15F_25	29/03/2007 15:16:53	146.937	-18.928133	26.4
	Gr	15F_3	29/03/2007 15:24:10	146.935917	-18.926733	26.3
RAP16	BI	16_1	28/10/2006 13:49:50	146.808208	-18.667018	39.4
	BI	16_2	28/10/2006 14:02:30	146.808071	-18.66551	40.2
	BI	16_25	28/10/2006 16:20:19	146.808605	-18.66688	39.6
	BI	16_3	28/10/2006 14:20:07	146.80632	-18.66656	40.2
	BI	16_4	28/10/2006 14:30:05	146.81064	-18.66648	41.1
	BI	16B_1	29/10/2006 8:12:50	146.808183	-18.66701	38.6
	BI	16B_2	29/10/2006 8:20:26	146.80806	-18.66555	38.9
	BI	16B_25	29/10/2006 8:03:43	146.808631	-18.6669	38.7
	BI	16C_1	29/03/2007 12:58:46	146.80835	-18.665317	38.4
	BI	16C_2	29/03/2007 13:02:40	146.807217	-18.666217	39.1
	BI	16C_25	29/03/2007 12:55:57	146.808933	-18.66665	38.6
	BI	16C_3	29/03/2007 13:07:20	146.8088	-18.66825	38.4

Location	Zone	Set	Deployment	Longitude	Latitude	Depth(m)
RAP2	Gr	2_1	12/07/2006 12:17:00	146.91614	-18.919442	26.2
	Gr	2_2	12/07/2006 12:22:23	146.905648	-18.915033	26.0
	Gr	2_3	12/07/2006 12:33:00	146.915197	-18.91488	25.8
	Gr	2_4	12/07/2006 12:44:00	146.910075	-18.919867	26.8
	Gr	2B_1	09/09/2006 9:02:00	146.91599	-18.91949	25.9
	Gr	2B_2	09/09/2006 9:52:18	146.91522	-18.91521	26.2
	Gr	2B_3	09/09/2006 10:00:00	146.9204	-18.91601	26.4
	Gr	2B_4	09/09/2006 10:12:07	146.90567	-18.91538	25.8
	Gr	2C_1	29/10/2006 16:29:37	146.91507	-18.9152	27.8
	Gr	2C_2	29/10/2006 16:38:50	146.90579	-18.91541	27.1
	Gr	2C_25	29/10/2006 16:22:46	146.92049	-18.91611	27.9
	Gr	2D_15	07/11/2006 10:25:18	146.90608	-18.91554	27.1
	Gr	2E_1	30/03/2007 10:34:42	146.912583	-18.914667	27.3
	Gr	2E_2	30/03/2007 10:38:00	146.91625	-18.914617	27.3
	Gr	2E_25	30/03/2007 10:30:17	146.9053	-18.915083	26.4
	Gr	2E_3	30/03/2007 10:41:21	146.920633	-18.915917	27.1
RAP4	BI	4_1	12/07/2006 14:27:31	147.001572	-18.8828	31.6
	BI	4_2	12/07/2006 14:34:20	147.002992	-18.879517	30.9
	BI	4_4	12/07/2006 14:47:00	147.006462	-18.882217	30.3
	BI	4B_1	10/09/2006 7:26:10	147.00347	-18.88161	30.2
	BI	4B_2	10/09/2006 8:42:28	147.00222	-18.88085	30.7
	BI	4B_3	10/09/2006 8:49:13	147.00318	-18.88211	30.0
	BI	4B_4	10/09/2006 8:55:00	147.00542	-18.88316	30.1
	BI	4C_1	29/10/2006 14:29:59	147.00323	-18.88216	32
	BI	4C_2	29/10/2006 14:40:21	147.0022	-18.8808	32.5
	BI	4C_25	29/10/2006 14:49:51	147.00315	-18.88145	32.4
	BI	4D_15	07/11/2006 13:50:21	147.00306	-18.88213	30.2
	BI	4E_1	31/03/2007 9:13:52	147.0018	-18.880917	32.5
	BI	4E_2	31/03/2007 9:17:18	147.003183	-18.881733	32.6
	BI	4E_25	31/03/2007 9:10:03	147.003083	-18.882433	32.7
	BI	4E_3	31/03/2007 9:21:23	147.003	-18.88305	32.3
RAPMP	BI	MP_1	08/09/2006 13:49:19	147.13476	-19.15701	15.5
	BI	MP_2	08/09/2006 13:41:37	147.13567	-19.15551	16.2
	BI	MP_3	08/09/2006 13:33:09	147.13365	-19.1527	16.3
	BI	MPB_1	30/10/2006 8:35:55	147.13368	-19.15272	18.7
	BI	MPB_2	30/10/2006 8:42:21	147.13375	-19.15561	18.9
	BI	MPB_25	30/10/2006 8:29:26	147.13434	-19.15405	18.7
	BI	MPB_3	30/10/2006 8:48:05	147.13569	-19.15546	18.7
	BI	MPC_1	31/03/2007 12:01:35	147.140733	-19.15695	19.6
	BI	MPC_2	31/03/2007 12:05:08	147.1339	-19.153683	18.9
	BI	MPC_25	31/03/2007 11:55:06	147.135633	-19.155583	19.6
	BI	MPC_3	31/03/2007 12:08:00	147.132567	-19.152117	18.9

Further information

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