Temporal monitoring of northern shoals off Cardwell and Townsville

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Acronyms Used in this Report

ARP..... Annual Research Plan
BRUVS..... Baited Remote Underwater Video Stations
GBRMP..... Great Barrier Reef Marine Park
GBRMPA ..... Great Barrier Reef Marine Park Authority
MTSRF..... Marine and Tropical Sciences Research Facility
RAP..... Representative Areas Program
SBRUVS ..... Stereo Baited Remote Underwater Video Stations

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Executive Summary

Fishing constitutes one of the greatest pressures on fish stocks through both direct and indirect mechanisms. With the advent of ecosystem-based management principles, spatial management through marine protected areas has become a more popular tool for managing pressure on fish stocks. The Great Barrier Reef Marine Park was rezoned comprehensively in 2004 for marine conservation purposes under the Representative Areas Program (RAP) which greatly increased 'no-take' zones and created opportunity to monitor response of fish stocks released from fishing pressure. In recent years, the availability and sophistication of electronic navigation aids and fish-finding devices, and the increased price of fuel, has focussed more intense fishing pressure on isolated shoal grounds close to townships. Large lutjanid “red fish”, serranids and lethrinids are taken by these inter-reef recreational and commercial fisheries.

This report presents the results of three to five return visits (between July 2006 and May 2008) to shoal grounds in the Cardwell and Townsville regions of the Great Barrier Reef, comparing areas closed to fishing in 2004 with control areas that remain open to fishing. Fish abundance and species composition was established with baited video stations. Habitats were assessed by towed video camera and classified into broad categories of substratum and life form.

Off Cardwell, a green site (Brook Shoal) and two blue sites (Eva Rock and Forty Foot Rock) were repeatedly sampled with BRUVS, and off Townsville three pairs of green/blue sites were surveyed with both BRUVS and towed video.

Major findings by region were:

Townsville region shoals

- Habitats are typically low relief features on the seabed characterised by sessile life forms.
- Habitat changes were recorded on some sites. For example, seagrass was abundant on one site in 2006 and 2007 but absent in 2008. Another site showed increased abundance of soft corals.
- Fish diversity was greater on complex habitat than the surrounding open bottom but did not vary with the level of protection from fishing.
- The relative abundances of twenty-two targeted species were collectively significantly different between zones. However, these differences favoured higher abundances *outside* the green sites for tea leaf trevally (*Carangoides chrysophrys*), golden trevally (*Gnathanodon speciosus*), nannygai (*Lutjanus erythropterus* and *L. malabaricus*), frying-pan snapper (*Argyrops spinifer*), slatey bream (*Diagramma pictum*) and gold-spot cod (*Epinephelus coioides*). This is attributed to habitat and seasonal effects.
- The lack of a zoning impact is attributed to the transient use of these low-relief habitats by mobile species that migrate across zone boundaries.

Cardwell region shoals

- Brook Shoal is a small rocky reef that was protected in 2004. Similar habitats are rare in Rockingham Bay but one similar reef was located in a yellow zone that remains open to fishing. Thus the design is essentially pseudo-replicated and cannot provide general lessons about the effect of fishing.

- Species richness varied with habitat with an average of 10.5 species recorded from the rocky substrata and 5.5 on the surrounding muddy sand. Fish species richness did not vary with the level of protection or throughout the sampling period since September 2006.
- The relative abundances of fifteen targeted species were collectively indistinguishable between zones but individual differences included significantly higher abundance indices inside the green sites for grass emperor (*Lethrinus laticaudis*), small mouth nannygai (*Lutjanus erythropterus*) and barred-cheek trout (*Plectropomus maculatus*).
- The lack of suitable 'replicate' shoal systems in the mid Great Barrier Reef region renders a more rigorous survey design impossible. There is some suggestion however, that selected species of line-caught fish (grass emperor, small-mouth nannygai and barred-cheek trout) are now more abundant on the protected reef. Although unreplicated, this pair of reefs is worth infrequent monitoring to track temporal trends.

Introduction

Fishing constitutes one of the greatest pressures on fish stocks through both direct and indirect mechanisms. With the advent of ecosystem-based management principles, spatial management through marine protected areas has become a more popular tool for managing pressure on fish stocks. The Great Barrier Reef Marine Park was rezoned comprehensively in 2004 for marine conservation purposes under the Representative Areas Program (RAP) which greatly increased 'no-take' zones and created opportunity to monitor response of fish stocks released from fishing pressure. In recent years the availability and sophistication of electronic navigation aids and fish-finding devices, and the increased price of fuel, has focussed more intense fishing pressure on isolated shoal grounds close to townships. Large lutjanid "red fish", serranids and lethrinids are taken by these inter-reef recreational and commercial fisheries (see Mapleston *et al.* 2006 for review).

The RAP was established as the principal tool for regulating human activities in the Great Barrier Reef Marine Park and preserving its habitats and biodiversity. The rezoning greatly increased 'no-take' areas and created opportunity to monitor response of fish stocks released from fishing pressure.

Work on shallow reefs anticipating the rezoning change permitted a Before-After-Control-Impact (BACI) design. Studies to date on coral reef habitat have shown a rapid response in apex predators and even some compensatory responses by prey within two years of rezoning (Russ *et al.* 2008, Evans and Russ 2004). A large proportion of areas where extractive activities are now excluded include the deeper inter-reefal and lagoonal waters, which may have been trawled and line-fished over a long period of time. These activities may have resulted in habitat destruction or modification of low relief shoal systems, especially where trawling occurred. There may also be a decrease or change in the diversity of associated fish species through direct extraction by line fishing, as trawl bycatch or through habitat alteration (Mapleston *et al.* 2006, Pitcher *et al.* 2005, Sainsbury *et al.* 1997). Additionally, fishing has the potential to reduce the average size of targeted species (e.g. Russ and Alcala 1996).

The comparison of long-standing Marine Protected Areas (MPA) with adjacent control areas has usually been conducted in high relief and emergent reef (both coral and rocky) systems. Reports demonstrate that fishing results in the selective removal of species (especially apex predators), and is associated with indirect effects on fish community structure and other functional groups (Kingsford 1998, Willis and Anderson 2003).

The Great Barrier Reef Marine Park Authority (GBRMPA) were therefore fundamentally interested in learning about responses to protection in other habitats, like offshore reefs (provided by the AIMS Long Term Monitoring Program – see Russ *et al.* 2008) and responses in deeper shoal systems; the latter the target of increased fishing pressure in recent times. In ARP1, a number of northern shoals were located, mapped, and monitored with Baited Remote Underwater Video Stations (BRUVS) without finding significant effect due to reef zonation. This report extends the survey for another year and re-examines the habitats recorded in ARP1.

Objectives

The objectives of the northern shoals project (MTSRF Project 4.8.2) for the second year were to:

- Build on 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 to fishing, blue zones);
- Identify temporal changes in the fish communities that might be related to the level of protection provided by the RAP; and
- Resurvey habitats to identify any temporal changes in habitat characteristics and distributions since initial survey in 2006.

Methods

Study sites

Townsville region shoals

Multibeam acoustic surveys undertaken in a pilot study to identify study sites in 2006 (Speare and Cappo 2006, Stieglitz 2006), contributed the fine scale/ high resolution bathymetry detailing the topography and any anomalous features to guide close-up visual investigation of the seafloor off Townsville with a towed video system. This visual approach identified a discontinuous and patchy distribution of sessile filter feeding communities, seagrass and macroalgal beds generally established on coarse sediments. Concurrent acoustic sub-bottom profiling also indentified a Pleistocene clay layer that was capable of providing a foundation for the attachment of the filter feeders where it approached or penetrated sandy/muddy seafloor overlayers. Three blue zone sites and three green zone sites were selected for this study to be as comparable as possible in terms of habitat character. This was only marginally possible given the limited number of shoaling features in the region.

Blue Zone Sites
Two of the sites from the 2006 survey that remained open to fishing, displayed anomalous bathymetric features, which could be described as depressions or holes between two and ten metres across and one to two metres in depth. One site displaying these features was situated to the east of the green zone in Halifax Bay (RAP4) and revealed the wreck of an unidentified wooden trawler. This site is known to fishers as Shark Shoal or Shark Hole where they target nannygai (*Lutjanus erythropterus* and *L. malabaricus*), red emperor (*L.* sebae), cobia (*Rachycentron canadum*) and Spanish mackerel (*Scomberomorus commerson*). The other site (RAP16), east of Great Palm Island, has more dispersed and relatively irregular depressions but is fished similarly to RAP4. The third selected site open to fishing (Mackerel Patch), is situated off Cape Cleveland in Bowling Green Bay and its fine scale topography and benthos are more similar to the sites in the green zone used in the comparisons (Speare and Stowar 2007).

Green Zone Sites
The three green zone sites are dispersed over an area referred to as Magnetic Shoal. This area is predominantly coarse sandy sediments formed into low relief broad sand waves lying in a general NW-SE orientation. They also include fine scale topographic features including depressions and, the filter feeding benthos tends to be associated with these anomalous features. RAP2 is situated to the west of RAP12 and RAP15 to the south (Figure 1 and Appendix 1).

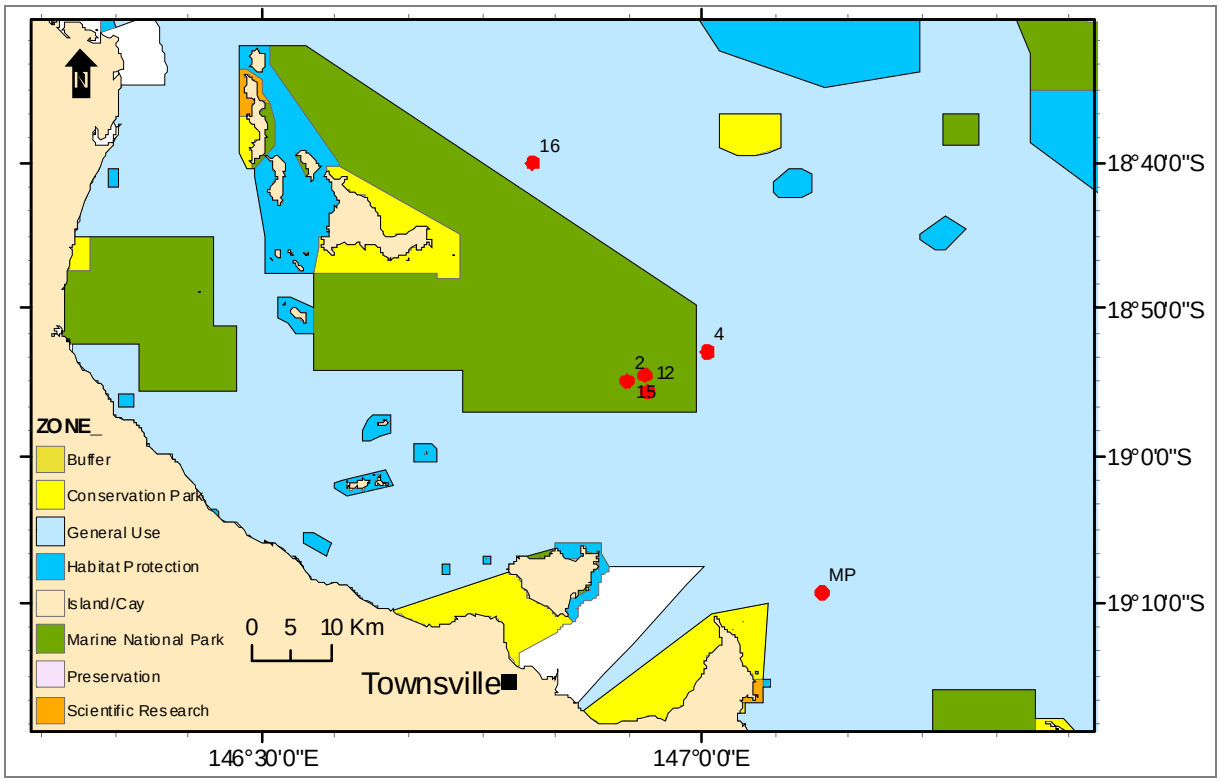

Figure 1. Townsville study sites in Halifax and Bowling Green Bays in relation to the RAP zoning. (Site reference numbers are detailed in Appendix 3)

Cardwell region shoals

Yellow Zone Sites

Yellow zones allow fishing albeit with restrictions on apparatus. Two shoal sites in yellow zones are available in this region. One of the two study sites suitable and open to fishing is a rocky shoal bridging between Eva and Hinchinbrook Islands and lying ten kilometres SSE of Brook Shoal. The other site, Forty Foot Rock, is twenty kilometres north of Brook Shoal and one kilometre off the southeast corner of Dunk Island. This site is more similar to Brook Shoal in extent. All three rocky sites emerge from a muddy sand bottom (Speare and Stowar 2007) (Figure 2 and Appendix 1).

Green Zone Sites

Brook Shoal represented the only green zone shoal site available and hence this part of the design is unbalanced. It was rezoned in 2004 to protect this small area from fishing. It lies between the Brook Islands and Hinchinbrook Island and consists of three small patches of rocky substrate. The largest central rock has an extent of ~75m and the outlying rocks are each ~20m across. The shoal rises to ~11m off a muddy sand bottom at ~15m.

