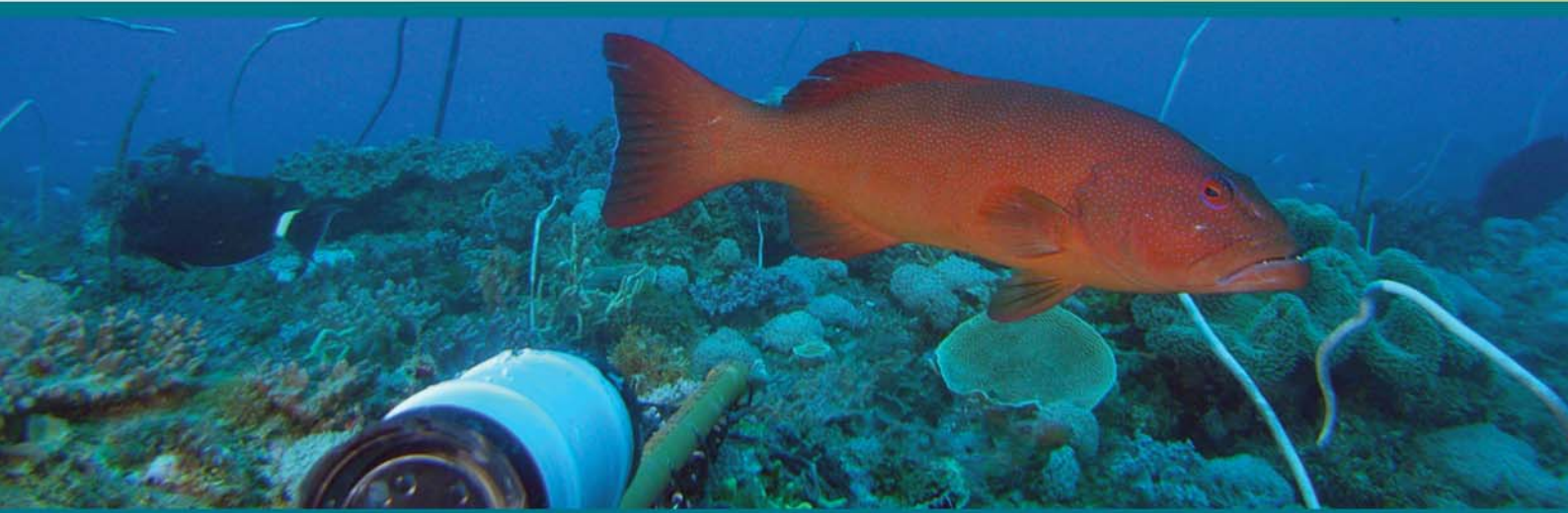




The influence of zoning (closure to fishing) on fish communities of the shoals and reef bases of the Great Barrier Reef Marine Park



Complementary analysis of observations from divers and baited video surveys to quantify the influence of region, habitat and zoning, and extension of results to regional groups



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Australian Government

Department of Sustainability, Environment,
Water, Population and Communities



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Water, Population and Communities**

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The four-year term of the Australian Government's Marine and Tropical Sciences Research Facility (MTSRF) officially concluded at the end of June 2010. The Commonwealth Environmental Research Facilities (CERF) Transition Program for the MTSRF aimed to deliver new and additional synthesis products based on the contemporary information needs of the primary end users through the synthesis and analysis of pre-existing MTSRF outputs. In addition, the MTSRF Transition Program extended research that is highly relevant to the future CERF key investment areas of the Great Barrier Reef and Torres Strait, northern Australia and terrestrial biodiversity.

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Acronyms Used In This Report

AIC	Akaike Information Criteria
AIMS	Australian Institute of Marine Science
ANSA	Australian National Sportfishing Association
ARP	Annual Research Plan
BRUVS	Baited Remote Underwater Video Stations
CERF	Commonwealth Environment Research Facilities
DEWHA	Commonwealth Department of the Environment and World Heritage Areas
FOV	Field of View
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GPS	Global Positioning System
KML	Keyhole Markup Language
KMZ	Compressed, zipped version of a KML
LMAC	Local Marine Advisory Committee
LTMP	Long-term Monitoring Program (AIMS)
MPA	Marine Protected Area
MTSRF	Marine and Tropical Sciences Research Facility
NTMPR	No-Take Marine Protected Reserve
RAP	Representative Areas Program (2004)
RRRC	Reef and Rainforest Research Centre Limited
SBRUVS	Stereo Baited Remote Underwater Video Stations
SCUBA	Self-Contained Underwater Breathing Apparatus
UVC	Underwater Visual Census

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Executive Summary

This report comprises a new synthesis of pair-wise comparisons of deep shoals open and closed to line fishing, by incorporating new data on seafloor habitats, complementary data from shallow water fish surveys, and public outreach using novel, video-based extension tools.

We estimated that pooled target species were about 1.42 times as abundant on ‘green’ shoals closed to fishing as they were on fished shoals after depths, substratum type and epibenthic cover were accounted for. The species richness, and abundance of other species groups based on their vulnerability to line fishing, were either significantly higher in zones closed to fishing or were neutral (bycatch species). Strong differences amongst regions and habitat types were detected, but they did not affect the primary estimates of the positive effects of zoning on attributes of the fish fauna.

Comparisons of counts by divers (UVC) and baited, remote underwater video stations (BRUVS) showed no discernible consistency between the effects of zoning detected by each technique amongst the same 16 pairs of open/closed reefs in the Pompey (Mackay), Swain and Capricorn-Bunker reef groups. There was clear evidence of an interaction between effects of zoning and hard coral cover on coral trout numbers for both the UVC transects and the BRUVS sets and for the red-throat emperor sighted on BRUVS. Unfortunately, the interaction could not be dissected further because of a lack of closed reefs with significant coral cover in the existing dataset for BRUVS. However, there was sufficient contrast amongst other pairs of shoals in the overall dataset from seven regions to account for the effect of coral cover when estimating the effects of zoning.

An objective analysis of the full set of BRUVS tapes has been linked with data summaries and images of the seafloor in the [e-Atlas](#) to encourage the public to visualise (on YouTube and Google Earth) both the regional variation in the effects of the 2004 Representative Areas Program zoning plan and the regional differences in the habitats they are visiting in the Great Barrier Reef Marine Park.

Introduction

Four years of study of deep shoals within the Great Barrier Reef Marine Park (GBRMP) have produced three clearly different patterns of response to the 2004 Representative Areas Program (RAP) zoning plan (hereafter referred to as 'RAP 2004') amongst pairs of shoals and reef bases open or closed to fishing (see Cappo *et al.* 2010 for review).

Comparisons of global means, with no accounting for differences in type of substratum or habitat type, showed the effects of zoning were not consistent amongst regions and species groups. Without accounting for habitat types, the Cairns and Pompey reef bases showed more target fish in 'green' (no-take) zones; however the Swain and Capricorn-Bunker reef group bases contained less target fish around reefs closed to line fishing. The diffuse Townsville shoals also had less target and bycatch species in 'green' zones, whilst the nearby discrete Cardwell shoals showed very high ratios of ~5 to ~17 for target groups between 'closed' and 'open' fishing zones.

However, the early studies off Cairns and Townsville during the first and second years of this MTSRF funded research did not incorporate measures of the substratum or epibenthos in the immediate BRUVS field of view in analyses of the fish communities. In the Townsville region, there were more target species on diffuse shoals open to fishing, yet there were twice as many target species on green shoals closed to fishing around the discrete, southern shoals off Gladstone. This indicated that the topographic complexity of the substratum and the amount of epibenthic cover must be considered when assessing the effects of zoning on shoal habitats in the GBRMP.

Subsequent studies in the third year of the study did incorporate measures of habitat in the field of view of the BRUVS and found a fundamental role for epibenthic 'cover' in influencing the 'signal' of effects of zoning. For example, in the coral-dominated habitats of the deep reef bases of the remote Pompey and Swain reefs there were about 1.5 times as many target species around the green reefs, but not in the Capricorn-Bunker Group, and not in other habitat types.

The matched pairs of 'open' and 'closed' reef bases surveyed with BRUVS in Year 3 (see Cappo *et al.* 2009) were the same as those surveyed by divers using UVC in the Pompey (Mackay), Swain and Capricorn-Bunker groups by Russ and others (2008). Those authors found a remarkably consistent, positive response of coral trout (*Plectropomus leopardus*) densities to the declaration of reef closures under the RAP 2004, but the BRUVS surveys of the deeper reef bases there did not. There was low confidence that sampling units (reefs) were independent in the third year BRUVS surveys and there was a compelling need to interpret the pair-wise BRUVS comparisons in the underlying context of the pair-wise differences in habitats.

To present an integrated picture of the effects of zoning on deep 'shoal' faunas we must, therefore, build on these separate studies in a manner that makes them transparently comparable by accounting for effects of region and habitat type. Furthermore, UVC data on shallow, target species generated by the MTSRF (Russ *et al.* 2008) should be combined with BRUVS counts of the same species on the same reef bases to see if the same regional signals are present in the deep and shallow fauna. This will build on all the existing MTSRF intelligence to enable managers to grasp a holistic picture of the regional effects of the zoning plan amongst the Pompey, Swain and Capricorn-Bunker management zones.

Outreach during the fourth year of research through the national media and public presentations showed that regional groups inside and outside the study areas were eager to hear more synthesis of 'results and lessons learned' for application to their immediate region.

This need could be addressed by presentations to selected peak bodies. To better inform the local public debate on the status of fish populations in 'green zones' there is also an opportunity to move beyond scientific reports to the summary of all data and video highlights through the e-Atlas using Google Earth and YouTube. This will enable visitors to the e-Atlas to select regions and shoals to visualise differences in the magnitude, appearance and behaviour of populations of key target species such as red emperor.

The activities to be conducted within the MTSRF transition period can, therefore, be summarised under three main objectives:

1. To account for region, substratum type and epibenthic 'cover' in measurement of effects of zoning, by designing and applying a standardised classification scheme for the seabed in the BRUVS field of view;
2. To compare shallow UVC (Russ *et al.* 2008) and deep BRUVS studies (Cappo *et al.* 2009) of populations of coral trout (*Plectropomus leopardus*) and red-throat emperor (*Lethrinus miniatus*) on 16 pairs of reefs open and closed to fishing; and
3. To present a summary of the four-year study of shoals to Local Marine Advisory Committees (LMACs) and other reef users, and design visualisation tools on the e-Atlas for use by the general public.

Materials and Methods

Models of fish abundance to account for substratum type, region and epibenthic ‘cover’ in measurement of effects of zoning on shoals in seven regions of the GBRMP

Previous studies have reported an important effect of epibenthic cover and substratum type on effects of RAP 2004 zoning (e.g. Speare & Stowar 2008, Stowar *et al.* 2008, Cappo *et al.* 2009). However, those studies did not make the same measurements or categorisations of epibenthos in the field of view (FOV) of the BRUVS. Towed video footage from nearby transects was used to classify habitat by Speare and Stowar (2008), and only coarse, subjective categorisations of the FOV were made by Stowar *et al.* (2008). For the current study, a standardised classification scheme for the seabed in the BRUVS field of view was developed and applied by reviewing all images of the seafloor collected during analysis of all 1,122 BRUVS tapes collected during the entire shoals study.

Images were assigned to one of eight qualitative categories of bedform – flat sand or gravel or silt, sand ripples, sand dunes, rubble field, *Halimeda* bank, low reef/outcrop, high reef/outcrop, boulder field. The classification scheme identified percentage cover in the images, to the nearest ten percent, of eight categories of substratum within these bedforms (mud/silt, sand, gravel, rubble, bedrock, boulder, calcareous reef, indeterminate) that summed to 100%.

In terms of epibenthic cover, or lack of it, the images were also assigned to one of six coarse, qualitative ‘habitat categories’: open sandy seabed, seagrass bed, macroalgal bed, low-relief rubble field, coral reef, gorgonian and sea whip (*megabenthos*) gardens. The classification scheme identified percentage cover in the images to the nearest ten percent of 15 categories of epibenthos (gorgonian fans, sponges, sea whips, soft corals, hard corals, macroalgae, seagrass, *Halimeda*, crustose coralline algae, anemones, bryozoans and encrusting animals, zoanthids, hydroids, forams and ‘None’). These classifications also summed to 100%.

Each of the ‘%cover’ variables was measured on the same scale, so no data transformations were made. They were likely to be correlated, so exploratory principal components analyses were used to select a set of environmental variables for analysis of relationships with attributes of the fish assemblage in univariate models.

Univariate analyses

Fish abundances were analysed using univariate statistical approaches with the ‘R’ statistical package (R Development Core Team, 2005). The *MaxN* data were over-dispersed or highly skewed by counts made when shoals of fish passed the field of view, so raw data was analysed with a negative-binomial function (`glm.nb`) using a log-link (Venables & Ripley 2002).

Univariate analyses were applied to the summary assemblage attributes of species richness, and pooled abundances. Separate analyses were done on species abundances pooled according to four subsets based on species vulnerability to line fishing (see below, as well as Appendices 1 and 2).

For each `glm.nb`, the response in the given assemblage attribute was tested for a significant relationship with variation in depth, habitat category, region and zone. We sought to produce the most parsimonious model possible to assess the effect of RAP 2004 zoning on attributes of the fish assemblages. To do this, terms were dropped from a series of models using both

fixed and random effects, and these were compared on the basis of their information content and complexity (Akaike Information Criteria – AIC).

Presentation of results from the final models comprises:

1. Partial effect plots for epibenthic cover, region and zoning status. Partial effect plots visually display the effect of each of these explanatory variables on the response (i.e. species richness or abundance of species groups) after accounting for the other two variables included in the model.
2. Tabulations, in the original units of richness and abundance, of fitted model estimates for each combination of epibenthic cover, region and zone. The estimates provide meaningful interpretations of the effect that a change in an explanatory variable has on the mean of the response.
3. Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the models. The standard errors and test statistics together provide information to determine whether an explanatory variable was statistically significant. This information is summarised by the corresponding p-values. An explanatory variable was deemed significant if it had a p-value less than 0.05.

Target status of species

For the purposes of assessing the effects of RAP 2004 zoning on shoal communities, fish species have been categorised by Stowar *et al.* (2008) and Cappo *et al.* (2010) in four sets depending on the likelihood they would be caught and retained by line fishers. The comparisons presented here focused on:

- i. **PRIZED TARGETS: Prized species.** These included the most desirable demersal species, based on their landed catch and size, such as red emperor and coral trout.
- ii. **ALL TARGETS: Sought-after species.** These included the prized species (i) and other desirable demersal and pelagic species, based on their landed catch and size, as well as their reef-dwelling habits.
- iii. **BYCATCH: All species considered likely to be caught by line fishers as by-catch.** Excluded species in categories (i) and (ii) and comprised the undesirable fishes, sharks and rays known to take a baited hook.
- iv. **UNFISHED: Species considered unlikely to be caught by line fishers.** This list included all species unlikely to be caught because of their dietary preferences (e.g. herbivores such as scarid parrotfishes) or small size (e.g. pomacentrid damselfishes and chaetodontid butterflyfishes).

Comparison of shallow and deep populations of coral trout and red-throat emperor on 16 pairs of reefs in the Pompey (Mackay), Swain and Capricorn-Bunker Groups

Studies of shallow-water coral trout showed effects of both region and zoning on abundance (see Russ *et al.* 2008) in the remote Pompey, Swain and Capricorn-Bunker reef groups. The deep bases of the same reefs were sampled during the third year of the project using BRUVS (Cappo *et al.* 2009) and differences in 'target' species abundances due to zoning were found mainly in coral-dominated habitats. However, the two data sets have not been drawn together and they have been considered separately in the scientific literature (see McCook *et al.* 2010).

