Influence of zoning on midshelf shoals of the southern Great Barrier Reef

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Acronyms Used In This Report

AIMS .... Australian Institute of Marine Science
BRUVS .... Baited Remote Underwater Video Station
CERF................. Commonwealth Environment Research Facilities
DEH................... Commonwealth Department of the Environment and Heritage
DTM................... Digital Terrain Model
GBRMP............. Great Barrier Reef Marine Park
GBRWHA.......... Great Barrier Reef World Heritage Area
GPS................... Global Positioning System
MPA .... Marine Protected Area
MTSRF.............. Marine and Tropical Sciences Research Facility
NTMRs.............. No-take Marine Reserves
RAP................... Representative Area Program
RRRC................ Reef and Rainforest Research Centre Limited
SBRUVS .... Stereo Baited Remote Underwater Video Station
SCUBA.............. Self-Contained Underwater Breathing Apparatus
UVC................... Underwater visual census

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Executive Summary

This report presents the results of seasonal surveys (Autumn/Spring 2007) on two pairs of discrete deepwater shoals in the southern Great Barrier Reef. Within each pair, one shoal was re-zoned 'Green' (closed to all fishing) in 2004 while the other 'Blue' (open to fishing) remained open to fishing. One pair (Barcoo / Karamea Banks) is north of Rockhampton, while the second pair (East / West Warregoes) is south of Gladstone. Each shoal or bank is a large submerged structure of several square kilometres rising from about 50 m depth to within 20-30 m of the surface. The demersal vertebrate communities were sampled using non-extractive Baited Remote Underwater Video Stations (BRUVS), which revealed a diverse (~250 species) and abundant fauna of fish, sharks, rays and seasnakes including those targeted and not targeted by recreational and commercial line fishers.

Univariate and multivariate statistical techniques were used to analyse the influence of zoning on the fish community. Negative binomial generalized linear model (GLM) analyses showed that there was a clear effect of zoning, where the mean abundance index of species primarily targeted by fishing in the blue zone were half those of the same species in green zones that were closed to fishing in 2004. This result was supported by multivariate analyses showing that all the most targeted species preferentially targeted by fishing had higher abundances in green zones than blue zones. Abundance ratios of these species in green and blue zones varied from 1.1 to 11.9 (geometric mean = 2.8) and ratios of 5 of the most targeted species were significantly greater in green than blue zones ($P<0.05$). These were the red emperor (*Lutjanus sebae*), red throat emperor (*Lethrinus miniatus*), venus tuskfish (*Choerodon venustus*), spangled emperor (*Lethrinus nebulosus*) and golden spot hogfish (*Bodianus perditio*).

The abundance of non-targeted species varied greatly between green and blue zones but overall showed little evidence of an effect of zoning. Though clear effects of zoning were shown for fished species, our results must be treated with caution, given that we had low sample size (only 4 shoals) and we did not attempt to examine the effect of habitat variation within shoals. Additionally, we lacked any data on spatial and temporal variation in fishing effort and for this reason our results should not be extrapolated regionally or throughout the Great Barrier Reef Marine Park (GBRMP).

Introduction

The Great Barrier Reef Marine Park (GBRMP) covers an area of over 345,000 km^2 (Day *et al.* 2003) extending along the continental shelf region of north-eastern Australia from latitude 10° 40'S to 24° 30'S. It contains a diversity of marine habitats and is a multi-use marine park where human activities are regulated by a zoning plan that prohibits extractive uses in certain areas. The zoning plan is aimed at achieving both conservation and human use management objectives for the Great Barrier Reef World Heritage Area (GBRWHA). A major revision of the GBRMP zoning plan implemented in 2004 greatly increased the proportion of no-take 'green' zones (where extractive activities such as fishing are completely prohibited) to over thirty percent of the total area of the marine park (GBRMPA 2008). The increase in green zones in the 2004 rezoning is anticipated to have measurable benefits to conservation and fisheries sustainability in the GBRWHA.

Closing such a large area to all forms of fishing has been politically and socially controversial, making it imperative that the effectiveness of this new network of no-take marine reserves (NTMRs) be assessed and monitored across the range of habitats encompassed by the Marine Park. This demands tangible, cost effective and reliable indicators that are closely tied to management objectives (Day *et al.* 2003). The survey of fauna and flora inhabiting shallow, emergent reefs is well established through the use of SCUBA (Russ *et al.* 2008). In the deeper, inter-reef areas inaccessible to SCUBA, the development of indicators initially requires investigation of the nature of the biotic communities occupying these habitats and establishment of sampling techniques and designs appropriate to those habitats. The broad aim of this study is to establish suitable indicators and sampling designs to monitor the effects of the zoning plan; in particular to monitor the effects on the fish communities of deep shoal habitats in response to closure to all forms of fishing.

Deep shoal habitats

The 'deep shoal' habitats of the GBRMP are those areas where hard substrata outcrop from the seabed in deeper (generally >20m) water. In contrast to emergent coral reefs, they do not form conspicuous structures, but rather may be either discrete or diffuse patches of hard substrata of varying relief above the surrounding sea floor. Shoal habitats are relatively unstudied but are known to support rich and diverse fish and benthic invertebrate communities (e.g. Cappo *et al.* 2007, Pitcher *et al.* 2007). Deep shoals are also prime areas for both recreational and commercial line fishing as they are the habitat of many of the larger and sought after table fishes such as snappers (Lutjanidae), cods and groupers (Serranidae) and emperors (Lethrinidae). 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.

Community consultation preceding the rezoning of the GBRMP indicated increasing effort in commercial and recreational fishing on deep shoals. There was evidence that the commercial fishery for live coral trout was increasingly shifting effort from shallow reef flanks to deeper inter-reefal shoals because of the more valuable red colour of coral trout living at depth. There was also anecdotal evidence in the recreational fishery of effort shift from shallow reefs to deeper waters away from the immediate vicinity of emergent and island fringing reefs. This shift in recreational effort may be in response to the high fishing pressure placed upon accessible and popular reefs, and advances in technology (e.g. faster boats with greater range; affordable and increasingly sophisticated echo sounders and GPS units etc.) that allow recreational fishers to find and reliably relocate small habitat features in deep water with ease (Mapleston *et al.* 2006).

The increasing attention on deep shoal habitats by users of the GBRMP places an increasing obligation on marine park and fisheries managers to include these habitats in a holistic programme of monitoring of the effectiveness of the multi-use zone plan. For this, effective techniques and sampling designs must be employed for the survey of fish community composition, abundance and biomass that may form the basis of metrics used as indicators of the performance of the zoning plan.

Using video techniques to sample deepwater fishes

Deep shoal habitats extend well beyond the workable depths for SCUBA diving. This precludes the use of the most commonly employed techniques for non-extractive surveys of fish community composition and abundance in shallow water habitats such as underwater visual census (UVC) (e.g. Samoilys and Carlos 2000). Instead, sampling must rely on remote techniques. Traditional remote techniques for survey of fish communities such as traps, trawls, nets etc. are generally extractive and often result in the mortality of the captured individuals, particularly in deeper water (see Cappo and Brown 1996 for review). This makes them undesirable for broad scale use where MPAs have been declared, given that the survey techniques may have the potential to impact upon the communities they seek to sample. They are also contrary to the conservation and management principles of no-take marine reserves NTMRs.

Non-extractive techniques for sampling deepwater habitats have become possible in recent years through the use of video technology. One such technique – Baited Remote Underwater Video Stations (BRUVS, or sometimes called BUVS) – enables reliable and replicated sampling of fish community composition and abundance in deepwater habitats.

BRUVS are simple assemblies based on compact consumer-grade video cameras in underwater housings, used to film fish visitation to a bait station. Being relatively inexpensive and easy to construct lends them to deployment in fleets thus attaining the necessary replication for a robust sampling programme. Because they are deployed and retrieved entirely from the surface, BRUVS are ideal for sampling habitats lying beyond diveable depths, such as deep water shoals. Being robust and stationary, they are well suited to deployment over rugose habitats. The technique is non-extractive and has the only pre-requisite of relatively clear water and adequate illumination – readily provided by natural daylight in depths of less than 100 m (see review by Cappo *et al.* 2003).

Using BRUVS, the community composition and relative abundance of fishes is quantified by recording the species observed within the field of view over a defined sampling period (see Cappo *et al.* 2004, 2007). Standard definition digital video enables most fishes that pass through the field of view to be readily identified to species level by colour pattern and shape by a trained observer. The swimming style, behaviour and mannerisms of fishes captured on video also assist in their identification. The process of identification by visual recognition is aided by the ability to capture still images from video for quality assurance and as specimens for future reference.

The utility of BRUVS as an approach to sampling fish communities is evident from the extraordinary diversity of fishes observed using this technique in a range of different habitats, e.g. 228 species in surveys of Scott Reef lagoon in NW Australia; ~250 species on deep shoals of the southern GBRMP (reported herein), 98 species in a range of temperate habitats of the Recherché Archipelago of southwestern Australia. The taxa commonly recorded include, not only the carnivorous species that might be expected by the presence of bait, but also herbivores, corallivores and planktivorous species (Harvey *et al.* 2007).

Surveys using BRUVS provide a conservative measure of *relative* abundance of fishes as there is no way to distinguish between individuals that repeatedly visit and new arrivals – something that would be required to determine absolute abundance (Cappo *et al.* 2003). Various metrics have been used for estimation of relative abundance of fishes from baited video observations. These metrics are based on the maximum number of individuals observed at any one moment in time during the observation period (e.g. *MaxN* – Cappo *et al.* 2003; *MAX* – Willis and Babcock 2000; n_{peak} – Priede *et al.* 1994); numbers observed at regular intervals throughout the footage (e.g. Priede *et al.* 1990); or a combination of arrival time and maximum number observed (e.g. Sainte-Marie and Hardgrave 1987). The Australian Institute of Marine Science (AIMS) routinely uses the simple metric of *MaxN* as an estimate of relative abundance in baited video studies as it is simple to quantify, proven to be a robust measure of relative abundance when compared directly to other techniques (e.g. UVC and angling – Willis and Babcock 2000), and has demonstrated ability to discriminate among sampled units in community level analyses (e.g. Cappo *et al.* 2007).

The capabilities of BRUVS can be extended beyond fish community composition and abundance to include measurement of fish size when a stereo pair of cameras is used (see Johansson *et al.* 2008). This approach uses the synchronised imagery from the pair of cameras in conjunction with specialised measurement software to mathematically calculate the actual size of fishes from on-screen measurements (SeaGis 2008). Comparative studies have indicated stereo measurements to be more accurate than diver estimations of length (Harvey *et al.* 2001) and the accuracy attained rivals that of length measurements attainable with the fish in hand (Harvey *et al.* 2003). The measurement capabilities of stereo BRUVS offer exciting possibilities for surveys with fisheries management objectives, with the measurements gained able to be used for estimation of length-frequency distribution, biomass and fecundity of fish populations. Russ (1991) highlights these as some of the parameters that are vital to measure as we move toward broader, ecosystem-level experiments to quantify the effects of NTMRs.

Bias is inherent in all techniques used for the survey of fish communities, and BRUVS are no exception. For example in concurrent sampling of sites using both BRUVS and otter trawls, Cappo *et al.* (2004) reported that BRUVS recorded a markedly different suite of species to the trawls. The BRUVS tended to sample larger, conspicuous, mobile, bait-attracted species while trawl catches were dominated by the less mobile, more cryptic species. The suite of species commonly sampled by BRUVS (i.e. larger, bait-attracted carnivorous species) lends them favourably to surveying fishes and fish communities targeted by line fishers. Thus BRUVS arguably offer the best sampling technique for the ongoing monitoring of line-fished species in the deeper shoal areas of ‘no-take’ marine protected areas. Indeed, Watson *et al.* (2007) used BRUVS to show that highly sought-after *Plectropomus leopardus, Lethrinus miniatus, Lethrinus nebulosus, Pagrus auratus* and *Glaucosoma hebraicum* were more abundant inside MPAs than in areas open to fishing in the Abrolhos reef habitats. Many non-targeted fish species were more abundant in areas open to fishing, but others were conversely more abundant inside MPAs.

Monitoring the effectiveness of Marine Protected Areas

Conceptually, the benefits of no-take Marine Protected Areas (MPAs) to both conservation and fisheries are many and there is an increasing body of evidence in the scientific literature describing measurable effects on marine communities that have been attributed to the creation of ‘no-take’ marine reserves (e.g. reviews by Babcock 2003, Gell and Roberts 2002, Halpern and Warner 2002, Roberts *et al.* 2001, Russ 1991).

It is predicted that no-take MPAs will result in increases in density and/or size and/or biomass of target species inside the MPA as a result of closure to fishing. This is a somewhat intuitive extension of the premise that total mortality of targeted species is significantly reduced in MPAs due to the absence of fishing. A number of studies published in the scientific literature have demonstrated increases in the abundance of target species, for example Russ *et al.* (2008) and Williamson *et al.* (2004) reported increases the abundance and size of coral trout (a species highly sought after by line fishers) following closure to fishing in the GBRMP. On coral reefs elsewhere in the world, similar trends have been documented. Westera *et al.* (2003) reported increases in targeted fish species such as lethrinids at Ningaloo Reef in Western Australia and Watson *et al.* (2007) found that the removal of abundant targeted species from an Abrolhos Islands ecosystem by fishing can indirectly impact non-fished species and alter the trophic structure of fish assemblages. In a New Caledonian study Wantiez *et al.* (1997) reported increases in the richness, density and biomass of the major exploited fish families. In a Carribean study, Roberts (1995) reported biomass and size of exploited species were generally greater in areas protected from fishing. Similar increases in abundance of target species following closure to fishing have been reported in temperate habitats, for example increases in snapper (*Pagrus auratus*) abundance have been reported in no-take marine reserves in New Zealand (Denny *et al.* 2004) and trumpeter (*Latridopsis forsteri*) in MPAs in Tasmania, Australia (Edgar and Barrett 1999).

Closure to fishing also has potential effects on non-target species within the MPA through trophic flow-on effects. These effects are likely to vary among species, i.e. abundance, size and biomass of different species may increase or decrease depending on complex species inter-relationships within the community. For example Graham *et al.* (2003) in a study on the Great Barrier Reef, found the abundance of some prey species to be higher outside of areas protected from fishing. In another study, Watson *et al.* (2007) report differences in the composition and abundance of both target and non- target species of fishes in areas open and closed to fishing in the Houtmans Abrolhos Islands of Western Australia. When the effects on non-target species are substantial and affect major functional components the community, changes in entire habitats can result. Changes in entire habitats have been well documented in relation trawl fishing (e.g. Sainsbury *et al.* 1997), however in these studies it is impossible to separate the direct effects the gear on habitat from the indirect ‘flow on’ effects caused by species removal. Studies based on reefal environments that cannot be trawled provide better evidence of the potential for creation of MPAs to affect habitat. In a study of fishing closure on temperate reef habitats in New Zealand, the percentage cover of macroalgae was found to increase substantially (Shears and Babcock 2003, Babcock *et al.* 1999). In that study it was proposed that prior to closure to fishing, the population of sea urchins had increased in the absence of predation, resulting in increased grazing on macroalgae. A review by Pinnegar *et al.* (2000) that documented numerous cases of trophic flow-on effects demonstrates the high likelihood that these effects might be expected from selective removal of species targeted by fishing.

The broader ecosystem level benefits of no-take MPAs beyond their boundaries, such as the so called ‘spill over’ effect – of adults or larvae moving into adjacent areas potentially offer the greatest benefits of no-take MPAs to fisheries and conservation. In one of the few studies that quantitatively demonstrates a regional effect of MPAs on overall fisheries yield, Roberts *et al.* (2001) demonstrated that creation of NTMRs in Florida and St Lucia significantly increased fishers’ catches in adjacent areas.

Despite the forementioned examples of demonstrated effects of no-take MPAs on fish and habitat, numerous studies have been published that failed to detect consistent and unequivocal (or in some cases any) evidence of the effects of no-take MPAs on fish diversity and abundance. Such failures are increasingly common as the scope of studies broaden from the direct effects on target species to flow on effects on other fish and invertebrate species, effects on habitat and effects on fisheries productivity beyond reserve boundaries. Demonstrations of ‘spill over‘ effects from MPAs are notoriously difficult to accomplish through direct surveys of adult fishes, and are best approached through the use of tagging or chemical mark-recapture studies of juveniles.

Russ (1991) proposes that such failures might be attributed to inadequacies of experimental design; as well as drawing inference without knowledge of key processes both ecological (e.g. movement dynamics, recruitment and dispersal) and social (e.g. fishing effort – both legal and illegal). Statistically robust designs are needed to definitively measure regional scale effects of marine reserves as well as spill-over effects. While accomplishing an experiment along these lines would be the ultimate approach to monitoring the performance of marine protected areas, achieving such rigour is beyond the resources and scope of most studies.

Where compromises must necessarily be made there is significant value in developing simple but reliable indicators based on community composition, abundance and biomass or size with statistically robust designs and good sampling techniques. However, it would be presumptive and naïve to focus solely on target species, because the major effects of closure to fishing such species may manifest most at other levels in the ecosystem, such as epibenthos and prey species (see Jones *et al.* 1993 for review).

Reliable and cost-effective indicators for assessing the usefulness of MPAs in the broader context of the goals of biodiversity conservation and fisheries sustainability are urgently needed for deeper, inter-reefal waters, because the recent closure of such vast areas of the GBRMP has been socially and politically controversial.

Objectives of the present study

The present study aims to develop the existing knowledge of deep shoal habitats of the southern GBRMP region, with a view to developing protocols for sampling and assessing the effects of zoning on the vertebrate communities of these habitats. These vertebrates (hereafter termed "fish") comprise fish, shark, ray and seasnake species that dwell on or near the seafloor.

The specific objectives of this study are:

- To describe the fish fauna in relation to habitat and spatial and temporal variables on selected deep shoals of the southern GBRMP.
- To demonstrate the capabilities of BRUVS in surveying fish communities of deep shoal habitats.
- To present baseline fish community data from BRUVS surveys of two pairs of 'blue' (open to fishing) and 'green' (closed to fishing) zoned shoals in the southern region of the GBRMP.
- To evaluate the baseline data collected to date for possible effects of zoning since the Representative Areas Programme rezoning in 2004.
- To assess the suitability of these shoals as representative sites for the ongoing monitoring of fish community diversity and abundance on deepwater shoals within the southern GBRMP.
- To recommend statistically robust sampling designs using BRUVS that might reliably measure the performance of the GBRMP zoning plan on deep shoals of the southern GBRMP into the future.

Materials and Methods

Study area

Initially, charts and zoning maps were examined to identify pairs of 'blue' (open to fishing) and 'green' (closed to fishing since the 2004 RAP rezoning) zoned deep water shoals in the southern region of the GBRMP. The objective was to find pairs of shoals, with one open and one closed to fishing, that were matched in terms of depth, habitat, areal extent, cross shelf position, latitude etc. Two pairs of suitable shoals were identified – Karamea (blue) and Barcoo (green) Banks offshore of Port Clinton and further south, the East Warregoes (green) and West Warregoes (blue) offshore of The Town of 1770 (Figure 1).

The areal extent, depth range and latitudinal position of the two pairs of sites selected are similar (Table 1). The East and West Warregoes are approximately 7nm apart in a cross-shelf direction. Karamea and Barcoo banks are approximately 12 nm distant from one another, their separation is alongshore. The two pairs of sites differ markedly in their distance from the zoning boundaries, a factor difficult to control in selecting paired sites because of the complex zoning boundaries. However, the shoals selected lay wholly within their designated zone.

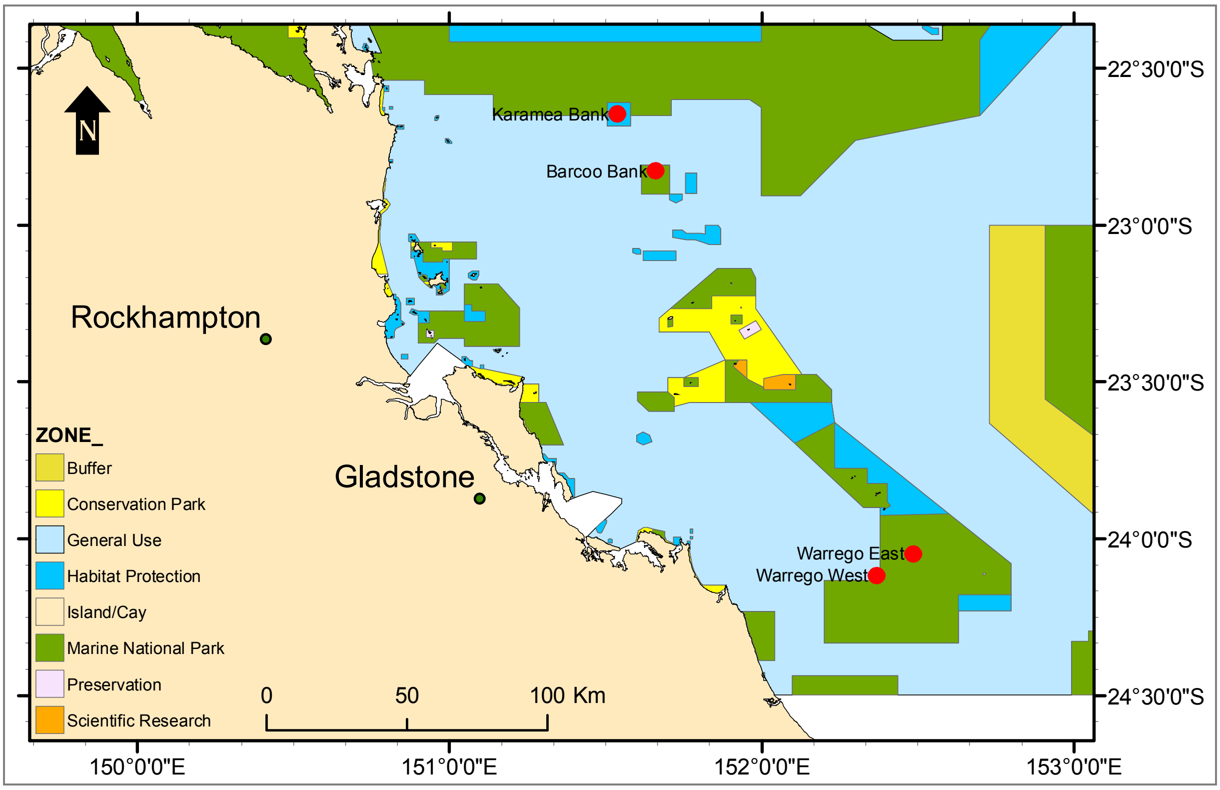


Figure 1. Map indicating the approximate locations of the study sites in relation to the Zoning Plan.

Table 1. Comparison of geographical characteristics of the study sites.