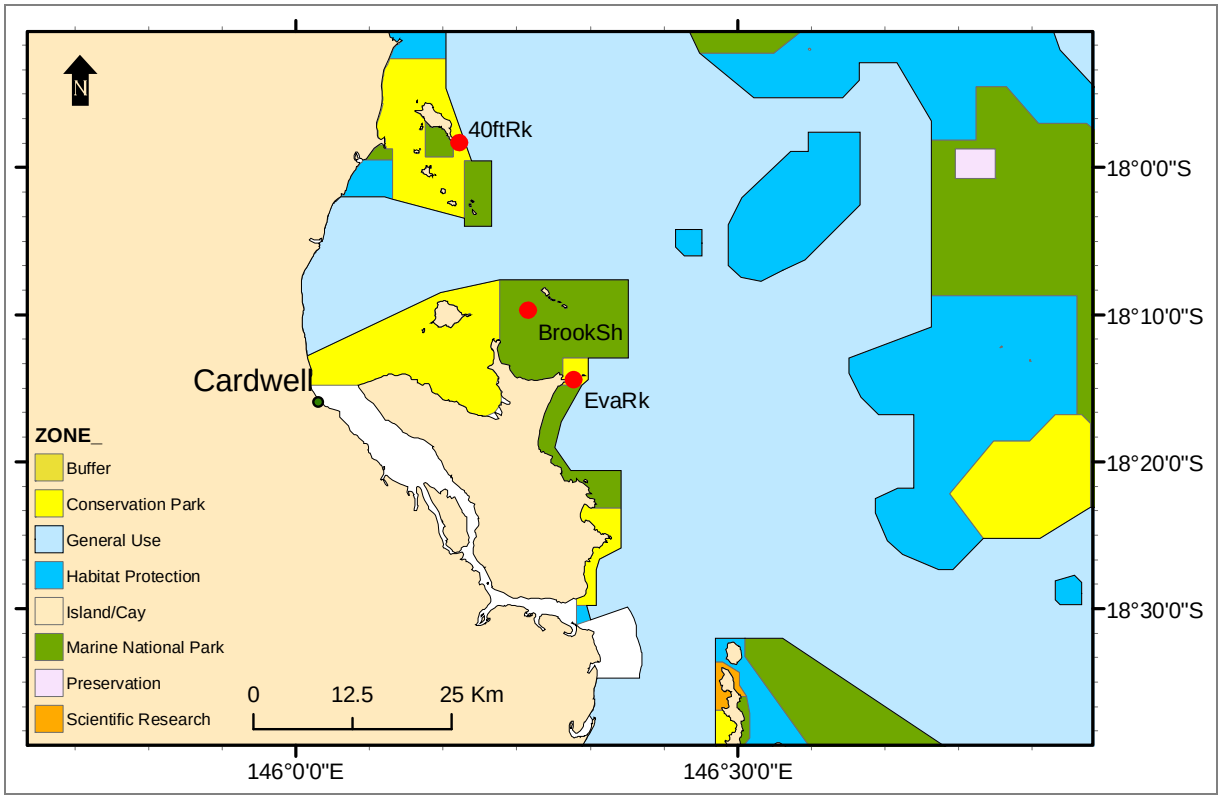

Figure 2. Cardwell study sites adjacent to Hinchinbrook and Dunk Islands in relation to the RAP zoning.

Sampling

Habitat mapping

Habitat classification was undertaken as per Speare and Cappo (2006) with a low-voltage underwater video system towed behind the vessel. The present study included remapping of Townsville sites in order to identify any changes in the extent and biophysical character of the benthic habitats since the initial survey carried out in 2006. The resurvey was attempted from the RV Cape Ferguson in November 2007 but adverse weather limited the task to three of the sites (RAP2, 15 and 16). Of these only RAP16 was adequately resurveyed to facilitate comparison with other surveys. All sites were resurveyed in May 2008 from the RV Apollo, including those done in November.

The classification system included a schema for the abiotic substrate components and the overlying benthos as per previous surveys. These data were summarised to provide information on the relative contributions of each class of substratum to the habitats on each of the study sites for comparison with the 2006 survey (and 2007 for RAP16). The respective datasets were spatially analysed to identify any changes in the areal extent and overall benthic characteristics.

Fish abundance

Baited remote underwater video stations (BRUVS), including a limited number of stereo video sets (SBRUVS), were redeployed on stations sampled in the pilot study (Speare and Cappo 2006) and ARP1 (Speare and Stowar 2007). Deployment sites were chosen to specifically target the small habitat patches previously identified and also to resample the surrounding relatively open bottom (Appendix 3). The video tapes from these sets were interrogated in a peer-reviewed, standardised manner (e.g. Cappo *et al.* 2004) to recover information on fish species and their relative abundances (*MaxN*).

Data Analysis

Habitats

Percentage cover for each of the benthic categories was calculated from incremental distances between waypoints for each consecutive record. Benthic classes were reduced to Seagrass, Macro Algae, Hard Coral, Soft Coral, Isolates, Filter Feeders, Burrowers and None (= no benthos). The data from the survey of RAP16 in November 2007 were retained as a distinct temporal subset and consequently the complete dataset included three survey periods. Measured changes in the cover contributions of the benthic classes were graphed for a visual assessment; permutational multivariate analysis to examine the factors of site and survey; and spatial analysis in the GIS environment.

Fish

The nominal experimental design was two fixed levels of protection (take and no-take) with replicate sites (three) sampled over time. This design was expanded to account for the distinct fish assemblages associated with the patches of relatively complex habitat compared to the surrounding open bottom. The design was compromised in Rockingham Bay, off Cardwell, due to the scarcity of suitable sites. One no-take site, Brook Shoal, was contrasted with two open sites.

Permutational distance based multivariate analyses were used because of the inherent skewness of census data where many zero counts occur. The species relative abundance matrices were 4^{th} root transformed and row standardised prior to conversion to Bray-Curtis dissimilarity matrices. SPlus statistical package was utilized to test the factors (zone, site, habitat and time) that might be responsible for dissimilarities in the data. Canonical analysis of principal coordinates (CAP) was employed to determine the integrity of fish assemblages with their statistically assigned groups (Anderson and Willis 2003). CAP also calculates the correlation values for each species and identifies those having the greatest influence over any observed differences.

Univariate analyses were applied to species richness (number of species/BRUVS set). The mean relative abundance (*MaxN* $\pm$ 1SE) of individual species is provided graphically where relevant to analyses supporting the aims of this study.

Results

Townsville region

Habitats

Thirty-seven kilometres of towed video mapping was undertaken in November 2008 and 9.4km in May 2007, which was close to the fifty kilometres mapped in the initial survey of 2006 (Appendix 2B).

The 2007 surveys of RAP12 and RAP15 were too limited by weather and extent to provide adequate coverage for comparison. The mean horizontal data resolution was marginally improved to 2.9 m in 2008 compared to 3.8m in 2006. The benthos displayed a general trend towards a decrease in seagrass and an increase in macroalgal cover across all sites between 2006 and 2008 surveys (Figure 3). The incomplete surveys from November 2007 included RAP16 which had a high cover of seagrass similar to the initial survey undertaken twelve months earlier. By the May 2008 survey, there was no seagrass on this site and very little benthic cover at all. The Mackerel Patch (blue zone) also recorded a substantial decline in the occurrence of phototrophs (macroalgae and seagrass) between surveys.

There was an increase in the cover of Filter Feeders on two of the three green sites (RAP2 and 15) and the Mackerel Patch (Appendix 5). The large increase in Filter Feeders at RAP15 was mostly attributed to the continuous medium to dense cover of monotypic soft corals. The differences in benthic cover across sites were less important in explaining the variation than the time between surveys.

Fish

Twenty-four BRUVS and SBRUVS sets were made on the study sites during the November 2007 cruise (Table 1 and Appendix 3). No sets were made on the blue site, Mackerel Patch. Previous surveys returned 136 species and the latest survey contributed an additional eight species to this list.

Table 1. Summary of BRUVS and SBRUVS sets on study sites between July 2006 and November 2007 off Townsville.

Site	Zone	Jul 2006	Sep 2006	Nov 2006	Mar 2007	Nov 2007
R2	Green	4	4	4	4	4
R12	Green		11	8	10	9
R15	Green		4	3	4	3
R4	Blue	3	4	4	4	4
R16	Blue			8	4	4
RMP	Blue		3	4	4	

The mean number of species (species richness) recorded from these sets compared to preceding surveys show no significant change over time or between sites closed or open to fishing. Similar to previous assessments, habitat was the most important factor ($p<0.05$) determining species richness with 16.4 (± 0.6 SE) and 8.4 (± 0.4) on average in complex habitat compared to the surrounding open bottom areas, respectively (Figure 4). Site also factored in species richness ($p<0.05$) irrespective of zonation (Appendix 4).

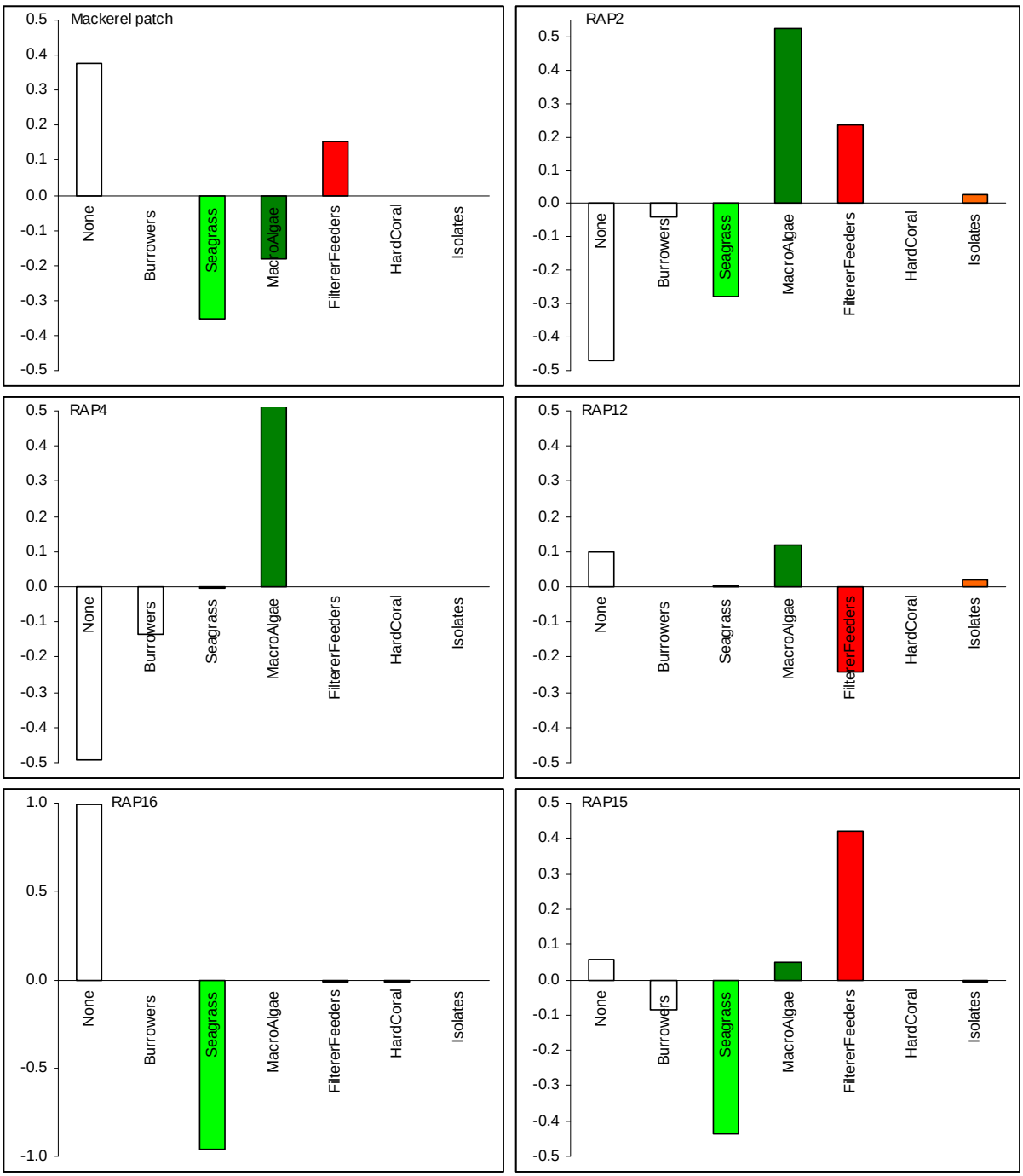

Figure 3. Shift in the proportion of cover for each major benthic class between surveys in 2006 and 2008 for each site.