The shallow water fish populations on the 16 pairs of reefs have been surveyed with UVC in 2007, 2008 and 2009, but we chose to use only the counts made in the year immediately prior to our BRUVS sampling to avoid the effect of storms and cyclones that occurred in the summer of 2009 after the BRUVS sampling. These UVC counts were made between November and December of 2007 (Capricorn-Bunker Group), December 2007 and February 2008 (Swain Group) and in June 2008 (Pompey Group).

For each sampling method we compared the individual replicate counts made within the pairs of reefs, to derive an average (mean) difference between 'green' and 'blue' reefs in each pair for measurements of both fish numbers and cover of hard coral. There were 15 replicate UVC counts (five sites per reef, with 3 x 50 metre transects per site) and 12 BRUVS sets per reef (no stratification by sites). To derive the average difference we randomly and repeatedly took one measurement (transect or BRUVS set) from each of the open and closed reefs within a pair and obtained their difference. This was completed 999 times and the mean difference was derived, with an associated standard error.

The measurements we compared in this manner were counts of all coral trout (*Plectropomus leopardus*, *P. maculatus*, *P. laevis* pooled) and red-throat emperor (*Lethrinus miniatus*), and estimates of cover of hard coral cover along transects (UVC) and within the field of view (BRUVS).

Public outreach and e-Atlas tools to visualize the effects of RAP 2004 zoning on shoal faunas

To transfer the knowledge gained from the overall study to managers, policy makers and the general public, two approaches were adopted. Firstly, personal presentations by the senior author were made to six Local Marine Advisory Committees (LMACs) along the GBRMP, and three 'Eye on the Reef' workshops were hosted by the Great Barrier Reef Marine Park Authority (GBRMPA). Another two presentations, outside the reporting period, will be made to the annual convention of the Queensland branch of the Australian National Sportfishing Association (ANSA) in Yeppoon in August 2011.

e-Atlas summary

Secondly, video clips, swathe maps and data summaries for each pair of shoals (blue/green) have been delivered via a KML using the e-Atlas. The KML shows the coast and reefs of the GBRMP in Google Earth. A second layer (the RAP 2004 Zoning) is also opened in the e-Atlas to provide context for the KML.

Keyhole Markup Language (KML) is an international standard scheme for expressing geographic annotation and visualization within Internet-based, two-dimensional maps and three-dimensional Earth browsers such as Google Earth. A compressed, zipped version of a KML is called a KMZ.

For this KML a selection of BRUVS footage for each shoal (162 videos from 1,102 BRUVS locations) were chosen based on BRUVS sets that showed the highest abundance of prized fish (such as red emperor and coral trout). The 'best' 30 seconds (highest occurrence of prized fish) of each of these one-hour BRUVS videos was then selected as part of this video series. In essence, the selection used the count data (*MaxN*) in an objective query to choose the 'best' moments in the 'best' three video tapes from each of the blue and green members in the pairs of shoals or reef bases compared in this study.

Thus, there was no preference in video selection made for the green or blue zones. These video clips show an unbiased view of the highest abundance of prized fish in each zone, and were mounted on YouTube with relevant tags. YouTube is a video-sharing website on which users can upload, share and view videos. It uses Adobe Flash Video technology to display a wide variety of user-generated video content, including movie clips, television clips and music videos, as well as amateur content such as video blogging and short original videos. Most of the content on YouTube has been uploaded by individuals. Unregistered users may watch videos, and registered users may upload an unlimited number of videos.

Data summaries, in terms of numbers of fish or sharks viewed during each ten hours of BRUVS footage were mounted under fish-shaped icons in the KML. The default pane of view has the fish icons for each pair of shoals scaled by the abundance of 'prized' fish species, and coloured by the zoning status of the pair member. Clicking on the icon brings up a data summary for prized, bycatch and unfished species groups, and a menu to select video footage and swathe maps for the shoal. Data summaries for selected individual species can be made active by selecting the relevant layers on the Toolbar of Google Earth (see below).

Feedback on the product from attendees at the public presentations indicated we should not display the data at the scale of individual BRUVS sets, for fear of attracting fishing effort to blue shoals or poaching to positions just inside green zones. The positions of the BRUVS place markers in this KML have therefore been quantised to 0.01 degrees (~500 metre error) to protect the exact locations of the individual BRUVS sets.

e-Atlas preparation

The preparation of the BRUVS dataset for the e-Atlas was performed using a custom script written in R (<http://r-project.org>). This script was developed to take the original observation data from 1,102 BRUVS sites, along with information about 162 sample BRUVS videos, to produce summaries for 48 shoal locations and produce the following outputs:

- An online KMZ for viewing the dataset in Google Earth. This version uses videos hosted on YouTube;
- An offline KML for presentations and field work where no Internet is available;
- A CSV file containing descriptions and titles to associate with each YouTube video; and
- Summary shapefile and Style Layer Descriptor (SLD) files for creating the Web Map Service for the dataset. This is used for displaying the dataset in the Australian Ocean Data Network (AODN) and the e-Atlas web map client.

The KML produced for this dataset contains ten layers showing the abundance of prized target fish (coral trout, red emperor, etc.), along with the abundance of nine individual species (red emperor, coral trout, large-mouth nannygai, small-mouth nannygai, Venus tuskfish, red-throat emperor, grey reef shark, collared sea bream and starry triggerfish). Each of the 48 shoal locations were displayed as placemarkers in the map with an icon shaped to match the fish species. Each placemaker was given a pop-up page that displays summary data (abundance, depth, number of BRUVS recordings in the area, and species richness), BRUVS video samples and a multibeam swathe map of the area, if that map was available.

Video Hosting

All of the video footage selected by the BRUVS team was uploaded to YouTube (<http://www.youtube.com/user/eAtlasAIMS>) for hosting. YouTube was selected to host the videos to improve the web presence of the dataset. This hosting allows the videos to be discovered through the YouTube and Google video search. New users who are unaware of the e-Atlas can, therefore, find these videos and follow links back to the e-Atlas for further information.

To ensure that the videos could be found using searches, each video was given a unique description including the names of the species and habitat visible in the video, an overview of the dataset, and links back to the e-Atlas for further information. In addition to this description each video was tagged with a range of keywords.

Placemark Icons

The icons used to show the abundance and zoning of each fish species were created using Inkscape® software by tracing photos of each fish species. The placemark icons for each location were scaled in area based on the average abundance and their colour was set to match the GBRMP zoning that they are located in. The same scaling of the icons was used for all layers to allow the user to visually compare the abundance of different species, allowing them to visually see, for example, that there were far fewer grey reef sharks than collared sea bream in the data set, and that coral trout were vastly more abundant in the south. The shapes of the icons were made to match the species being displayed in each layer.

Results

Models of fish abundance to account for substratum type, region and epibenthic ‘cover’ in measurement of effects of zoning on shoals in seven regions of the GBRMP

The simplest, most parsimonious models ($response \sim habitat + region + zone$) represented the explanatory variables as fixed factors, and did not include depth as a covariate or any interaction terms. The coefficients outlined in Table 1 show that all the responses measured for attributes of the fish community were either positively or neutrally (bycatch abundance) affected by the closure to fishing of the inter-reef shoals and reef bases under the RAP 2004 zoning.

The term plots for partial effects in Figure 1 and 2 illustrate strong differences amongst habitats and regions in species richness and abundance. Unfished species were numerically dominant in the overall dataset, so the term plots for *habitat* and *region* partial effects for ‘all fish’ and ‘unfished’ abundance are similar in shape (Figure 1). Similarly, ‘prized’ target species were a subset of the ‘all target’ species pool so these two groups also show partial effects of similar magnitude for *habitat*, *region* and *zone* (Figure 2).

Sandy habitats, and those dominated by marine plants, had lower species richness and fish abundance than rubble and coral habitats, and those dominated by megabenthos (gorgonian sea fans, sea whips and sponges). Townsville shoals, the southern banks (Barcoo, Karamaea, east and west Warregoes), and the reef bases of the Capricorn-Bunker groups also accounted for the higher residuals in the term plots for richness and ‘unfished abundance’ (Figure 1). The small features of the single Cardwell pair of shoals and the reef bases and channels sampled off Cairns accounted for the lower residuals in abundance of all species groups. The positive partial effects for coral habitats indicated that highest levels of richness and abundance of all species groups were found there.

The term plots and coefficients in Table 1 showed that ‘green’ zones closed to fishing had significantly higher richness and abundance for all groups (1.14-1.48 times as abundant), with the exception of bycatch species, where a difference of 1.05 times was not significant. There were more prized fish in the Pompey reef bases and submerged southern banks than elsewhere and more prized fish in coral dominated habitats (Figure 2).

Table 1: Fitted estimates for each response in the model $response \sim habitat + region + zone$ for species richness and relative abundance ($MaxN$) of all fish pooled. The ratios (closed:open) of estimates equate to the effect sizes of zoning for richness (1.08) and relative abundance (1.14) in this main effects model without interactions.

Habitat type	Region	Richness Closed (Green)	Richness Open (Blue)	Abundance Closed (Green)	Abundance Open (Blue)
Sandy (<i>sndy</i>)	Townsville (<i>twnsvl</i>)	11.6	10.7	56.3	49.5
	Cardwell (<i>crdwell</i>)	6.3	5.9	20.6	18.1
	Cairns (<i>cns</i>)	7.5	7	19	16.7
	Swains (<i>swns</i>)	9.4	8.7	38.6	33.9
	Cap-Bunks (<i>cpbnks</i>)	10.8	10	64.6	56.8
	Pompeys (<i>pmpey</i>)	9.3	8.6	36	31.6
	Sthn Banks (<i>sthn</i>)	11.5	10.6	39.6	34.8
Seagrass (<i>seagr</i>)	Townsville	11.3	10.5	72.2	63.5
	Cairns	7.4	-	24.4	-
Macroalgae (<i>mcralg</i>)	Townsville	13.1	-	79.2	-
	Swains	10.6	9.8	54.4	47.8
	Cap-Bunks	12.2	-	91	-
	Pompeys	10.6	9.8	50.6	44.5
	Sthn Banks	13	12.1	55.7	49
<i>Halimeda</i> (<i>hlmda</i>)	Sthn Banks	29	-	99	-
Rubble (<i>rbbl</i>)	Townsville	18.4	-	82.4	-
	Cardwell	10.1	-	30.2	-
	Cairns	-	11.1	-	24.5
	Swains	14.9	13.8	56.6	49.7
	Cap-Bunks	17.2	15.9	94.7	83.2
	Pompeys	14.8	13.7	52.7	46.3
	Sthn Banks	18.3	16.9	58	51
Megabenthos (<i>gorg</i>)	Townsville	19.2	17.8	85.4	75.1
	Cardwell	10.5	9.7	31.2	27.5
	Cairns	12.5	11.6	28.8	25.3
	Swains	15.5	14.3	58.6	51.5
	Cap-Bunks	17.9	16.6	98.1	86.2
	Pompeys	15.4	14.3	54.6	48
	Sthn Banks	19	17.6	60.1	52.8
Coral (<i>coral</i>)	Townsville	-	25	-	134.6
	Cairns	17.6	16.3	51.7	45.4
	Swains	21.8	20.2	105	92.3
	Cap-Bunks	25.2	23.3	175.8	154.6
	Pompeys	21.7	20.1	97.9	86
	Sthn Banks	26.8	24.8	107.7	94.7

Table 2: Fitted estimates for each response in the model $response \sim habitat + region + zone$ for relative abundance ($MaxN$) of ‘all target’ species, and ‘prized target’ species. The ratios (closed:open) of estimates equate to the effect sizes of zoning for all target species (1.45) and prized target species (1.48) in this main effects model without interactions.

Habitat type	Region	Richness Closed (Green)	Richness Open (Blue)	Abundance Closed (Green)	Abundance Open (Blue)
Sandy (<i>sndy</i>)	Townsville	4.6	3.2	3.4	2.3
	Cardwell	3.3	2.3	1.8	1.2
	Cairns	1	0.7	0.8	0.6
	Swains	3.5	2.4	3.4	2.3
	Cap-Bunks	3.2	2.2	2.9	2
	Pompeys	4.3	2.9	4.1	2.8
	Sthn Banks	5.2	3.6	4.7	3.2
Seagrass (<i>seagr</i>)	Townsville	6.4	4.4	4.9	3.3
	Cairns	1.4	-	1.2	-
Macroalgae (<i>mcralg</i>)	Townsville	3.7	-	2.7	-
	Swains	2.8	1.9	2.7	1.8
	Cap-Bunks	2.6	-	2.3	-
	Pompeys	3.4	2.4	3.2	2.2
	Sthn Banks	4.2	2.9	3.6	2.5
<i>Halimeda</i> (<i>hlmda</i>)	Sthn Banks	13	-	9	-
Rubble (<i>rbbl</i>)	Townsville	7.1	-	4.9	-
	Cardwell	5.1	-	2.6	-
	Cairns	-	1.1	-	0.8
	Swains	5.3	3.7	4.9	3.3
	Cap-Bunks	5	3.4	4.2	2.8
	Pompeys	6.5	4.5	6	4
	Sthn Banks	7.9	5.5	6.7	4.6
Megabenthos (<i>gorg</i>)	Townsville	7.9	5.5	5.4	3.7
	Cardwell	5.7	3.9	2.9	2
	Cairns	1.7	1.2	1.3	0.9
	Swains	6	4.1	5.4	3.7
	Cap-Bunks	5.6	3.8	4.6	3.1
	Pompeys	7.3	5.1	6.6	4.4
	Sthn Banks	8.9	6.1	7.4	5
Coral (<i>coral</i>)	Townsville	-	5.9	-	4.2
	Cairns	1.9	1.3	1.5	1
	Swains	6.4	4.4	6.2	4.2
	Cap-Bunks	6	4.1	5.2	3.5
	Pompeys	7.9	5.4	7.5	5
	Sthn Banks	9.6	6.6	8.4	5.7

Table 3: Fitted estimates for each response in the model $response \sim habitat + region + zone$ for relative abundance ($MaxN$) of 'bycatch' species, and 'unfished' species not vulnerable to line fishing. The ratios (closed:open) of estimates equate to the effect sizes of zoning for bycatch species (not significant ~ 1.05) and unfished species (1.14) in this main effects model without interactions.