Shoal	Position	Depth range	Areal extent	Approximate position
Karamea Bank ('blue' zone)	22° 38.6 S 151° 32.4 E	22-57 m	5.4 km^2	72 km offshore of Port Clinton
Barcoo Bank ('green' zone)	22° 49.6 S 151° 39.9 E	20-52 m	7.6 km^2	82 km offshore of Port Clinton
West Warregoes ('blue' zone)	24° 07.0 S 152°22.1 E	16-37 m	1.9 km^2	45 km offshore of The Town of 1770
East Warregoes ('green' zone)	24° 02.9 S 152°29.2 E	21-45 m	2.0 km^2	58 km offshore of The Town of 1770

Multibeam acoustic mapping

The bathymetry of each shoal was surveyed in detail by multibeam acoustic swathe mapping prior to sampling of fish and benthic habitat. This work was conducted under contract by Dr Thomas Steiglitz (James Cook University, Physics Department) using a Reson Seabat 8101 hull mounted multibeam echo sounder. At each site the survey was conducted along grid of parallel survey tracks spaced to provide one hundred percent swathe overlap, with the exception of Barcoo Bank where deteriorating weather necessitated increasing the survey track spacing. The GPS, gyrocompass and ships motion were logged from onboard instruments alongside echo sounder data during the survey. The data was processed onboard to produce Digital Terrain Models (DTMs) of each shoal at 0.5m spatial resolution. Georeferenced images of seabed topography were produced from the data and used in conjunction with the navigation program Oziexplorer ™ to enable real time navigation over the digital terrain model (Figure 2).

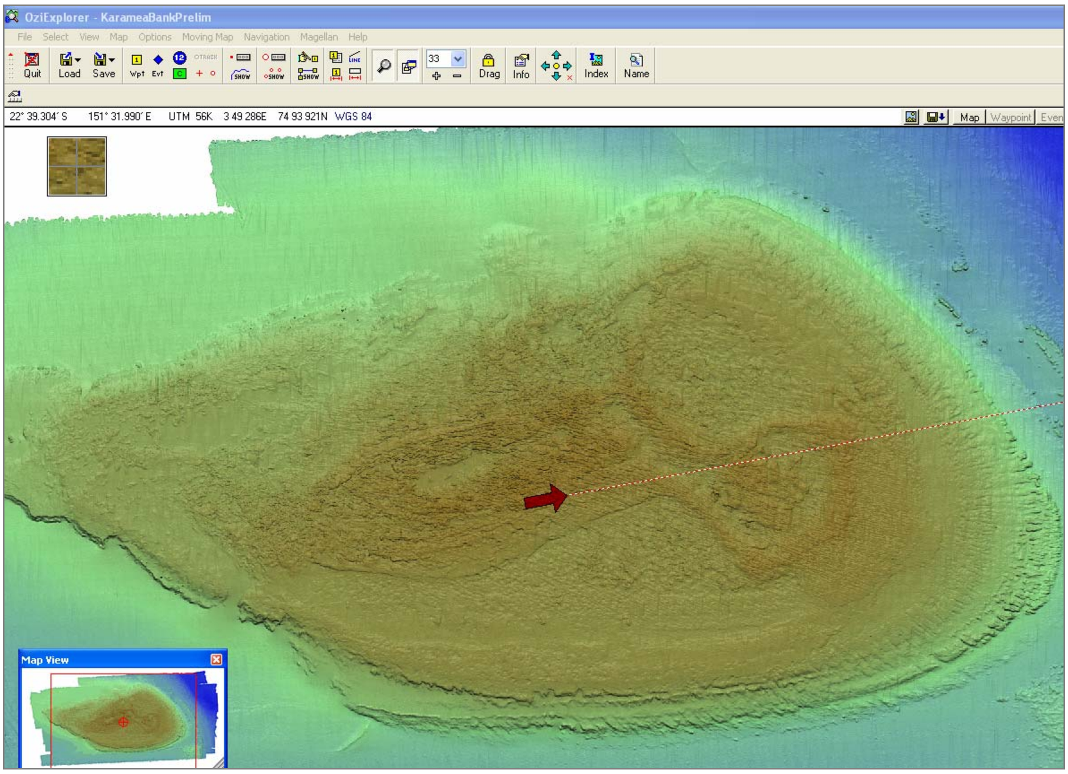


Figure 2. Screen grab from Oziexplorer™ showing real time navigation over the digital terrain model of Karamea Bank.

Towed video surveys

A lightweight towed video system developed by AIMS was used to survey seabed habitats on and around the four shoal sites. The camera was deployed and towed from the stern of *RV Cape Ferguson* while maintaining a speed of approximately two to three knots. During camera deployment an observer used custom software developed for use with the towed video system to conduct a real-time seabed classification based on biotic and abiotic habitat components. The classification data was logged simultaneously with GPS position, depth sounder data and time. The resultant habitat observations were thus geo-referenced for later spatial analysis.

Because of the spatial extent of the shoals, systematic survey of the entire shoals was not possible. Instead, video tows were focused on habitat features identified as likely productive fish habitats (e.g. rugged seabed topography) on the digital terrain models.

Figure 3. The AIMS towed video camera being retrieved from the water on the aft deck of the *RV Cape Ferguson*.

Fish community surveys using BRUVS

Sampling design

Sampling of the fish community on each shoal was undertaken on two separate cruises aboard the AIMS research vessels *RV Cape Ferguson* and *RV Lady Basten* in February 2007 and August 2007 respectively.

On the first cruise, a fleet of eight BRUVS (including two stereo BRUVS) was used to survey fish communities on the shoals. The deployments on each shoal were targeted at habitat features identified by the multibeam acoustic mapping and towed video surveys. The targeted features were mainly deep water structures at the base of the shoal with only a few sets targeted at open habitat adjacent to the shoal and the shoal plateau. Emphasis was placed in the sampling effort on deeper water outcrops and structures. The fleet of BRUVS was deployed twice on each shoal, giving a total of sixteen replicate samples from each shoal on the first cruise. The positions for each BRUVS deployment on trip 1 are shown in Figures 4-7.

A more structured sampling approach was adopted on the second sampling cruise in August 2007, specifically to investigate fish community differences between the shallower and deeper habitats of the shoals and for assessment of short term temporal variability in BRUVS sampling. For this, the sampling effort on each shoal was stratified by deploying four of the BRUVS fleet on “shallow” features on the shoal top and the remaining four on “deep” features at the base. The BRUVS fleet was deployed twice on different waypoints (a total of 8 deep and 8 shallow deployments) and then the sampling was then repeated on precisely the same waypoints typically on the same or next day. This resulted in sixteen BRUVS, repeated twice with a short (but variable) interval between, for each shoal (a total of 32 samples for each shoal). The temporal repeats enabled investigation of short term variability in fish assemblage composition and abundance on these shoals. The positions for each BRUVS deployment on trip 2 are shown in Figures 4-7.

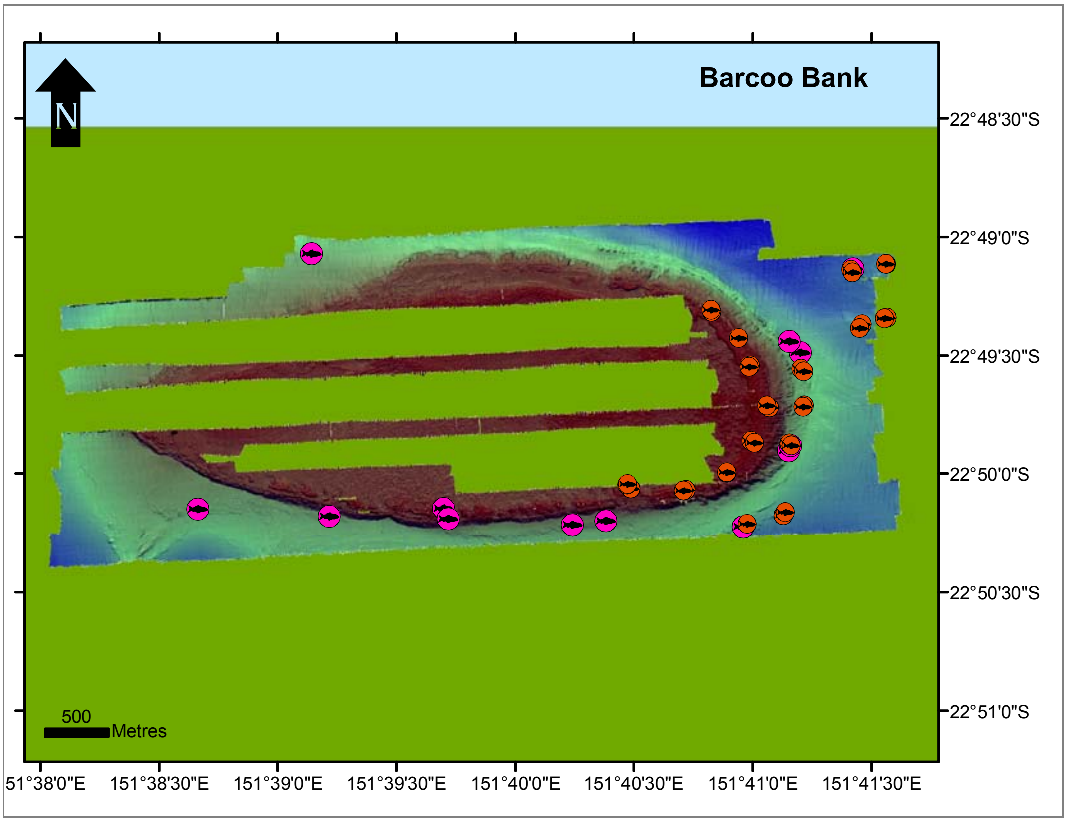


Figure 4. BRUVS sample positions on Barcoo Bank during cruise 1 (pink symbols) and cruise 2 (orange symbols).

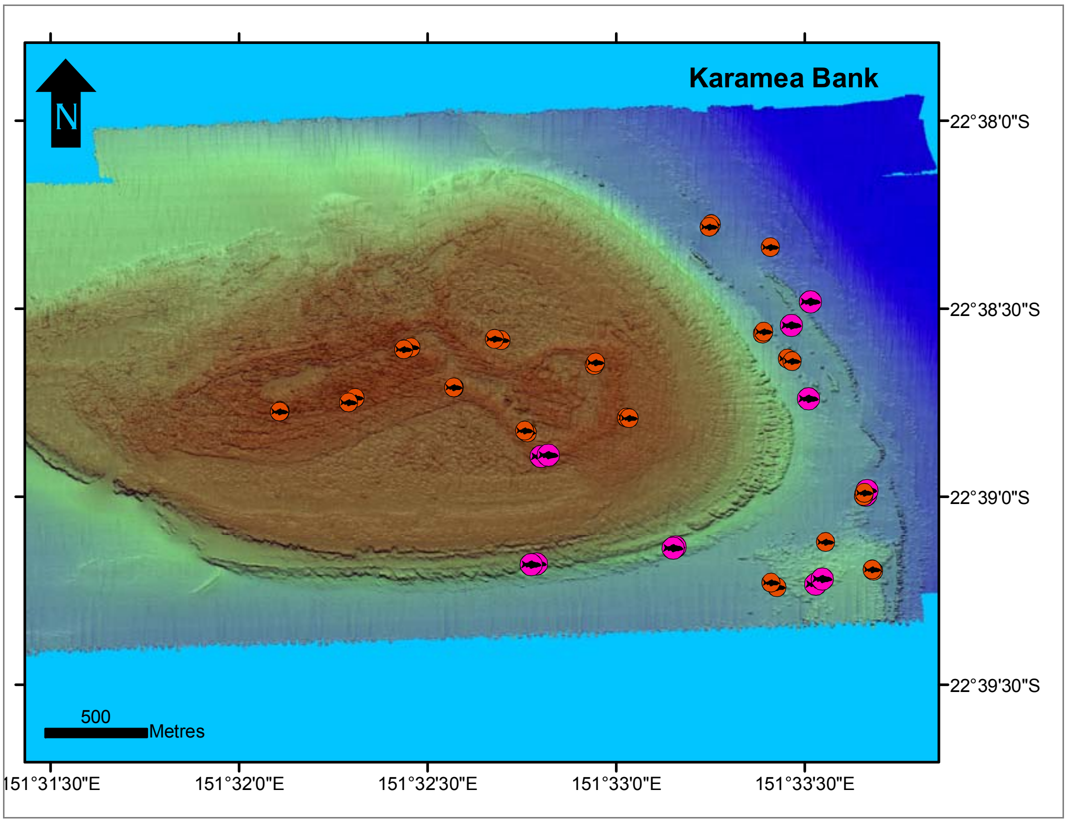


Figure 5. BRUVS sample positions on Karamea Bank during cruise 1 (pink symbols) and cruise 2 (orange symbols).

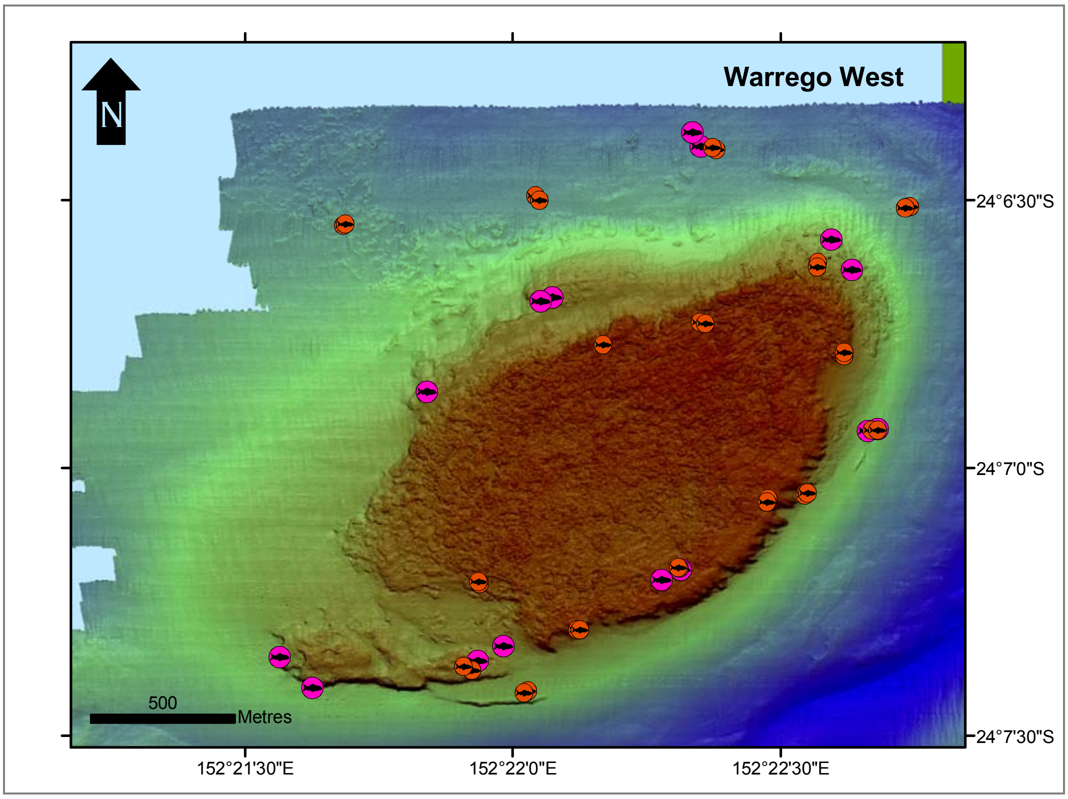


Figure 6. BRUVS sample positions on the West Warregoes during cruise 1 (pink symbols) and cruise 2 (orange symbols).

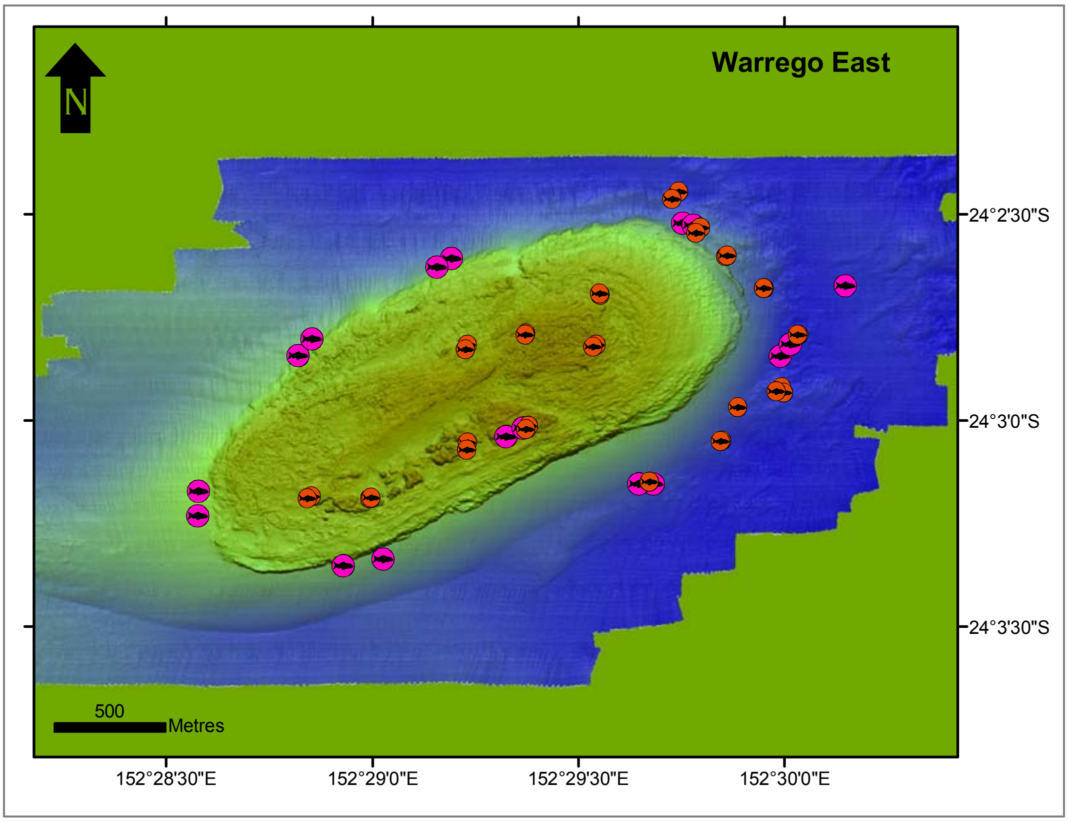


Figure 7. BRUVS sample positions on the East Warregoes during cruise 1 (pink symbols) and cruise 2 (orange symbols).

Sampling gear

The BRUVS used to sample the fish community consisted of a Sony Mini-DV handycam inside a simple underwater housing custom made from PVC sewer pipe and pressure rated to over 100 m. The housed camera was mounted inside a pyramid-shaped galvanised steel frame that protected the camera, maintained its orientation (tilted 10 degrees below horizontal and held approximately 400 mm above the seafloor) and facilitated attachment of a bait arm, ballast weights and rope to the surface. The flexible bait arm made of rigid PVC conduit held a plastic mesh bait bag containing 1 kg of minced pilchards (*Sardinops* or *Sardinella* spp.) at a distance of approximately 1m in front of the camera. BRUVS frames were ballasted with steel bars according to the prevailing sea-state and current conditions to ensure stability on the seabed. An 8mm diameter polypropylene rope with surface floats attached enabled the BRUVS to be deployed and later retrieved from the surface (Figure 8). The scope of the rope was approximately twice the water depth.

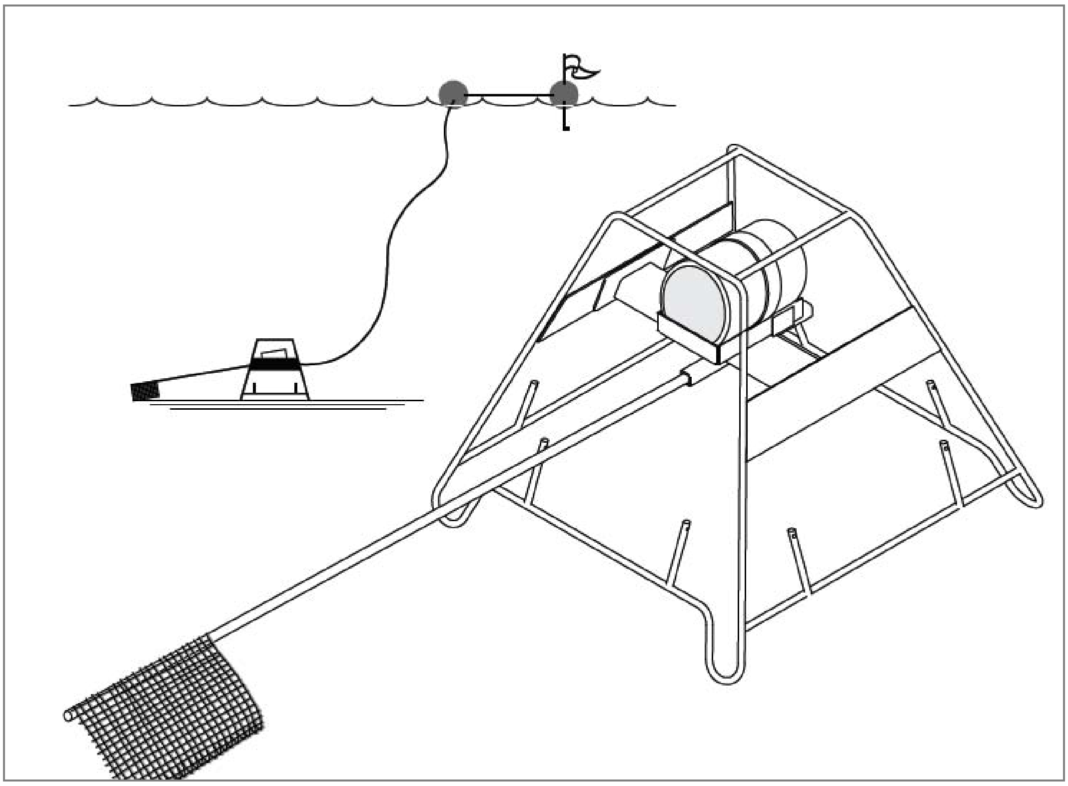


Figure 8. An AIMS Baited Remote Underwater Video Station (BRUVS). Steel ballast bars are attached to pegs on the base according to local sea surface and current conditions to prevent movement *in situ*.

The BRUVS fleet was comprised of six single and two stereo BRUVS. Stereo BRUVS differ from single BRUVS in that they have a wider steel frame enclosing a stereo pair of housed cameras spaced approximately 500 mm apart and orientated with respect to each other so that their fields of view converged on the bait bag. A flashing LED array was centrally mounted and visible in the field of view of both cameras to facilitate synchronisation of the video footage from the two cameras (Figure 9).