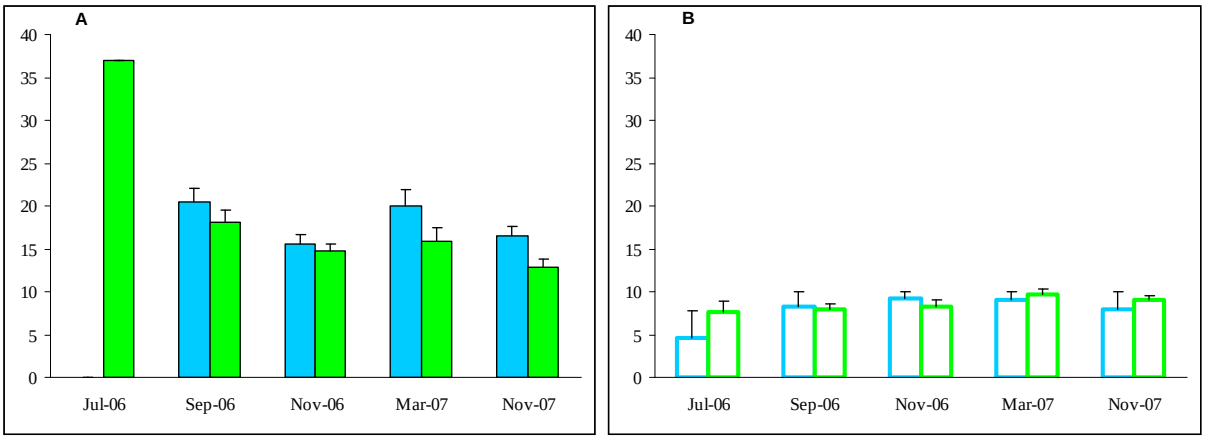

Figure 4. Mean number of species (±1SE) across all sites on the structurally complex habitats (*A*) and the surrounding sandy phototrophic habitats (*B*) in blue and green zones over the five sampling periods off Townsville.

As there was a seasonal component to these data, surveys undertaken in November 2006 and November 2007 were compared to determine any annual change in species richness. In this case, the only significant difference ($p<0.01$) was due to habitat.

The fish assemblages on each site varied between habitat type, site and over time ($p<0.01$) (Table 2). CAP analysis confirmed a low 8% misclassification rate in respect to habitat. Fish assemblages on sites Rap4 and Rap16 displayed high fidelity, 100% and 88% respectively while those on the green sites were similar. Limiting the analyses to the November periods in 2006 and 2007 did not reveal any significant changes in the fish assemblages.

Table 2. Results of multivariate analysis to test the significance of factors potentially influencing the structure of fish assemblages on shoals in the Townsville region.

Factor	df	MS	F	p(perm)
Zone	1	0.93932	13.986	ns
Habitat	1	0.53590	7.979	<0.01
Site	4	0.19903	2.964	<0.01
Sample	1	0.30134	4.487	<0.01
residual	110	0.06716		

Twenty-two species likely to be retained by fishers displayed significant differences in their relative abundances with respect to the level of protection afforded, but there was no evidence of any change over time for this aggregate group (Table 3). With the exception of the school mackerel (*Scomberomorus queenslandicus*), species with differential relative abundances favoured the blue sites (Figures 5 and 6). The tea leaf trevally (*Carangoides chrysophyrs*) and golden trevally (*Gnathanodon speciosus*), nannygai (*Lutjanus erythropterus* and *L. malabaricus*), fryingpan snapper (*Argyrops spinifer*), slatey bream (*Diagramma pictum*) and gold spot cod (*Epinephelus coioides*) were all more abundant in blue sites.

Table 3. Results of multivariate analysis to test the significance of factors potentially influencing the distribution and relative abundance of 22 economic species on shoals in the Townsville region.

Factor	df	MS	F	p(perm)
Zone	1	3.9298	15.311	<0.01
Habitat	1	0.5359	11.261	ns
Site	4	0.5355	2.086	ns
Sample	1	0.3211	1.251	ns
residual	110	0.2567		

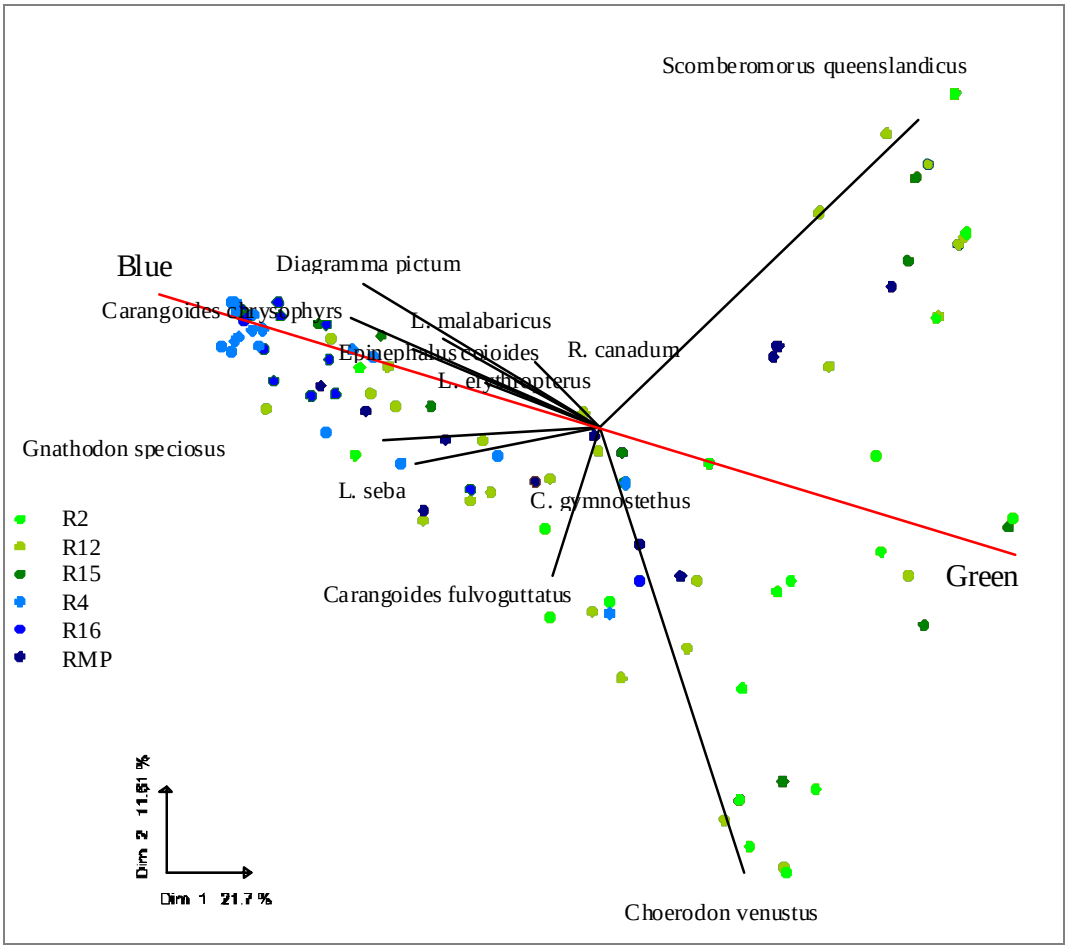

Figure 5. Multidimensional biplot of 22 targeted species relative abundances (4th root transformed and row standardised) from BRUVS and SBRUVS sets on blue and green sites over all sampling periods in the Townsville area. The species vectors are indicative of the direction and strength of correlation with sets in respect of the level of protection vector shown in red (Green – take, Blue – no-take).

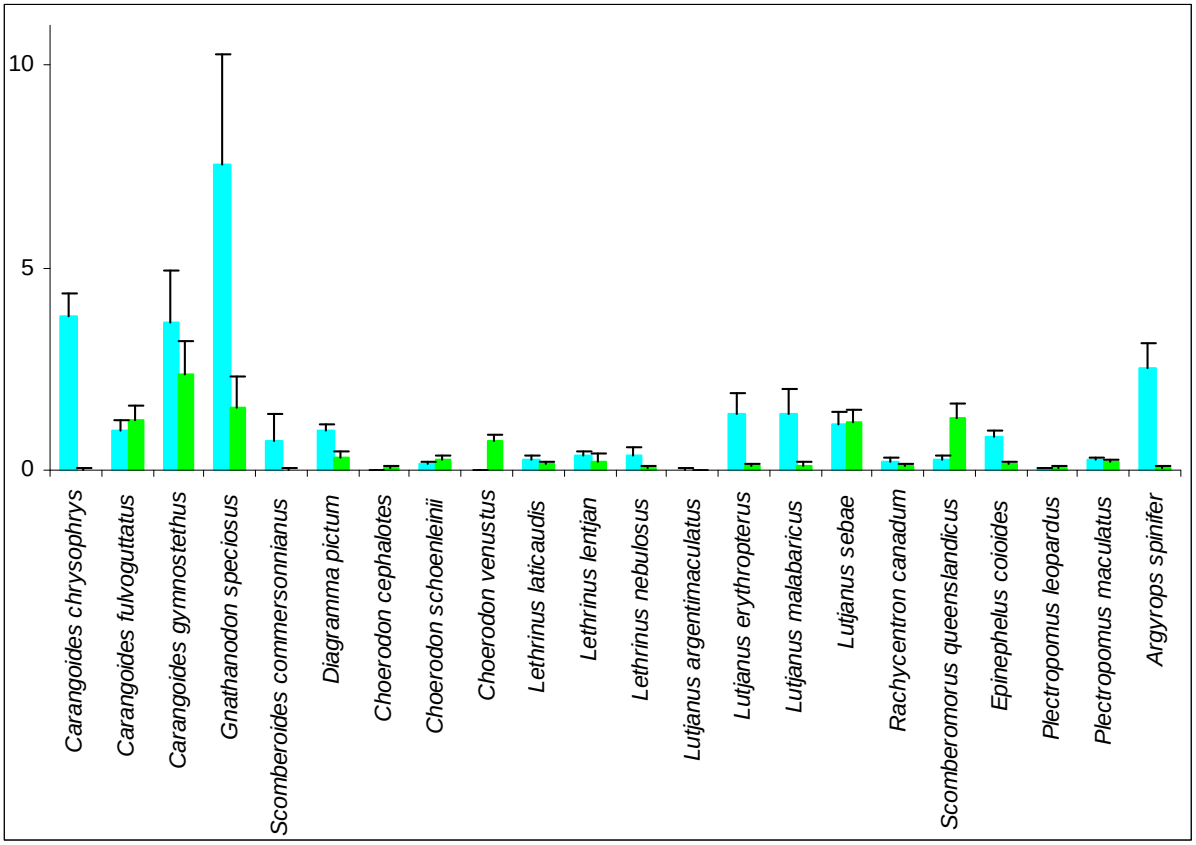

Figure 6. Mean relative abundance (±1SE) of 22 targeted species on blue and green zone sites in the Townsville area.

Discussion

Marine Protected Areas are generally recognised for their contribution to increasing fish abundance, average length, largest length, and biomass within their boundaries (e.g. Halpern and Warner 2002, Denny *et al.* 2004, Evans and Russ 2004, Russ *et al.* 2008, Williamson *et al.* 2004). Most studies to date have occurred on high relief coral and rocky reef systems. Less studied are low relief reef or shoal systems in deeper water, which are inaccessible to common SCUBA-based survey methods. These systems have usually been the subject of intensive non-selective fishing pressure by trawlers in addition to selective commercial and recreational line fishing.

The responses of fish communities to closure to fishing in 2004 on deeper shoal reefs was examined in this study using novel, non-extractive video tools. Species richness on the Townsville study sites was maintained over the monitoring period with generally twice as many species in the scattered and diverse structurally complex habitats as the surrounding depauperate habitats. The fish assemblages recorded with BRUVS included the popular target species of lutjanids, serranids and lethrinids. The standardised surveys revealed both spatial and temporal differences in abundance, but there was no evidence of a change which could be directly attributed to the level of protection afforded by the Representative Areas Program. The significant spatial differences in the abundance of targeted species tended to favour more fish in the unprotected blue zone. This may be due to fish migration and/or the different and changing characteristics of the underlying benthic habitat, unrelated to zoning. It may also be due to uncontrolled factors relating to inter-annual and seasonal variability as well as the mobility of these fish (e.g. Mapleston *et al.* 2006). The majority of species of interest to fishers are mobile species that are likely to range over a relatively large area, including the adjacent blue zone sites (see Ashworth and Ormond 2005). Also, there is no quantitative information to indicate the level of fishing pressure that these sites are subjected to and what impact this might have on fish abundance.

There was evidence of a seasonal component to the measured fish assemblages but this was not reflected in the subset of targeted species. This may be due to a sampling constraint imposed by these small patches of habitat which are problematic for the acquisition of adequate independent samples. Also, to provide data for the comparison of changes that may occur in fish abundance would require multiple sampling times (multiple bi-annual surveys) both before and after the creation of a reserve (Underwood 1998). The major line-fished species have high longevities (Newman *et al.* 2000), suggesting that a time-span of decades would be a minimum length of time over which marine reserves should be monitored. To date, while there is no evidence to indicate an improvement in the relative abundances of many of the targeted species afforded protection inside the green zone, several of these species have maintained a higher abundance outside the protected area.

Cardwell region

Fish

Six BRUVS and SBRUVS sets were made on the three study sites during the November 2007 cruise (Table 4 and Appendix 3). Previous surveys returned 63 species from these sites and the latest survey added 6 species to this list. The mean number of species recorded from these sets compared to preceding surveys showed no significant change over time or between sites closed or open to fishing. Similar to previous assessments, habitat was the most important factor ($p<0.05$) determining species richness with 10.5 (± 1.2 SE) and 5.5 (± 0.5) species on rock habitat compared to the surrounding muddy sand bottom, respectively (Figure 7).

Table 4. Summary of BRUVS and SBRUVS sets on study sites between September 2006 and November 2007 off Cardwell.