Habitat type	Region	Bycatch Closed (Green)	Bycatch Open (Blue)	Unfished Closed (Green)	Unfished Open (Blue)
Sandy (<i>sndy</i>)	Townsville	22.3	21.2	29.8	26.2
	Cardwell	4.4	4.2	12.8	11.2
	Cairns	6.1	5.8	11.1	9.8
	Swains	9.6	9.2	24.9	21.8
	Cap-Bunks	12.7	12.1	46	40.3
	Pompeys	12.3	11.7	19.6	17.1
	Sthn Banks	14.6	13.8	20.7	18.1
Seagrass (<i>seagr</i>)	Townsville	20.9	19.8	45.1	39.5
	Cairns	5.7	-	16.8	-
Macroalgae (<i>mcralg</i>)	Townsville	16	-	52.7	-
	Swains	6.9	6.6	44	38.6
	Cap-Bunks	9.1	-	81.3	-
	Pompeys	8.9	8.4	34.6	30.3
	Sthn Banks	10.5	10	36.5	32
<i>Halimeda</i> (<i>hlmda</i>)	Sthn Banks	71	-	15	-
Rubble (<i>rbbl</i>)	Townsville	25.4	-	48.5	-
	Cardwell	5	-	20.8	-
	Cairns	-	6.6	-	15.9
	Swains	11	10.4	40.5	35.5
	Cap-Bunks	14.5	13.7	74.9	65.6
	Pompeys	14.1	13.4	31.8	27.9
	Sthn Banks	16.6	15.8	33.6	29.5
Megabenthos (<i>gorg</i>)	Townsville	28.1	26.7	48.8	42.8
	Cardwell	5.5	5.2	20.9	18.3
	Cairns	7.7	7.3	18.2	16
	Swains	12.1	11.5	40.7	35.7
	Cap-Bunks	16	15.2	75.3	66
	Pompeys	15.5	14.8	32	28.1
	Sthn Banks	18.3	17.4	33.8	29.7
Coral (<i>coral</i>)	Townsville	-	31.6	-	96.4
	Cairns	9.1	8.7	41	36
	Swains	14.4	13.7	91.8	80.5
	Cap-Bunks	18.9	18	169.6	148.7
	Pompeys	18.4	17.5	72.1	63.2
	Sthn Banks	21.7	20.6	76.2	66.8

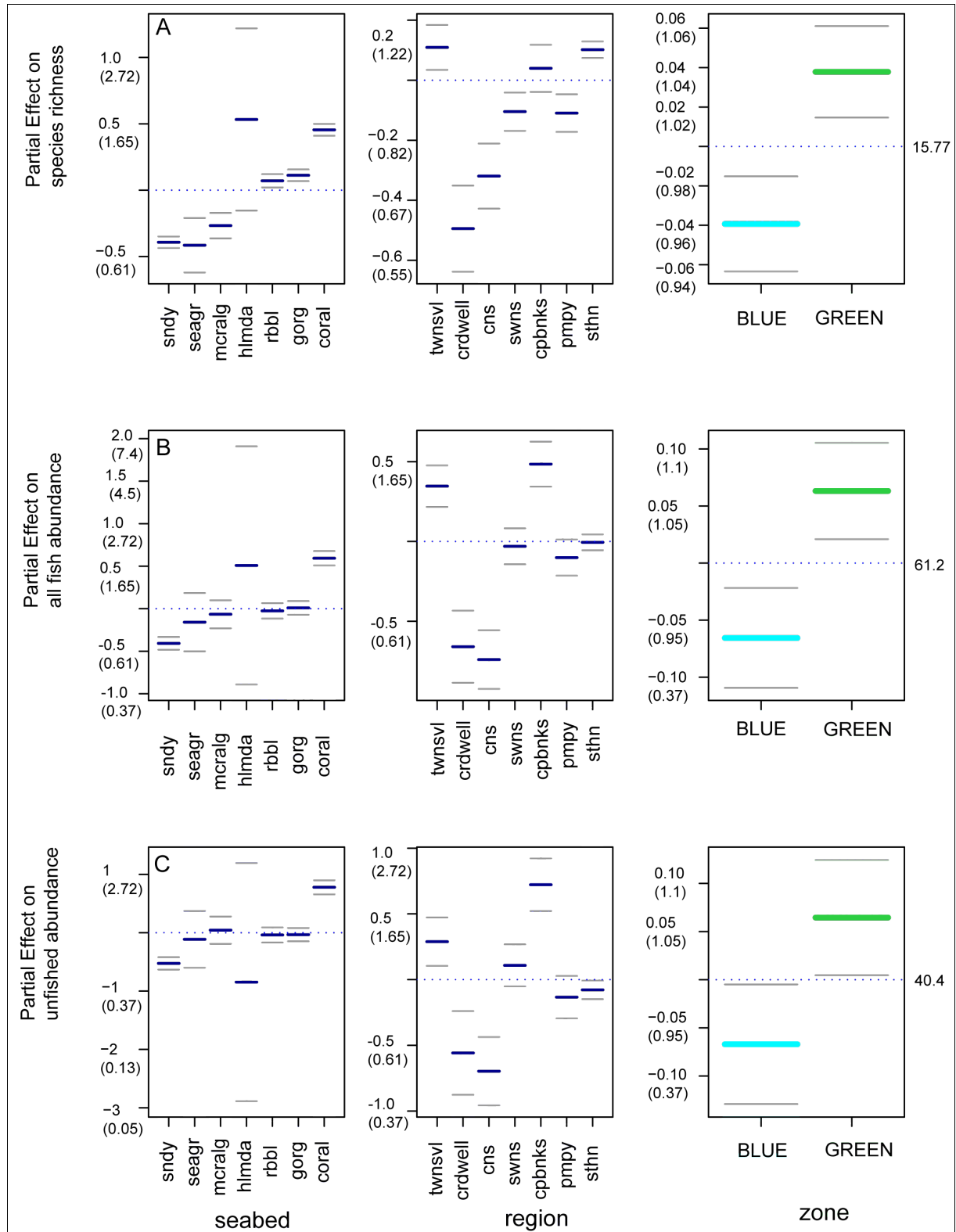


Figure 1: Term plots for habitat, region and zoning for species richness, and abundance of ‘all fish’ and ‘unfished’ species. Term plots present the fit of the terms to the residuals resulting from the fitting of all other terms in the *glm.nb* models to the response variable. For example, zone is fitted to the residuals of the model *response ~ habitat + region*. The y-axis values (log scale, with effect sizes in brackets) and standard errors (grey lines) represent the deviation of the zone levels from the overall mean value of the response (dashed horizontal lines). The green, closed zones had effects of ~1.04 times higher richness and ~1.6 times higher fish abundances. Abbreviations follow Table 1.

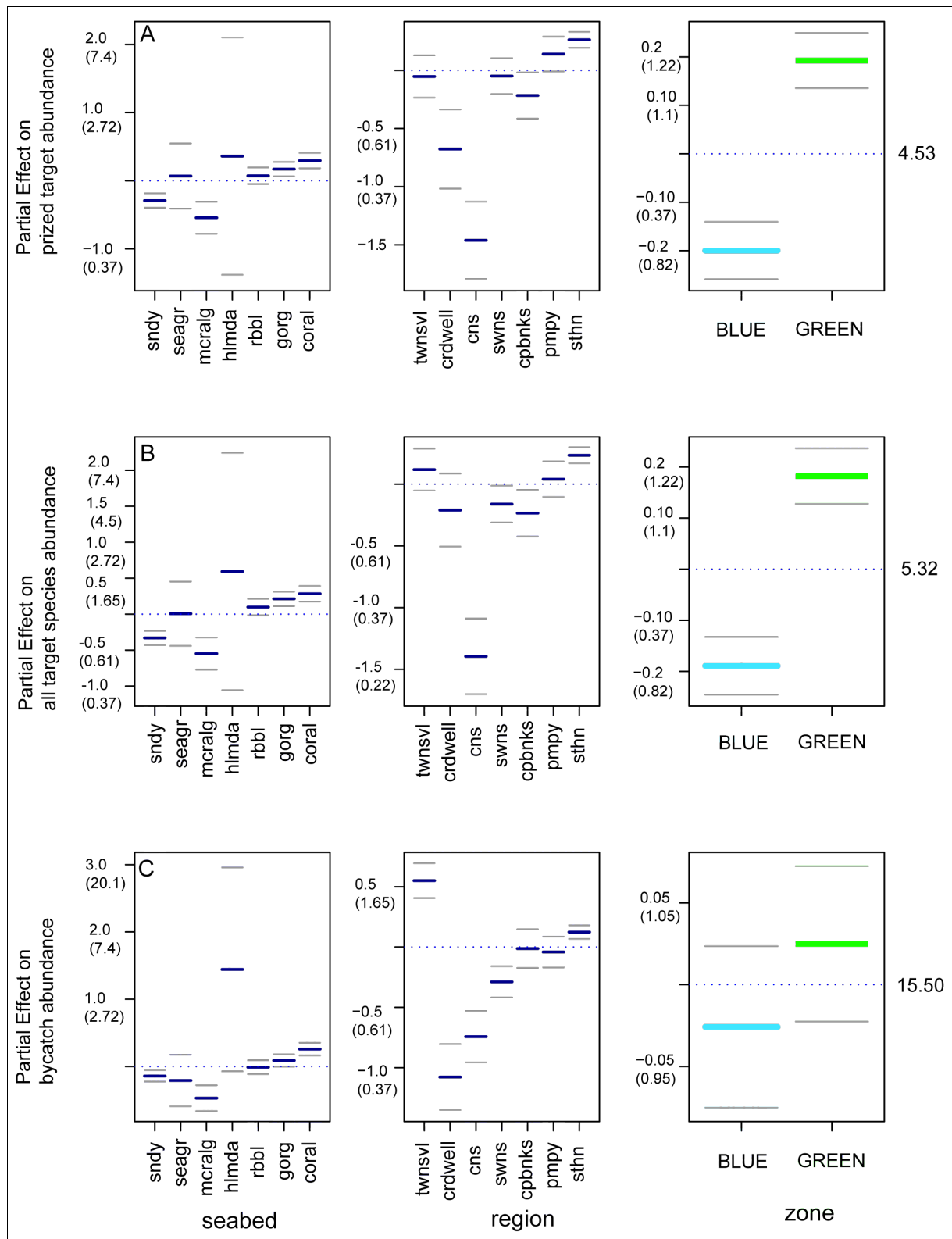


Figure 2: Term plots for seabed, region and zoning from `glm.nb` models for abundance of 'prized target', 'all target' and 'bycatch' species. See the caption for Figure 1 for full definitions. The green, closed zones were associated with the positive residuals (higher fish abundances) of the model $response \sim seabed + region$, indicating a strong positive effect for target species (~ 1.22 times the mean), but not bycatch species.

The second type of univariate analyses recognized that *region* was a surrogate for shoal type (e.g. depth, diffuse and large, small and distinct, submerged banks, reef bases) and other covariates in Table 1, so this term was removed. It was replaced by water depth and principal component scores for each site representing epibenthic cover and substratum type.

These `glm.nb` models were written as:

response ~ depth + PC1.snd2structr + PC2.enc2crl + PC1.reef2snd + PC2.reef2rbbl + zone

Here, *PC1.snd2structr* and *PC2.enc2crl* were the scores for each BRUVS site on the first two dimensions of an ordination of sites onto '%cover' of 15 categories of epibenthos. These two dimensions accounted for over 76% of the variation in site scores in an ordination that explained ~58% of the variation amongst sites (Figure 3A). Their names imply an axis from bare, sandy habitats to structure-forming epibenthos, such as corals, and a second dimension from simpler, encrusting epibenthos to complex hard coral habitats.

Similarly, the covariates *PC1.reef2snd* and *PC2.reef2rbbl* were the scores for each BRUVS site on the first two dimensions of an ordination of sites onto '%cover' of eight categories of substratum type. These two dimensions accounted for over 86% of the variation in site scores in an ordination that explained ~57% of the variation amongst sites (Figure 3B). Their names imply separation of sites along an axis from complex reefal substrata to bare sand, with a second separation along a gradient from complex reefal substrata to rubble.

The results for this modeling, where terms were dropped sequentially to find and remove non-significant explanatory covariates, are shown in Table 4 with test statistics shown in Appendix 9. The effects of closure to fishing were positive or neutral for all responses, but were highest for target species groups at about 1.42 times the number of target species in blue zones. This is slightly lower than zoning effect (1.48) detected in Table 2.

With the prior knowledge of the importance of hard coral in Tables 1-3, it was notable that *PC1.snd2structr* had a relatively strong effect on 'all fish' and 'unfished', but was not significant for target species. Instead, numbers of prized target species were higher for BRUVS at the higher values of the gradient in substrata from reef to rubble, and lower at sites on the sandy ends of the reef to sand gradient. Numbers of prized target species were higher for BRUVS at the higher values of the gradient in substrata from reef to rubble, and lower at sites on the sandy ends of the reef to sand gradient. It may be that there was some collinearity between epibenthic cover and substratum type that was not investigated in the modeling.

Table 4: Significant ($P < 0.05$) coefficients for each response in the model

response ~ depth + PC1.snd2structr + PC2.enc2crl + PC1.reef2snd + PC2.reef2rbbl + zone

for species richness and abundance ($MaxN$) of all fish pooled, and the four species groups. The intercepts of each model were estimates of richness and abundance in the original units. The other coefficients are effect sizes. For example, 'prized' target species were estimated to be 1.42 times as abundant on green shoals closed to fishing as they were on fished shoals after depths, substratum type and epibenthic cover were accounted for. The 95% confidence intervals for the mean effect sizes for green zones closed to fishing are shown with the mean estimate of the coefficient in bold.

The coefficients can be used to compare abundances. For example, numbers of prized target species were higher for BRUVS at the higher values of the gradient in substrata from reef to rubble, and lower at sites on the sandy ends of the reef to sand gradient. The effects of closure to fishing were positive or neutral for all responses, but were highest for target species groups. Test statistics for these models are shown in Appendix 9.

term	richness	All fish	unfished	bycatch	All targets	Prized targets
(Intercept)	14.38	55.04	75.72	15.36	2.37	1.49
depth	-	-	0.98	-	1.02	1.03
PC1.snd2structr	1.07	1.24	1.30	-	-	-
PC2.enc2crl	0.93	0.94	-	-	0.89	0.86
PC1.reef2snd	0.85	-	-	0.91	0.83	0.80
PC2.reef2rbbl	1.05	-	-	1.03	1.09	1.10
zoneGREEN	1.03 – 1.08 – 1.13	1.03 – 1.13 – 1.23	1.05 – 1.19 – 1.34	-	1.26 – 1.42 – 1.58	1.27 – 1.42 – 1.60

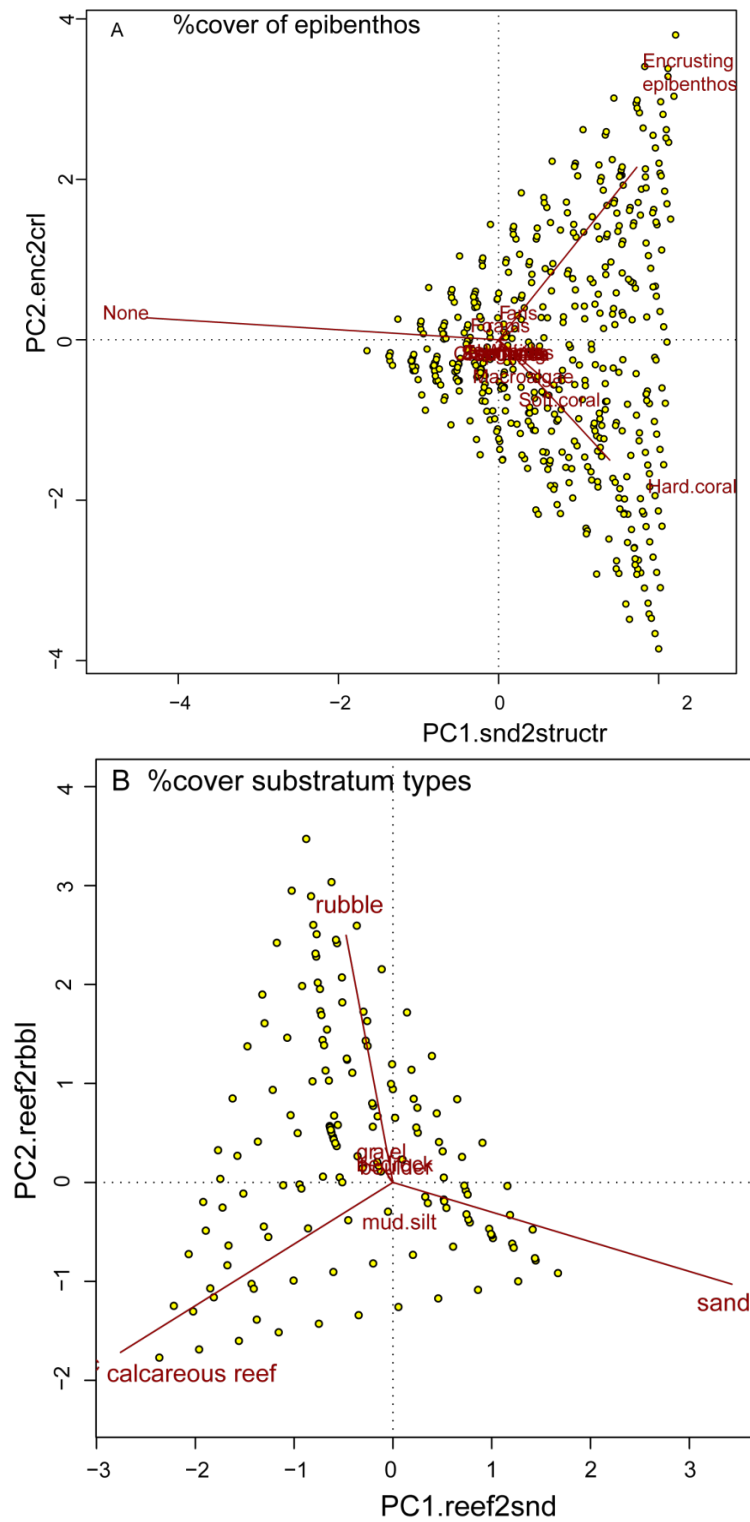


Figure 3: Principal components biplot of the BRUVS site scores for '%cover' of epibenthic categories (A) and substratum types (B). The scores along all four labelled axes were used as covariates in modelling the response of fish assemblage attributes to zoning