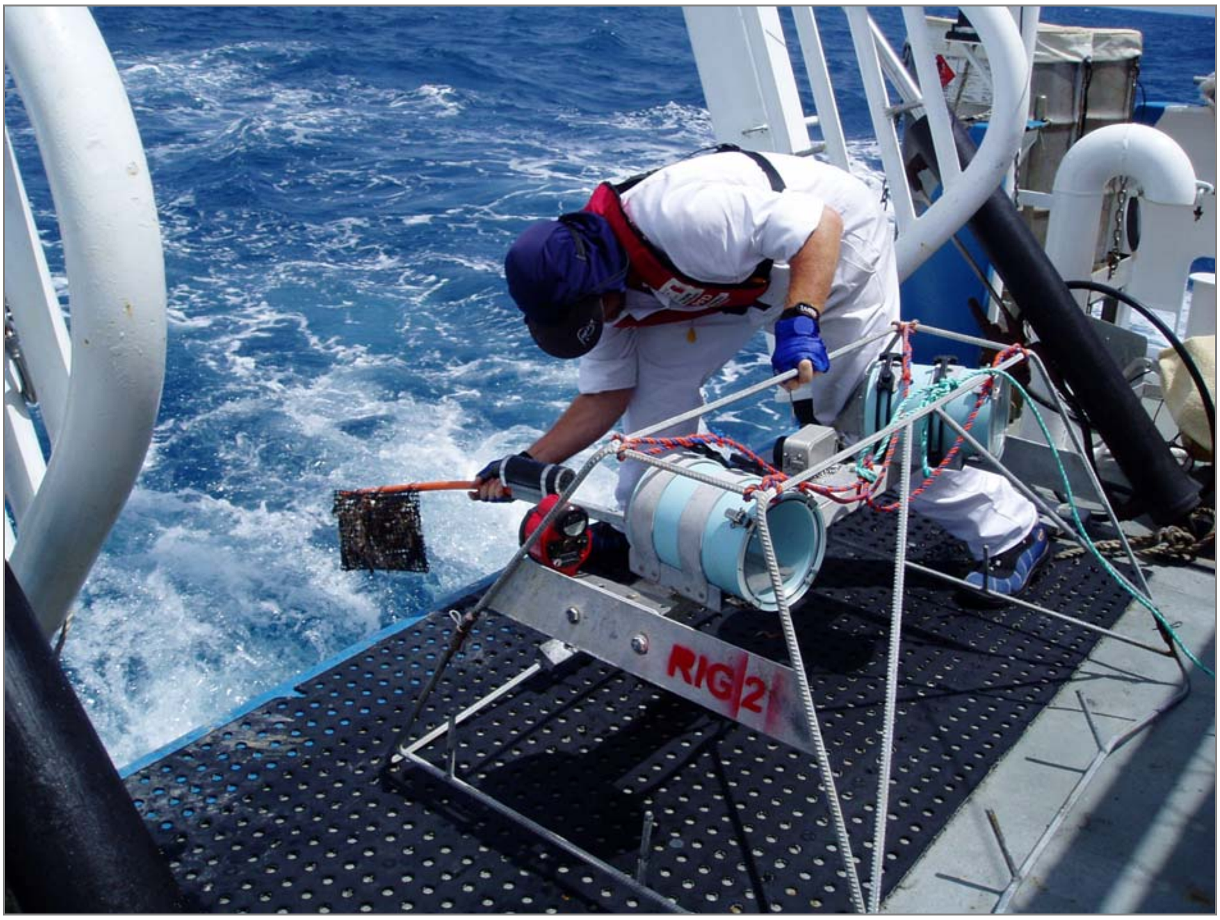


Figure 9. Readying a stereo BRUVS for deployment on the back deck of the RV Cape Ferguson.

Deployment and retrieval

BRUVS were deployed by steaming up to pre-determined deployment waypoints and dropping the BRUVS, mooring line and buoys from the stern of the vessel. The deployment waypoint, time and depth were electronically logged into a database from the ships navigation instruments at the moment of deployment. The BRUVS were then allowed to soak for 1 hour before they were retrieved by grappling the buoys with rope attached and winching the assembly to the surface using a hydraulic pot hauler.

Tape analysis

Each BRUVS deployment yielded one hour of footage of the fish community within the camera's field of view. The footage on each tape was analysed in conjunction with the AIMS BRUVS database v2.1.04 (AIMS 2008). This custom built Access™ database interfaces with a video playback device to enable an operator experienced in video-based fish taxonomy to review the footage in detail, pausing and advancing frame-by-frame where necessary using a shuttle control. The operator captures the timing of events and 'frame grabs' still images as a permanent record of species occurrences (Figure 10). Parameters recorded in the database for each species observed included taxonomic details, time of first arrival (T_{arr}), the maximum number observed in the camera's field of view at any one time (*MaxN*) and the time that *MaxN* occurs (T_{maxn}). Life stage (adult or juvenile), and behavioural observations (passing, feeding, chasing conspecifics, chasing other species, time of first feed) were also recorded.

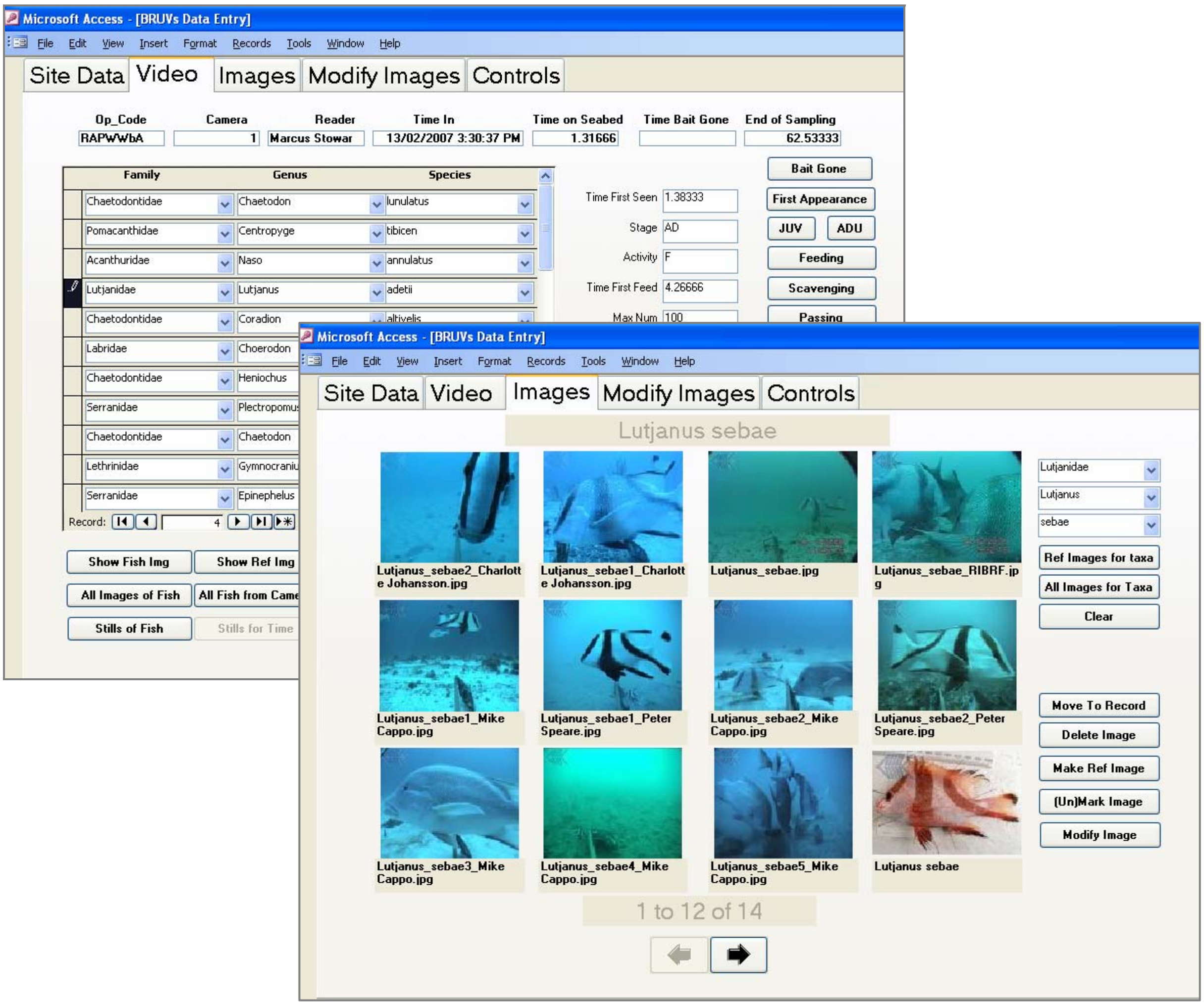


Figure 10. Screen grabs form the AIMS BRUVS database showing the main entry form and an example of reference imagery.

Habitat classification

The benthic habitat within the field of view of each BRUVS was categorised during the tape reading process. Estimates were made of percentage cover (to the nearest ten percent) of abiotic substratum types and also major benthos components. In addition, one of five habitat categories was assigned to each sample based on the habitat observed (Table 2).

Table 2. Habitat variables recorded in conjunction with BRUVS deployments.

Variable	Comment
Underlying Substratum Composition	*(Estimated from BRUVS field of view as percentage cover of each component of following types, to nearest ten percent)* SAND RUBBLE CONSOLIDATED OUTCROP OR REEF
Epibenthic Flora and Faunal Composition	*(Estimated from BRUVS field of view as percentage cover of each component of the following types, to nearest ten percent)* HARD CORAL SOFT CORAL SPONGE MACROALGAE WHIPS AND GORGONIANS ENCRUSTING ORGANISMS BARE SUBSTRATUM
Habitat Category	*(Category allocated based on overall habitat within the BRUVS field of view)* OPEN SANDY SEABED ALGAL MEADOW GORGONIAN and SEAWHIP GARDEN CORAL DOMINATED REEF LOW RELIEF RUBBLE FIELD
Deployment position	*(Recorded as ship's GPS position at deployment)* LATITUDE LONGITUDE
Depth	*(Recorded from ship's depth sounder at deployment)*

Data treatment and analysis

Fish abundances were analysed using univariate and multivariate statistical approaches with the R statistical package (R Development Core Team 2005).

Univariate analyses

The univariate analyses assessed differences in fish abundances between the green (closed to fishing) and blue (open to fishing) zoned shoals after adjusting for the explanatory variables of habitat, location, depth and trip using generalised linear models with a log link function and variance proportional to the mean. Detail on the analyses and the rationale behind them is provided in the results section

Multivariate analyses

Multivariate analyses were conducted on two data sets. One contained all fish species, and the second was a subset of species considered to be the *'highly sought after reef dwelling species'* by fishers (see below and Appendix 5). This enabled comparison of the zoning effects on both targeted and non-targeted species.

Rare species were removed from multivariate analyses by including only the species occuring on at least 10 sampling site-occasions. Ten *'highly sought after reef dwelling species'* were included in the analyses on this basis. The effects of habitat (4 classes), location (north-south), depth (shallow-deep) and trip were controlled for in all multivariate analyses of the effects of zoning.

The multivariate analyses used partial redundancy analysis and permutation tests to assess the significance of effects. Biplots were used to illustrate all results. The analyses were done for the ten targeted species and also for all species. The redundancy models were fitted hierarchally. The order of inclusion of effects was (1) habitat, (2) location and depth, (3) trip and (4) green/blue. Thus each effect was adjusted for previously included terms. Details on specific analyses are provided in the results section.

Explanatory variables

Although the pairs of shoals were matched as closely as possible for all characteristics other than zoning, explanatory variables considered likely to contribute to fish community differences between the shoals, other than zoning, were also incorporated into the analysis.

The explanatory variables used in this study were (names or acronyms in parentheses give the short form used in model descriptions):

1. Zone: ***Green*** or ***Blue*** (`GB`)
2. Geographical location: ***North*** or ***South*** (`NS`)
3. Habitat class: a categorical variable with four classes, (labelled 'CORAL DOMINATED REEF', 'GORGONIAN and SEAWHIP GARDEN', 'LOW RELIEF RUBBLE FIELD' or 'OPEN SANDY SEABED'). For presentation purposes these names are sometimes replaced by ***Coral***, ***Garden***, ***Rubble*** and ***Sand*** (`Habitat`)
4. Depth: sometimes used as a continuous predictor, but mostly classified into two classes ***Shallow*** or ***Deep***, corresponding as closely as possible to the top of the shoal or the deeper region beside. This was readily identified as the depths recorded for the BRUVS on each shoal formed two clear groups. The mean depth corresponding to the 'shallow'

and 'deep' samples from each shoal varied, an indication of this variation is provided in the depth range for each shoal in Table 1 (SD)

5. Trip. There were two trips made to the shoals, ***Trip1*** or ***Trip2***, one in February and one in August/September. 'Trip' is possibly a surrogate for seasonal differences (`Trip`)

The response variables were the maximum number (*MaxN*) of fish of any given species from each BRUVS deployment. This is taken as an index of local abundance and is comparable within species across sampling times.

A feature of the second trip was that most BRUVS sets were duplicated at some later time in an attempt to re-survey the same station. This was only partially successful, as there were slight depth and habitat class differences in many paired samples.

Target and non-target species

For the purposes of assessing the possible direct and indirect effects of fishing on the fish communities, fish species were categorized into a number of subsets depending on the likelihood they would be caught and retained by line fishers. The four species subsets were:

i. *'Highly sought after reef dwelling species'* (Appendix 5). These included the most desirable reef dwelling species based on their eating qualities and size, as well as their reef dwelling habits.
ii. *'Sought after reef dwelling and pelagic species'* (Appendix 6). Includes the species in (i) but expanded to include pelagic and semi-pelagic species (e.g. trevallies (Carangidae) and mackerels (Scombridae), as well as smaller but none-the-less acceptable food fishes (e.g. smaller snappers of the family Lutjanidae).
iii. *'All species considered likely to be caught by line fishers including by-catch'* (Appendix 7). Includes the species in (ii) as well as the undesirable fishes caught by line fishers that form by-catch.
iv. *'Species considered unlikely to be caught by line fishers* (Appendix 8). This includes all species unlikely to be hooked because of their dietary preferences (e.g. herbivores such as parrotfishes, Scaridae) or small size (e.g. damselfishes, family Pomacentridae and butterflyfishes, family Chaetodontidae).

Species subsets 1-3 were inclusive of the previous subset – for example all the 'highly sought after reef dwelling species' were included in the next subset 'sought after reef dwelling and pelagic species' and similarly both these subsets of fishes were included in the broader 'all species likely to be caught by line fishers including by-catch' category. The fourth subset 'species considered unlikely to be caught by line fishers' excluded all species in the previous three categories.

Although there was some degree of subjectivity in such a classification, the rationale for analyzing the community data in this manner was to distinguish among species that were highly targeted, by-catch and those species unlikely to be caught by line fishers. Distinguishing between 'highly sought after reef dwelling species' and 'sought after reef dwelling and pelagic species' was also considered useful since the former excludes a number of pelagic fishes such as mackerels and trevallies, both of which are often sought after by fishers but are highly mobile. Fishes of these families may migrate seasonally, or move randomly, beyond the bounds of zoned reefs and are thus less likely to show any effect of zoning, at least at this spatial scale.

Repeat sampling

Most BRUVS deployments on the second field trip were duplicated in an attempt to re-survey the same station. However, results indicated that most duplicate shots were not in precisely the same location, as there are noticeable depth and habitat class differences in many repeated samples. Furthermore, examination of the fish community differences indicated no significant short term temporal effect when adjusted for possible explanatory variables of depth, zone and habitat (see results). Consequently, in all analyses repeat deployments were considered to be independent samples.

Results

Multibeam acoustic mapping

The multibeam acoustic survey of the shoals revealed that each shoal consisted of a discrete plateau-shaped structure of consolidated calcareous rock surrounded by a predominantly sandy seabed. Beyond the discrete edge of all four shoals were isolated patches of outcropping rock and rubble. These adjacent habitats were considered to be important as they are known to be favoured by many sought after reef dwelling fishes such as red emperor (*Lutjanus sebae*) and as a consequence are areas where fishing effort is often focused.

The topography of the pairs of shoals (Barcoo-Karamea and East Warregoes- West Warregoes) was similar, while there were some notable differences in the areal extent and depth range between the pairs. Barcoo and Karamea were considerably larger than the East and West Warregoes (5.4km^2 and 7.6 km^2 c.f. 2.0km^2 and 1.9.km^2) with deeper water immediately adjacent to the shoal (52 m and 57 m c.f. 45 m and 37m).

The digital terrain models for each shoal were used extensively in determining BRUVS deployment positions, providing detailed information on the extent, depths and precise location of habitat features of each shoal.

Towed video survey

The towed video survey revealed a diversity of habitats present on the shoals. Generally, the plateau tops were dominated by hard and soft corals. The conspicuous benthos on the outcrops in deeper waters adjacent to the shoals included seawhips and large gorgonian fans. Further away from the shoals the seabed was sandy and some areas of rubble and boulders occurred on and adjacent to the shoals. In these latter habitats the benthos was predominantly low growing and encrusting, possibly reflecting the mobile nature of the rubble substratum that precludes the long term growth of sessile benthos.

The habitats on the top of the shoals were generally more extensive and less patchy than in the deeper waters near the base of the shoals where gorgonian and seawhip covered outcrops were typically interspersed with patches of sand.

The towed video survey did not attempt to quantify the spatial extent of the various habitats on the shoals, but was used only to identify areas of suitable habitat for the deployment of BRUVS. These were identified as the areas at the base of the shoal where hard substratum was outcropping and areas on top of the shoal with rugged topography that were likely to be productive fish habitats (Figures 11-14).

Figure 11. Towed video tracks and associated benthos classification for Barcoo Bank.

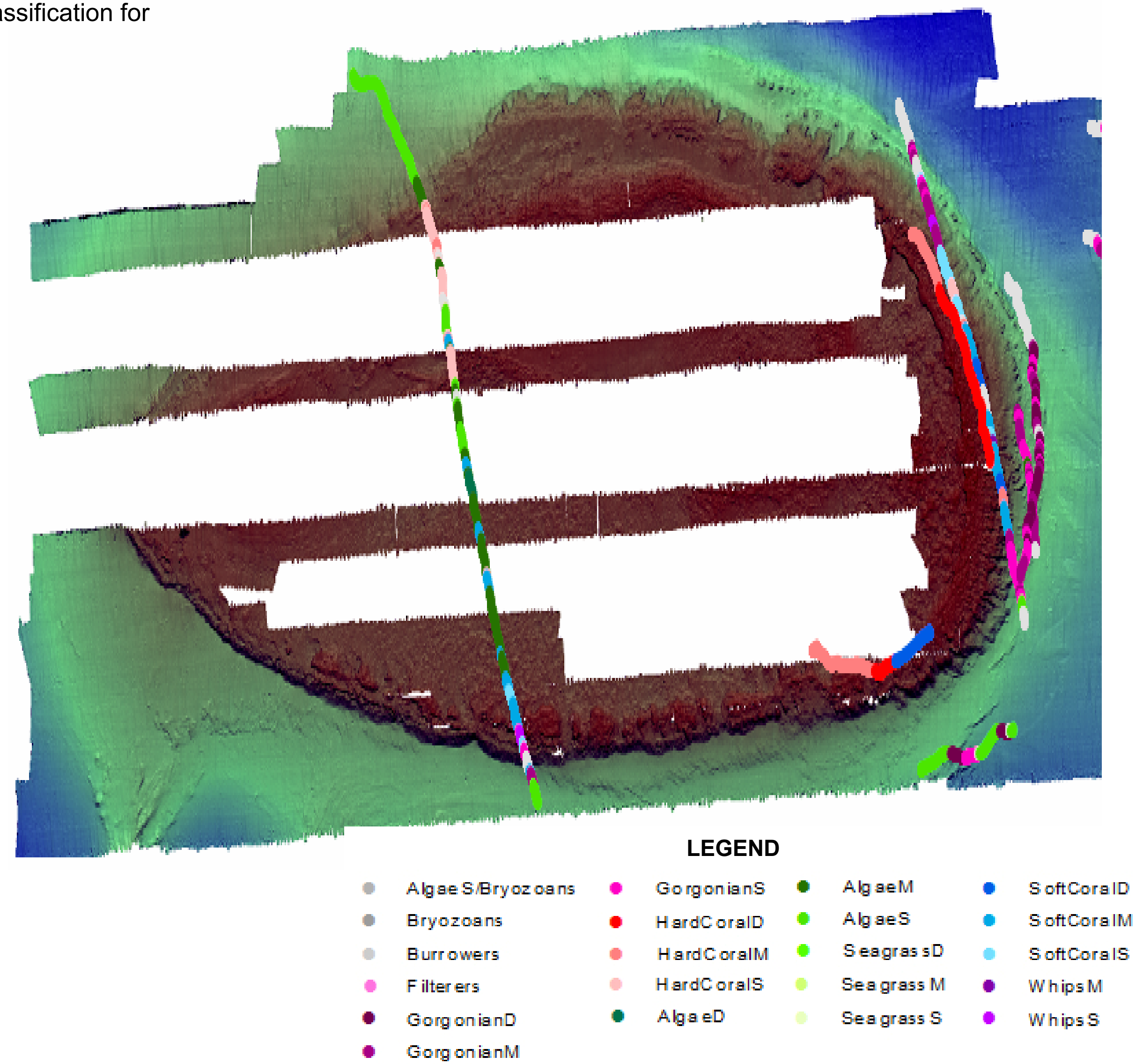


Figure 12. Towed video tracks and associated benthos classification for Karamea Bank.

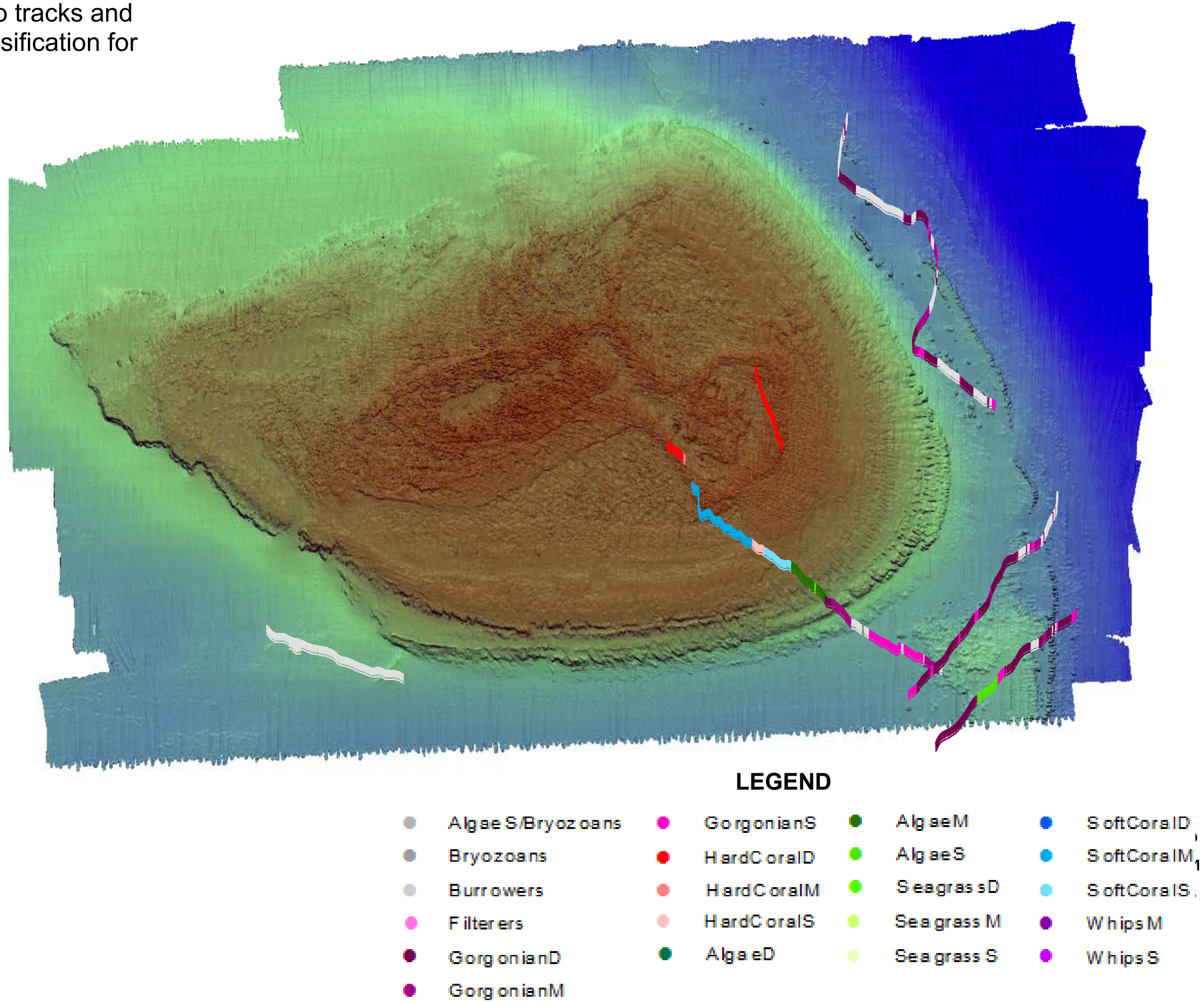


Figure 13. Towed video tracks and associated benthos classification for the West Warregoes.