Site	Zone	Sep 2006	Dec 2006	Nov 2007
BrookShoal	Green	4	4	2
EvaRock	Blue	5	4	2
FortyFootRock	Blue		3	2

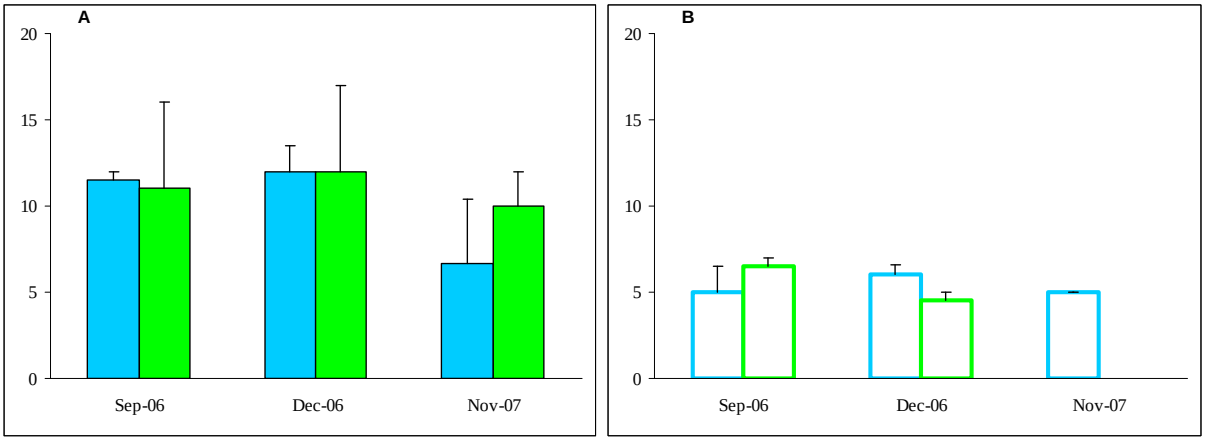

Figure 7. Mean number of species (±1SE) across all three sites on the rock substrate (*A*) and the surrounding muddy sand habitats (*B*) in blue and green zones over the three sampling periods off Cardwell.

The fish assemblages varied between the two habitat types ($p<0.01$) and without regard to the level of protection, site and time. (Table 5). CAP analysis confirmed a zero-percent misclassification rate with respect to habitat type.

Fifteen of the recorded species were considered to be targeted or retained by anglers. Similar to the complete recorded fish assemblages, their distributions and relative abundances only varied between the two distinct habitats ($p<0.05$) (Figure 8). Of these fifteen species, the grass emperor (*Lethrinus laticaudis*), small mouth nannygai (*Lutjanus erythropterus*), barred-cheek coral trout (*Plectropomus maculatus*) and black spot tuskfish (*Choerodon schoenleinii*) were associated with the rocky habitats and the school mackerel (*Scomberomorus queenslandicus*) with the surrounding muddy sand areas.

Table 5. Factors influencing the distribution and relative abundance of fish assemblages on shoals in the Cardwell region.

Factor	df	MS	F	p(perm)
Zone	1	0.2309	1.857	ns
Habitat	1	0.4225	3.398	<0.01
Site	1	0.1819	1.463	ns
Sample	1	0.1914	1.540	ns
residual	21	0.1243		

The majority of targeted species had higher recorded relative abundances in the green zone but only two species (grass emperor and small mouth nannygai) had significantly greater relative abundances ($p<0.05$) on Brook Shoal than the two sites open to fishing (Figure 9).

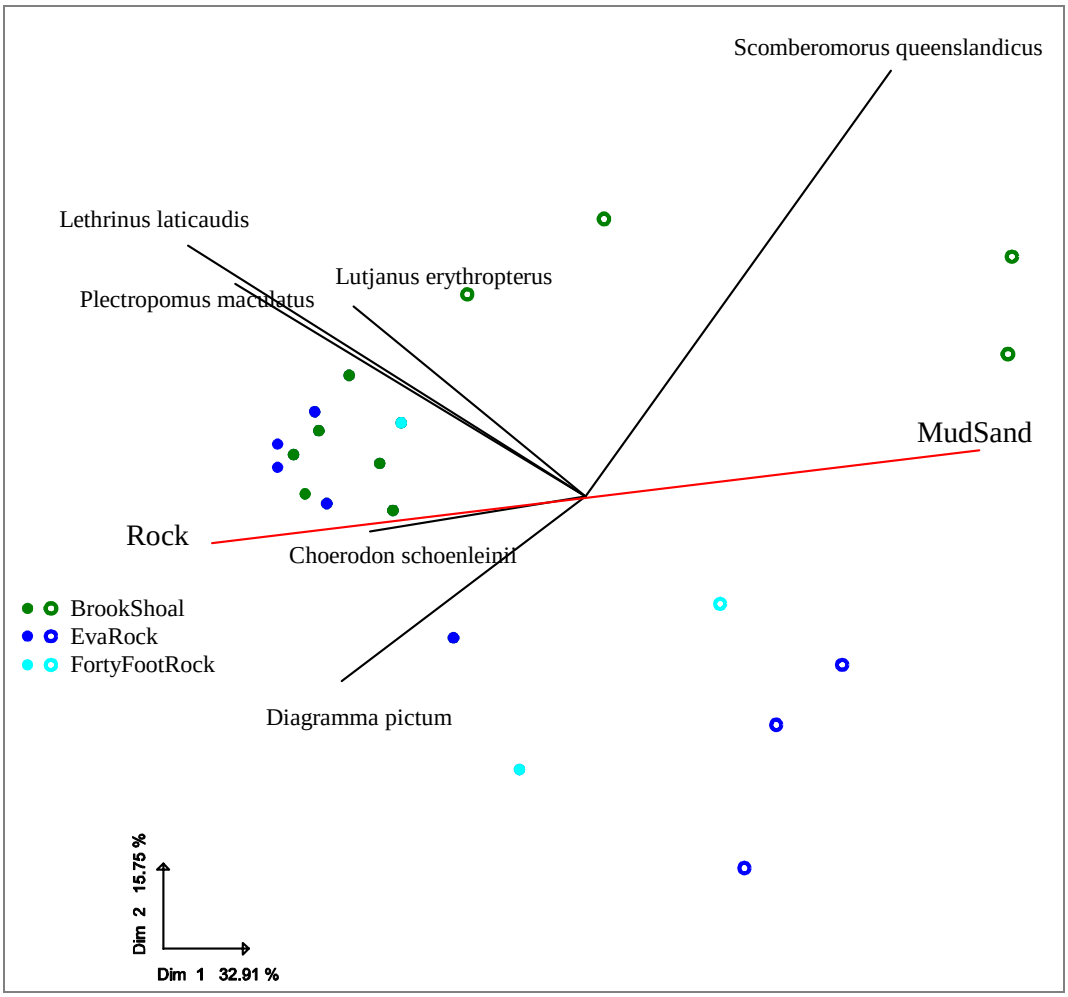

Figure 8. Multidimensional biplot of fifteen targeted species (4^{th} root transformed and row standardised) from BRUVS and SBRUVS sets on blue and green sites off Cardwell; closed markers (rocky habitat), open markers (muddy sand). The species vectors indicate the direction and strength of correlation with sets and the two habitat types shown in red.

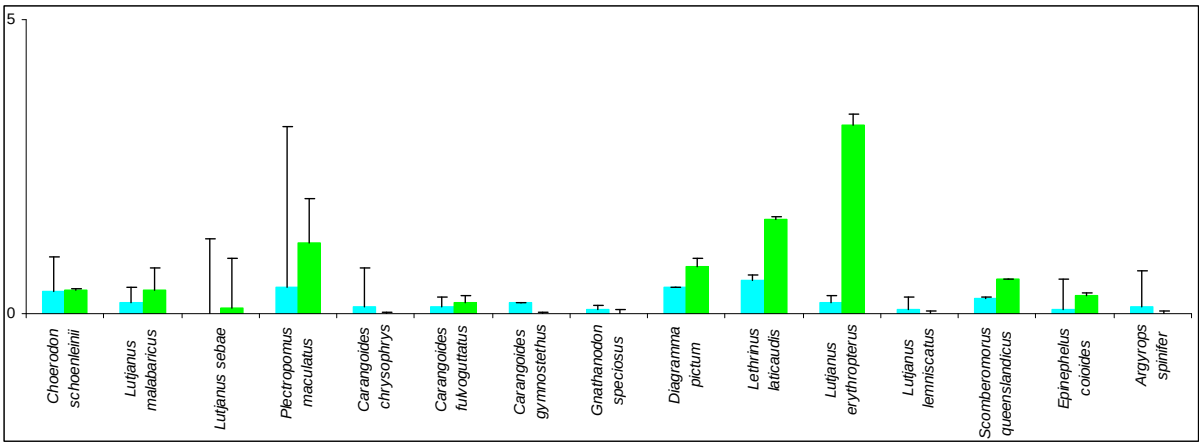

Figure 9. Mean relative abundance (±1SE) of 15 targeted species on blue and green zone sites off Cardwell.

Discussion

The most significant factor determining the fish assemblages on study sites off Cardwell continued to be the distinctive rocky and muddy sand habitats. The level of protection had no influence on the species richness, the fish assemblages nor the overall distribution and abundance of the fifteen targeted species. Notwithstanding its relatively small size, the abundances of some target species on Brook Shoal were significantly greater than on the sites exposed to fishing.

Data up to one year ago (Speare and Stowar 2007) showed non-significant but greater recorded abundances for ten target species and the more recent data indicates a similar situation enhanced by the addition of two species with significantly greater mean abundances on Brook Shoal.

Surveying the fish assemblages on the two small rocky outcrops, Brook Shoal and Forty Foot Rock, remain problematic due to issues of independent sampling. With accurate deployment onto the rocky substrates and the assumption that fish will not move between simultaneous baited sets no more than one hundred metres apart, Brook Shoal is limited to three and Forty Foot Rock to two BRUVS/SBRUVS. Further monitoring might include all stereo sets to maximise the return of information, both numbers and size, from these small rocky shoals.

Conclusions

The study reported here represents one of the very few examining deep water tropical shoal habitats in a comparison of protected and unprotected sites. Novel, non-extractive video tools were used to survey fishes and their habitats in waters beyond the reach of normal SCUBA-based observation. By the nature of the scarcity of these habitats in the mid section of the Great Barrier Reef, the survey design was far from ideal. The fact remains however that these systems are known to be important habitats for fishes of interest to the commercial and recreational fishing industry (Mapleston *et al.* 2006, Higgs 1996, Williams and Russ 1994). These grounds are not abundant in extent near to populated coastal locations, and they are known to be highly targeted as fishing grounds. Examination of these systems is therefore relevant to understanding the effects of protection in both an ecological sense and also in a social context.

The results show that these systems are important habitat for pelagic, semi-pelagic and reef-associated fishes of value to fishers. The lack of replication between take and no-take sites does not permit the level of statistical refinement desired to make definitive statements about the effects of protection. There appears to be a trend for more fishes within the blue zones than in the green, but this observation needs to be treated with caution given the mobility of the fishes concerned over the relatively small spatial distances between blue and green zones in this region. It is however suggested that longer term monitoring at a frequency relevant to the situation be undertaken, together with assessment of size/frequency patterns for key species.

Of interest are the changes identified in habitat structure of the seafloor within the study sites. These did not show a clear trend and possibly indicate seasonal or longer term community dynamics of shoal and inter-reefal seafloor communities. Given the linkage between benthic structure and fish community assemblages (Sainsbury *et al.* 1997), and the possibility that effects of protection have cascading influence on benthic character (Graham *et al.* 2003), it is suggested that longer-term (infrequent) habitat resurvey may be of some advantage in interpreting local changes in fish community structure.