Comparison of shallow and deep populations of coral trout and red-throat emperor on 16 pairs of reefs in the Pompey (Mackay), Swain and Capricorn-Bunker Groups

Comparison of mean differences in both coral cover and fish counts were made between individual samples within each reef pair in the Pompey (Mackay), Swain and Capricorn-Bunker reef groups recorded by UVC in August 2008 (6-9 metres) and BRUVS in February 2009 (range 14-48.4 metres, mean = 34.2 ± 2.08 metres). Only coral trout (*Plectropomus leopardus*) and red-throat emperor (*Lethrinus miniatus*) were analysed in this way because most other large, target species sampled by BRUVS are not seen in shallow UVC, or cannot be counted using the small 50 x 5 metre transects used by Russ *et al.* (2008).

The most important feature to note from subsequent Figures (4-9) is that coral cover was matched evenly in the pairs included in the UVC surveys, but not in the BRUVS surveys of the same reef pairs. The UVC studies were based on selection of sites on mapped reef margins, visible on satellite imagery, with reef pairs chosen carefully to avoid confounding influences of reef size, site location and coral cover. In contrast, the BRUVS sets almost always had more coral cover in the field of view when set in blue zones open to fishing. There was no prior knowledge of the location or shape of reef bases sampled by the BRUVS, and the deployments were made in the lee of the reefs by following depth contours (see Cappo *et al.* 2009). There was no systematic bias we know of that could have resulted in the mismatch between coral-dominated habitats amongst the BRUVS sets in the green and blue zones of the reef bases.

Coral trout showed consistently higher abundance in green zones for three-quarters of the pairs sampled by UVC (Figure 4). In contrast, the BRUVS sets almost always had more coral cover in the field of view when set in blue zones, and only one quarter of the reef pairs counted more coral trout in the green zones (Figure 4). There was clear evidence of a wider difference between green and blue zones depending upon the difference in coral cover for the BRUVS sets, although this included some high leverage by a single reef pair in the Pompey group (PO.17), which had high coral cover and abundant coral trout (Figure 5). There was clear evidence of a wider difference between green and blue zones depending upon the difference in coral cover for the UVC sampling of this species (Figure 6).

Sightings of red-throat emperor were very low in the UVC surveys (Figure 7). BRUVS commonly recorded red-throat emperor in the deeper waters (Figure 7), but less than half of the reef pairs had more red-throat emperor counted by BRUVS in the green zones. There was equivocal evidence of a wider difference between green and blue zones depending upon the difference in coral cover for red-throat emperor sighted by BRUVS, although there was no leverage by the reef pair in the Pompey group (PO.17), where coral cover was high in the green zone (Figure 8). There was no evidence of such an interaction for the UVC counts, but sightings of this species were very low (Figure 9).

In summary, there was little consistency between the 'signals' of the effect of fishing closures between the deep and shallow counts apart from an interaction visible between the pair-wise differences in coral cover and the pair-wise differences in coral trout counts. The greater the difference in coral cover between closed and open reefs, the greater the difference in coral trout numbers for both UVC and BRUVS.

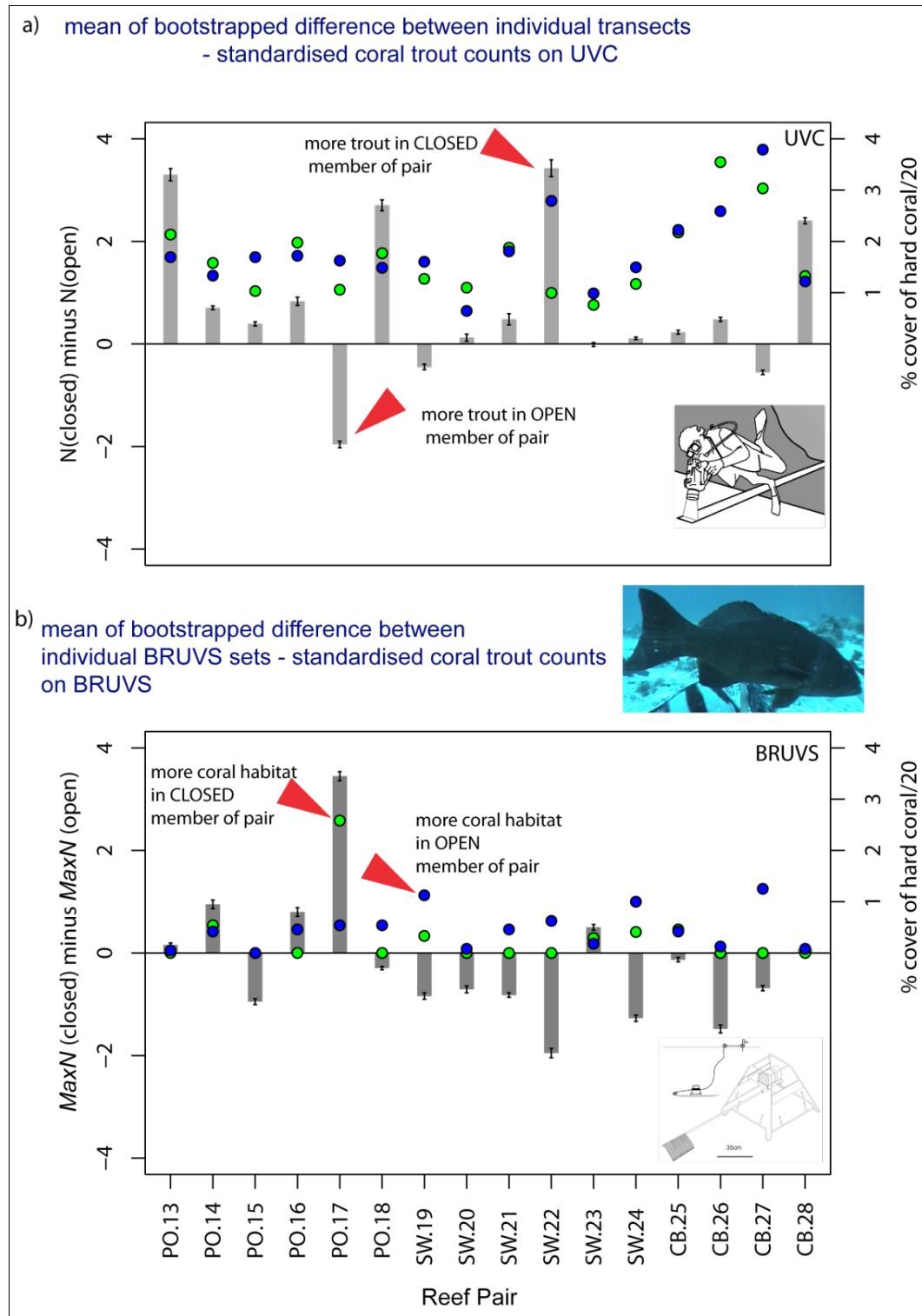


Figure 4: Comparison of mean differences in both coral cover and coral trout counts between individual samples within each reef pair in the Pompey (Mackay), Swain and Capricorn-Bunker groups of reefs, recorded by (a) UVC in 2007/2008, and (b) BRUVS in 2009. Coral cover was matched evenly in the pairs included in the UVC surveys and coral trout showed consistently higher abundance in green zones for three-quarters of the pairs. In contrast, the BRUVS sets almost always had more coral cover in the field of view when set in blue zones, and only one quarter of the reef pairs counted more coral trout in the green zones.

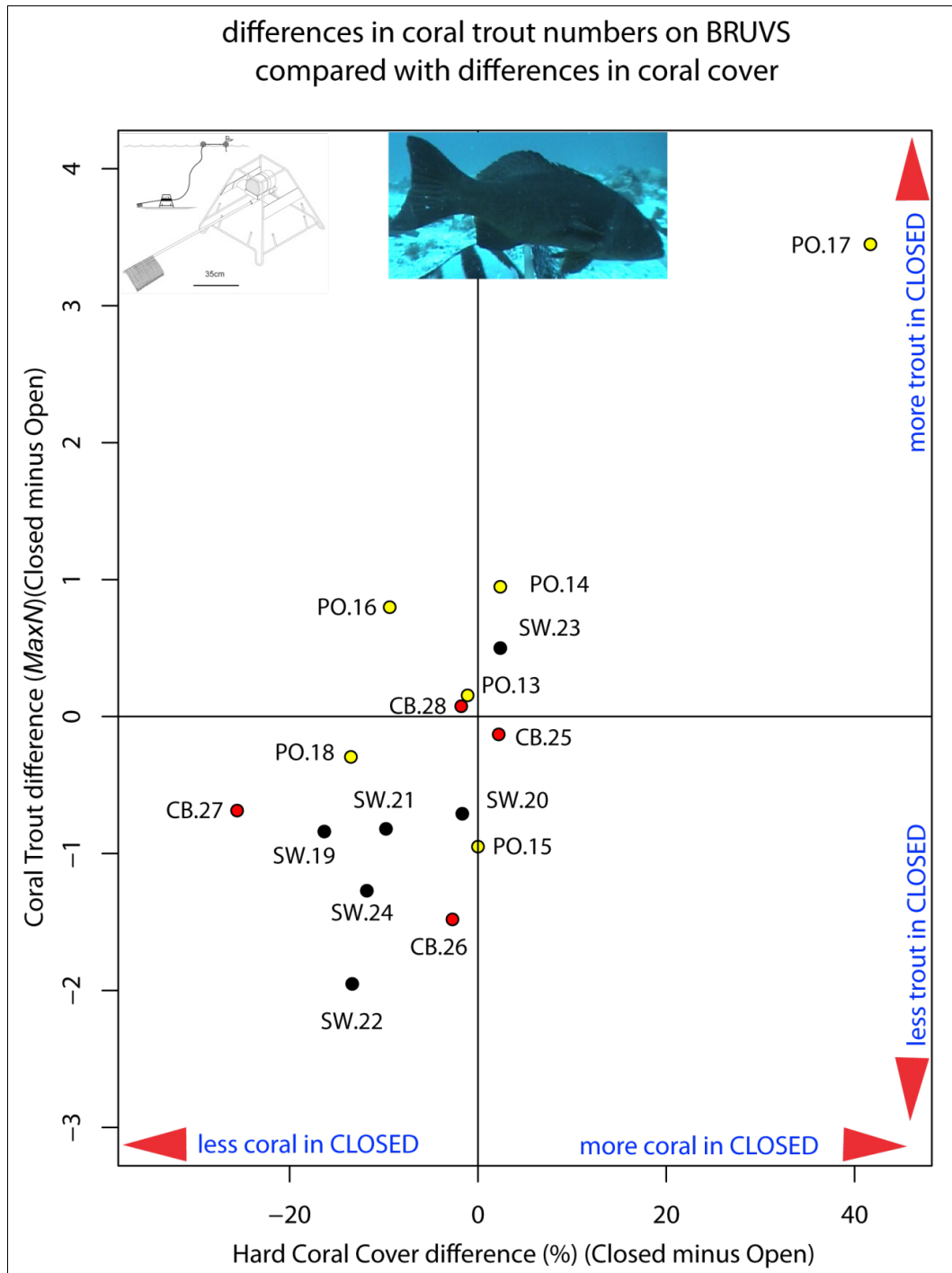


Figure 5: Comparison of mean differences in both coral cover and coral trout counts between individual samples within each reef pair in the Pompey (PO), Swain (SW) and Capricorn-Bunker (CB) reef groups recorded by BRUVS in 2009. There was clear evidence of a wider difference between green and blue zones depending upon the difference in coral cover, although this included some high leverage by a single reef pair in the Pompey group (PO.17).

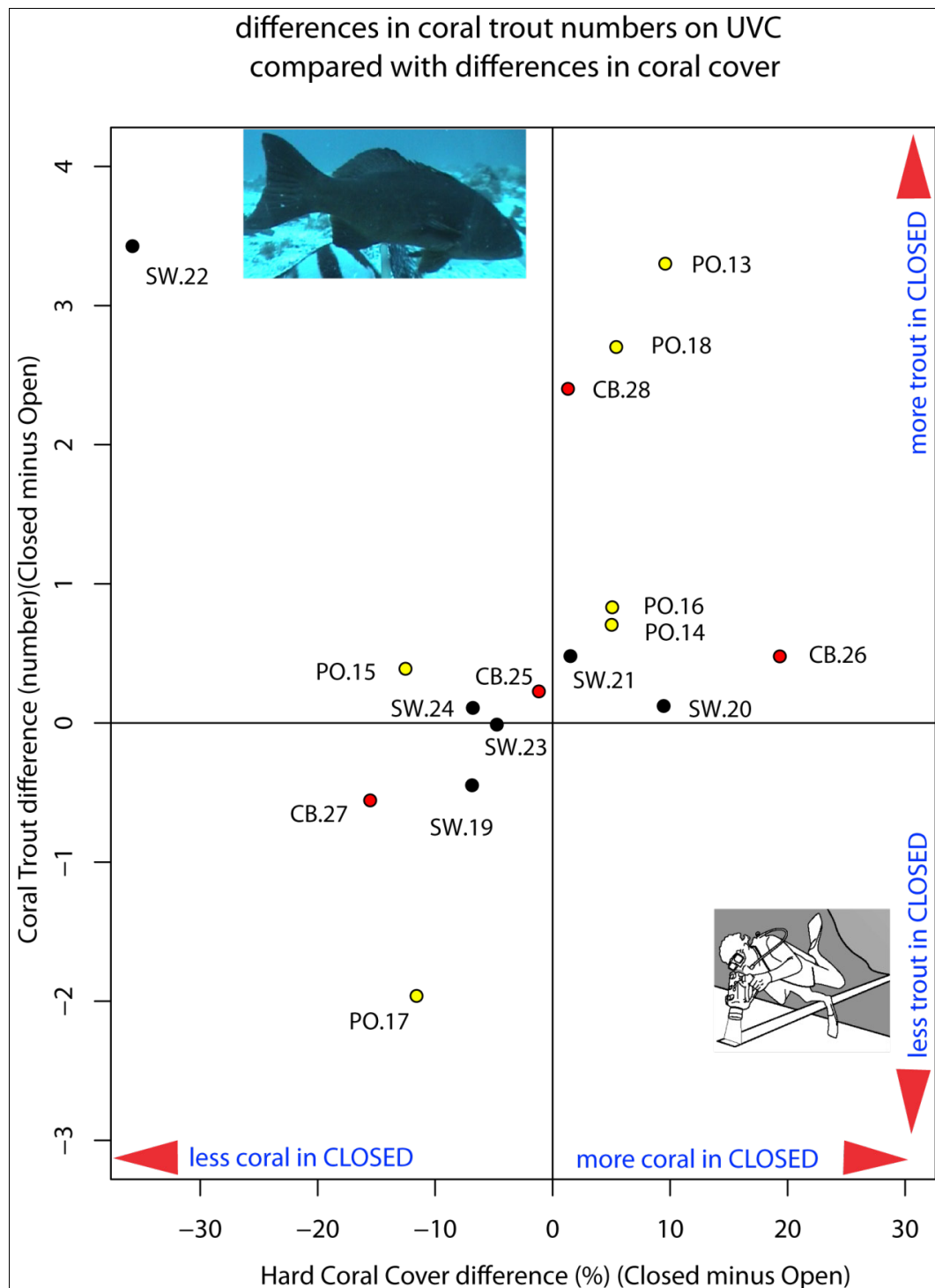


Figure 6: Comparison of mean differences in both coral cover and coral trout counts between individual samples within each reef pair in the Pompey (PO), Swain (SW) and Capricorn-Bunker (CB) reef groups recorded by UVC in 2007/2008. There was clear evidence of a wider difference between green and blue zones depending upon the difference in coral cover.