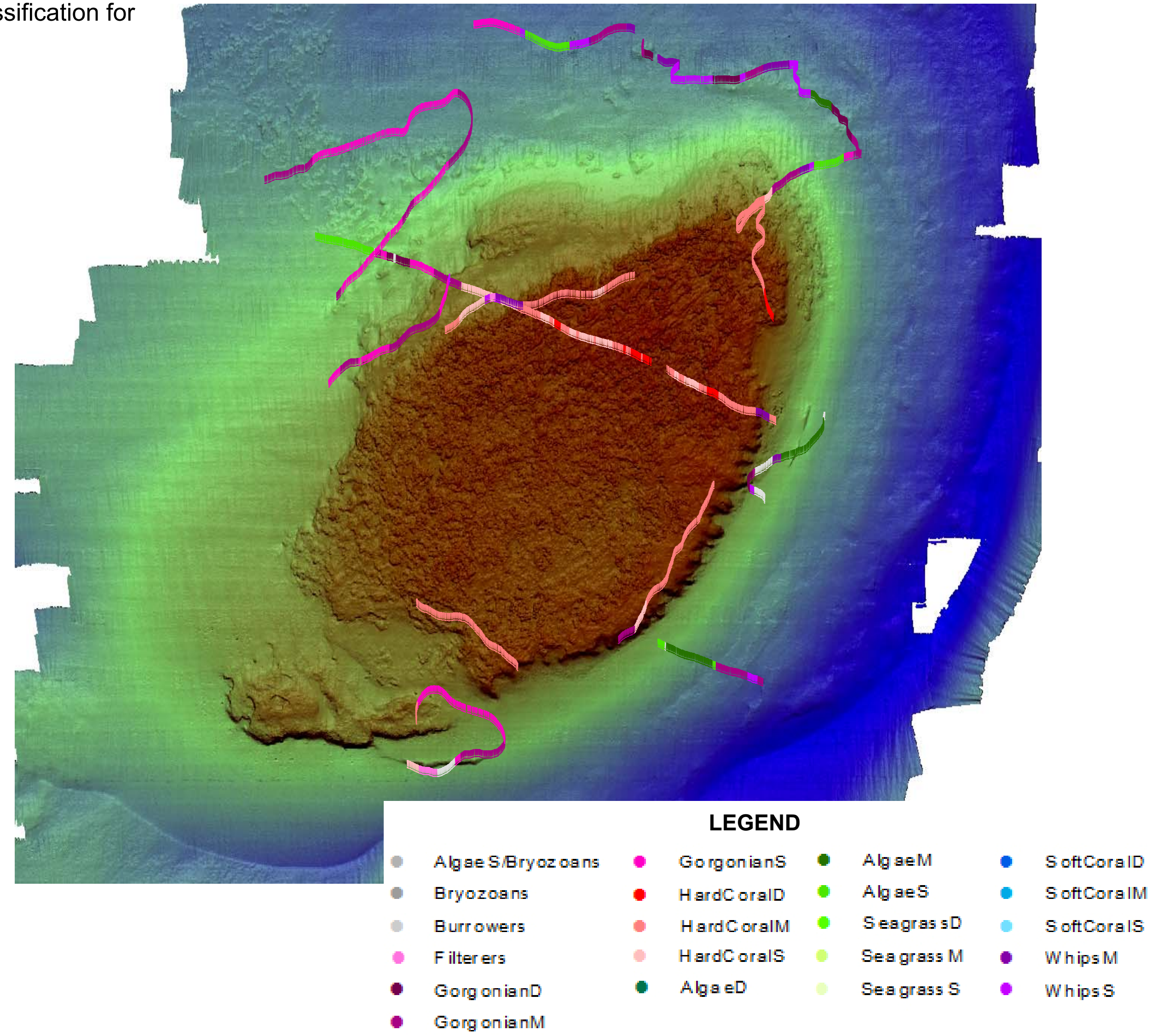
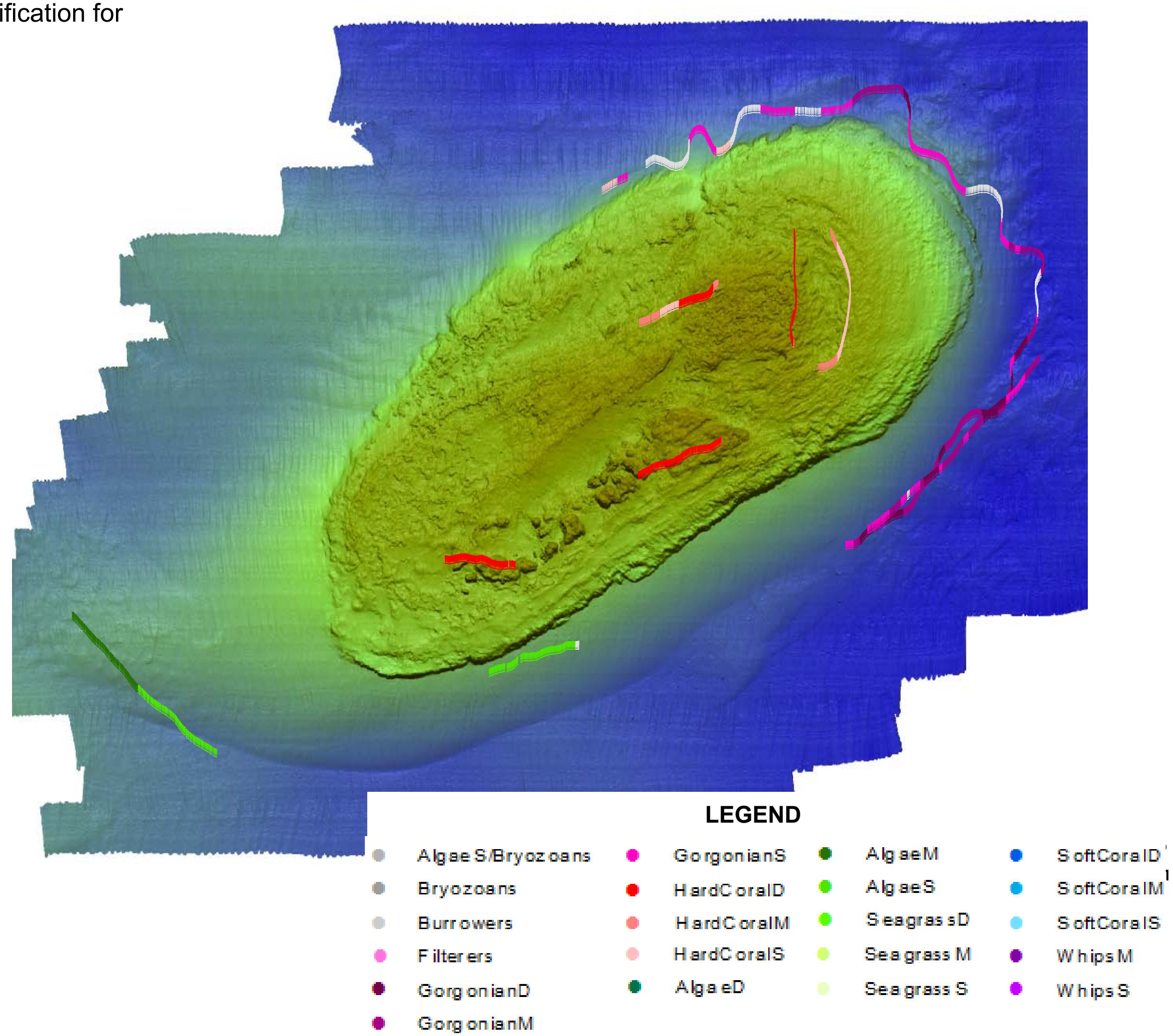


Figure 14. Towed video tracks and associated benthos classification for the East Warregoes.



Fish diversity and abundance

A total of 245 species of fishes were recorded on the four southern shoals. Of these, sixty were recorded on all shoals and eighty on only one shoal. There were substantial differences in species richness between the northern pair of shoals (135 species at Barcoo Bank and 101 species at Karamea Bank) and the southern pair of shoals, which were considerably more diverse (175 species at the East Warregoes and 164 species at the West Warregoes) (Figure15). Within the Barcoo–Karamea Banks pair, 81 species were common to both shoals, while 72 were recorded on only one shoal. A total of 128 species were common to both the East and West Warregoes and 83 species unique to one of the pair. In nearly all cases the species found to be unique to one of the pair of shoals were recorded in relatively low abundance.

Total mean asbundance (recorded as mean of combined *MaxN* values for each BRUVS) was greater on the southern pair of shoals than the more northern shoals (Barcoo Bank: 72 ± 7 [mean±s.e.m.]; Karamea Bank: 58 ± 7; East Warregoes: 106 ± 22; West Warregoes: 145 ± 26) (Figure16).

The fish fauna of the shoals included an extremely diverse range of families, size classes and functional groups, from large, apex predators such as sharks (Carcharhinidae) and mackerels (Scombridae) through to carnivorous reef dwelling species such as groupers, emperors and snappers (Serranidae, Lethrinidae and Lutjanidae), herbivores such as parrot fishes (Scaridae) and small coral-dwelling species such as butterfly fishes (Chaetodontidae) and damsel fishes (Pomacentridae) (Table 3).

The shoals had an abundance of species considered highly desirable as food fishes and which dominate the catches of recreational and professional reef line fishers. Some examples of the more common of these include red emperor (*Lutjanus sebae*), coral trout (*Plectropomus* spp), red throat emperor (*Lethrinus miniatus*), Venus tuskfish (*Choerodon venustus*) and various cods (*Epinephelus* spp). Other highly desirable food fishes recorded in lesser abundance included coronation and lyretail trout (*Variola* spp), gold-banded and green jobfish (*Pristipomoides multidens* and *Aprion virescens),* spangled and grass emperors (*Lethrinus nebulosus* and *L. laticaudis*), golden spot hogfish (*Bodianus perditio*), southern snapper (*Pagrus auratus)* and other tuskfishes (*Choerodon* spp). Also recorded were many less sought after food and by-catch species including trevallies (Carangidae), small snappers and small emperors (Lutjanidae and Lethrinidae).

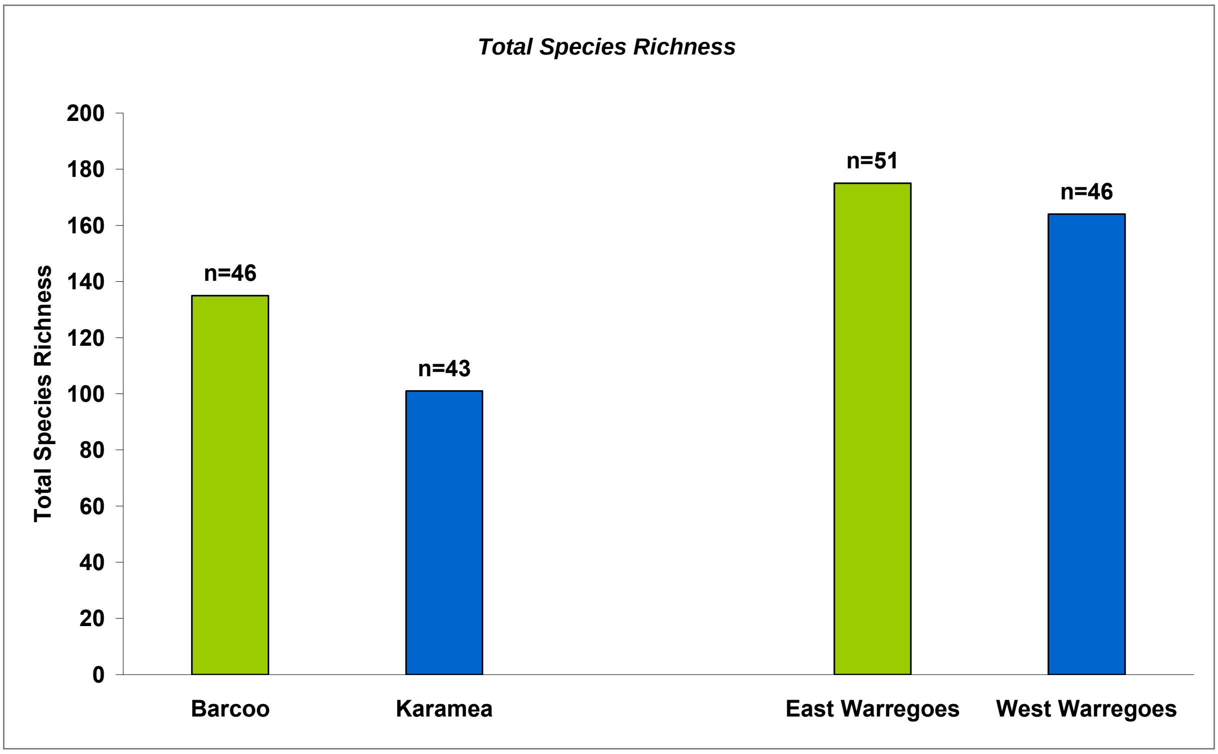


Figure 15. Total species richness of fishes at each shoal (all samples from both trips combined).

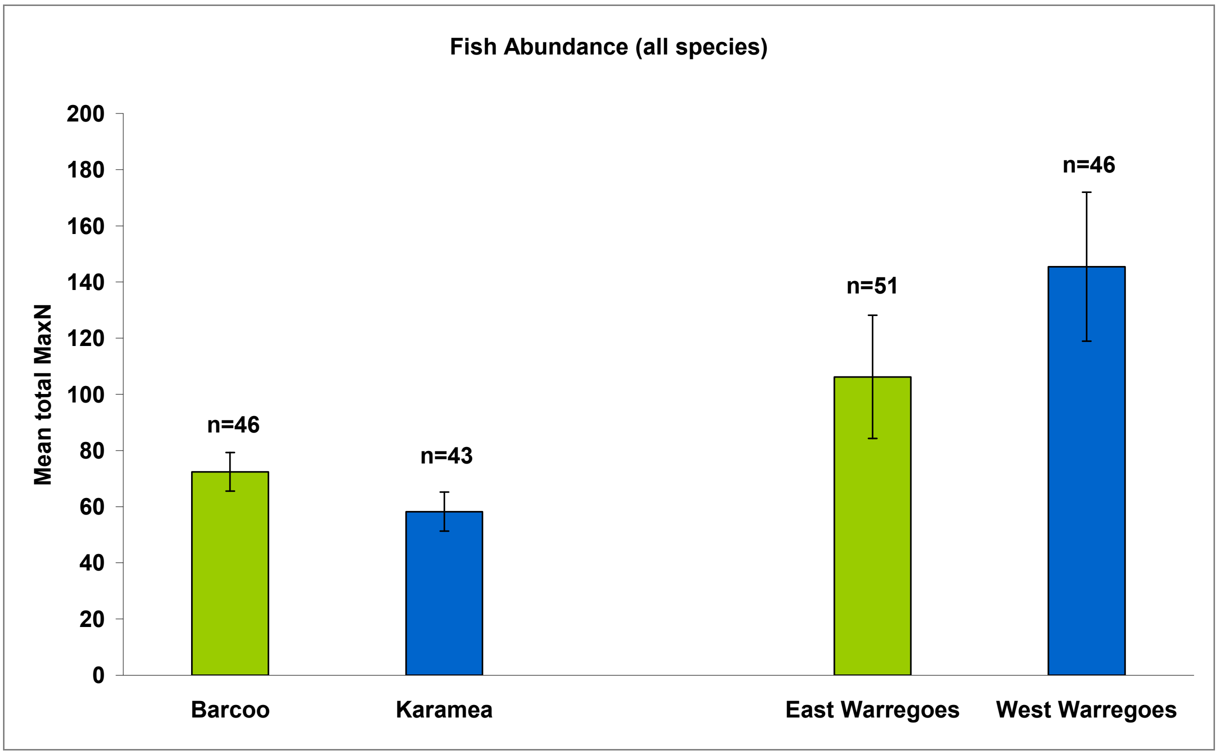


Figure 16. Mean fish abundance at each shoal as measured by ΣMaxN for all fishes, including all samples from both trips. Error bars indicate s.e.m.

Table 3. Summary of main families of fishes (and also seasnakes) recorded at the study sites.

Order	Family	Common name	West Warregoes	East Warregoes	Barcoo	Karamea	N_{total}
Carcharhiniformes	Carcharhinidae	(Whaler sharks)	5	61	11	0	77
	Sphyrnidae	(Hammerhead sharks)	0	0	0	2	2
Orectolobiformes	Hemiscylliidae	(Catsharks)	3	10	1	5	19
	Stegostomatidae	(Leopard sharks)	1	2	0	0	3
	Ginglymostomatidae	(Nurse sharks)	1	2	0	0	3
Rajiformes	Rhinidae	(Shark rays)	2	0	3	4	9
Myliobatiformes	Dasyatidae	(Stingrays)	6	12	2	1	21
	Myliobatidae	(Manta and eagle rays)	1	4	0	0	5
Anguilliformes	Muraenidae	(Moray eels)	0	1	2	0	3
Aulopiformes	Synodontidae	(Lizardfishes)	0	1	2	0	3
Beryciformes	Holocentridae	(Squirrelfishes)	1	0	3	0	4
Gasterosteiformes	Aulostomidae	(Trumpetfishes)	3	2	0	0	5
	Fistulariidae	(Flutemouths)	1	2	0	0	3
Scorpaeniformes	Scorpaenidae	(Scorpionfish and lionfish)	0	0	1	0	1
Perciformes	Apogonidae	(Cardinal fishes)	1962	0	0	1	1963
	Pomacentridae	(Damselfishes)	616	865	1020	528	3029
	Serranidae	(Groupers and coral cods)	170	133	148	60	511
	Haemulidae	(Sweetlips)	90	35	27	9	161
	Malacanthidae	(Tilefishes)	0	1	0	0	1
	Echeneidae	(Suckerfishes)	11	16	5	5	37
	Rachycentridae	(Cobias)	2	14	0	0	16
	Carangidae	(Trevallies)	280	101	130	424	935
	Lutjanidae	(Snappers and sea perches)	641	307	302	163	1413
	Caesionidae	(Fusiliers)	1096	1810	317	498	3721
	Sparidae	(Sea breams)	3	6	13	23	45

Order	Family	Common name	West Warregoes	East Warregoes	Barcoo	Karamea	N_{total}
	Lethrinidae	(Sweetlip emperors)	185	357	391	150	1083
	Nemipteridae	(Threadfin bream)	470	540	132	170	1312
	Mullidae	(Goatfishes)	43	59	50	24	176
	Chaetodontidae	(Butterflyfishes)	346	211	98	39	694
	Pomacanthidae	(Angelfishes)	86	51	63	41	241
	Kyphosidae	(Drummers)	0	3	0	0	3
	Cheilodactylidae	(Morwongs)	1	1	1	1	4
	Labridae	(Wrasses and tuskfish)	237	304	299	101	941
	Scaridae	(Parrotfishes)	23	10	26	2	61
	Pinguipedidae	(Grubfishes)	16	12	5	9	42
	Blenniidae	(Blennies)	11	6	2	0	19
	Ephippidae	(Batfishes)	13	3	0	1	17
	Siganidae	(Rabbitfishes)	79	53	85	103	320
	Zanclidae	(Moorish Idols)	18	9	0	0	27
	Acanthuridae	(Surgeon-fishes)	188	289	75	58	610
	Sphyraenidae	(Barracudas)	11	0	2	4	17
	Scombridae	(Mackerels and tunas)	4	32	9	5	50
Tetraodontiformes	Balistidae	(Triggerfishes)	55	91	98	74	318
Tetraodontiformes	Monacanthidae	(Filefishes and leatherjackets)	5	8	5	0	18
Tetraodontiformes	Tetraodontidae	(Pufferfish)	3	2	2	0	7
Squamata	Hydrophiidae	(Sea snakes)	44	42	18	12	116

Influence of habitat on targeted and non- targeted species

Habitat had a strong influence on the fish community composition and abundance. The greatest differences were seen between between coral-dominated and the open sandy habitats, with the coral habitats generally having the highest species richness and abundance while sand dominated habitats were relatively depauperate and had the lowest richness and abundance (Figure 13-20). Species strongly associated with sand habitats included whiptails (*Pentapodus* spp.) and starry triggerfish (*Abalistes stellatus*) while the coral-dominated habitats had a great diversity of fishes including damselfishes (Pomacentridae), fusiliers (Caesionidae) and surgeonfishes (Acanthuridae) (Figure). Rubble, seawhip and gorgonian garden habitats were intermediate in species richness and diversity and also had species associations shared between the coral and more open habitats. Small emperors (*Lethrinus rubrioperculatus* and *L. ravus)* were commonly associated with the rubble field habitats.

Of the highly sought after table fish species, coral trout (*Plectropomus leopardus*) were seen to have a strong affiliation with coral habitats, while red emperor (*Lutjanus sebae*) was strongly associated with the deeper, more open, gorgonian and sand habitats. Tuskfishes (*Choerodon* spp), red throated emperor (*Lethrinus miniatus*) and spangled emperor (*Lethrinus nebulosus*) were also most commonly affiliated with the more open habitats of gorgonian and seawhip gardens, rubble fields and sandy seabed adjacent to the shoal (Figure).