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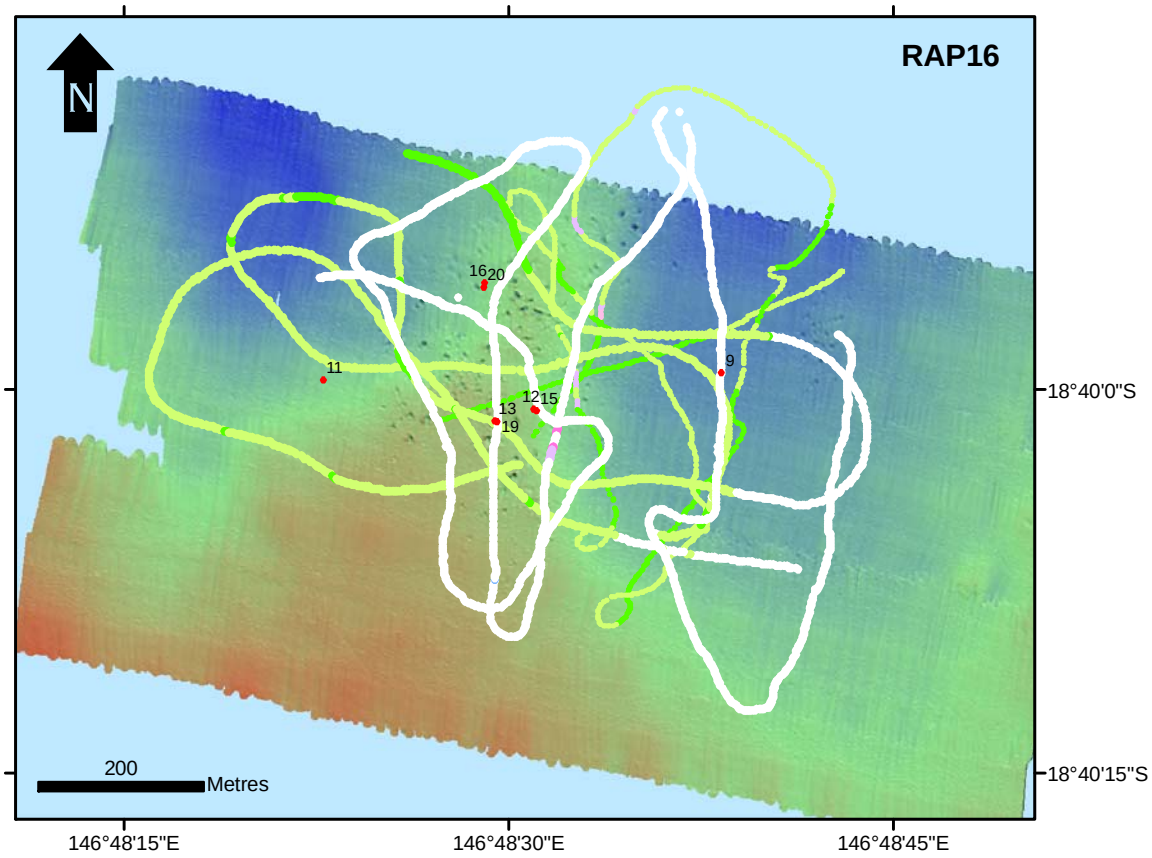
Appendix 1 – Images of study sites

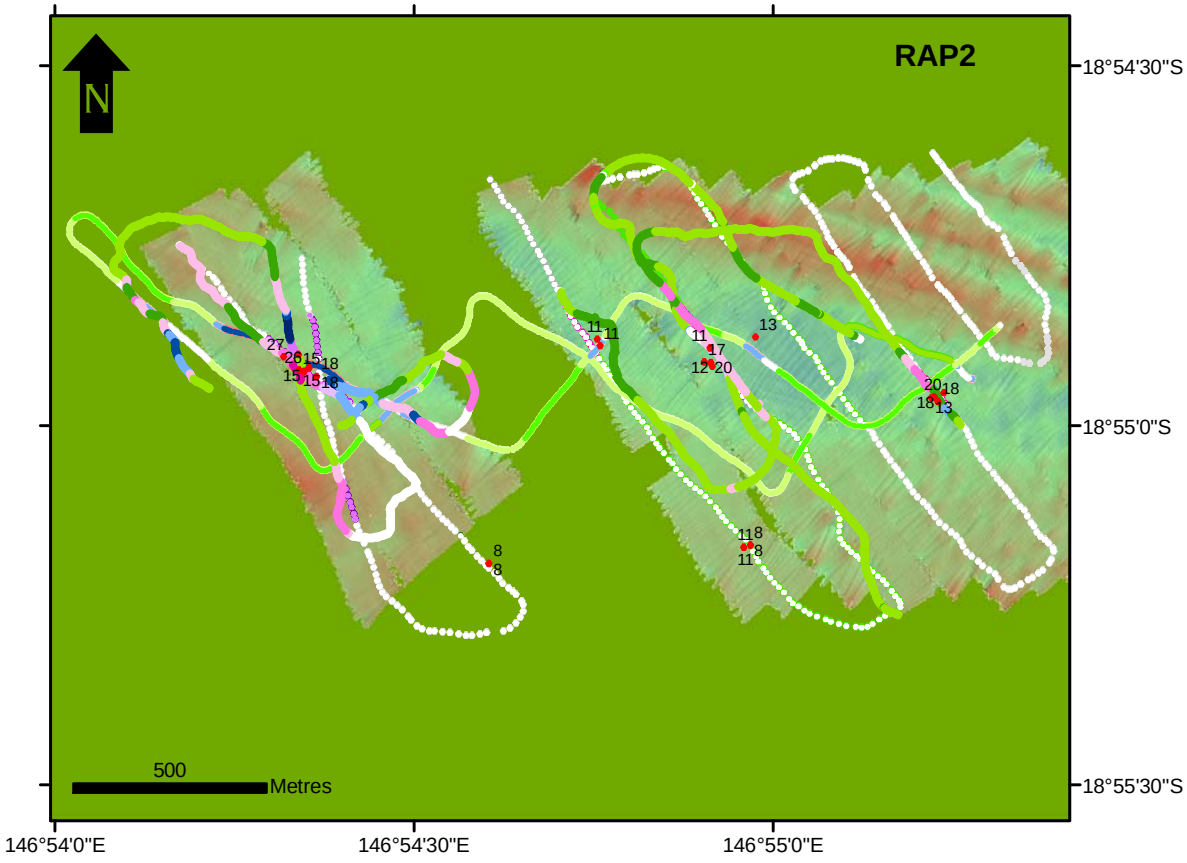
Bathymetric acoustic images of study sites overlayed on the RAP zoning of the Great Barrier Reef for the Cardwell and Townsville regions. Images for each site display the locations of BRUVS and SBRUVS sets with the number of species recorded against each set. Towed video tracks represent the classified benthos from initial survey (smaller dots) and resurvey (larger dots).

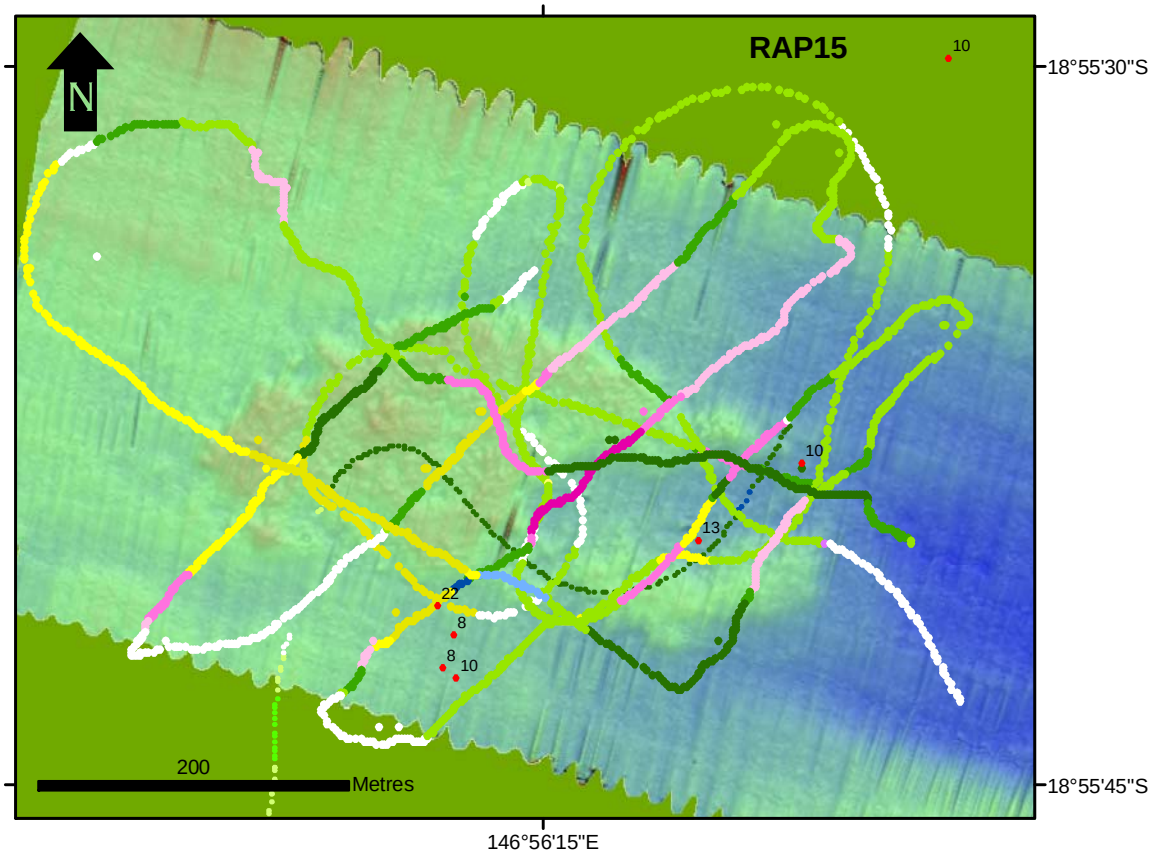
Tow path classification legend

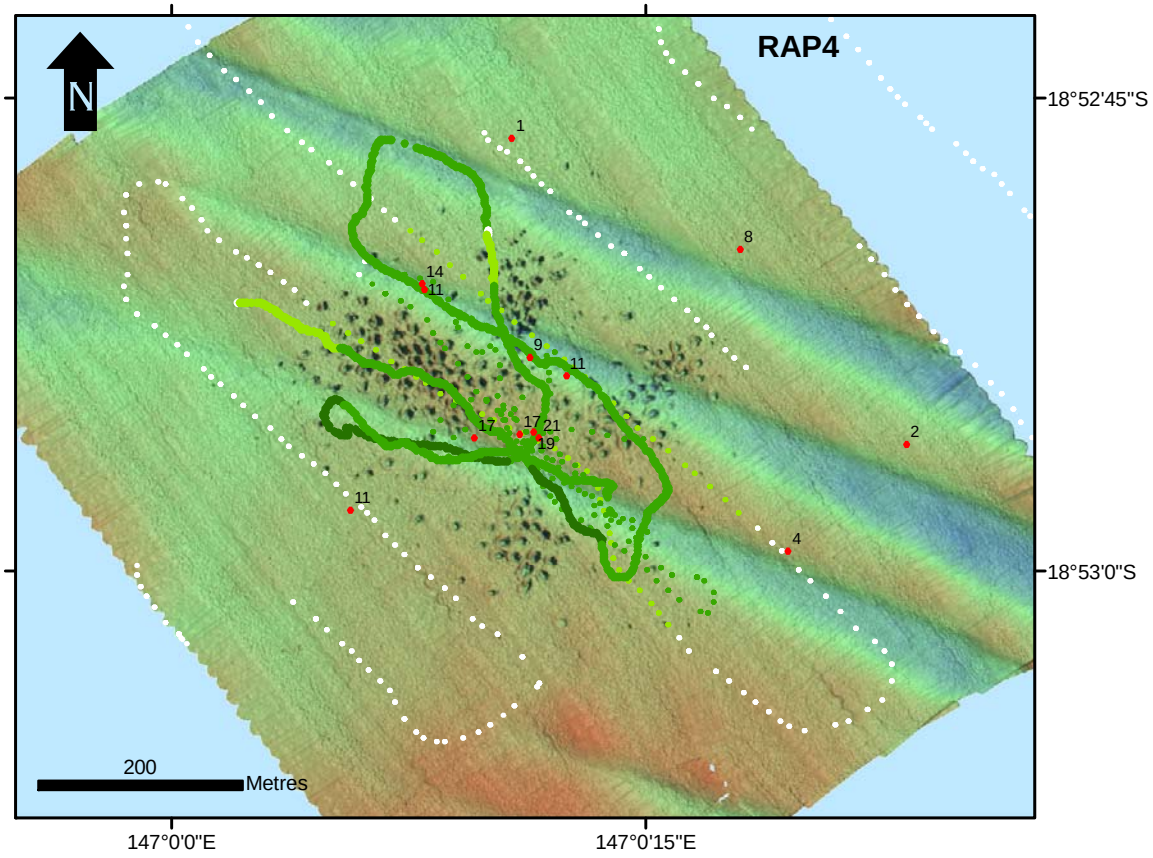
BenthosKey			
AlgaeD	FilterersM	IsolatesD	SoftCoralD
AlgaeGrass	FilterersS	IsolatesM	SoftCoralM
AlgaeM	GorgonianD	IsolatesS	SoftCoralS
AlgaeS	GorgonianM	None	WhipsD
FilterersD	GorgonianS	SeagrassM	WhipsM
	HardCoralS	SeagrassS	WhipsS