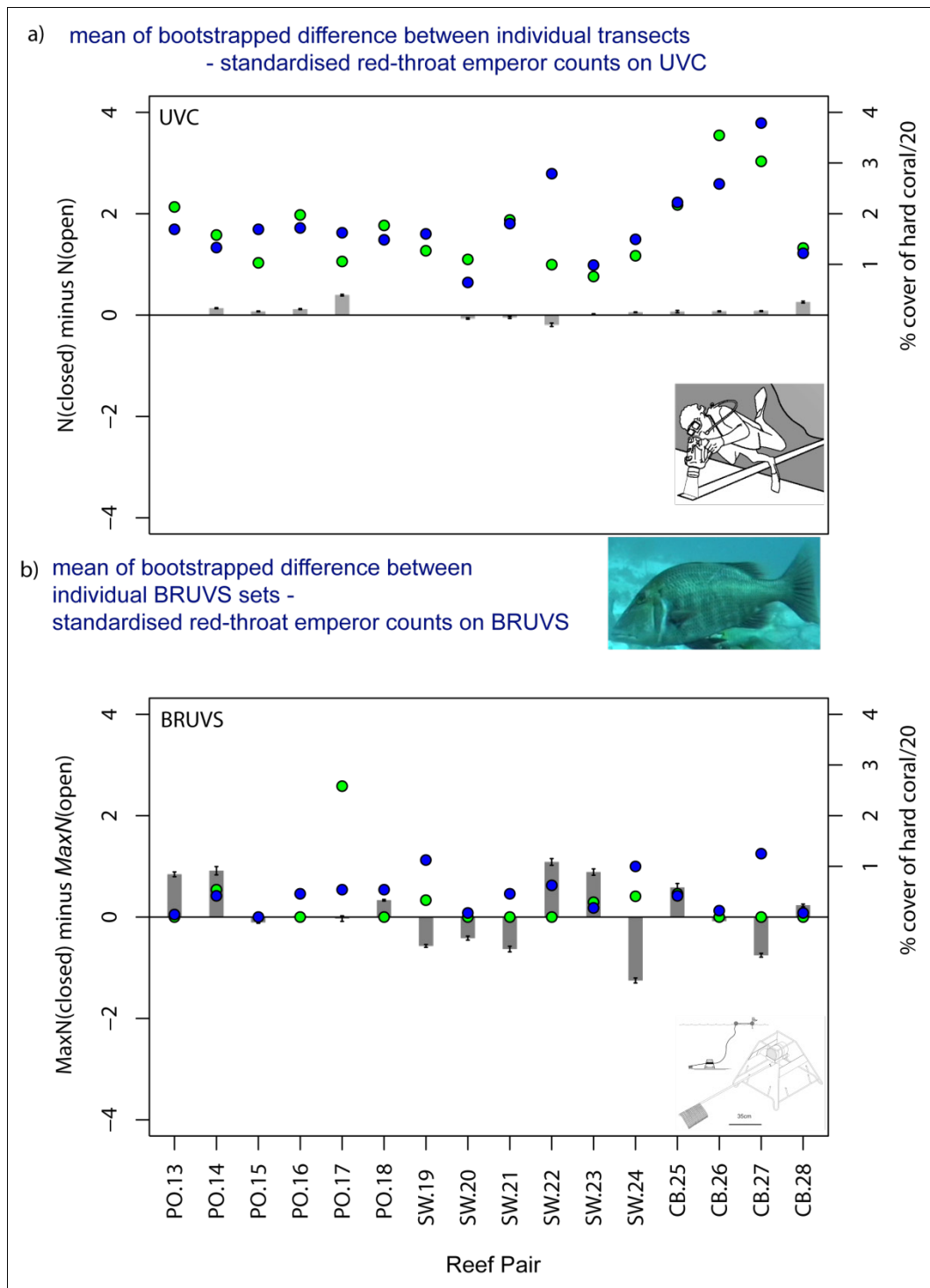


Figure 7: Comparison of mean differences in both coral cover and red-throat emperor counts between individual samples within each reef pair in the Pompey (Mackay), Swain and Capricorn-Bunker reef groups, recorded by (a) UVC in 2007/2008, and (b) BRUVS in 2009. Coral cover was matched evenly in the pairs included in the UVC surveys but sightings of red-throat emperor were very low. BRUVS commonly recorded red-throat emperor in the deeper waters. However, the BRUVS sets almost always had more coral cover in the field of view when set in blue zones, and less than half of the reef pairs counted more red-throat emperor in the green zones.

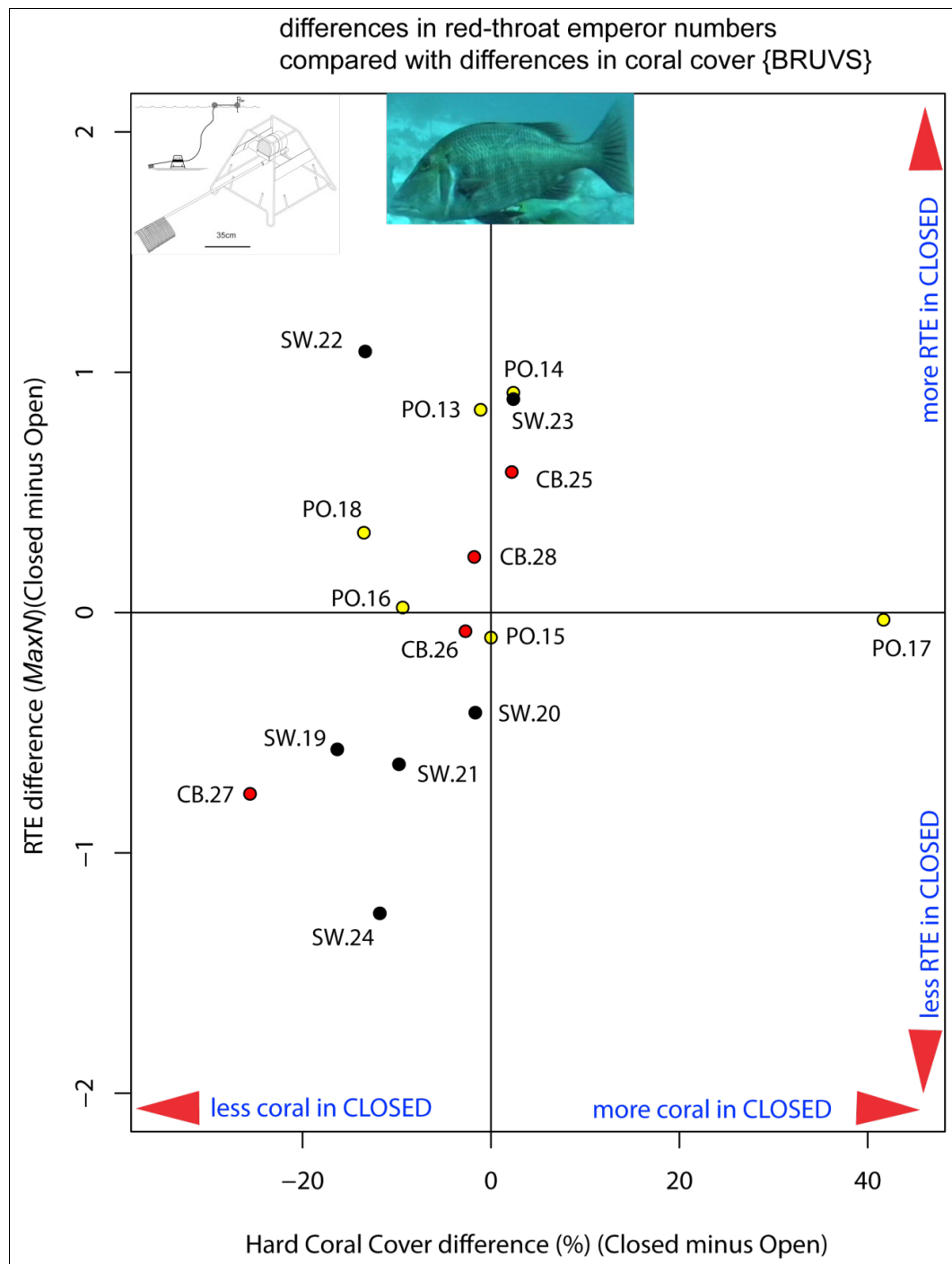


Figure 8: Comparison of mean differences in both coral cover and red-throat emperor counts between individual samples within each reef pair in the Pompey (PO), Swain (SW) and Capricorn-Bunker (CB) reef groups recorded by BRUVS in 2009. There was equivocal evidence of a wider difference between green and blue zones depending upon the difference in coral cover, and there was no leverage by the reef pair in the Pompey group (PO.17), where coral cover was high in the green zone.

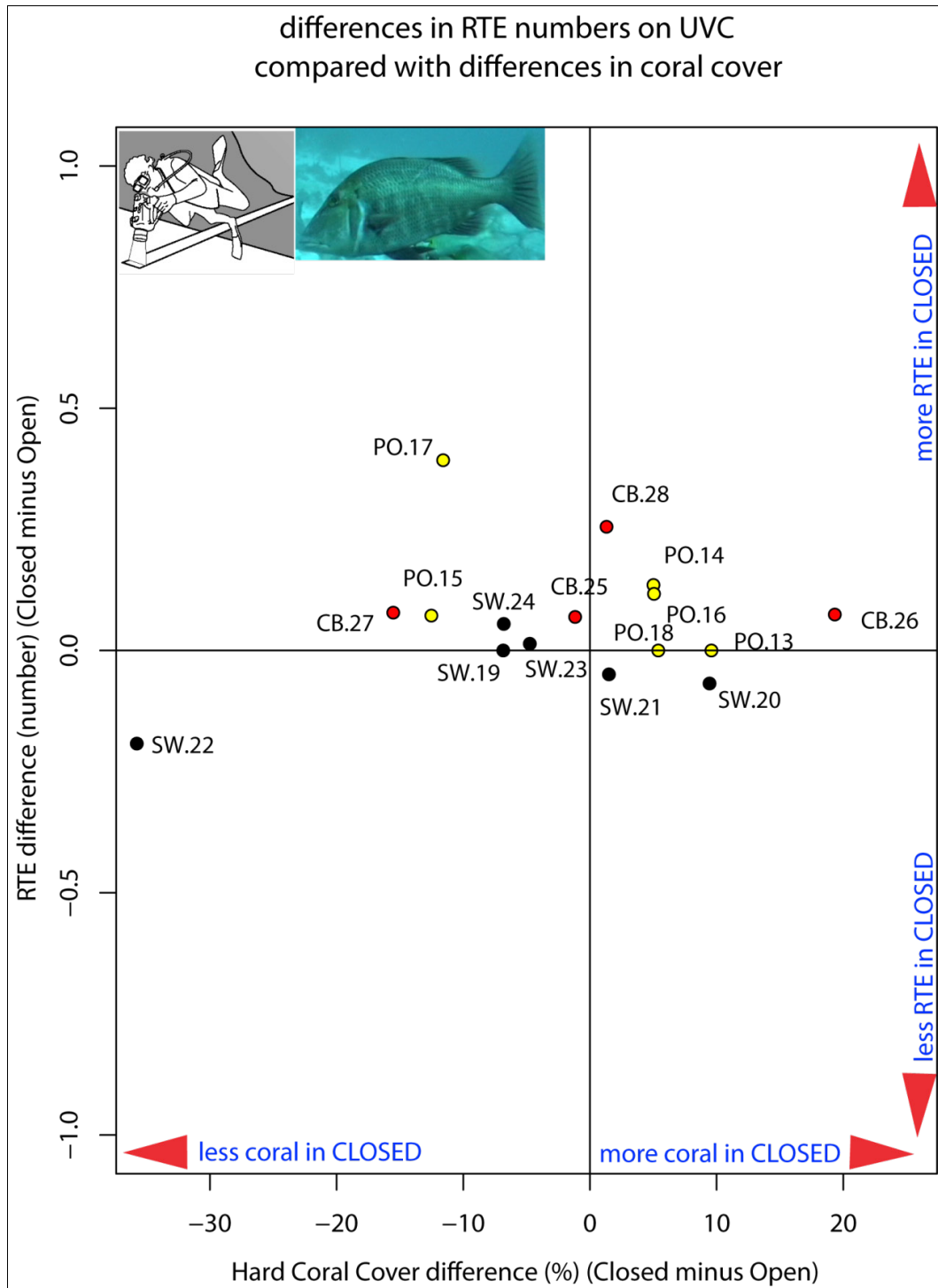


Figure 9: Comparison of mean differences in both coral cover and red-throat emperor counts between individual samples within each reef pair in the Pompey (PO), Swain (SW) and Capricorn-Bunker (CB) reef groups recorded by UVC in 2007/2008. There was no evidence of a wider difference between green and blue zones depending upon the difference in coral cover, but sightings of this species were very low.

This interaction might be suspected to cause problems in interpreting the models in Tables 1-4, but there was no significant effect of zoning on coral cover when a test was made using the `glm.nb` model $\text{coral} \sim \text{depth} + \text{region} + \text{zone} + (\text{region} \times \text{zone})$. The tests in Table 5 show that there were no major differences in hard coral cover between open and closed zones in the entire dataset, when the effects of *depth* and *region* were accounted for. The open/closed effect was estimated across all samples, and co-linearity in the reef base pairs mentioned above was more than compensated for by the mixture of more/less coral in the many other pairs of blue/green shoals included in the overall study.