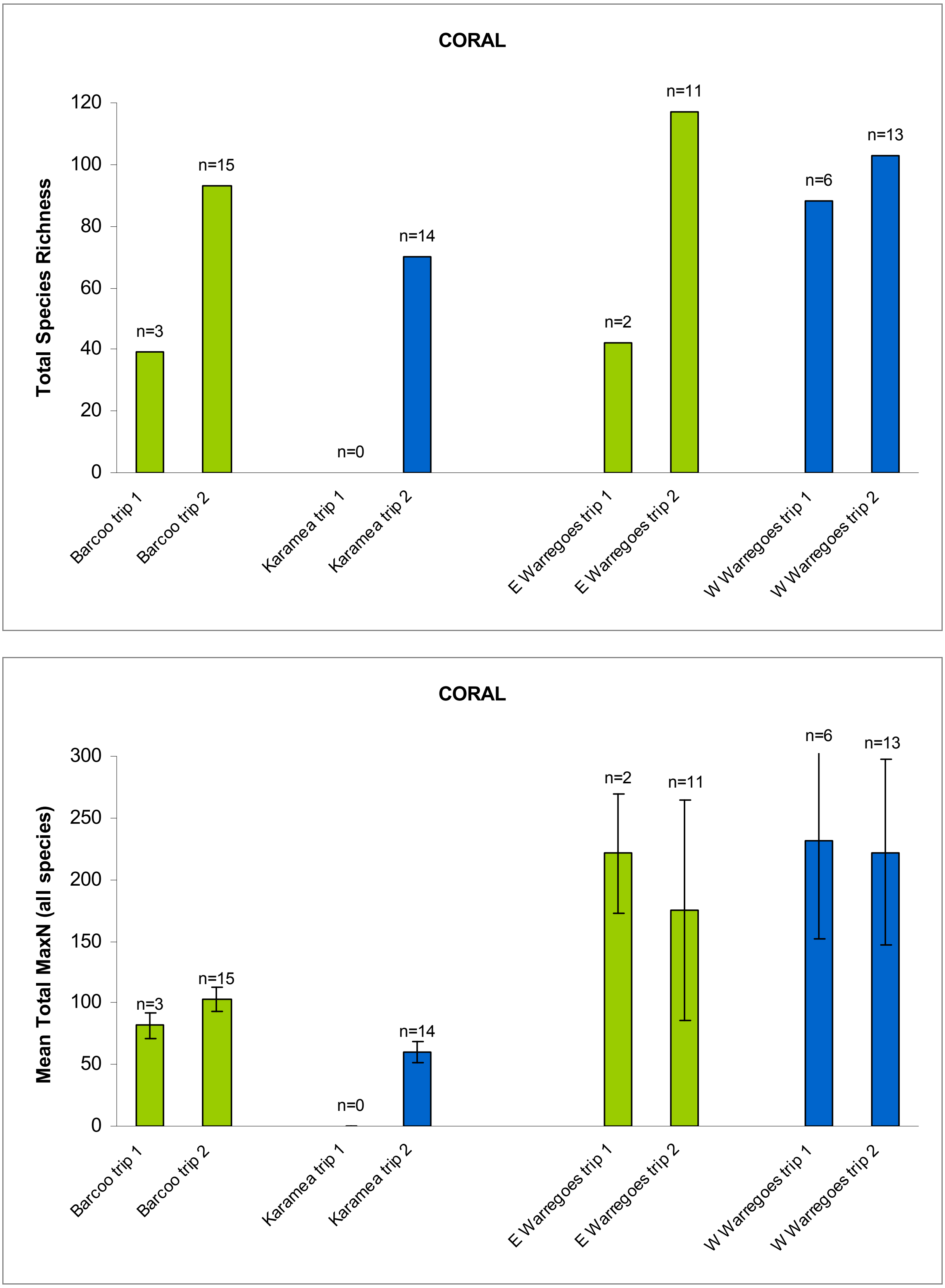
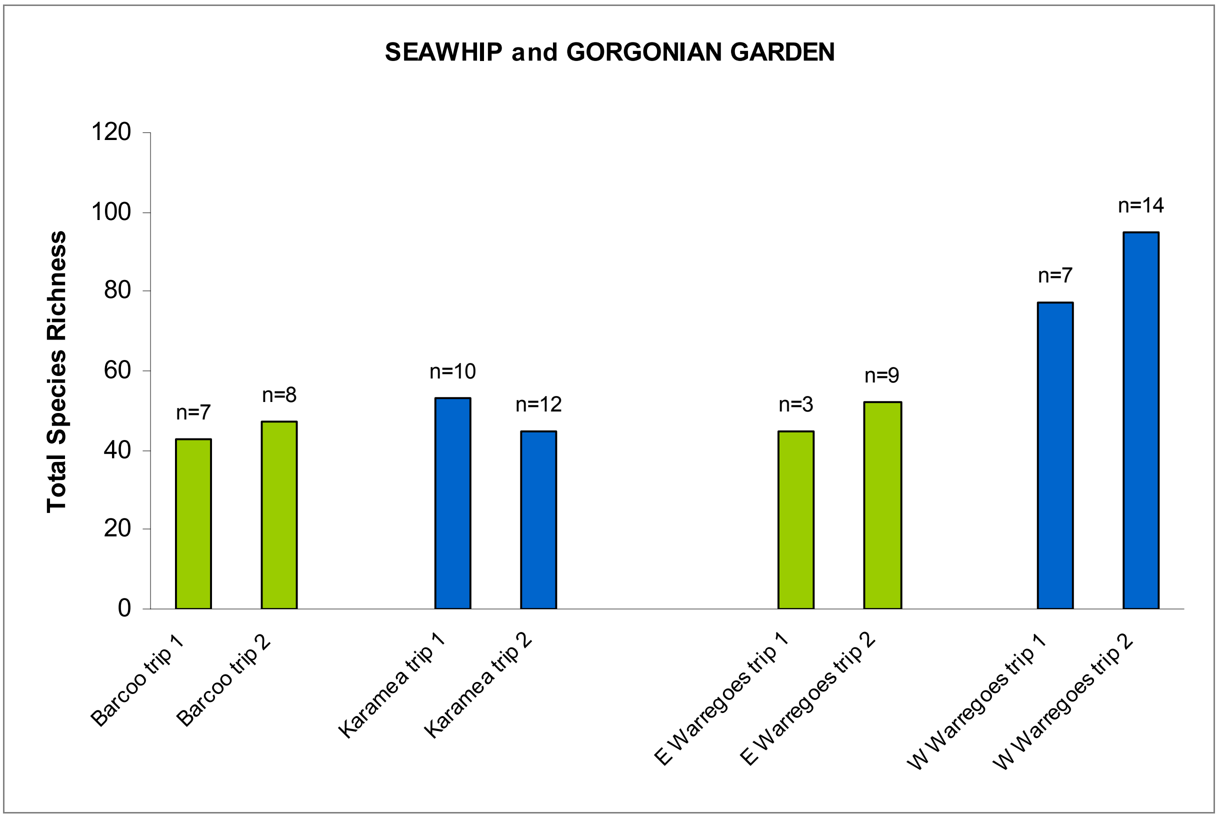


Figure 17. Species richness and mean total abundance of fishes in the ‘coral dominated reef’ habitat. Error bars indicate s.e.m.



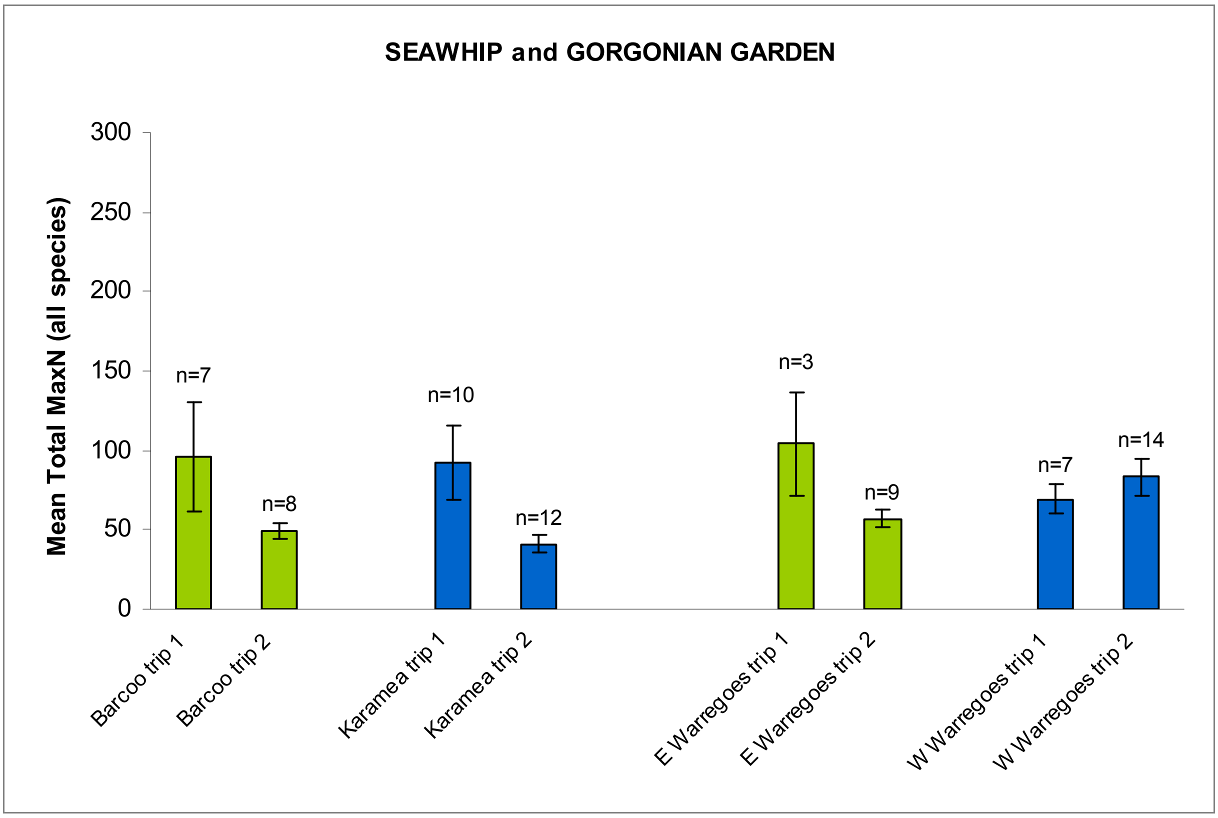
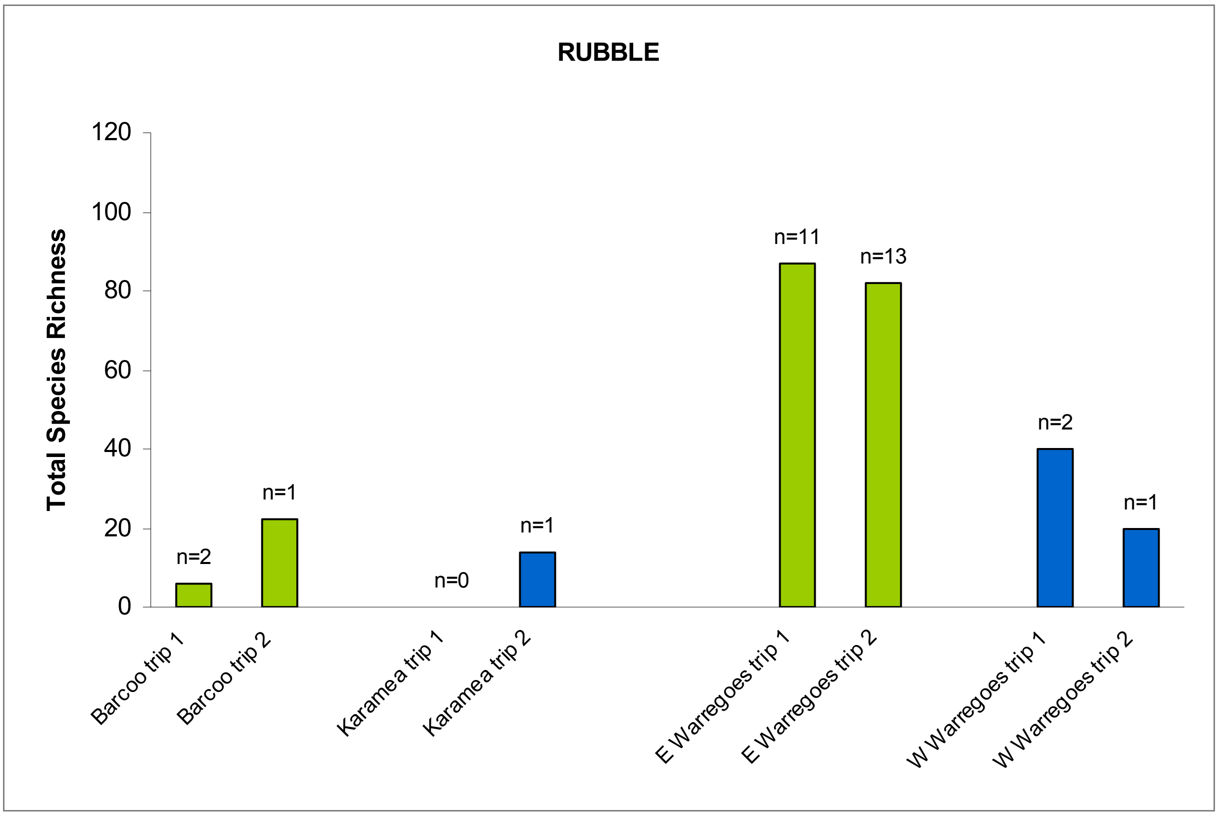


Figure 18. Species richness and mean total abundance of fishes in the ‘sea whip and gorgonian garden’ habitat. Error bars indicate s.e.m.



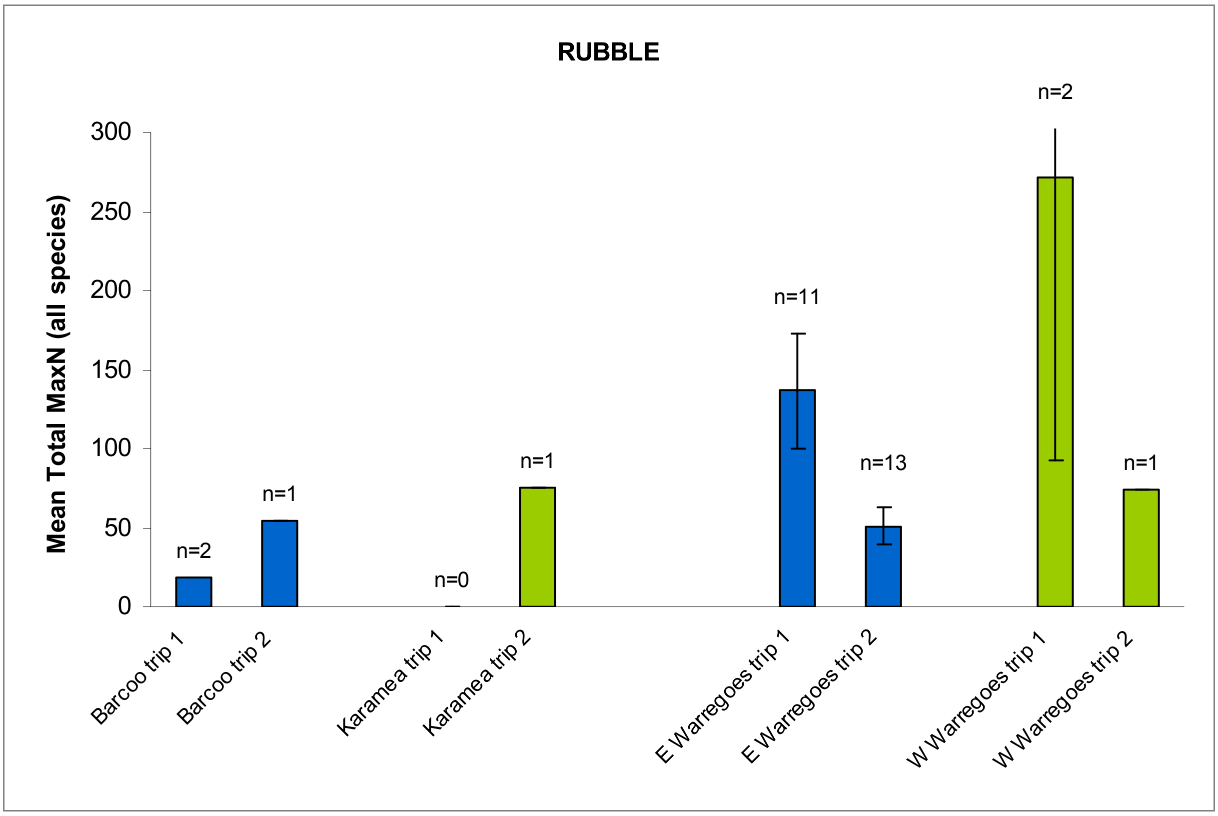
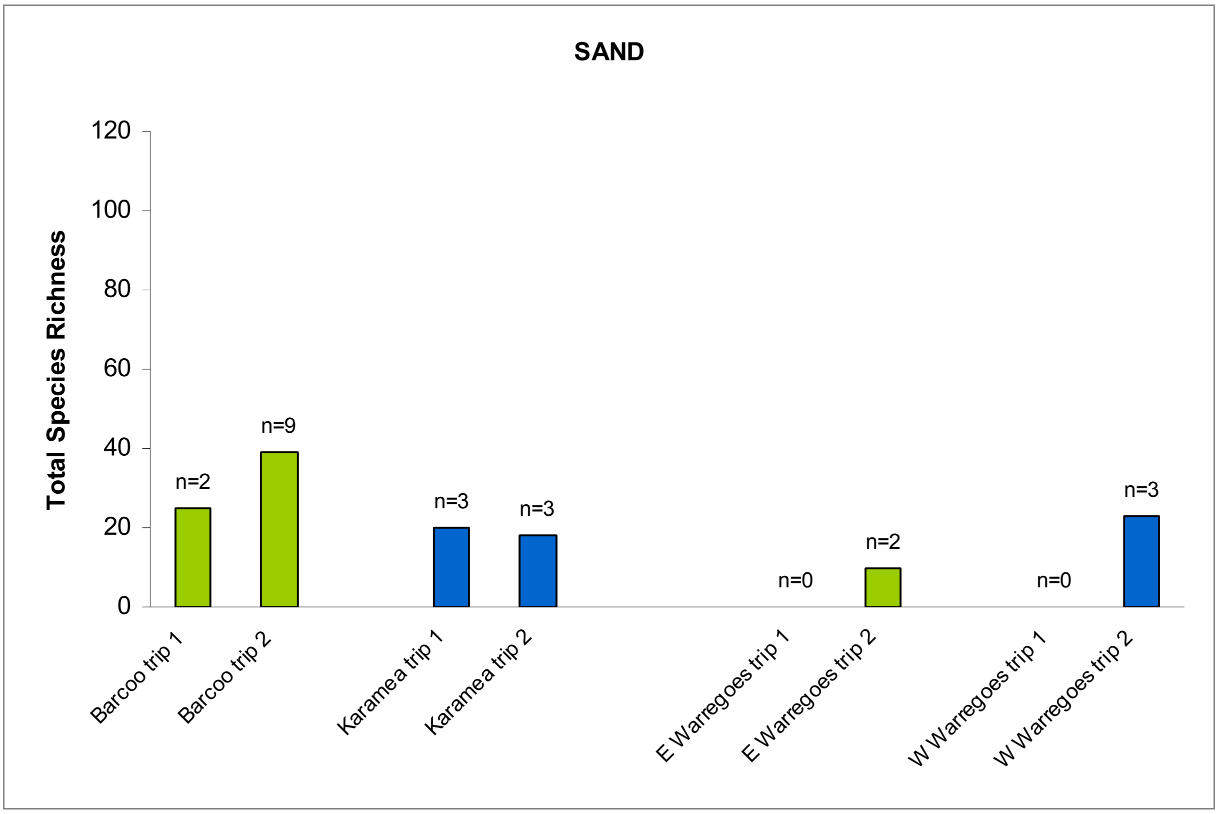


Figure 19. Species richness and mean total abundance of fishes in 'low relief rubble' habitat. Error bars indicate s.e.m.



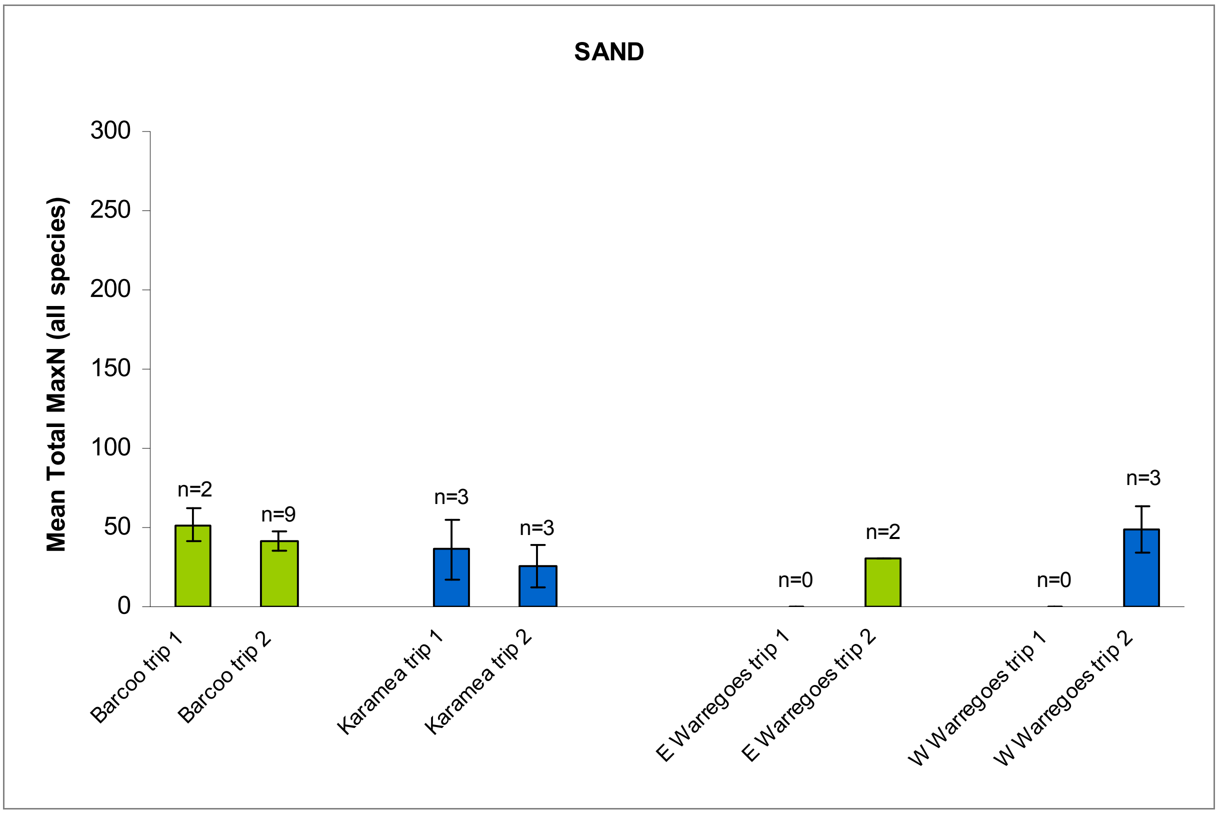


Figure 20. Species richness and mean total abundance of fishes in 'open sandy seabed' habitat. Error bars indicate s.e.m.