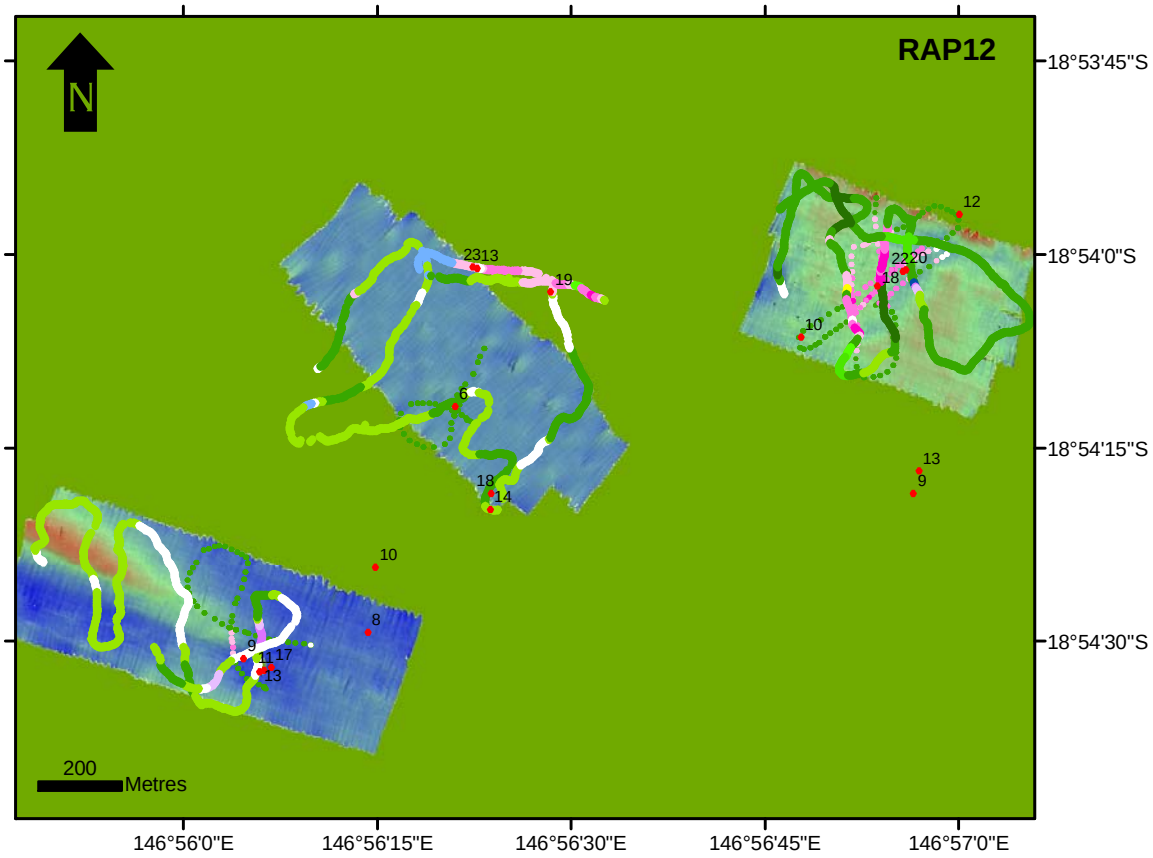
Townsville

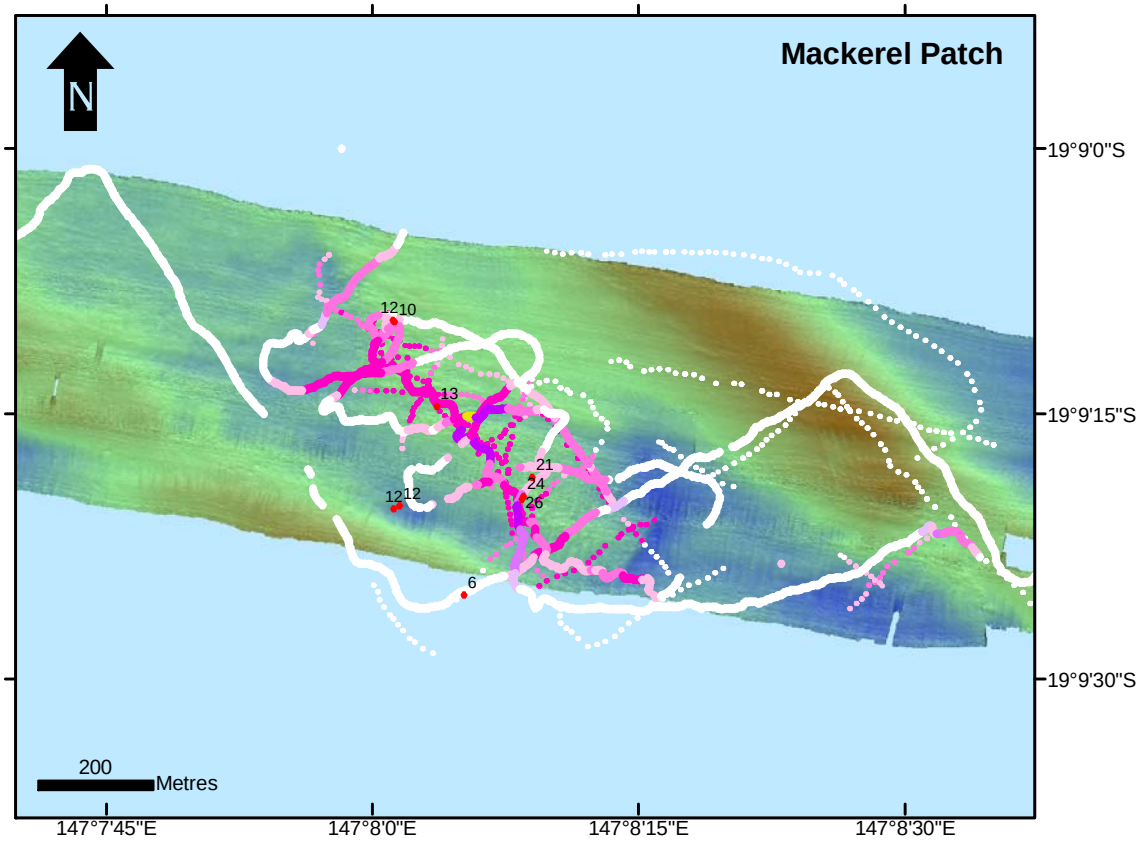



RAP2
N
500
Metres
18°54'30"S
18°55'0"S
18°55'30"S
146°54'0"E
146°54'30"E
146°55'0"E

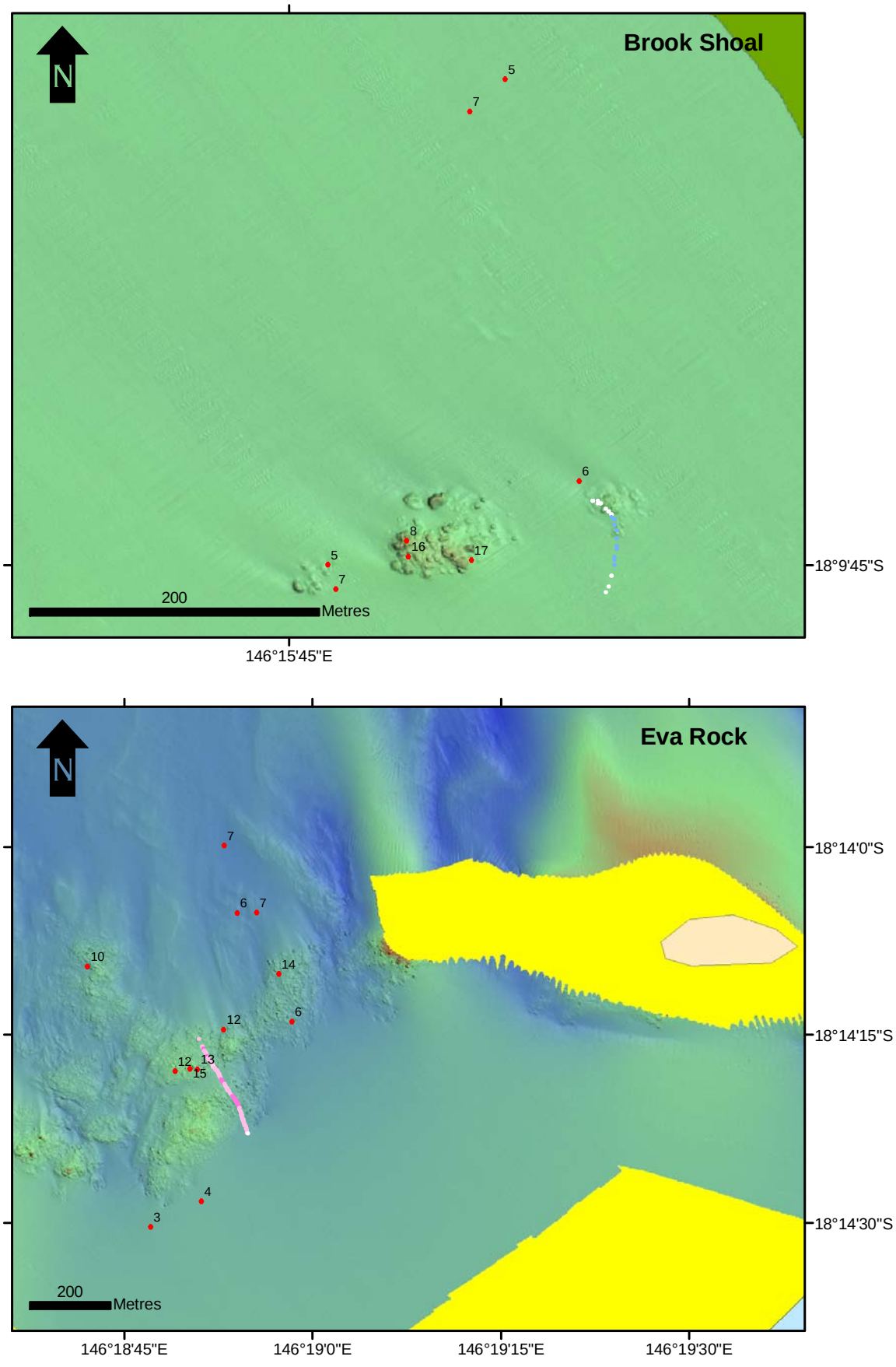

RAP15
N
200
Metres
18°55'30"S
18°55'45"S
146°56'15"E

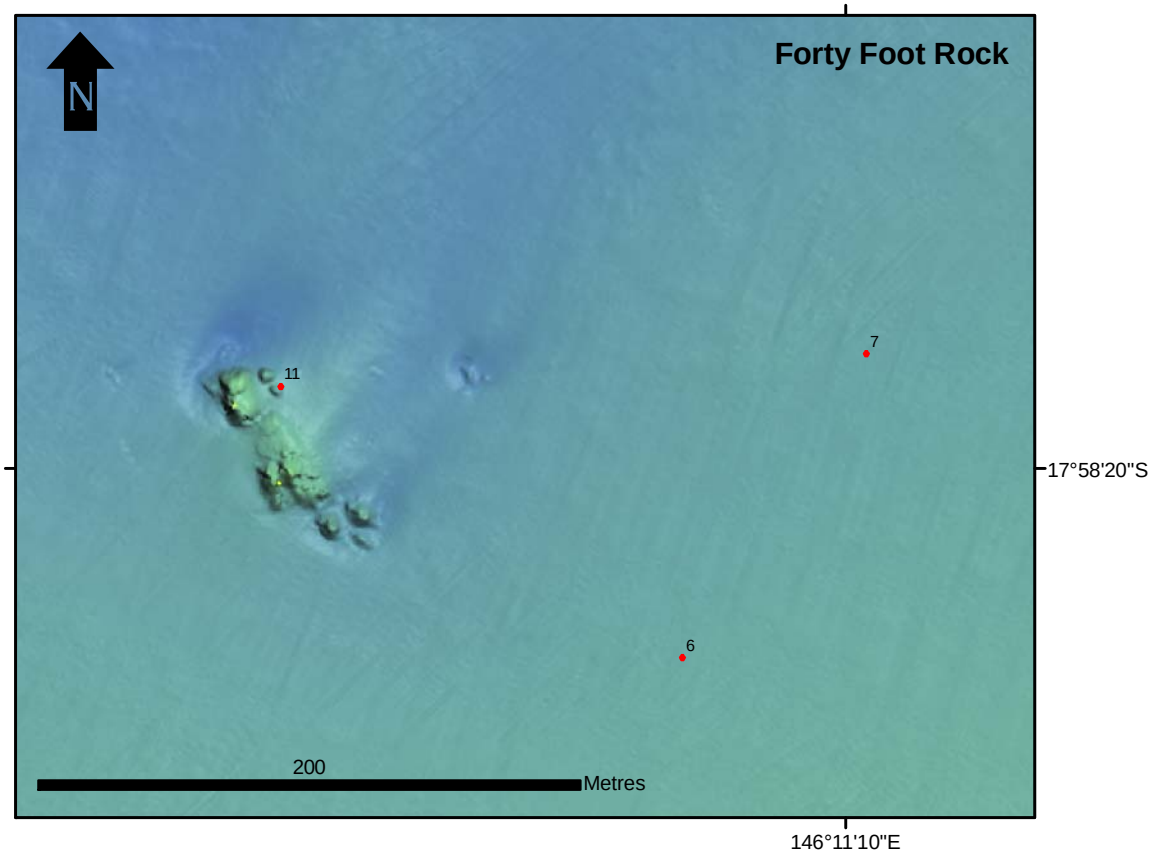

RAP4
N
200
Metres
18°52'45"S
18°53'0"S
147°0'0"E
147°0'15"E


RAP12
N
200
Metres
18°53'45"S
18°54'0"S
18°54'15"S
18°54'30"S
146°56'0"E
146°56'15"E
146°56'30"E
146°56'45"E
146°57'0"E


Mackerel Patch
N
19°9'0"S
19°9'15"S
19°9'30"S
147°7'45"E
147°8'0"E
147°8'15"E
147°8'30"E
200
Metres
12
10
13
21
24
26
12
12
6

Cardwell


Brook Shoal
N
5
7
6
8
16
17
5
7
200
Metres
18°9'45"S
146°15'45"E
Eva Rock
N
7
6
7
10
14
12
6
12
13
15
4
3
200
Metres
18°14'0"S
18°14'15"S
18°14'30"S
146°18'45"E
146°19'0"E
146°19'15"E
146°19'30"E