Table 5: Analysis of deviance of the `glm.nb` model $\text{coral} \sim \text{depth} + \text{region} + \text{zone} + (\text{region} \times \text{zone})$. The dispersion parameter for the negative binomial was 0.12. The response *coral* estimated the '%cover' of hard corals within the field of view of the 1,102 BRUVS. There was a significant interaction between *region* and *zone*, but the effect of zoning was marginally non-significant. This implies that some reef pairs (such as the Swains) had lower coral cover in the green zones, but also that there was sufficient contrast amongst other pairs in the dataset to account for the effect of coral cover when estimating the effects of zoning.

	Degrees of freedom (Df)	Deviance	Residual Df	Residual Deviance	Pr(>Chi)
NULL			1114	957.98	
depth	1	92.76	1113	865.22	<0.0001
region	6	192.16	1107	673.06	<0.0001
zone	1	3.18	1106	669.88	0.07
region2:zone	6	23.35	1100	646.54	<0.0001

e-Atlas tools to visualise effects of RAP 2004 zoning on shoal faunas

The relevant tools can be found at: <http://e-atlas.org.au/content/gbr-aims-bruvs>

There have been over 100 unique YouTube users viewing at least one BRUVS video in one month (February 2011) without the e-Atlas page having been published or promoted.

e-Atlas Bruv Pre-release | Log out | About the e-Atlas | Contact Us

Browse by: Topic | Institution | Funding | Interactive Maps | Recent Activity

Home > Browse by Topics > Biology and biodiversity > Seafloor > Seabed fish communities: Baited Remote Underwater Video Stations (BRUVS) > Influence of zoning (closure to fishing) on fish communities of the Great Barrier Reef (BRUVS)

View | Edit | Workflow

Influence of zoning (closure to fishing) on fish communities of the Great Barrier Reef (BRUVS)

Bruv Pre-release
AIMS
Posted on 24 November 2010

This study investigated the influence of Great Barrier Reef Marine Park Zoning on fish abundance of the Great Barrier Reef. The fish populations of pairs of shoals, one in a Green zone (closed to fishing) and the other in a Blue (open to all fishing) were compared using Baited Remote Underwater Video Stations (BRUVS).

These BRUVS revealed a diverse fauna of fish, sharks, rays and sea snakes, including species prized by fishers, taken as bycatch, or not vulnerable to hook and line fishing.

View in Google Earth

View a summary of this dataset and 162 underwater videos from 48 study locations in Google Earth.

Online Google Earth KMZ [800 kB]. Videos are viewed from YouTube.

Offline Google Earth KML [310 MB zip]. Includes all videos (MPEG4 format) and swathmaps. Unzip and check the README.txt.

Reference Layers

The following are a set of useful reference layers:

Great Barrier Reef Marine Park Zoning 2003 [KMZ 1.3 MB], e-Atlas page for this dataset.

Abundant coral trout (Plectropomus leopardus) and other reef fish species

Numerous juvenile red emperor (Lutjanus sebae), as well as starry trigger fish (Abalistes stellatus)

Red emperor (Lutjanus sebae)

Introduction

During the extensive community consultation that accompanied the rezoning of the Great Barrier Reef Marine Park in 2004, anecdotal information emerged about the importance of submerged "shoals" and low-relief seabed features as intensified targets for commercial and recreational fishing.

In the offshore domain, there was evidence of effort shift in the commercial fishery for live coral trout from shallow

Figure 10: Screenshot of the e-Atlas page introducing the KML for the shoals study. Note that the GBRMP Zoning KML should also be opened when clicking on the Online Google KML. This introductory page includes a full synthesis of the results of the shoals study in plain English.

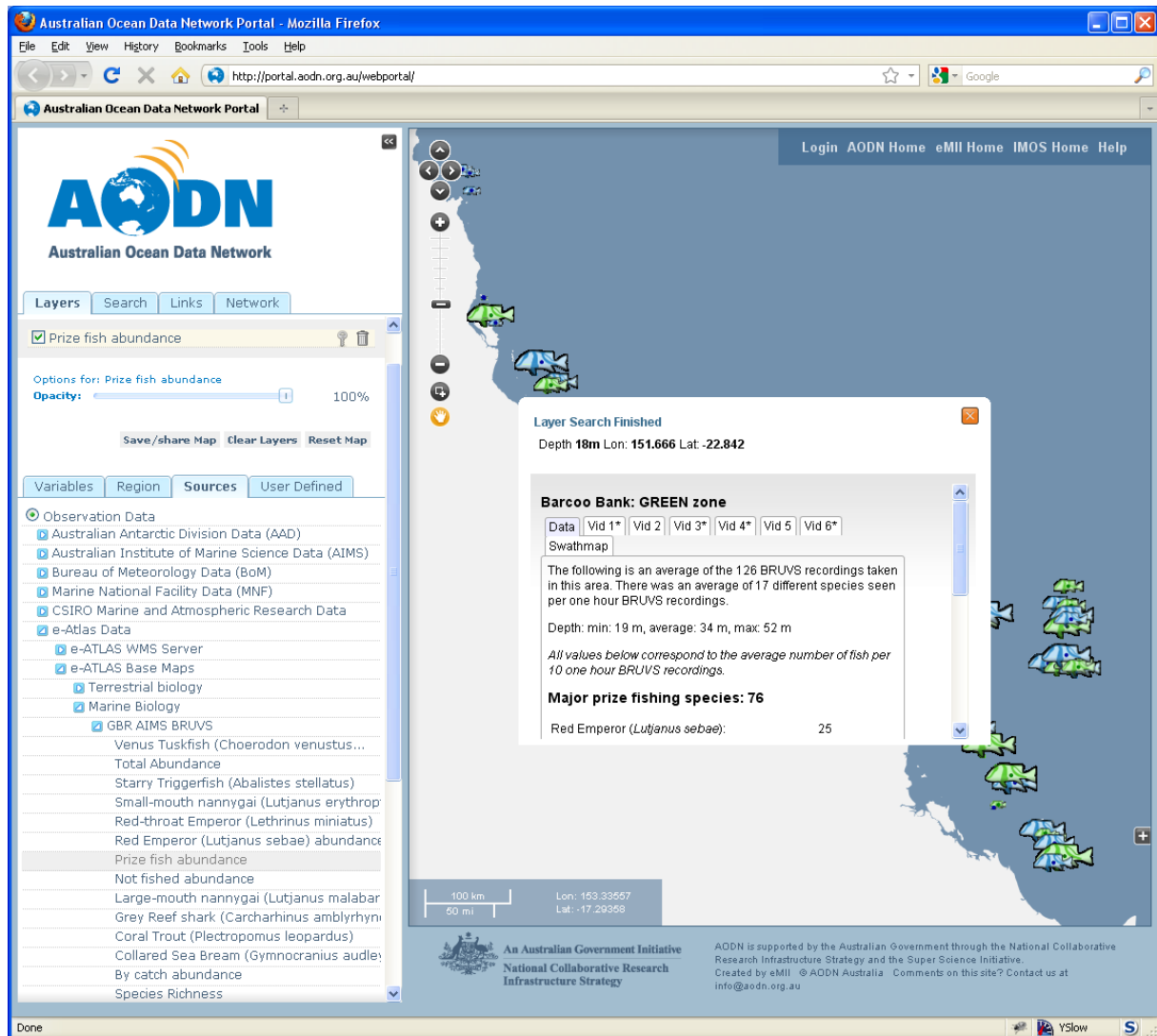


Figure 11: Screenshot of the e-Atlas link to the Australian Ocean Data Network, showing data layers for all groups of species, and individual species. The individual species layers comprise prized target species (Venus tuskfish, coral trout, red emperor, red-throat emperor, small and large-mouth nannygais), key bycatch species (grey reef sharks, collared sea bream) and abundant unfished species (starry triggerfish).

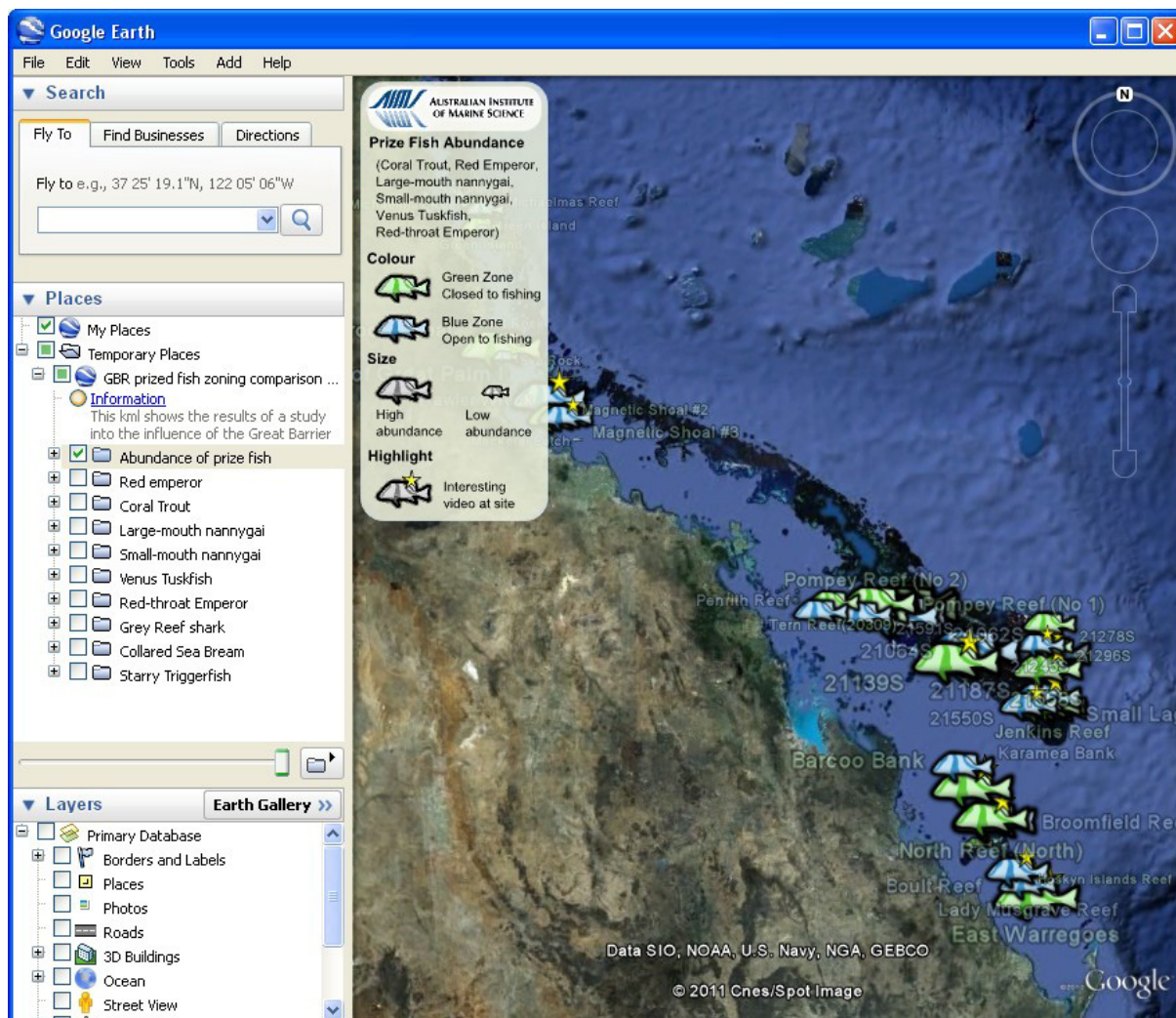


Figure 12: Screenshot of the primary Google Earth layer in the KML. Fish icons are scaled to the abundance of pooled, prized target species. Scaled icons can also be selected in layers for individual target species (Venus tuskfish, coral trout, red emperor, red-throat emperor, small and large-mouth nannygais), key bycatch species (grey reef sharks, collared sea bream) and abundant unfished species (starry triggerfish).

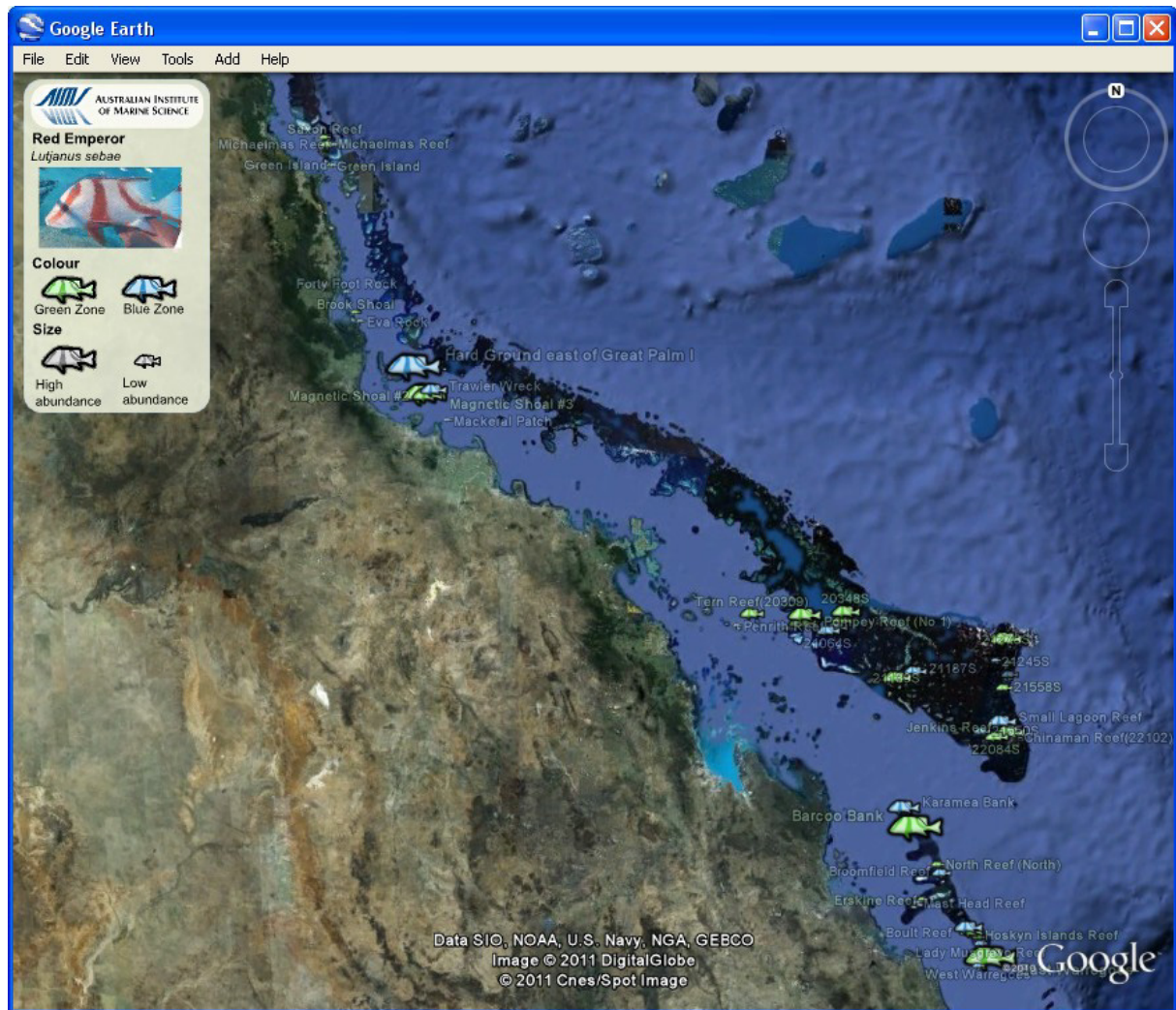


Figure 13: Screenshot of the Google Earth layer comprising BRUVS data for red emperor. Icons are scaled by the abundance of this species, and coloured by the zoning from which the data were collected.