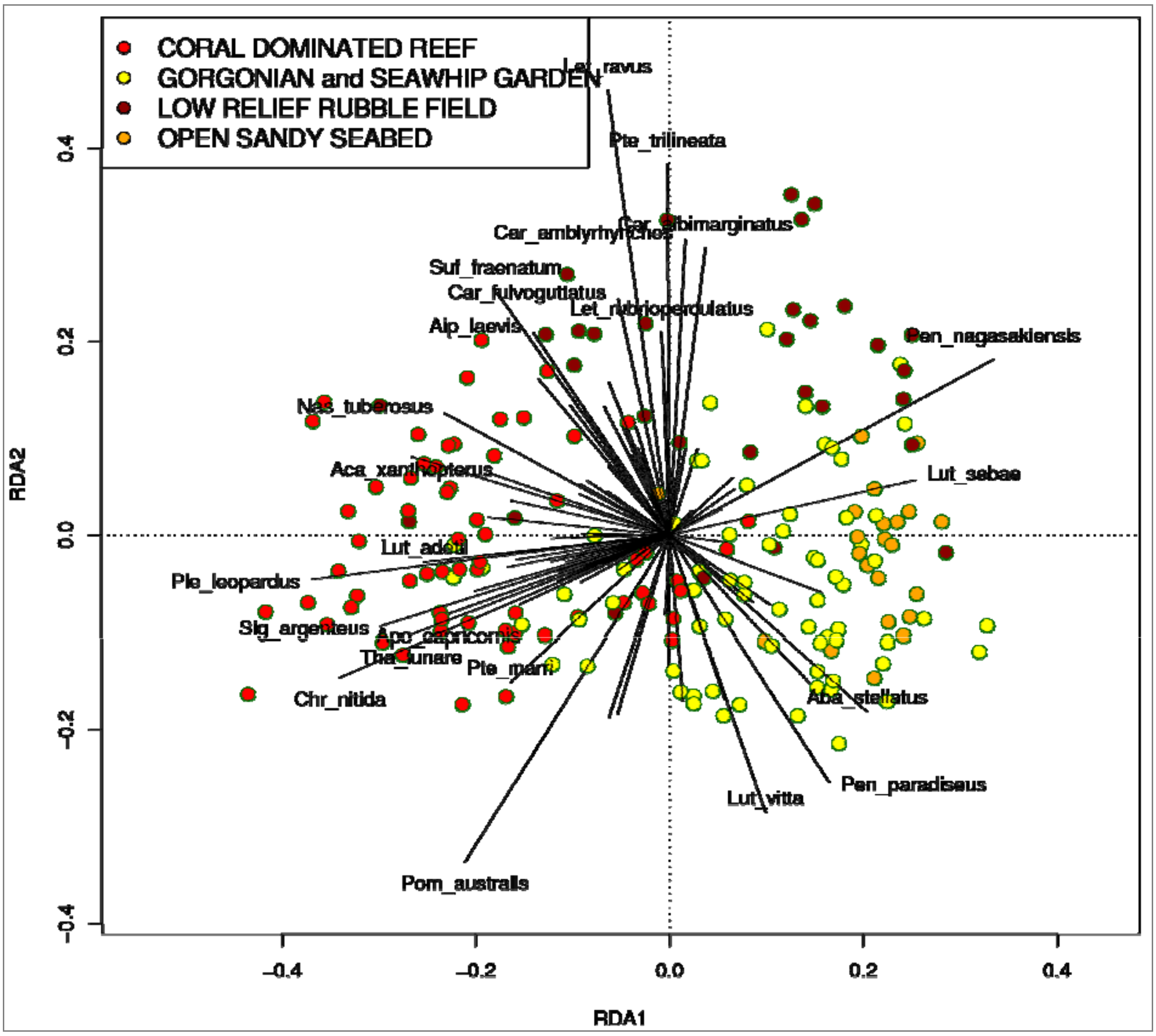


Figure 21. Habitat associations of all species: redundancy analysis principal components biplot showing the effects of habitat on species composition, based on all species that occur at ten or more sites. The 25% longest species vectors are labeled on the plot.

(A key to abbreviations used for species names is provided in Appendix 10.)

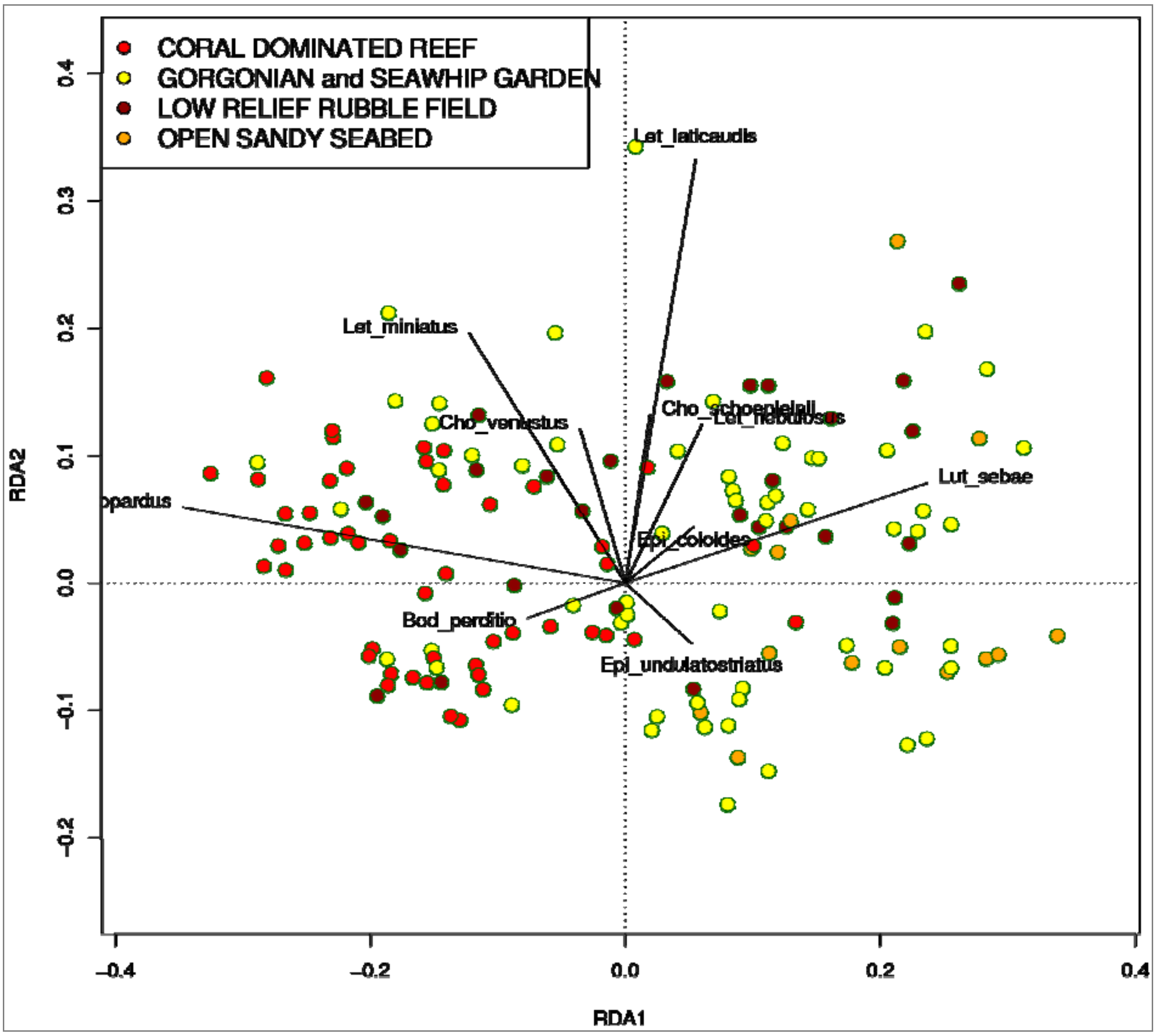


Figure 22. Habitat associations of highly sought after species: redundancy analysis principal components biplot showing the effects of habitat on species composition, based on highly sought after species species which occur at ten or more sites. The differences were greatest between coral dominated reefs and open sandy seabeds.

(A key to abbreviations used for species names is provided in Appendix 10.)

Influence of location and depth on targeted and non- targeted species

The species composition of the shoals was further influenced by latitudinal differences in location and depth. This difference was evident both in overall species richness, which was greater on the southern shoals, and also in the abundance of selected individual species. Certain damselfishes (*Pomacentrus australis* and *Chromis nitida*) were more abundant on the northern shoals and other fishes, such as hussar (*Lutjanus adetti*) and lunar wrasse (*Thalassoma lunare*) more commonly recorded on the southern shoals (Figure 23). The presence of some typically subtropical and temperate fish species was notable on the more southern shoals (East and West Warregoes) with species recorded including southern snapper (*Pagrus auratus),* long-finned drummer (*Kyphosus vaigiensis*) and yellowtail kingfish *(Seriola lalandi*).

Of the species most targeted by line fishers, red throat emperor (*Lethrinus miniatus*) was more common on the northern shoals while tuskfishes (principally *Choerodon venustus*), grass and spangled emperors (*Lethrinus laticaudis* and *L. nebulosus*) were more common on the southern shoals. The abundance of red emperor (*Lutjanus sebae*) was strongly correlated with depth, demonstrating the affinity of this species for the deeper habitats at the base of the shoals (Figure).

There was an interaction between depth and location, with a stronger effect of depth on composition and abundance in the southern than the northern shoals. This is noteworthy given that the depth differential between the shallowest and deepest samples from the southern shoals was actually less than on the northern shoals (~33m for the northern shoals c.f. ~23m for the southern shoals). This may be evidence that the shallower depths and closer inshore position of the southern shoals attracts an additional suite of species that are not found on the deeper, northern shoals that lie further offshore.

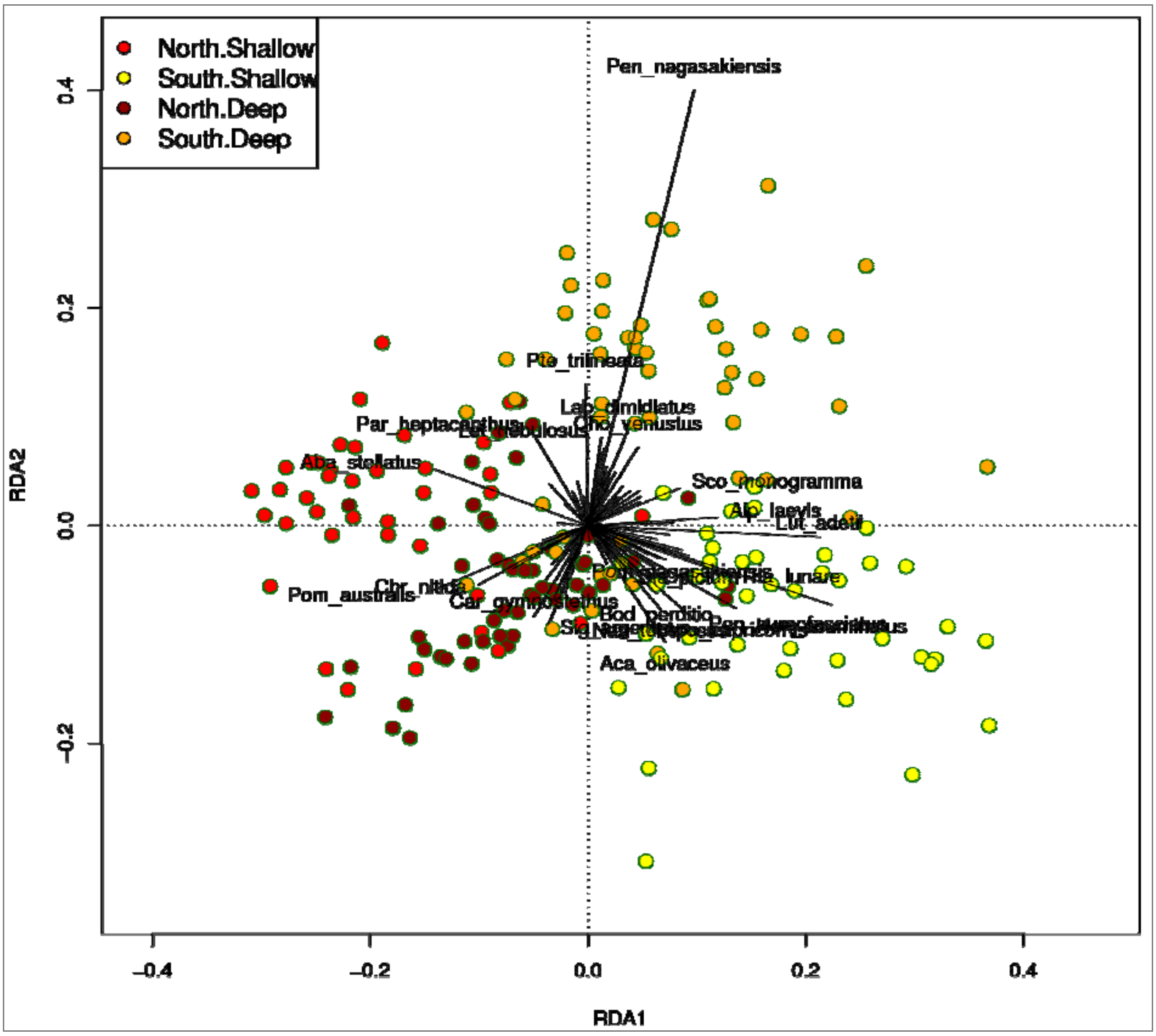


Figure 23. Location and depth associations of all species: redundancy analysis principal components biplot showing the joint effects of location (north-south) and depth (shallow-deep) on species composition, based on all species that occur at ten or more sites. The effects were adjusted for habitat. The 25% longest species vectors are labeled on the plot. There were strong differences in species composition due to both location and depth and there was also an interaction effect with a stronger depth effects in the south than the north.

(A key to abbreviations used for species names is provided in Appendix 10.)

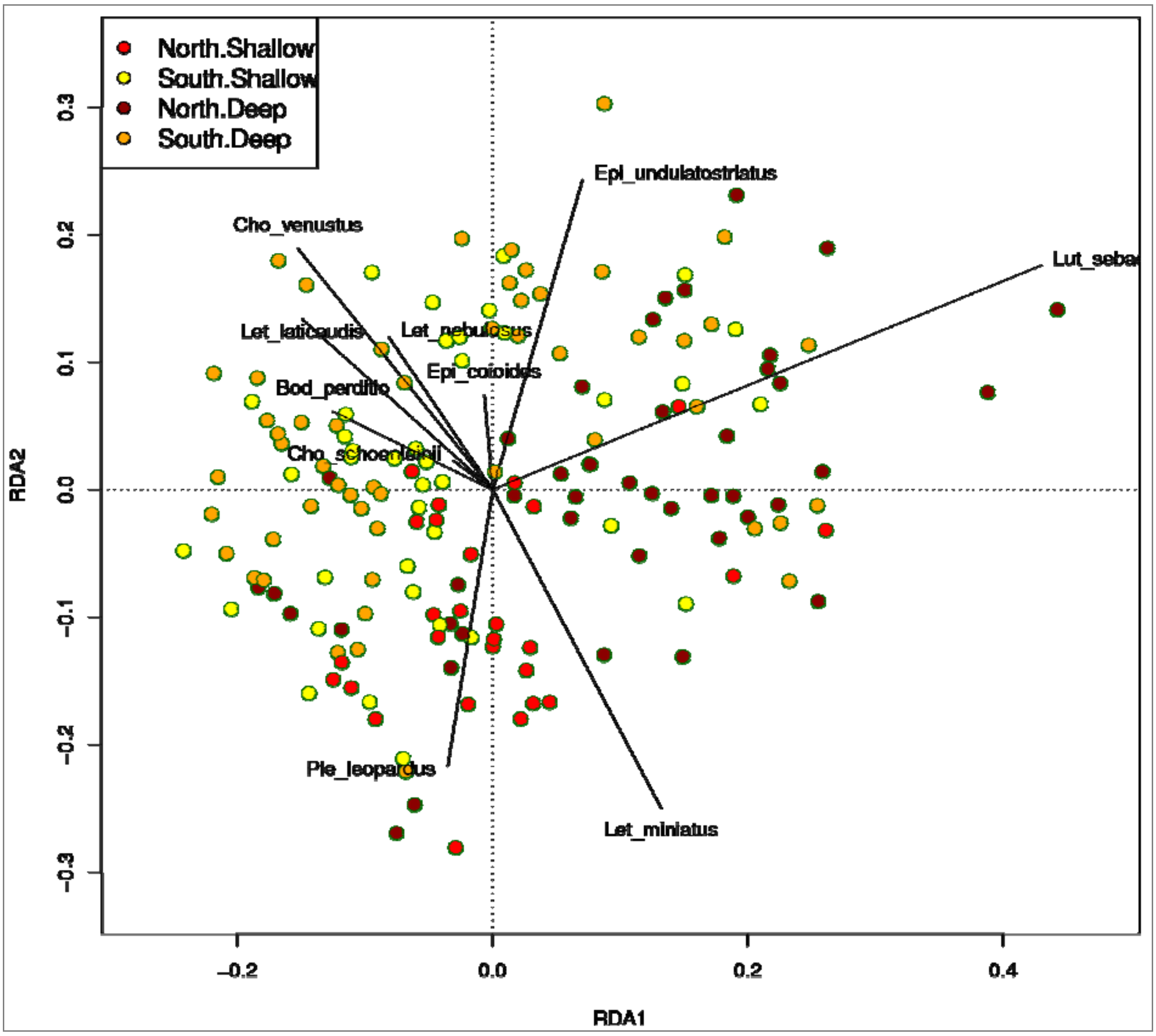


Figure 24. Location and depth associations of highly sought after species: redundancy analysis principal components biplot showing the joint effects of location (north-south) and depth (shallow-deep) on species composition, based on highly sought after species species that occur at ten or more sites. The effects were adjusted for habitat. There were differences in species composition due to both location and depth and there is also an interaction effect with a stronger depth effects in the north than the south.

(A key to abbreviations used for species names is provided in Appendix 10.)

Seasonal variability in fish communities

A diverse range of species showed a change in abundance between trips in February 2007 and August 2007, with no consistent pattern of increases or decreases in abundance (Figure). Of the highly targeted species, Venus tuskfish (*Choerodon venustus*) and spangled emperor (*Lethrinus nebulosus*) were more abundant in trip 2 samples, while coral trout (*Plectropomus leopardus*) and grass emperor (*Lethrinus laticaudis*) were more abundant in trip 1 (Figure). Further sampling would be required to determine if this was a consistent, seasonal pattern or longer term trend in the fish communities.

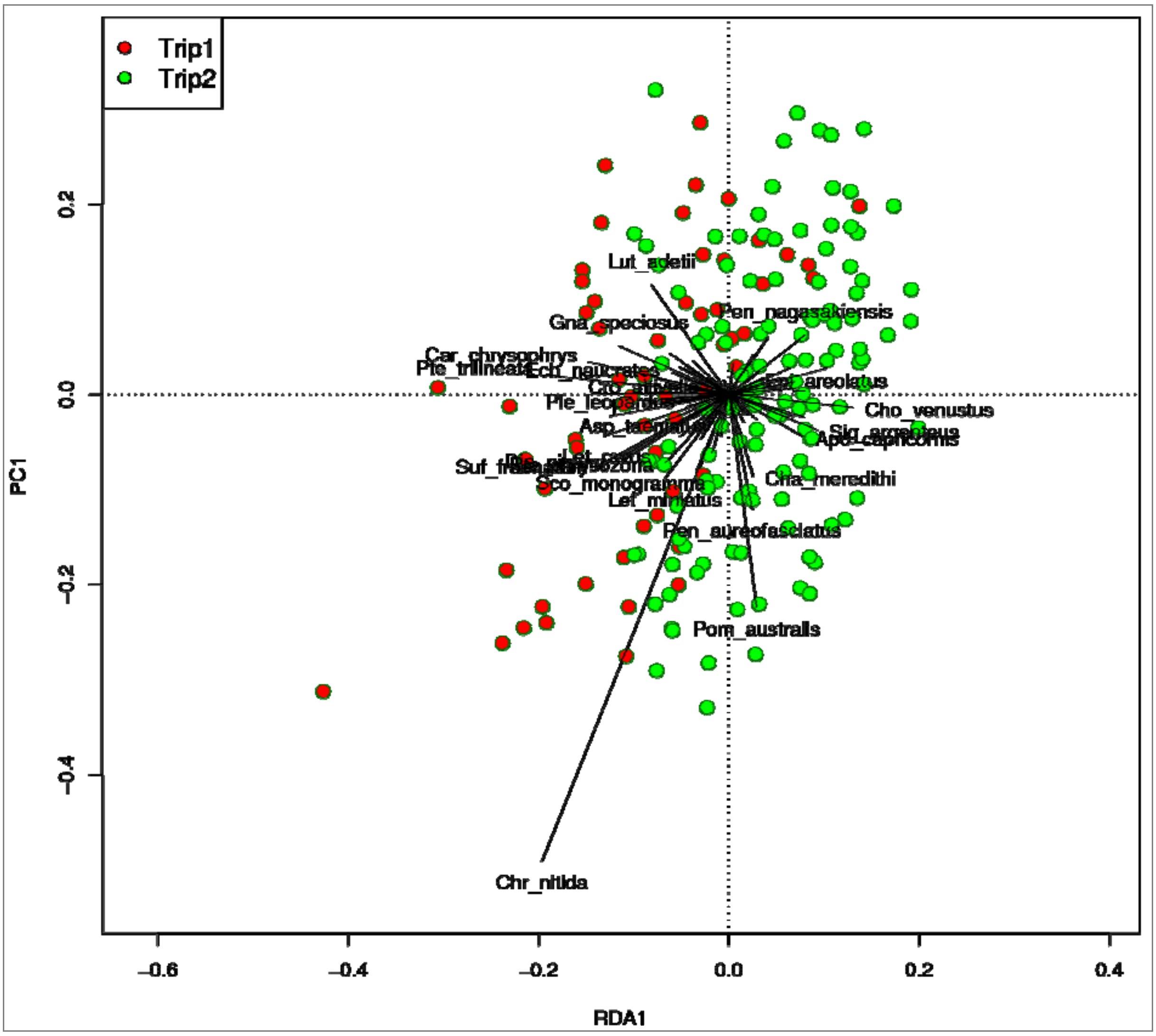


Figure 25. Influence of trip on all species data: redundancy analysis principal components biplot showing the effects of trip on species composition, based on all species that occur at ten or more sites. The effects are adjusted for north-south, depth and habitat. The 25% longest species vectors are labeled on the plot. There were clear differences in abundances of several species between the trips.

(A key to abbreviations used for species names is provided in Appendix 10.)