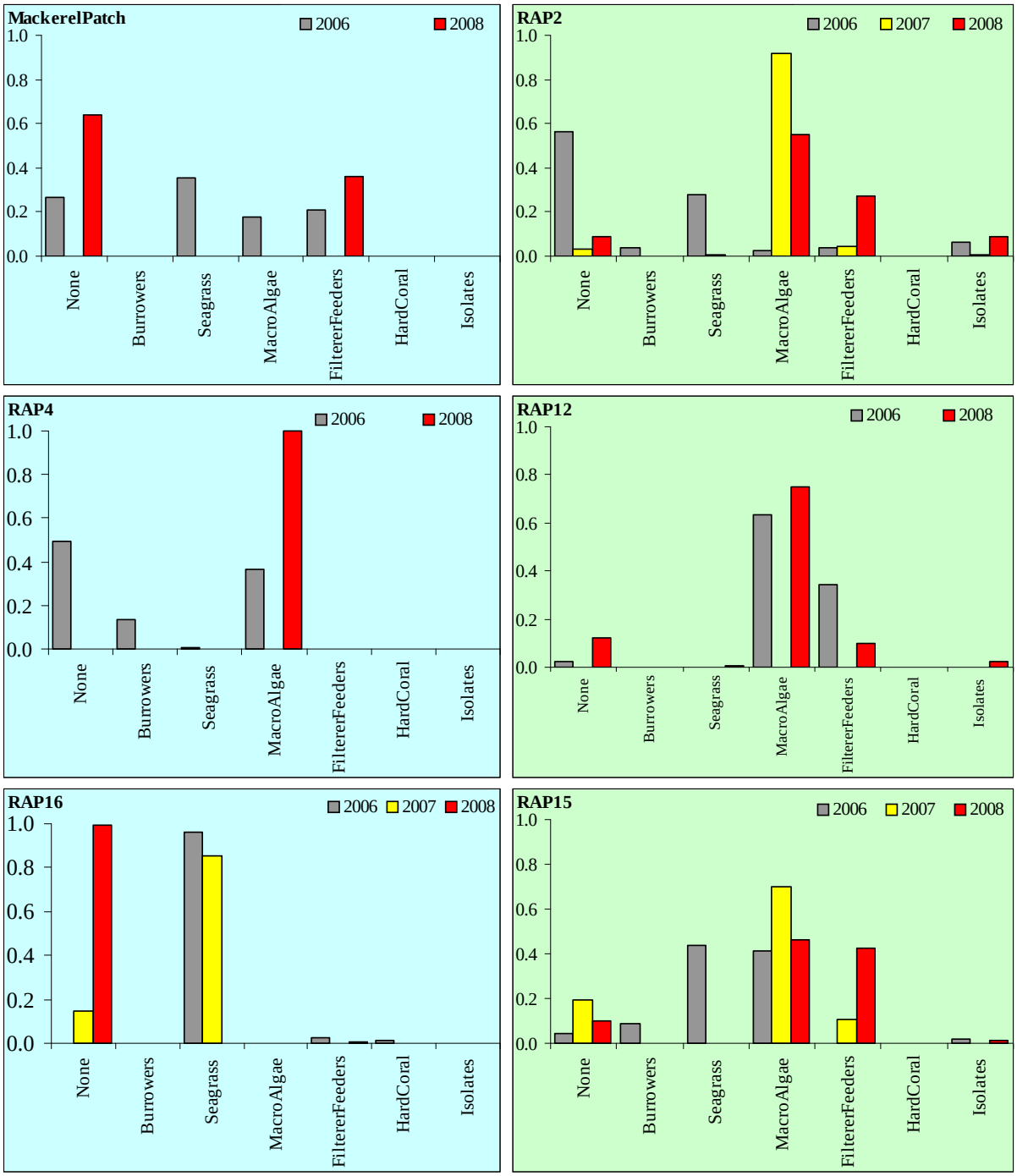

Forty Foot Rock
N
11
7
6
200
Metres
17°58'20"S
146°11'10"E

Appendix 2 – Towed video operational data and benthos cover estimates

(a) Operational data for towed video surveys of study sites off Townsville

Location	Zone	Survey	Survey Date	Tow Name	Site Name	Vessel	Number of Records	Res'n (m)	Dist. Travel (m)	Depth (m)
Townsville	Green	1	02/07/2006	RAP2	RAP2	Apollo	1983	4.1	7827	25.3 - 27.6
	Green	1	02/07/2006	RAP3	RAP2	Apollo	607	4.6	2660	26.0 - 27.2
	Green	1	10/09/2006	RAP5_1	RAP2	Lady Basten	1563	4.5	6960	23.5 - 26.5
	Green	2	15/11/2007	RAP2B	RAP2	Cape Ferguson	891	3.1	2520	25.9 - 28.3
	Green	2	16/05/2008	RAP2C	RAP2	Apollo	1565	2.4	3150	25.6 - 27.3
	Green	2	16/05/2008	RAP2D	RAP2	Apollo	518	2.4	1044	26.2 - 26.9
	Green	2	16/05/2008	RAP2E	RAP2	Apollo	1340	2.5	2891	24.5 - 27.0
	Green	1	25/08/2006	RAP12	RAP12	Apollo	240	4.2	973	27.0 - 27.9
	Green	2	15/05/2008	RAP12B	RAP12	Apollo	1159	2.8	2651	26.3 - 28.5
	Green	1	25/08/2006	RAP13	RAP13	Apollo	150	4.5	662	27.4 - 28.3
	Green	2	15/05/2008	RAP13B	RAP13	Apollo	1653	3.0	3875	27.5 - 29.4
	Green	1	25/08/2006	RAP14	RAP14	Apollo	560	4.3	2385	27.3 - 28.5
	Green	2	16/05/2008	RAP14B	RAP14	Apollo	1367	2.5	3118	27.3 - 28.5
	Green	1	10/09/2006	RAP15	RAP15	Lady Basten	318	3.3	952	25.1 - 26.6
	Green	2	16/11/2007	RAP15B	RAP15	Cape Ferguson	872	3.2	2478	25.6 - 28.7
	Green	2	15/05/2008	RAP15C	RAP15	Apollo	2210	2.6	4676	26.5 - 27.5
	Blue	1	02/07/2006	RAP4	RAP4	Apollo	1574	4.1	6279	31.3 - 32.7
	Blue	1	25/08/2006	RAP4B	RAP4	Apollo	703	3.4	2195	28.6 - 31.5
	Green	2	16/05/2008	RAP4C	RAP4	Apollo	1236	2.4	2269	30.5 - 32.1
	Blue	1	28/10/2006	RAP16	RAP16	Apollo	247	4.7	1071	38.8 - 41.1
	Blue	1	28/10/2006	RAP16B	RAP16	Apollo	1409	2.6	2892	39.3 - 41.7
	Blue	2	17/11/2007	RAP16C	RAP16	Cape Ferguson	1629	3.0	4694	39.6 - 42.2
	Blue	2	17/05/2008	RAP16D	RAP16	Apollo	2781	4.0	8277	31.1 - 40.9
	Blue	1	10/08/2006	MackerelPatch1	RapMP	Apollo	3489	4.0	13426	18.8 - 22.0
	Blue	1	13/08/2006	MackerelPatch1B	RapMP	Apollo	815	3.4	2630	19.0 - 20.4
	Blue	2	14/05/2008	MackerelPatch1C	RapMP	Apollo	1890	2.6	4095	18.4 - 21.1
	Blue	2	14/05/2008	MackerelPatch1D	RapMP	Apollo	1940	3.7	4592	18.4 - 20.0
	Blue	2	14/05/2008	MackerelPatch1E	RapMP	Apollo	1025	3.5	3095	18.2 - 19.8

(b) Epibenthos classes and their proportional contributions to benthic cover of the substrates as surveyed with towed underwater video at study sites in Townsville between 2006 and 2008.