Figure 14: Screenshot of the data page selected when clicking on the prized target icon for the Barcoo Bank sampling. This menu includes three video clips for the shallow shoal-top samples and three clips for the deep, shoal base. For 'Vid 1', the caption specifies the content of the video clip and details of sampling. There is also a 'Swathmap' selection on the top menu.

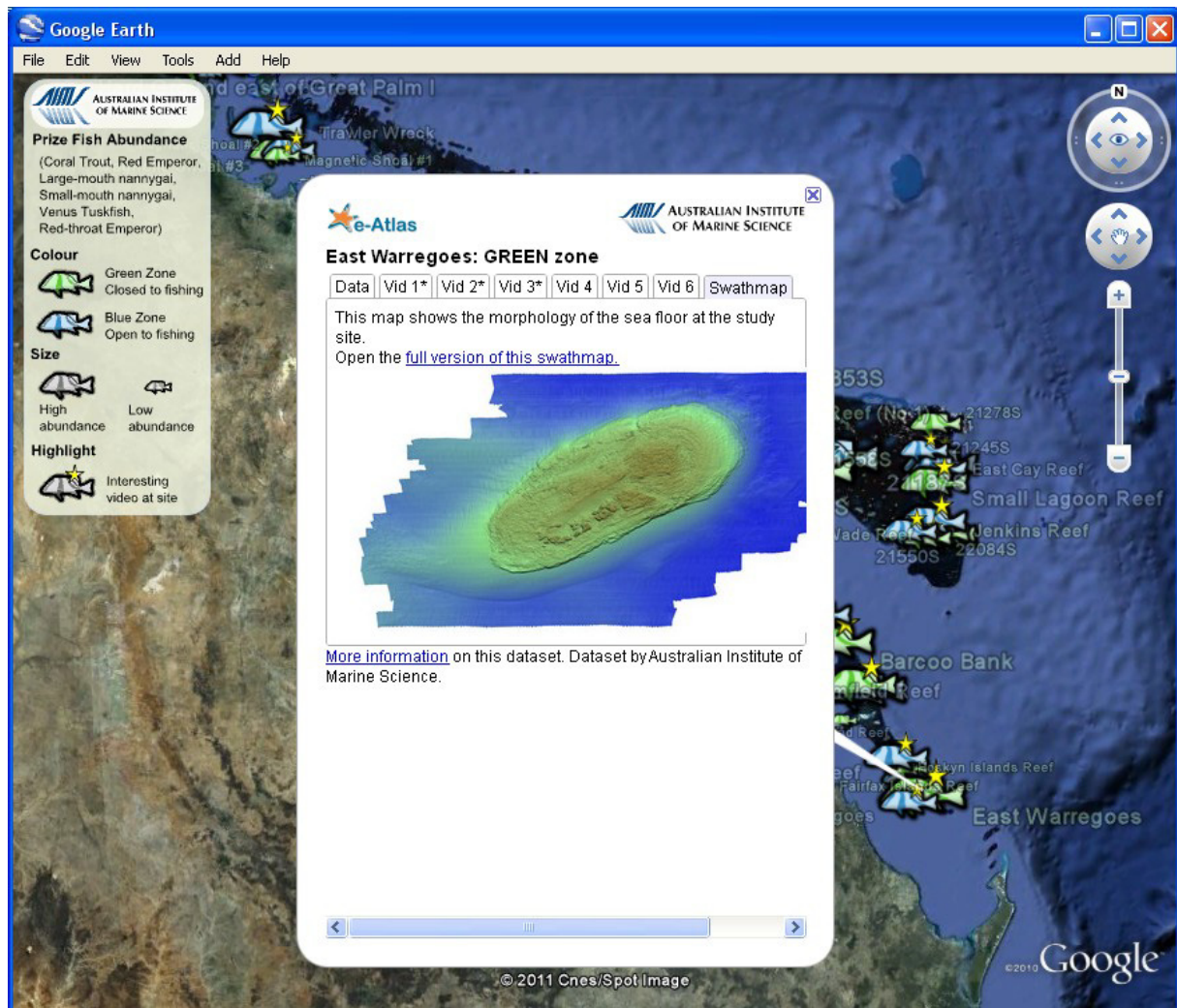


Figure 15: Screenshot of the view selected when clicking on the 'Swathmap' tab for the East Warregoes.

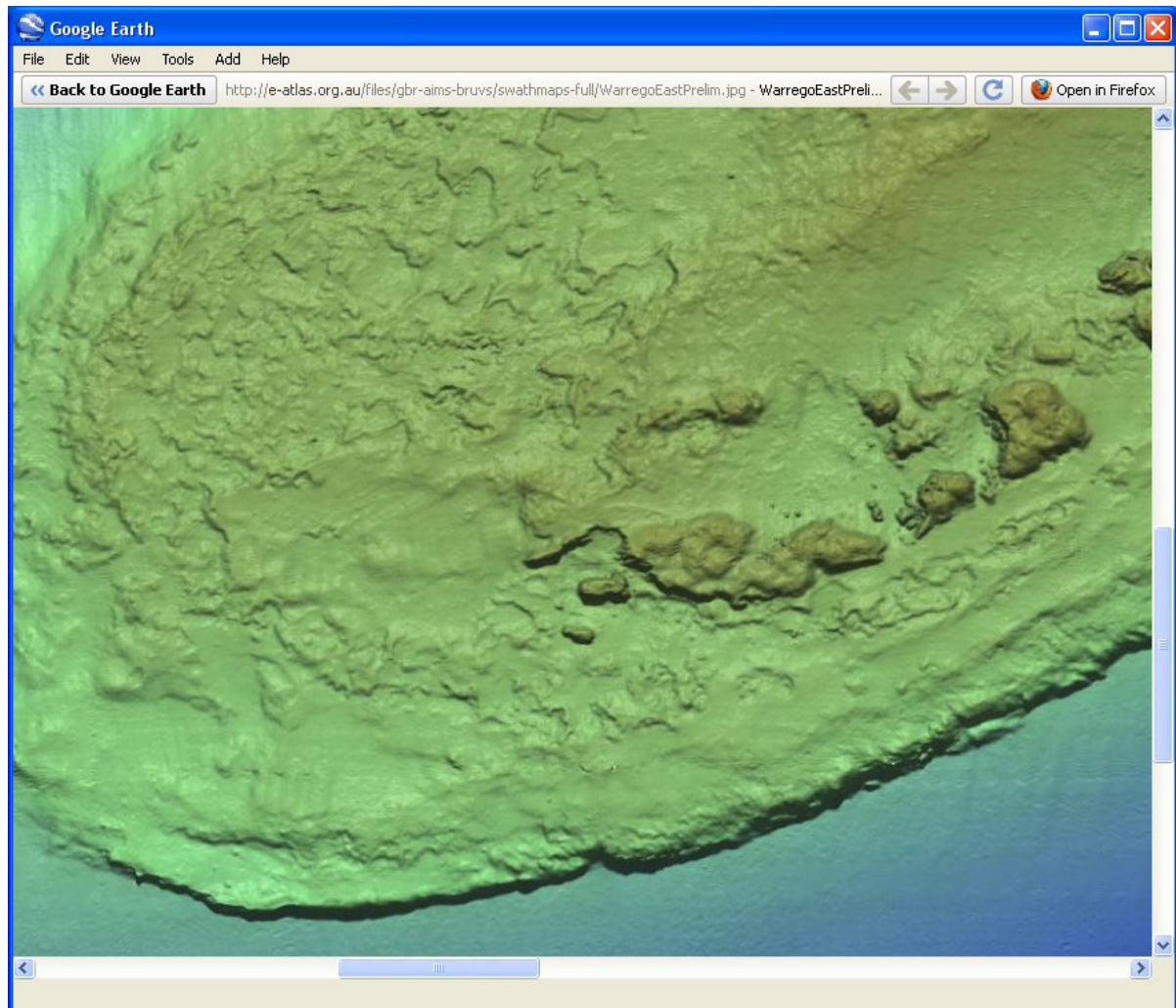


Figure 16: Screenshot of the view selected when clicking on the full version option under the 'Swathmap' tab for the East Warrego. This shows some of the topographic complexity on the shoal top. All multibeam swathe maps were constructed by Dr Thomas Steiglitz (James Cook University) in the early years of the project.

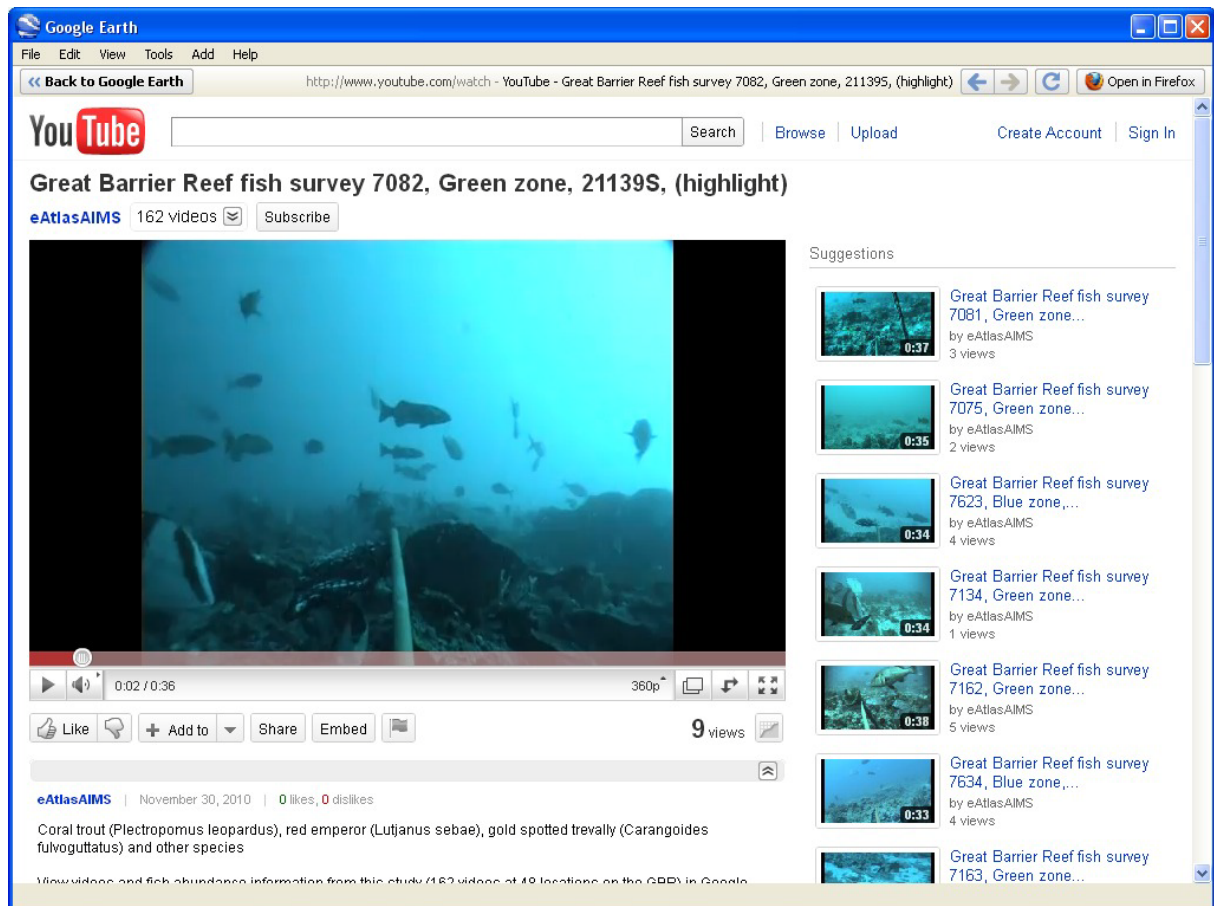


Figure 17: Screenshot of some of the 162 tagged videos uploaded to YouTube. YouTube uses Adobe Flash Video technology to display a wide variety of user-generated video content. Unregistered users may watch videos, and registered users may upload an unlimited number of videos. Each video is stored on YouTube, but also accessible using the KML on Google Earth. Therefore, unregistered users can access them without entering the e-Atlas website. A counter shows the number of visitors, and at least 100 were counted in February 2011 before the product had been completed.

Communication activities

Public Presentations

'One fish, two fish, green fish, blue fish: comparisons of deep shoal grounds open and closed to fishing using baited video'

- M. Cappel: Rockhampton LMAC Meeting, 2 November 2010
- M. Cappel: Gladstone LMAC Meeting, 3 November 2010
- M. Cappel: Cape York LMAC Meeting, 10 November 2010
- M. Cappel: Mackay LMAC Meeting, 15 November 2010
- M. Cappel: Townsville LMAC Meeting, 18 November 2010
- M. Cappel: Cairns 'Eye on the Reef' Workshop, 21 February 2011
- M. Cappel: Port Douglas 'Eye on the Reef' Workshop, 22 February 2011
- M. Cappel: Airlie Beach 'Eye on the Reef' Workshop, 24 February 2011
- M. Cappel: Whitsunday LMAC Meeting, 11 April 2011

Another presentation, outside the reporting period, will be made to the annual convention of the Queensland branch of the Australian National Sportfishing Association (ANSA) to be held in Yeppoon in August 2011.

Discussion

The development of a standard protocol for classifying epibenthos in the field of view of BRUVS has allowed us to revise our analyses in single models incorporating all regions, habitat types and zones, to provide an overview of the entire shoals study at a scale useful to managers. Our findings have refined and clarified the previous synthesis in Cappo *et al.* (2010), showing that the pooled target species were estimated to be 1.42 times as abundant on green shoals closed to fishing as they were on fished shoals after depths, substratum type and epibenthic cover were accounted for. The species richness, and abundance of other species groups based on their vulnerability to line-fishing, were either significantly higher in zones closed to fishing or were neutral (bycatch species).

There were some important influences of habitat type discovered in the new analyses by using ordination techniques to place BRUVS sites along easily interpretable gradients in seafloor characteristics. For example, numbers of prized target species were higher for BRUVS at the higher positions on a gradient in substrata from reef to rubble and lower at sites on the sandy ends of a reef to sand gradient. However, the effects of zoning detected in these models were almost identical to those estimated using simpler, qualitative classifications of the predominant habitat type in the field of view. Strong differences amongst regions and habitat types were detected, but they did not affect the primary estimates of the positive effects of zoning on attributes of the fish fauna.

Both UVC (shallow waters) and BRUVS (deep reef bases) have inherent sampling biases (see Cappo *et al.* 2003, Willis *et al.* 2000), so valid comparisons amongst the two techniques could be made only for reef-associated coral trout and red-throat emperor. The comparisons presented here showed no discernible consistency between the effects of zoning detected by each technique amongst 16 pairs of open/closed reefs in the Pompey (Mackay), Swain and Capricorn-Bunker reef groups.

Shallow-water coral trout sampled by UVC showed consistently higher abundance in green zones for three-quarters of the reef pairs, yet the only one quarter of the reef pairs recorded more coral trout on the BRUVS in the green zones. Coral cover was evenly matched in the UVC surveys, but the BRUVS sets almost always had more coral cover in the field of view when set in blue zones. Despite these differences, there was clear evidence of an interaction between effects of zoning and hard coral cover on coral trout numbers for both the UVC transects and the BRUVS sets in the three groups of reef bases. There were signs of a similar interaction for the red-throat emperor sighted on BRUVS.