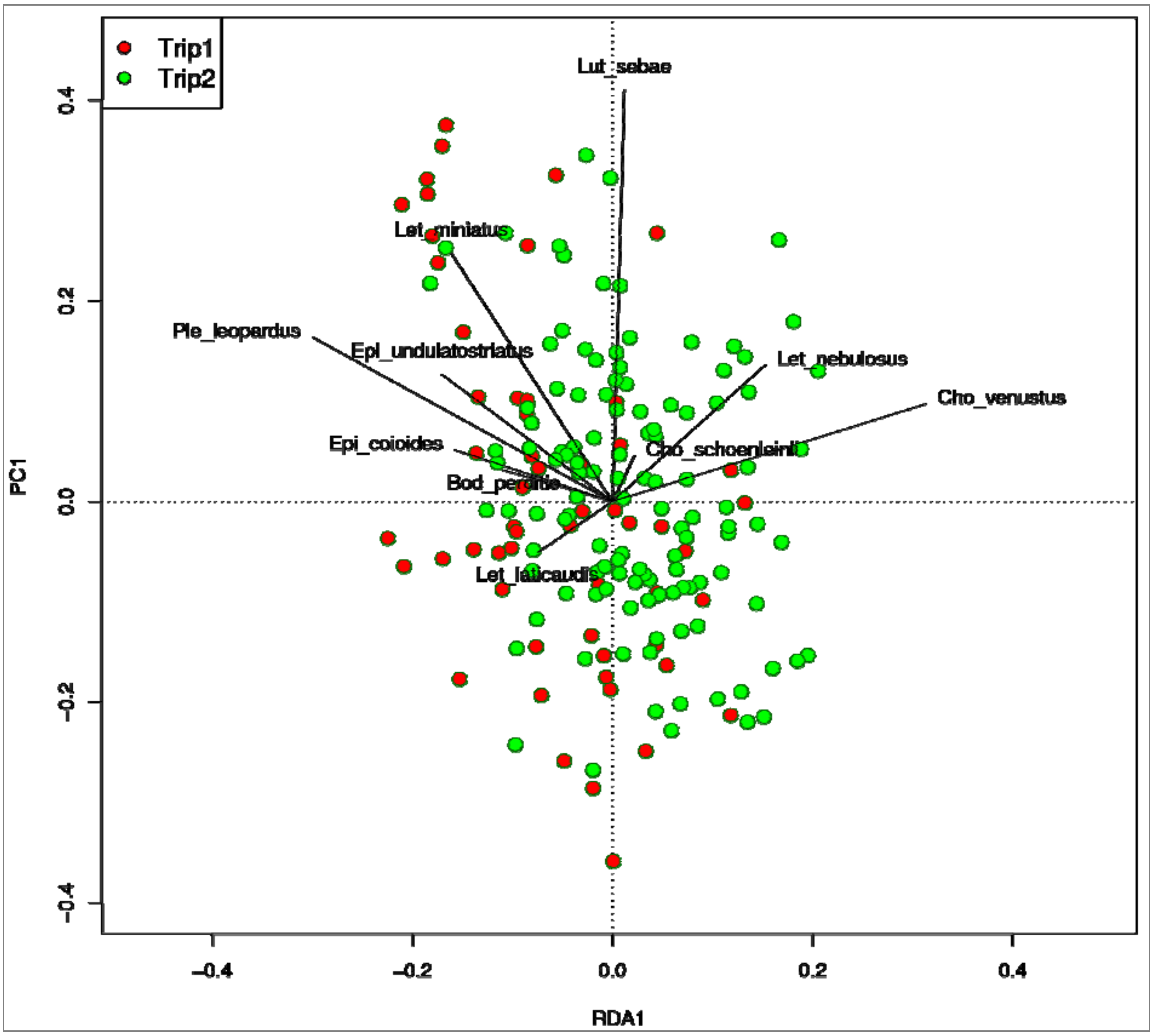


Figure 26. Influence of trip on highly sought after species: redundancy analysis principal components biplot showing the effects of trip on species composition, based on the highly targeted species that occur at ten or more sites. The effects were adjusted for north-south, depth and habitat. There were clear differences in abundances of several species between trips.

(A key to abbreviations used for species names is provided in Appendix 10.)

Short term temporal variabilityand sampling precision in the fish communities sampled

BRUVS deployments that were duplicated on short temporal scales (hours to days) revealed noticeable depth and habitat class differences in many paired samples. This suggested extreme patchiness of the seafloor habitats and topography, making it very difficult to resample a particular location and habitat precisely (Appendix 9**Error! Reference source not found.**). As indicated in the Note below, these differences were deemed to not have a significant influence on the outcome of analyses and hence repeated visits are regarded as effectively independent.

Note on the Analysis of Repeat Surveys:

An inspection of the data shows some consistent patterns in the repeated survey points on trip 2. There were 51 such repeat visits.

FigureFigure 23 shows the depths of BRUV shots against the time of the survey. Pairs of points attempting to survey the same location are linked by straight lines. Some systematic patterns are apparent in the depths of linked points, which are likely to be mainly the effect of movements in tide between first and second visit.

Figure 24 shows the log-ratio of the indices of total abundance (measured by the sum of MaxN) for visits 1 and 2 to the same GPS way point, against the time gap in hours between visits. There were three clearly defined clusters of time gaps, and the median log-ratios are shown on the figure as well by a dot and horizontal line. The median time gaps for these three groups are shown in Table 4.

For those visits made relatively soon after each other (group 1) the median log ratio was slightly positive, indicating a drop in abundance index on the second occasion, possibly due to a satiety effect. The other two time gaps had median log-ratios slightly lower than zero, suggesting the contrary. However, statistical analysis failed to show any significance in these apparent effects, even allowing for other possible explanatory variables such as depth, zone and habitat classes. For purposes of analysis, we therefore regard repeat visits as effectively independent.

Table 4. Median and range of time gaps, in hours, between visits to the same GPS way points.

Group	Median (hrs)	Range in time gaps (hrs)
1	2.62	2.08 – 5.38
2	18.55	17.53 – 19.92
3	95.88	95.21 – 95.80

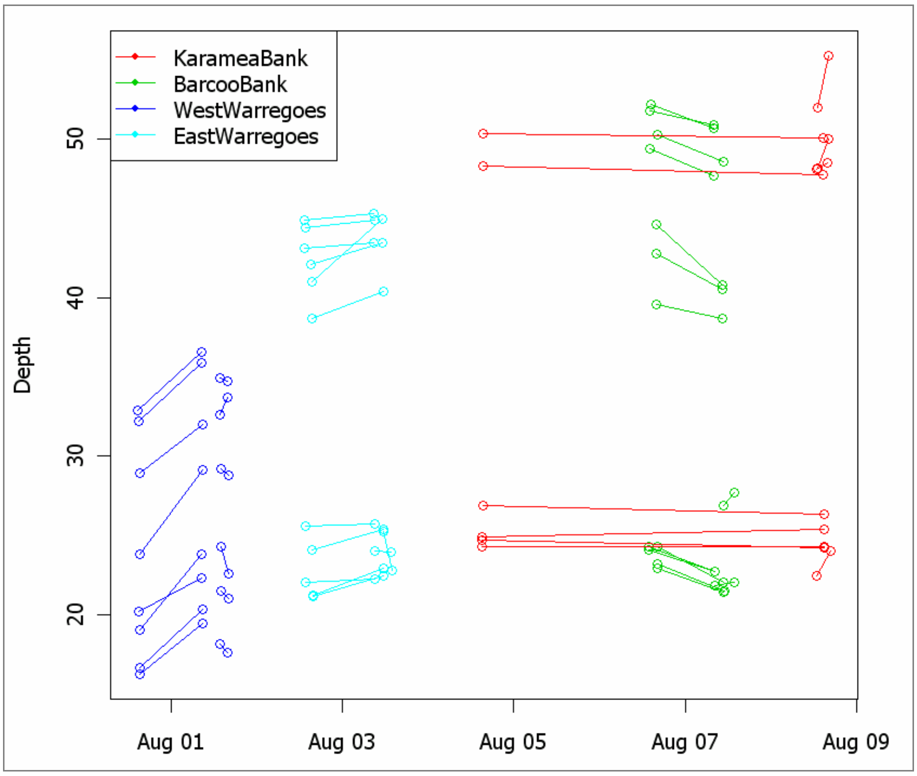


Figure 27. Times of repeat BRUV shots on trip 2, showing links, depth and location.

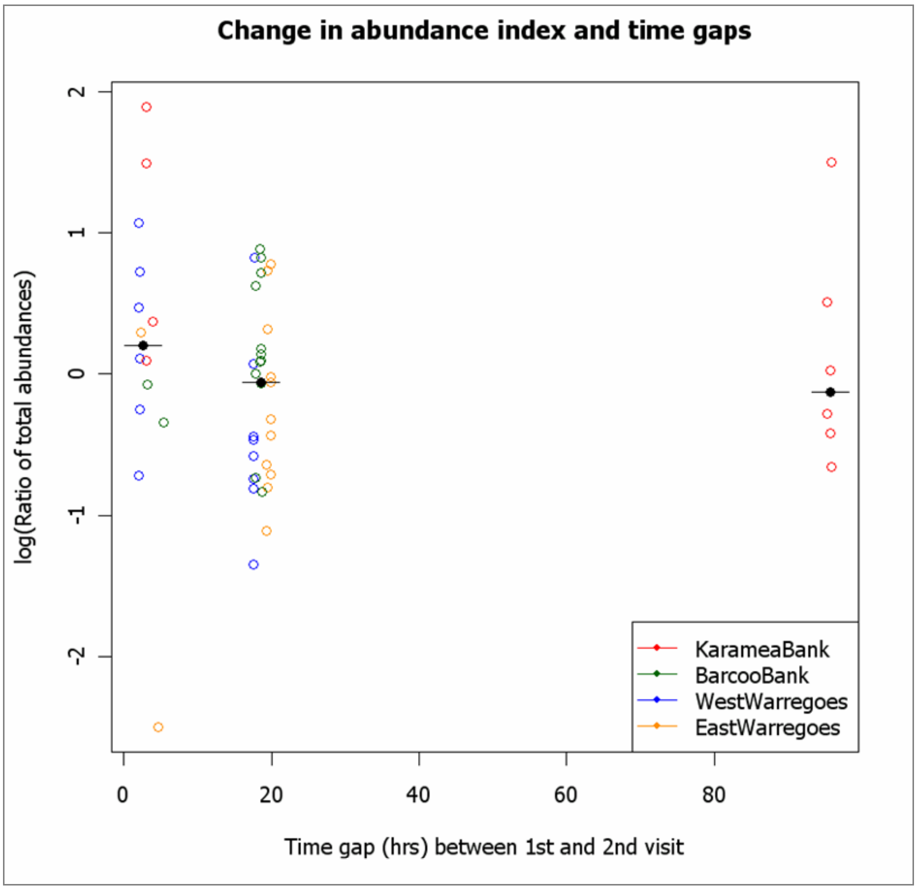


Figure 28. Ratio of first to second abundance index for visits to the same GPS way point, (log scale), and time gaps (in hours) between visits.

Effects of zoning (closure to fishing) on fish communities

Since several of the explanatory variables were not completely under experimental control, here we consider aspects of the efficiency of the resulting design that the survey achieved.

Table 5 shows the factor replications for the design, that is, the number of times each combination of the five factors was sampled. Since the primary focus of the study was to contrast blue and green zones, the most import comparison was of the left side, (four columns) of the table with the right.

The design shows some obvious imbalance, for example the ‘rubble’ areas were more frequently visited in the green zone than in the blue (13 versus 2 in Trip 1 and 14 versus 2 in Trip 2). The ‘coral’ areas were also much more frequently visited in the second trip than in the first. These imbalances may have been unavoidable because of the topography of the regions, but reduce the efficiency of the comparison of green and blue zones.

Table 5. Factor replications for the survey design.

		Blue				Green			
		North		South		North		South	
		Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
Trip 1	***Coral***	0	0	3	3	2	1	2	0
	Garden	4	6	3	4	0	6	0	3
	Rubble	0	0	0	2	0	2	0	11
	Sand	0	3	0	0	0	2	0	1
Trip 2	***Coral***	14	0	13	0	15	0	11	0
	Garden	0	12	5	9	0	8	0	9
	Rubble	1	0	0	1	1	0	5	8
	Sand	1	2	0	3	0	9	0	1

Notes on Survey Design:

Note that the Habitat factor partly subsumed the SD factor in that the 'Shallow' areas were largely confined to the top of the shoal, and hence predominantly 'Coral', and the other three habitat classes were mostly in the 'Deep' areas. This means that it may be difficult to separate the effects of SD and Habitat and having both in the same model *may* be unnecessary.

The classical efficiency of the experiment with respect to the green/blue zone comparison may be gauged by the squared canonical correlation (which in this one degree of freedom case is identical to the multiple correlation coefficient) between the green/blue indicator variable and the model matrix for all combinations of the other factors. The complement of this squared correlation, usually expressed as a percentage, is the efficiency of the design. For this realised design these efficiencies are shown in Table 6.

Table 6. Classical efficiencies of the green/blue comparison for Trips 1 and 2 separately and combined.

	Trip 1	Trip 2	Trips 1 and 2
Efficiency of green/blue comparison	60.8%	82.3%	75.6%

These are 'classical' efficiencies in that they refer to the efficiency relative to a classical analysis of variance model. Typically, the models we fitted were not ordinary least squares models but were generalized linear models and their efficiencies will be affected by the working weights. They are, however, entirely indicative of the situation.

The inefficiency of the design does not necessarily invalidate the inferences drawn from it. Their main effect is to reduce the effective replication, that is, the real information content of the data.A more subtle concern, however, is that if terms are omitted from the design these efficiencies will change, *possibly* leading to invalid inferences. Some care needs to be exercised in omitting terms simply because they are non-significant, as this may lead to attributing an effect to the green/blue comparison that is partly due to the imbalance in the experiment with respect to the omitted factors.

Analysis based on the aggregates of highly sought after reef dwelling species

In order to assess the most direct and general effect of fishing, analysis was performed based on the aggeregate *MaxN* for what we considered to be the most highly sought after reef dwelling species (species listed in Appendix 5). For this a total abundance index, as measured by the sum of `MaxN` over these species, was analysed.

A natural starting model for a count response was a Poisson log-linear regression model, but initial testing showed appreciable overdispersion relative to the Poisson model. We could, however, adequately account for this overdispersion using a Negative Binomial model, also with a log link.

The initial model we considered used predictors Trip, NS, SD, Habitat and GB, together with all two-way interactions between them. Screening the terms using the standard AIC criterion led to a model with the following significances for the non-marginal terms:

```
Single term deletions
Model:
T1Abun ~ Trip + NS + SD + habitat + GB + Trip:SD + Trip:habitat +
    NS:habitat + SD:habitat
             Df     AIC     LRT   Pr(Chi)
<full model>     994.37
GB            1 1035.98   43.60   <0.0001
Trip:SD       1  997.25    4.87   0.02731
Trip:habitat  3  996.85    8.48   0.03708
NS:habitat    3  994.86    6.48   0.09039
SD:habitat    3  998.27    9.90   0.01946
```

The most significant term was the contrast between green and blue zones. The interaction term, NS:habitat, raised the AIC criterion only slightly if omitted and was non-significant at the 5% level. Re-fitting the model omitting this term and testing again showed that the underlying main effect, NS, was also non-significant, and could also be removed. This led to a simplified model where all terms were justified both in the AIC and in the statistical significance sense:

```
Single term deletions
Model:
T1Abun ~ Trip + SD + habitat + GB + Trip:SD + Trip:habitat +    SD:habitat
             Df     AIC     LRT   Pr(Chi)
<full model>     993.06
GB            1 1038.61   47.55  <0.00001
Trip:SD       1  996.35    5.29  0.021460
Trip:habitat  3  995.46    8.40  0.038372
SD:habitat    3  998.40   11.35  0.009987
```

A formal likelihood ratio analysis of deviance showed that neither adjustment to the model led to any significant omission of terms.

```
Likelihood ratio tests of Negative Binomial Models

Response: T1Abun
Model
1 Trip + SD + habitat + GB + Trip:SD + Trip:habitat + SD:habitat (theta = 5.997494)
2 Trip + NS + SD + habitat + GB + Trip:SD + Trip:habitat + NS:habitat + SD:habitat (theta =
6.529534)
3 (Trip + NS + SD + habitat + GB)^2 (theta = 7.236158)
  Resid. df    2 x log-lik.   Test    df LR stat.   Pr(Chi)
1       172       -965.0567
2       168       -958.3742 1 vs 2     4 6.682421 0.1536532
3       160       -949.2236 2 vs 3     8 9.150678 0.3297450
```

While the interaction terms were significant, the main effects were the most appreciable and the main influences in the model were evident from the partial effects of these main effects. These are shown in the plot in Figure 25. These diagrams show the additive components in the log scale due to each of the components in the model, omitting interactions. The ‘habitat’ component was on a separate scale due to the obvious depauperate nature of the ‘sand’ category. The other three panels were on the same (vertical) scale to aid comparison. The final panel, ‘green/blue’ was the key comparison and was free of interactions. The points on the panels are the partial residuals, giving some idea of the variability around the result, which is, of course, considerable. Nevertheless, the green/blue component was the effect showing highest non-marginal significance.

On the log scale the estimate of the 'green/blue' effect was 0.69, with a 95% confidence interval (0.50, 0.88). On the natural scale, this translated into an estimate of 2.00, with confidence interval (1.65, 2.42). Thus, the median effect was estimated to be approximately a doubling of the median T1 abundance in the green zone over the blue, with confidence interval 65% to 142% possible increase.

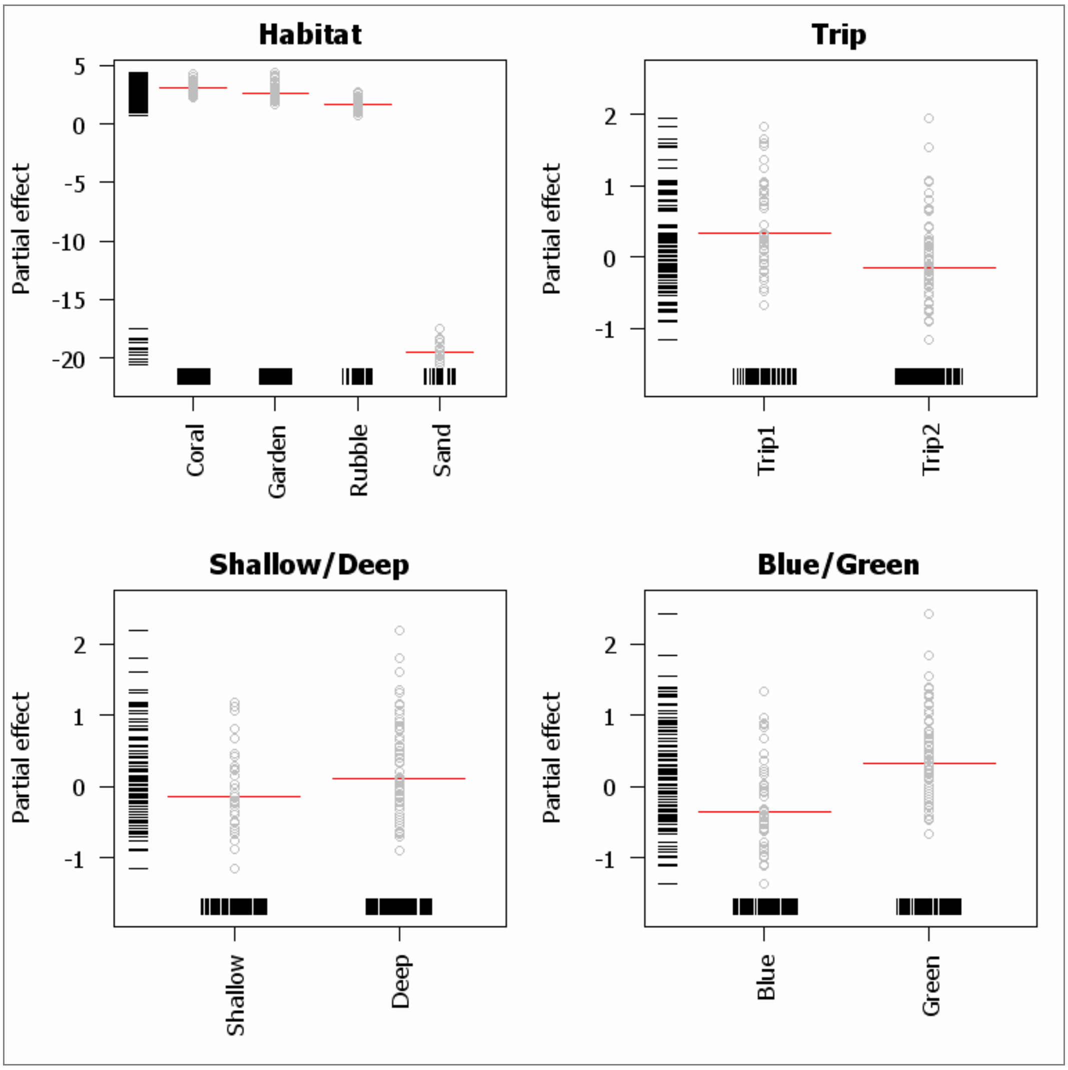


Figure 29. Partial main effects for the negative binomial model for T1 aggregate abundance in the log scale.

Data driven aggregate selection

The disadvantage of the analysis based on the aggregates of '*highly sought after reef dwelling species*' was that it made a subjective judgement *a priori* of the species that were likely to have been most directly afftected by fishing. An alternative approach was a data driven selection process that considered "*which suite of species shows the greatest difference between green and blue Zones?*" It is therefore independent of any prejudgement of which species might be most affected by fishing, however it is an investigative or hypothesis generating process only.

Notes on Data Driven Aggregate Selection:

T1 abundance was a weighted sum of the abundance indices of all species where the weights for the species in the T1 group were one, and zero for the others.

Rather than select the species to aggregate a priori, we could pose the question in an inverse way and ask "Which weighted sum of species abundances would show the greatest difference between green and blue zones?" This data driven selection process may give useful insights, but remains only an investigative tool and a hypothesis generating process.

Rather than limit to weights exactly 0 or 1, we allowed the weights in the eventual weighted sum to range anywhere between these values. This allowed the optimisation process to determine the degree to which any given species was included or excluded in the eventual aggregate. Species receiving weights close to 1 were then regarded as showing, in their aggregate, the clearest distinction between green and blue zones.Note that the selection of species with weights close to zero may also show a reasonably clear distinction between green and blue zones, but in the opposite direction, and weaker.

Comparison of green/blue zones and weight selection

The analysis protocol was as follows:

The weighted sum of abundance indices and it's logarithm were calculated

Using this as the response, an analysis of variance to test for the main effect of GB, allowing for (Trip+Habitat+SD)^2 (in Wilkinson-Rogers notation) was calculated, i.e. the same model as we arrived at in the T1 abundance model.

We then chose the weights to maximise the resulting F-statistic.