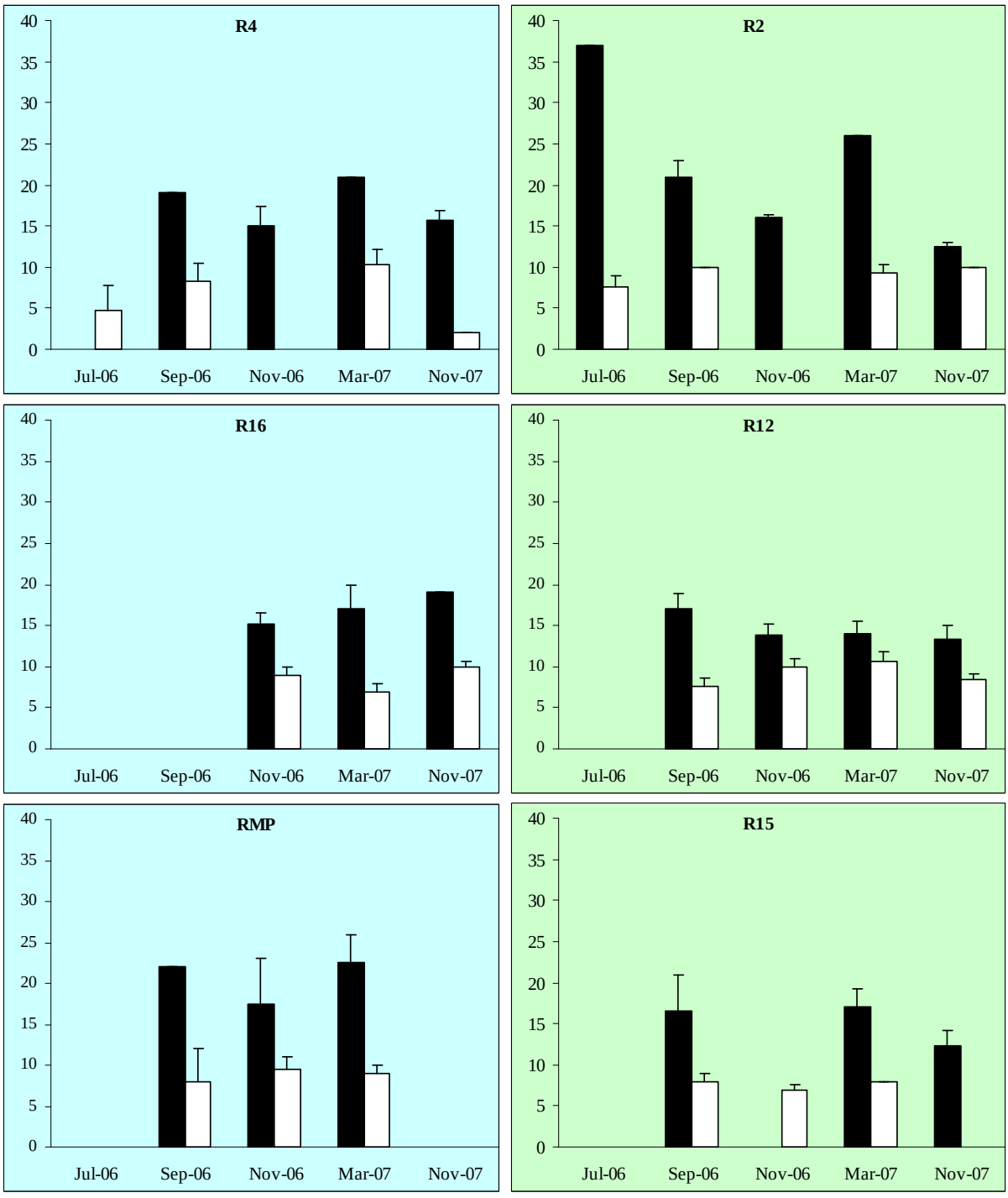


Appendix 3 – BRUVS Operational data

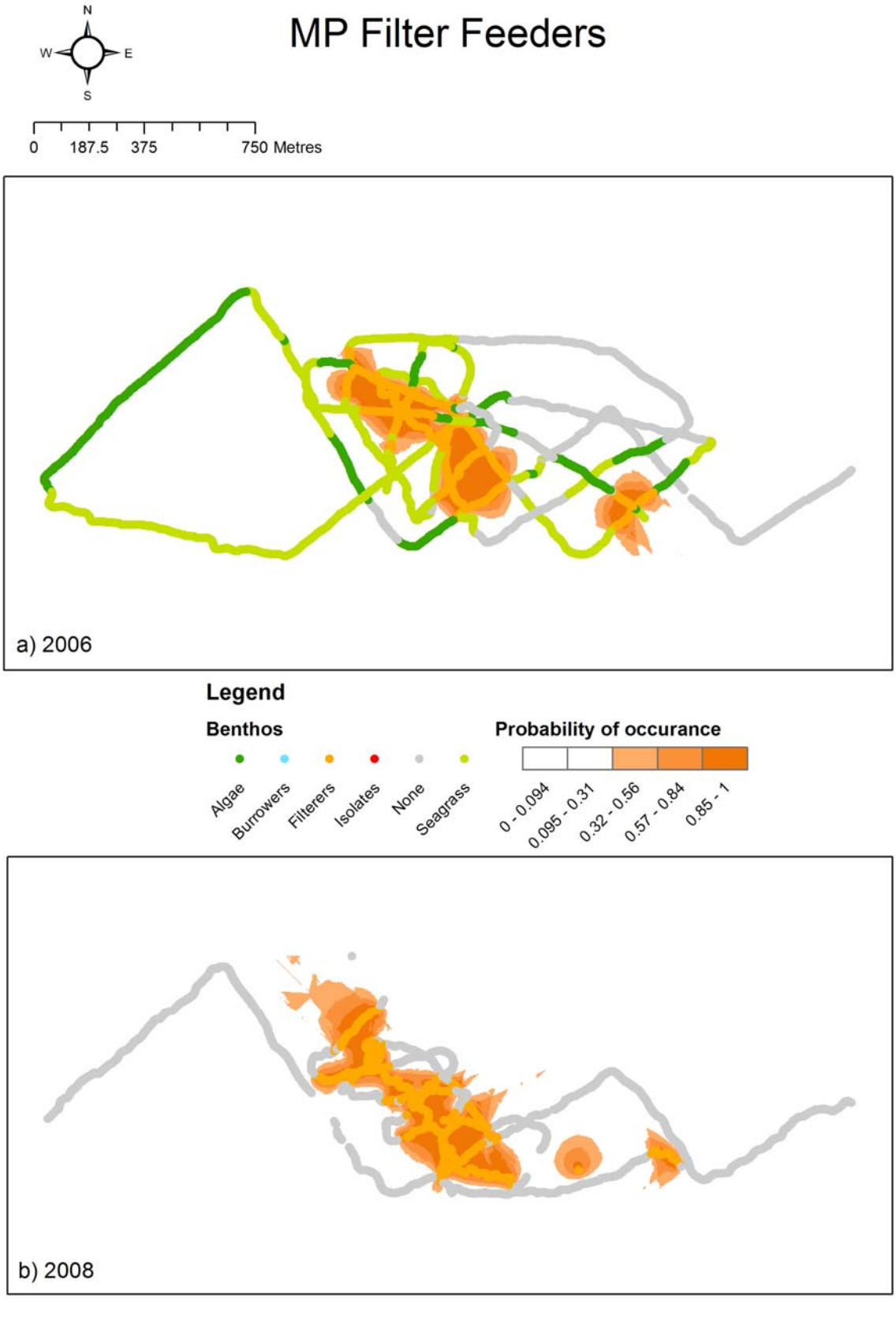
Location	Zone	Set	Deployment	Longitude	Latitude	Depth
CARDWELL						
Brook Shoal	Gr	BSC_3	18/11/2007 8:17:48	146.2636	-18.1624	12.3
	Gr	BSC_2	18/11/2007 8:25:39	146.2644	-18.1620	15.2
	Gr	BSC_1	18/11/2007 8:33:06	146.2627	-18.1626	15.3
Eva Rock	Bl	ERC_25	18/11/2007 10:48:52	146.3139	-18.2382	16.6
	Bl	ERC_1	18/11/2007 10:55:46	146.3161	-18.2360	21.5
	Bl	ERC_2	18/11/2007 11:04:50	146.3116	-18.2359	22.4
Forty Foot	Bl	FFB_25	18/11/2007 14:17:06	146.1842	-17.9719	21.8
Rock	Bl	FFB_1	18/11/2007 14:24:33	146.1847	-17.9734	22.8
TOWNSVILLE						
RAP2	Gr	2F_25	15/11/2007 15:15:40	146.9127	-18.9148	26.3
	Gr	2F_1	15/11/2007 15:20:09	146.9059	-18.9153	25.4
	Gr	2F_2	15/11/2007 15:28:01	146.9153	-18.9153	26.3
	Gr	2F_3	15/11/2007 15:33:29	146.9203	-18.9160	26.3
RAP12	Gr	12F_25	16/11/2007 10:38:28	146.9373	-18.9081	26.7
	Gr	12F_1	16/11/2007 10:47:17	146.9352	-18.9089	26.6
	Gr	13F_3	16/11/2007 10:55:04	146.9375	-18.9067	27.3
	Gr	13F_15	16/11/2007 11:05:15	146.9395	-18.9002	27.8
	Gr	13F_2	16/11/2007 11:13:39	146.9360	-18.9024	27.7
	Gr	14G_25	16/11/2007 13:27:14	146.9488	-18.9003	28.0
	Gr	14G_1	16/11/2007 13:35:16	146.9476	-18.9010	27.7
	Gr	14G_2	16/11/2007 13:43:03	146.9469	-18.8986	27.9
	Gr	14G_3	16/11/2007 13:46:20	146.9500	-18.8990	27.7
RAP15	Gr	15G_25	16/11/2007 8:01:33	146.9368	-18.9280	25.6
	Gr	15G_1	16/11/2007 8:12:16	146.9360	-18.9267	25.5
	Gr	15G_2	16/11/2007 8:18:05	146.9386	-18.9275	26.0
RAP4	Bl	4F_25	17/11/2007 10:38:09	147.0032	-18.8814	30.4
	Bl	4F_1	17/11/2007 10:48:01	147.0015	-18.8828	30.2
	Bl	4F_2	17/11/2007 10:56:24	147.0018	-18.8809	30.6
	Bl	4F_3	17/11/2007 11:02:41	147.0032	-18.8821	30.1
RAP16	Bl	16D_25	17/11/2007 13:54:40	146.8089	-18.6666	38.9
	Bl	16D_1	17/11/2007 14:02:25	146.8063	-18.6665	39.0
	Bl	16D_2	17/11/2007 14:05:22	146.8087	-18.6683	38.4
	Bl	16D_3	17/11/2007 14:14:07	146.8080	-18.6655	38.8

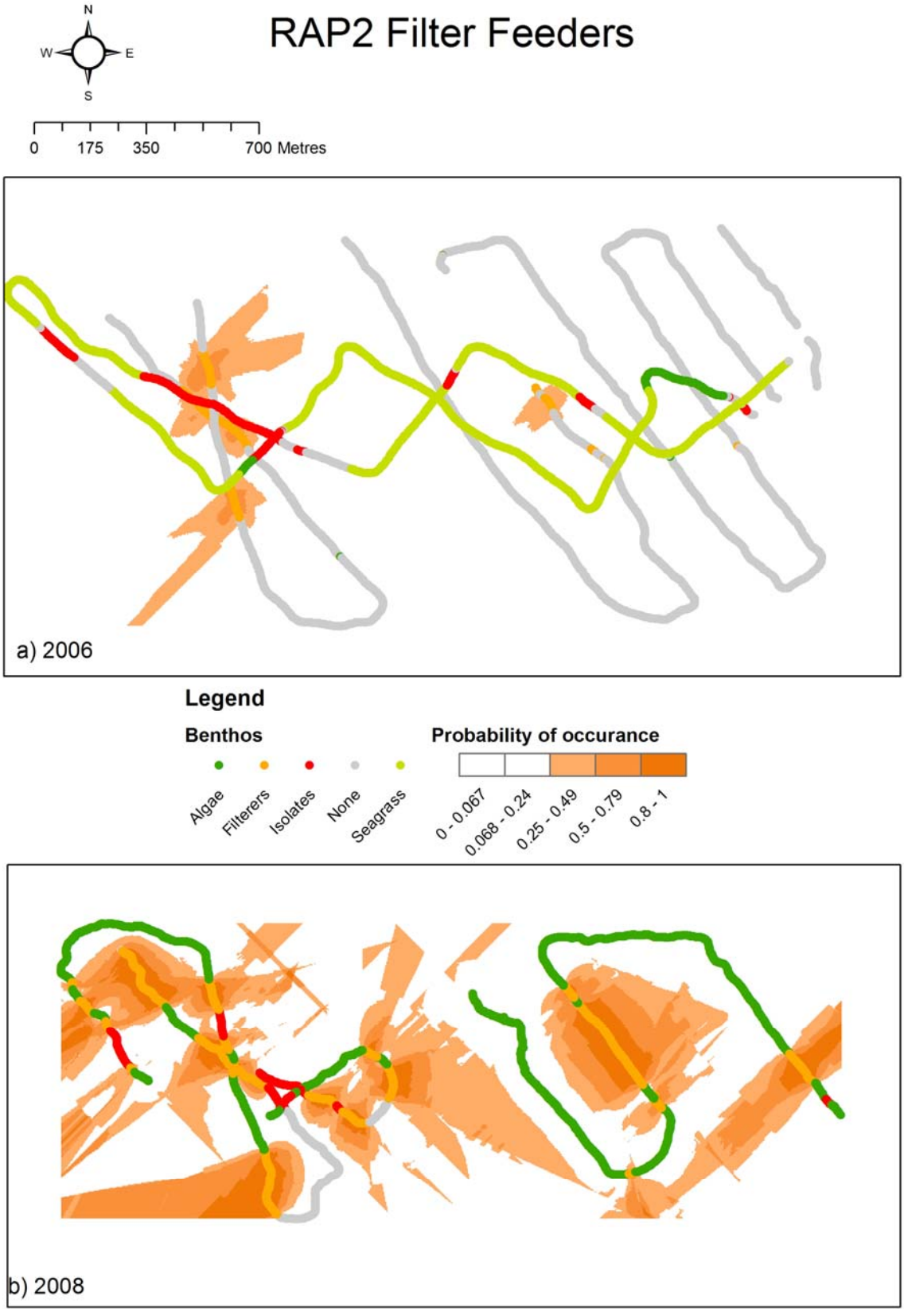
Appendix 4 – Species Richness

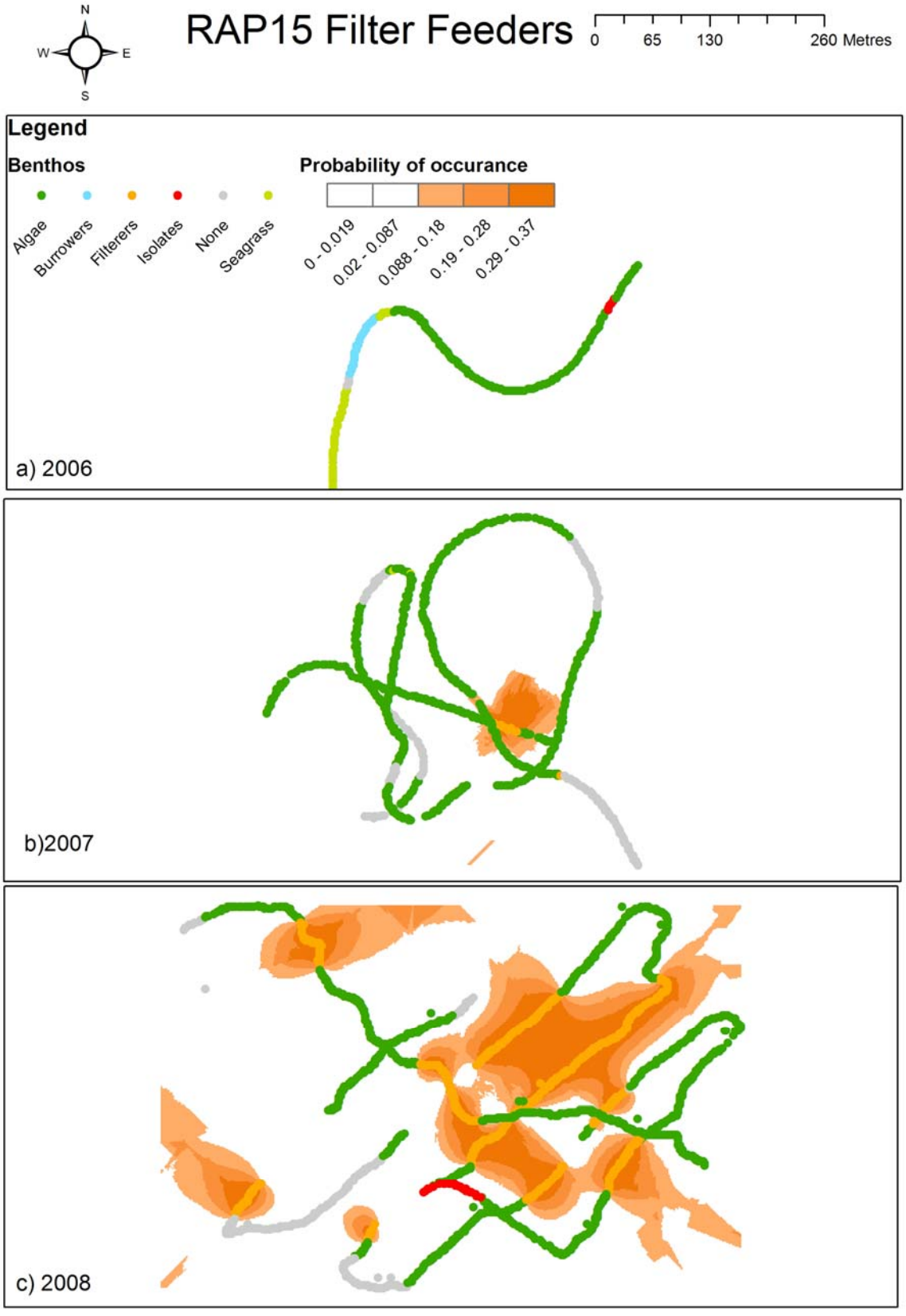
Mean number of species (±1SE) on the structurally complex habitats (closed bars) and the surrounding sandy phototrophic habitats (open bars) over the five sampling periods at each of the three green and three blue sites off Townsville.



Appendix 5 – Examples of spatial analysis of benthic cover distributions from repeat surveys with towed video




RAP2 Filter Feeders
N
W
E
S
0
175
350
700 Metres
a) 2006
Legend
Benthos
Algae
Filterers
Isolates
None
Seagrass
Probability of occurance
0 - 0.067
0.068 - 0.24
0.25 - 0.49
0.5 - 0.79
0.8 - 1
b) 2008


N
W
E
S
RAP15 Filter Feeders
0
65
130
260 Metres
Legend
Benthos
Algae
Burrowers
Filterers
Isolates
None
Seagrass
Probability of occurance
0 - 0.019
0.02 - 0.087
0.088 - 0.18
0.19 - 0.28
0.29 - 0.37
a) 2006
b)2007
c) 2008