In summary, there was little consistency between the 'signals' of the effect of fishing closures between the deep and shallow counts, apart from an interaction visible between the pair-wise differences in coral cover and the pair-wise differences in coral trout counts. The greater the difference in coral cover between closed and open reefs, the greater the difference in coral trout numbers for both UVC and BRUVS in the three groups of southern reefs.

Unfortunately, the interaction cannot be dissected further because of a lack of green reefs with significant coral cover in the existing dataset for BRUVS. The pairs of reefs surveyed by Russ *et al.* (2008) in the three regions were selected carefully to match the amount of coral cover, the reef sizes and shapes, and the position of transects on the shallow (~6-9 metres) reef corners and slopes. This selection was based on prior knowledge of coral cover measured by the Australian Institute of Marine Science (AIMS) Long-term Monitoring Program (LTMP). The sampling design accounted for habitat type (coral cover and location on a reef) and units (reefs) were considered to be independent because coral trout are known to be sedentary at the scale of single, isolated reefs (Mapstone *et al.* 2005). Whilst coral trout are known to move up and down reef slopes, and move to spawning aggregation

sites on particular reefs, they are not known to cross wide expanses of inter-reef sand amongst widely dispersed reefs (Maplestone *et al.* 2006).

In contrast, the BRUVS surveys carried out in the study's third year had no prior knowledge of topography or epibenthic cover around the deep bases ($\sim 34 \pm 2$ metres) of these reef pairs. Whilst the shallow margins of the emergent reef tops are visible and well known from satellite imagery, the margins of the deep reef bases are invisible to such remote sensing and are uncharted. The BRUVS sets in Year 3 were made more or less randomly by following the reef base using the ship's echosounder, and there was no control on the types or amount of epibenthic cover in the sampling design. We cannot invoke any explanation, other than chance, about the predominance of higher coral cover amongst the blue reefs open to fishing in the Swain and Capricorn-Bunker reef groups. The green reefs closed to fishing in the same pairs often had no hard coral in the field of view of BRUVS, yet coral trout and red-throat emperor were recorded on them, inhabiting rubble or rugose topography dominated by filter-feeding megabenthos or soft corals.

Previous analysis of the effects of zoning in the three reef groups concluded that there were more target species in coral-dominated habitats of green zones (Cappo *et al.* 2009). In this habitat type, 'target' species were about 1.5 times, and unfished species about 1.9 times, as abundant in the green zones as the same groups in the blue zones in the Pompey and Swain reef groups, but not the Capricorn-Bunker group. This consistent difference, coupled with the lower coral cover in the BRUVS footage from green zones, poses important questions regarding the alternative hypothesis that reef bases with less area of live coral had higher local densities of fish dwelling in the fewer stands of deeper coral, irrespective of fishing closures, in these three reef groups.

The existence of an interaction between hard coral cover and numbers of reef-associated species might, therefore, be expected to confound measurement of the effects of zoning. However, a test using the entire BRUVS dataset (all seven regions pooled) found the effect of zoning on hard coral cover was marginally non-significant. There was a significant interaction between region and zone because some reef pairs (especially in the Swain and Capricorn-Bunker groups) had much lower coral cover in the green zones. Other pairs, such as the shoal tops of the southern banks, were much better matched, so there was sufficient contrast amongst other pairs in the overall dataset to account for the effect of coral cover when estimating the effects of zoning.

There has been little evidence of citation or public use of the numerous reports published on-line during the shoals study, although some results (for the pair-wise comparisons of discrete southern banks) were included in a recent review by McCook *et al.* (2010) that sparked considerable on-line debate about the role of science in assessment of the 'effectiveness' of marine parks. Our development of the e-Atlas products to visualise the differences between the green and blue shoals is intended to encourage the public to view videos and summaries to 'make up their own minds' about their local area of interest. There were over 100 visits to the videos in the month of uploading to YouTube, although the e-Atlas site had not been released. As one recent user commented, "...being able to pick and choose and check out those underwater video clips across all those reefs is nothing short of amazing. I felt the addiction creeping in as I clicked on just one more reef..." (B. Ebner of Mareeba, pers. comm.)

The presentations to peak bodies and reef users supplied valuable information to us on fish spawning aggregations, and feedback on how best to design the e-Atlas KML. We hope that these and other groups will use the results of the shoals study to inform themselves about both the positive effects of the RAP 2004 zoning plan and the regional differences in the habitats they are fishing or diving in.

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Appendices

Appendix 1: Identity of 'all target species'. 'Prized target' species are highlighted in boldface type.

Family	Genus	Species
Labridae	<i>Bodianus</i>	<i>perditio</i>
	<i>Choerodon</i>	<i>cephalotes</i>
	<i>Choerodon</i>	<i>schoenleinii</i>
	<i>Choerodon</i>	<i>venustus</i>
Lethrinidae	<i>Lethrinus</i>	<i>laticaudis</i>
	<i>Lethrinus</i>	<i>miniatus</i>
	<i>Lethrinus</i>	<i>nebulosus</i>
Lutjanidae	<i>Aprion</i>	<i>virescens</i>
	<i>Lutjanus</i>	<i>erythropterus</i>
	<i>Lutjanus</i>	<i>malabaricus</i>
	<i>Lutjanus</i>	<i>sebae</i>
	<i>Pristipomoides</i>	<i>multidens</i>
Serranidae	<i>Epinephelus</i>	<i>coioides</i>
	<i>Epinephelus</i>	<i>undulatostratus</i>
	<i>Plectropomus</i>	<i>laevis</i>
	<i>Plectropomus</i>	<i>leopardus</i>
	<i>Plectropomus</i>	<i>maculatus</i>
	<i>Variola</i>	<i>albimarginata</i>
	<i>Variola</i>	<i>louti</i>
Sparidae	<i>Pagrus</i>	<i>auratus</i>

Appendix 2: Identity of major 'bycatch species'.

Family	Scientific Name
Carangidae	<i>Carangoides chrysophrys</i> <i>Carangoides fulvoguttatus</i> <i>Carangoides gymnostethus</i> <i>Caranx ignobilis</i> <i>Gnathanodon speciosus</i> <i>Pseudocaranx dentex</i>
Carcharhinidae	<i>Carcharhinus albimarginatus</i> <i>Carcharhinus amblyrhynchos</i> <i>Galeocerdo cuvier</i> <i>Triaenodon obesus</i>
Ginglymostomatidae	<i>Nebrius ferrugineus</i>
Hemiscylliidae	<i>Chiloscyllium punctatum</i>
Labridae	<i>Choerodon cyanodus</i> <i>Choerodon fasciatus</i>
Lethrinidae	<i>Gymnocranius audleyi</i> <i>Gymnocranius grandoculis</i> <i>Lethrinus genivittatus</i> <i>Lethrinus ravus</i> <i>Lethrinus rubrioperculatus</i> <i>Lethrinus semicinctus</i>
Lutjanidae	<i>Lutjanus adetii</i> <i>Lutjanus carponotatus</i> <i>Lutjanus vitta</i> <i>Symphorus nematophorus</i>
Rhynchobatidae	<i>Rhynchobatus djiddensis</i>
Scombridae	<i>Gymnosarda unicolor</i> <i>Scomberomorus commerson</i>
Serranidae	<i>Cephalopholis boenak</i> <i>Epinephelus fasciatus</i> <i>Epinephelus quoyanus</i>

Appendix 3: Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the model where species richness was the response. The standard errors and test statistics together provide information to determine whether an explanatory variable is statistically significant. This information is summarised by the corresponding p-values. An explanatory variable was deemed significant if it had a p-value less than 0.05.

Richness	Estimate	Standard Error	z.Value	Prob.>z
(Intercept) Townsville-sandy	2.37	0.04	58.64	<0.001
seagrass	-0.02	0.10	-0.22	0.829
macroalgae	0.12	0.06	2.24	0.025
Halimeda	0.92	0.34	2.68	0.007
rubble	0.46	0.04	11.96	<0.001
megabenthos	0.50	0.04	13.70	<0.001
coral	0.85	0.04	22.96	<0.001
Cardwell	-0.60	0.08	-7.35	<0.001
Cairns	-0.43	0.07	-6.41	<0.001
Swains	-0.21	0.05	-4.07	<0.001
Cap-Bunks	-0.07	0.06	-1.22	0.224
Pompeys	-0.22	0.05	-4.11	<0.001
Sthn Banks	-0.01	0.04	-0.17	0.864
zone.GREEN	0.08	0.02	3.26	0.001

Appendix 4: Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the model where the total abundance (pooled MaxN) of all species was the response. All conventions follow Appendix 3.

All fish	Estimate	Standard Error	z.Value	Prob.>z
(Intercept) Townsville-sandy	3.90	0.07	55.73	<0.001
seagrass	0.25	0.17	1.44	0.150
macroalgae	0.34	0.10	3.57	<0.001
Halimeda	0.92	0.70	1.30	0.192
rubble	0.38	0.07	5.60	<0.001
megabenthos	0.42	0.06	6.45	<0.001
coral	1.00	0.07	15.08	<0.001
Cardwell	-1.01	0.13	-7.65	<0.001
Cairns	-1.09	0.11	-9.60	<0.001
Swains	-0.38	0.09	-4.12	<0.001
Cap-Bunks	0.14	0.10	1.37	0.171
Pompeys	-0.45	0.09	-4.76	<0.001
Sthn Banks	-0.35	0.08	-4.46	<0.001
zone.GREEN	0.13	0.04	3.00	0.003

Appendix 5: Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the model where the total abundance (pooled MaxN) of 'prized target' species was the response. All conventions follow Appendix 3.

Prized	Estimate	Standard Error	z.Value	Prob.>z
(Intercept) Townsville-sandy	0.84	0.10	8.47	<0.001
seagrass	0.36	0.24	1.49	0.137
macroalgae	-0.25	0.14	-1.85	0.064
Halimeda	0.65	0.87	0.75	0.456
rubble	0.36	0.09	3.92	<0.001
megabenthos	0.46	0.09	5.25	<0.001
coral	0.59	0.09	6.46	<0.001
Cardwell	-0.62	0.20	-3.18	0.001
Cairns	-1.41	0.19	-7.25	<0.001
Swains	-	0.13	0.03	0.975
Cap-Bunks	-0.16	0.14	-1.15	0.251
Pompeys	0.19	0.13	1.51	0.131
Sthn Banks	0.32	0.11	2.89	0.004
zone.GREEN	0.39	0.06	6.74	<0.001

Appendix 6: Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the model where the total abundance (pooled MaxN) of 'all target' species was the response. All conventions follow Appendix 3.

All Targets	Estimate	Standard Error	z.Value	Prob.>z
(Intercept) Townsville-sandy	1.15	0.09	12.54	<0.001
seagrass	0.34	0.23	1.49	0.137
macroalgae	-0.22	0.13	-1.67	0.095
Halimeda	0.92	0.83	1.12	0.265
rubble	0.43	0.09	4.85	<0.001
megabenthos	0.54	0.08	6.52	<0.001
coral	0.62	0.09	7.09	<0.001
Cardwell	-0.33	0.17	-1.9	0.057
Cairns	-1.51	0.18	-8.41	<0.001
Swains	-0.28	0.12	-2.32	0.02
Cap-Bunks	-0.35	0.13	-2.62	0.009
Pompeys	-0.08	0.12	-0.64	0.526
Sthn Banks	0.12	0.1	1.14	0.256
zone.GREEN	0.37	0.06	6.71	<0.001

Appendix 7: Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the model where the total abundance (pooled MaxN) of 'bycatch' species was the response. All conventions follow Appendix 3.

Bycatch	Estimate	Standard Error	z.Value	Prob.>z
(Intercept) Townsville-sandy	3.05	0.08	39.37	<0.001
seagrass	-0.07	0.19	-0.35	0.728
macroalgae	-0.33	0.11	-2.99	0.003
Halimeda	1.58	0.76	2.08	0.037
rubble	0.13	0.08	1.69	0.091
megabenthos	0.23	0.07	3.15	0.002
coral	0.4	0.08	5.34	<0.001
Cardwell	-1.63	0.16	-10.43	<0.001
Cairns	-1.29	0.13	-9.97	<0.001
Swains	-0.84	0.10	-8.14	<0.001
Cap-Bunks	-0.56	0.11	-4.96	<0.001
Pompeys	-0.59	0.10	-5.63	<0.001
Sthn Banks	-0.43	0.09	-4.86	<0.001
zone.GREEN	0.05	0.05	1.05	0.295

Appendix 8: Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the model where the total abundance (pooled MaxN) of 'unfished' species was the response. All conventions follow Appendix 3.

Unfished	Estimate	Standard Error	z.Value	Prob.>z
(Intercept) Townsville-sandy	3.26	0.10	32.8	-
seagrass	0.41	0.24	1.68	0.093
macroalgae	0.57	0.14	4.20	<0.001
Halimeda	-0.32	1.02	-0.31	0.754
rubble	0.49	0.10	5.04	<0.001
megabenthos	0.49	0.09	5.37	<0.001
coral	1.30	0.09	13.85	<0.001
Cardwell	-0.85	0.19	-4.56	<0.001
Cairns	-0.99	0.16	-6.15	<0.001
Swains	-0.18	0.13	-1.39	0.165
Cap-Bunks	0.43	0.14	3.02	0.002
Pompeys	-0.42	0.13	-3.16	0.002
Sthn Banks	-0.37	0.11	-3.27	0.001
zone.GREEN	0.13	0.06	2.16	0.031

Appendix 9: Tabulations of standard errors, test statistics and p-values for each of the original coefficient estimates (log link) in the most parsimonious models where the richness and total abundance (pooled MaxN) of attributes of the fish species assemblage were response variables. All conventions follow Appendix 3 and Table 4.

richness	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	2.666	0.018	150.083	<0.0001
PC1.snd2structr	0.071	0.020	3.498	<0.0001
PC2.enc2crl	-0.071	0.012	-5.960	<0.0001
PC1.reef2snd	-0.160	0.019	-8.481	<0.0001
PC2.reef2rbbl	0.050	0.010	4.734	<0.0001
zoneGREEN	0.075	0.025	3.050	0.002

All fish	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	4.008	0.032	124.106	<0.0001
PC1.snd2structr	0.219	0.018	12.144	<0.0001
PC2.enc2crl	-0.067	0.018	-3.721	<0.0001
zoneGREEN	0.122	0.045	2.703	0.007

Prized target species	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	0.399	0.128	3.125	0.002
depth	0.026	0.004	7.076	<0.0001
PC2.enc2crl	-0.151	0.029	-5.168	<0.0001
PC1.reef2snd	-0.220	0.023	-9.730	<0.0001
PC2.reef2rbbl	0.095	0.025	3.738	<0.0001
zoneGREEN	0.354	0.059	5.961	<0.0001

All target species	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	0.863	0.122	7.068	<0.0001
depth	0.018	0.004	4.948	<0.0001
PC2.enc2crl	-0.120	0.028	-4.252	<0.0001
PC1.reef2snd	-0.184	0.022	-8.431	<0.0001
PC2.reef2rbbl	0.089	0.025	3.622	<0.0001
zoneGREEN	0.348	0.057	6.061	<0.0001

Bycatch species	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	2.732	0.026	106.630	<0.0001
PC1.reef2snd	-0.093	0.019	-4.989	<0.0001
PC2.reef2rbbl	0.034	0.019	1.810	0.07

Unfished species	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	4.327	0.125	34.522	<0.0001
depth	-0.025	0.004	-6.808	<0.0001
PC1.snd2structr	0.263	0.025	10.426	<0.0001
zoneGREEN	0.172	0.062	2.772	0.006