Note that this process was neutral on whether the weighted sum showed an increase or decrease in the green zone, so the onus is then to discover which it was. The weighted sum with complementary weights should then show either no difference or a smaller difference in the opposite direction.

Omitting NS from the model, in accordance with what was observed in the T1 Abundance case, placed more importance on generalization to other spatial locations.

Rather than try to optimise weights for all 252 species in the data base, we used only those species that were seen at a minimum number of BRUV stations, and we arbitrarily chose 10 as this minimum number. This brought the number of species for this analysis down to 93, but included many of the important target species.

The optimisation process resulted in a clear distinction between species that should be included and excluded from analysis. A histogram of the weights is provided at Figure 26. Table 7 shows the species groups formed by rounding the weights to one decimal place. In this table, species coloured red were in the primary target group, T1, those coloured blue belonged to a secondary target group, T2, and those coloured green to a group T3 that were not targeted, but may be caught in line fishing. All others were non-target species, unlikely to be caught in line fishing. The data driven aggregate selection analyses suggested that many of the species that we had considered to be 'high sought after' were most affected by the zoning. These species included, red throat emperor (*Lethrinus miniatus*), red emperor (*Lutjanus sebae*) Venus tuskfish (*Choerodon venustus*, grass emperor (*Lethrinus laticaudis*) and golden spot hogfish (*Bodianus perditio*).

Table 7 shows the full list of species selected by the data driven selection, with the full analyses detailed in the following section.

In addition, Table 8 shows frequency of species in the 'rounded weight' groups in each of the primary target groups, T1, T2, and T3, and the non-target species.

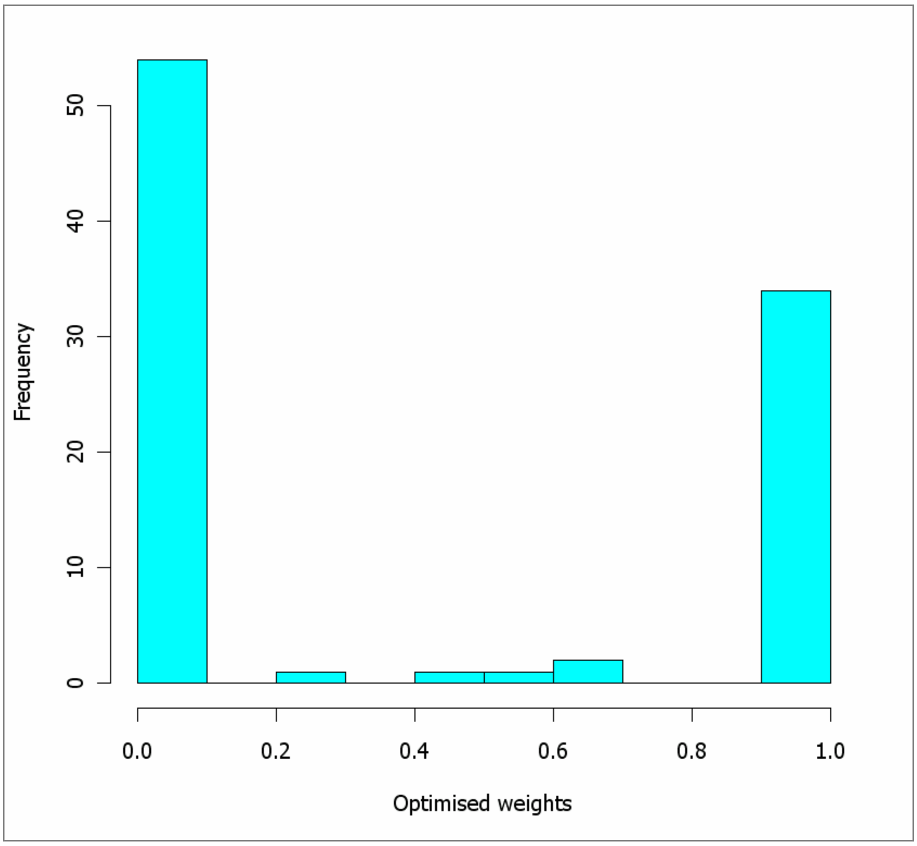


Figure 30. Histogram of the aggregation weights.

Table 7. Species groups as determined by the data driven selection process.

(A key to abbreviations used for species names is provided in Appendix 10.)

Wt	Group	Species
High	T1	Bod_perditio, Cho_venustus, Epi_coioides, Epi_undulatostriatus, Let_laticaudis, Let_miniatus, Let_nebulosus, Lut_sebae
	T2	Epi_fasciatus, Lut_russelli
	T3	Car_albimarginatus, Car_amblyrhynchos, Chi_punctatum, Epi_areolatus, Gal_cuvier, Gym_audleyi, Let_ravus, Let_rubrioperculatus, Lut_bohar, Suf_fraenatum, Tae_meyeni
	NT	Aca_olivaceus, Cha_duboulayi, Chr_nitida, Cir_punctatus, Lep_cyanopleura, Nas_tuberosus, Nem_furcosus, Par_cyclostomus, Par_heptacanthus, Par_multifasciatus, Pom_australis, Pri_microlepidotus, Sca_flavipectoralis
Mid	T1	
	T2	
	T3	Lut_vitta
	NT	Nas_annulatus, Pen_nagasakiensis, Pom_semicirculatus, Sco_monogramma
Low	T1	Cho_schoenleinii, Ple_leopardus
	T2	Arg_spinifer, Car_chrysophrys, Car_coeruleopinnatus, Car_fulvoguttatus, Car_gymnostethus, Dia_pictum, Gna_speciosus, Lut_adetii, Lut_carponotatus, Sco_queenslandicus, Ser_lalandi, Ser_rivoliana
	T3	Aba_stellatus, Cep_boenak, Cro_altivelis, Dip_bifasciatum, Ech_naucrates, Ple_flavomaculatus, Ple_gibbosus, Sym_nematophorus, Tha_lunare
	NT	Aca_xanthopterus, Aip_laevis, Amb_aureus, Apo_capricornis, Asp_taeniatus, Cae_cuning, Cen_tibicen, Cha_kleinii, Cha_lineolatus, Cha_meredithi, Cha_rainfordi, Cha_trifascialis, Che_rostratus, Cor_altivelis, Cor_chrysozonus, Das_reticulatus, Hen_acuminatus, Lab_dimidiatus, Nas_brevirostris, Nas_unicornis, Par_barberinoides, Par_xanthozona, Pen_aureofasciatus, Pen_paradiseus, Pom_nagasakiensis, Pte_chrysozona, Pte_marri, Pte_trilineata, Sca_schlegeli, Sig_argenteus, Zan_cornutus

Table 8. Numbers of species in aggregation weight and target groups.

Rounded Weights	0.0	0.3	0.5	0.6	1.0
T1	2	0	0	0	8
T2	12	0	0	0	2
T3	9	0	0	1	11
Non-target	31	1	1	2	13

The analysis of variance table with this weight selection is then:

```
              Df Sum Sq Mean Sq F value    Pr(>F)
Trip           1  1.667   1.667  3.9174 0.0493837
Trip:habitat   6 10.857   1.810  4.2516 0.0005095
Trip:SD        2  1.354   0.677  1.5901 0.2068857
habitat:SD     3  1.710   0.570  1.3390 0.2633662
GB             1 18.627  18.627 43.7641 <0.000001
Residuals    172 73.206   0.426
```

For this analysis the coefficient for GB (Green) is 0.6987109 (in the log scale) indicating that for this optimal weights the effect of the green zone was to increase the measure to exp(0.6987109) = 2.0111585 its blue zone value, that is, by about 101%.

Using the complementary set of weights shows a median aggregate abundance measure in the green zone of about 65% of what it was in the blue. It is formally significant, but much less so than for the direct weights.

Notice that in both cases these hypothesis tests are deliberately biased and therefore technically invalid, but nevertheless they remain useful as an informal guide.

For presentation purposes we omitted Habitat and NS in the graphical presentations below and showed the results as boxplots conditioned on the combinations of SD and Trip. Figure 27 shows the result for the direct weights, that is, essentially the group of species with weights near unity, which indicated a clear positive effect in favour of the green zones. Using complementary weights, (i.e. those species with weights close to zero), shows a smaller reduction of the green zone relative to the blue (Figure 28).

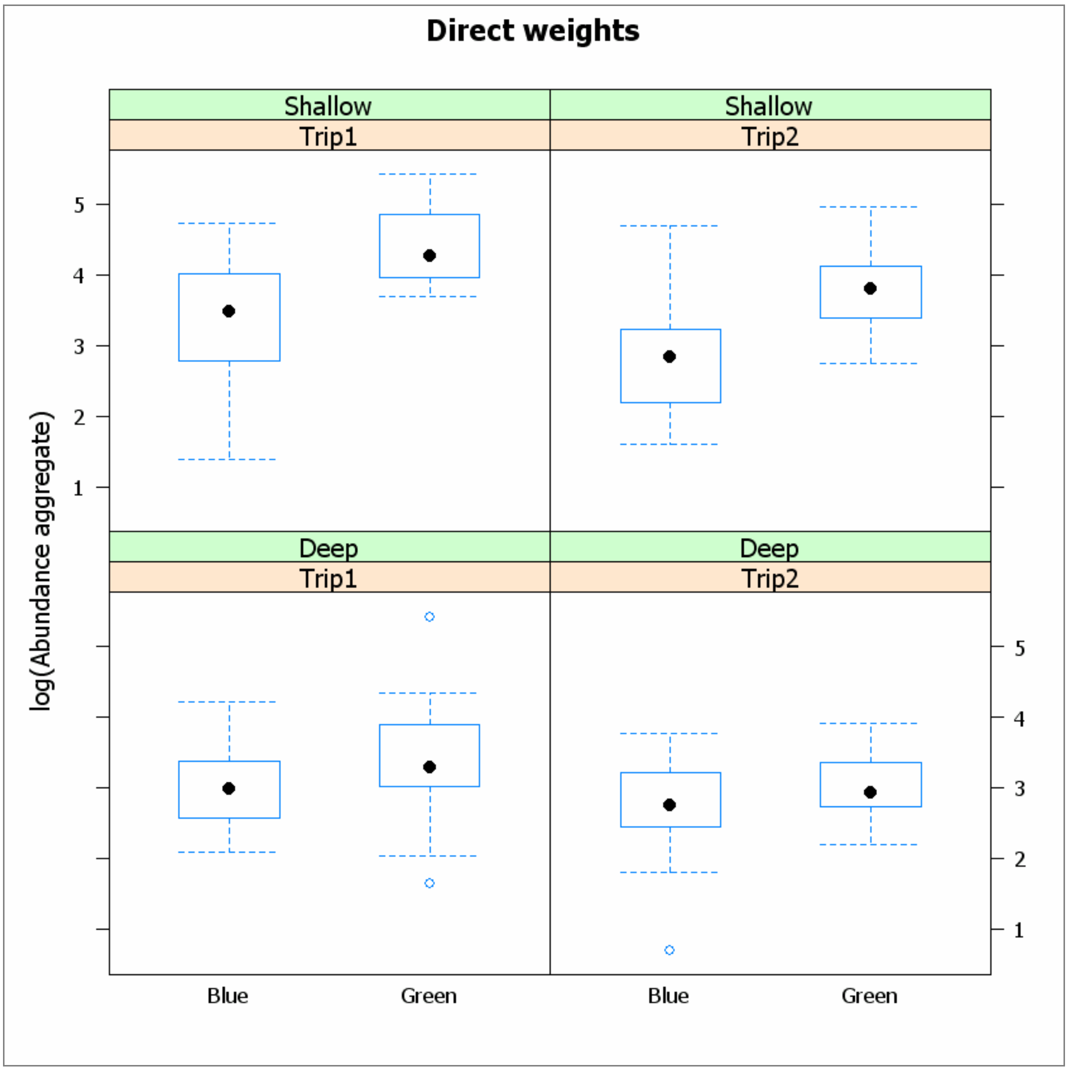


Figure 31. Boxplots for the aggregated abundance index using direct weights.

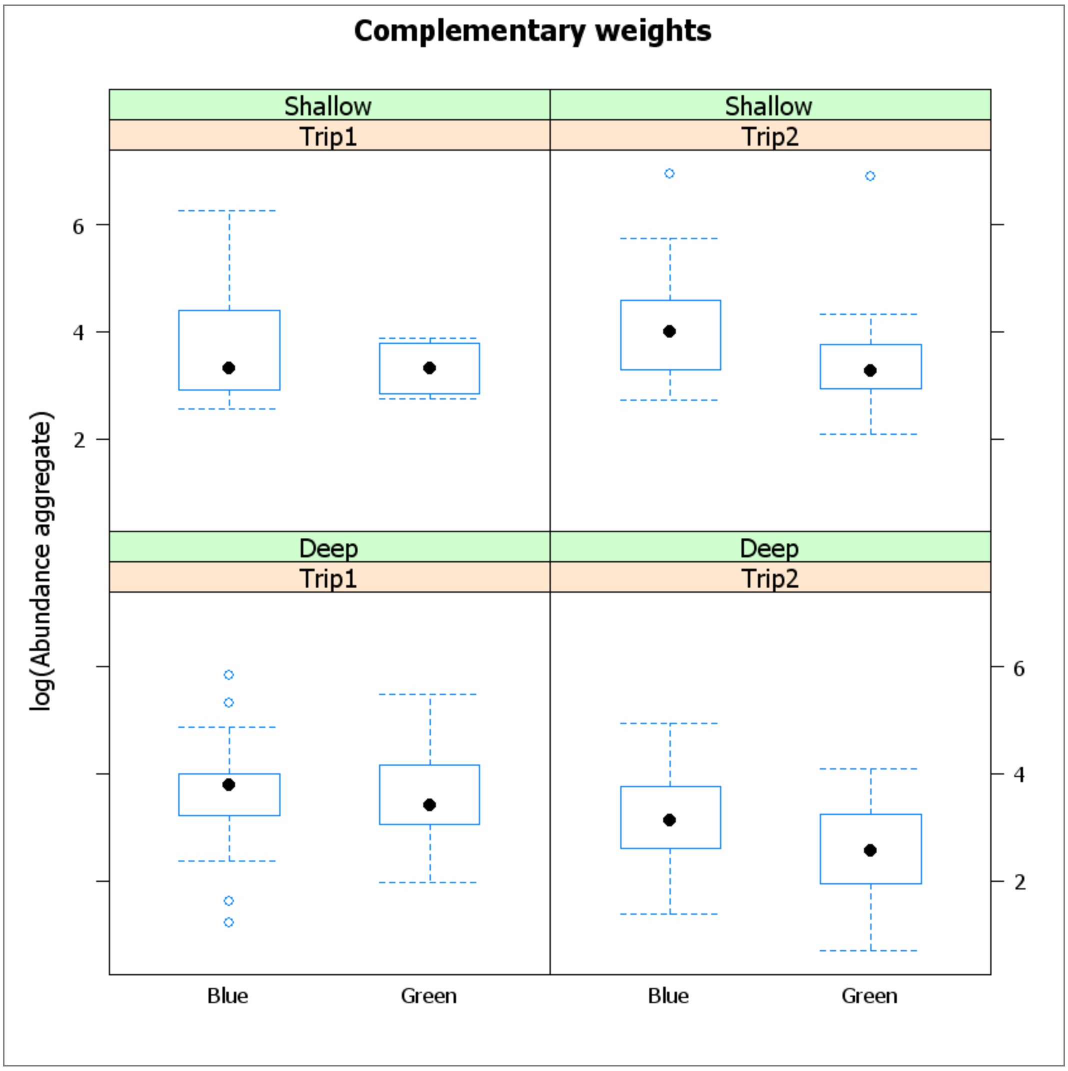


Figure 32. Boxplots for the aggregated abundance index using complementary weights.

Uni- and multivariate analysis of the effects of zoning on individual fish species

The abundances of all species were analysed using univariate and multivariate approaches to further assess blue-green differences. Fish were broken into targeted and non-targeted species and only species occurring on at least ten sampling site-occasions were considered. There were ten targeted and 83 non-targeted species that satisfied that condition. The effects of habitat (four classes), location (north-south), depth (shallow-deep) and trip were controlled for in all analyses.

Univariate analyses assessed green-blue (GB) differences having adjusted for habitat, location, depth and trip using generalised linear models with a log link function and variance proportional to the mean.

All ten targeted species had estimated higher levels in green zones than blue zones. The green/blue ratios varied from range from 1.1 to 11.9 (geometric mean = 2.8) and five of the ten species showed significant increases ($P<0.05$) (Table 9); these were *Bodianus perditio, Choerodon venustus, Lethrinus miniatus, Lethrinus nebulosus* and *Lutjanus sebae.*

The 83 non-targeted species varied greatly between green and blue zones. The green/blue ratios varied from 0.05 to 38.5 (geometric mean=1.01) and 33 of the 83 species showed significant change ($P<0.05$) with eighteen increasing and fifteen decreasing (Table 9).

Table 9. Abundances of fish species and blue-green effects. *t* values ≥2 and ≤-2 correspond to a significance level of approximately <0.05.

(A key to abbreviations used for species names is provided in Appendix 10.)

Species	Blue	Green	raw-Ratio	est-Ratio	t	NT-T1
Aba_stellatus	1.13	1.02	0.9	0.86	-1.03	NT
Aca_olivaceus	0.16	0.28	1.77	2.32	2.29	NT
Aca_xanthopterus	0.62	0.48	0.78	0.88	-0.38	NT
Aip_laevis	0.62	0.58	0.93	0.98	-0.1	NT
Amb_aureus	0.24	0.09	0.39	0.49	-1.68	NT
Apo_capricornis	17.44	0	0	0	-0.01	NT
Arg_spinifer	0.26	0.13	0.52	0.33	-5.96	NT
Asp_taeniatus	0.12	0.08	0.67	0.65	-0.72	NT
Bod_perditio	0.08	0.14	1.84	3.13	3.28	T1
Cae_cuning	0.53	0.39	0.74	0.83	-0.52	NT
Car_albimarginatus	0.01	0.26	22.94	19.35	3.08	NT
Car_amblyrhynchos	0.01	0.32	28.44	31.05	3.23	NT
Car_chrysophrys	0.81	0.11	0.14	0.15	-3.22	NT
Car_coeruleopinnatus	0.18	0.1	0.57	0.76	-0.5	NT
Car_fulvoguttatus	2.06	0.61	0.3	0.32	-3.06	NT
Car_gymnostethus	2.01	0.01	0.01	0.01	-2.16	NT
Cen_tibicen	0.17	0.07	0.43	0.59	-1.33	NT
Cep_boenak	0.16	0.04	0.26	0.28	-2.34	NT
Cha_duboulayi	0.03	0.12	3.67	4.6	3.34	NT
Cha_kleinii	0.24	0.15	0.66	0.76	-0.87	NT
Cha_lineolatus	0.09	0.18	1.95	2.64	2.07	NT
Cha_meredithi	1.1	0.82	0.75	0.77	-1.81	NT
Cha_rainfordi	0.51	0.37	0.73	0.79	-0.83	NT
Cha_trifascialis	0.1	0.06	0.61	0.64	-1.74	NT
Che_rostratus	0.17	0.05	0.31	0.3	-2.78	NT
Chi_punctatum	0.09	0.11	1.26	1.31	0.57	NT
Cho_schoenleinii	0.08	0.09	1.18	1.21	0.37	T1
Cho_venustus	1.63	2.37	1.46	1.43	4.06	T1
Chr_nitida	8.09	14.19	1.75	2.35	2.71	NT
Cir_punctatus	0.22	0.85	3.76	6.19	3.56	NT
Cor_altivelis	0.45	0.38	0.85	0.9	-0.41	NT
Cor_chrysozonus	0.15	0.14	0.99	1.13	0.28	NT
Cro_altivelis	0.18	0.06	0.34	0.44	-2	NT
Das_reticulatus	0.22	0.09	0.41	0.43	-1.73	NT

Species	Blue	Green	raw-Ratio	est-Ratio	t	NT-T1
Dia_pictum	0.81	0.52	0.64	0.69	-1.19	NT
Dip_bifasciatum	0.28	0.19	0.66	0.66	-1.13	NT
Ech_naucrates	0.18	0.22	1.2	1.21	0.57	NT
Epi_areolatus	0.09	0.36	4.01	3.54	2.45	NT
Epi_coioides	0.07	0.14	2.14	1.75	1.09	T1
Epi_fasciatus	0.15	0.25	1.69	1.94	2.45	NT
Epi_undulatostriatus	0.19	0.31	1.62	1.62	1.55	T1
Gal_cuvier	0	0.11	Inf	Inf	0.01	NT
Gna_speciosus	1.47	0.03	0.02	0.02	-2.59	NT
Gym_audleyi	3.29	3.97	1.21	1.22	1.7	NT
Hen_acuminatus	2.02	1.3	0.64	0.81	-0.78	NT
Lab_dimidiatus	0.25	0.37	1.5	1.55	1.49	NT
Lep_cyanopleura	0.34	1.3	3.85	4.01	2.27	NT
Let_laticaudis	0.18	0.25	1.38	1.21	0.53	T1
Let_miniatus	0.1	0.97	9.58	11.9	5.75	T1
Let_nebulosus	0.04	0.4	8.95	7.17	3.1	T1
Let_ravus	0.04	1.64	36.47	38.54	5.31	NT
Let_rubrioperculatus	0.01	0.18	15.6	21.94	2.19	NT
Lut_adetii	6.48	2.75	0.42	0.44	-2.25	NT
Lut_bohar	0.03	0.09	2.75	3.38	3.94	NT
Lut_carponotatus	0.27	0.06	0.23	0.24	-3.14	NT
Lut_russelli	0.24	0.12	0.52	0.57	-1.26	NT
Lut_sebae	0.61	2.13	3.52	3.25	4.39	T1
Lut_vitta	1.04	0.76	0.73	0.67	-1.31	NT
Nas_annulatus	0.42	0.48	1.17	1.25	0.54	NT
Nas_brevirostris	0.16	0.29	1.84	2.16	1.58	NT
Nas_tuberosus	0.58	0.74	1.27	1.59	1.68	NT
Nas_unicornis	0.08	0.1	1.31	1.69	1.24	NT
Nem_furcosus	0.17	0.26	1.53	0.99	-0.05	NT
Par_barberinoides	0.16	0.02	0.13	0.14	-4.1	NT
Par_cyclostomus	0.07	0.18	2.6	3.15	2.26	NT
Par_heptacanthus	0.37	0.63	1.7	1.39	1.31	NT
Par_multifasciatus	0.03	0.14	4.28	4.6	3.56	NT
Par_xanthozona	0.25	0.14	0.58	0.55	-1.66	NT
Pen_aureofasciatus	1.19	0.53	0.44	0.62	-1.09	NT
Pen_nagasakiensis	3.55	4.81	1.36	0.88	-0.41	NT
Pen_paradiseus	1.48	0.49	0.33	0.31	-3.02	NT

Species	Blue	Green	raw-Ratio	est-Ratio	t	NT-T1
Ple_flavomaculatus	0.11	0.03	0.28	0.3	-2.42	NT
Ple_gibbosus	0.19	0.09	0.49	0.6	-1.6	NT
Ple_leopardus	1.27	1.25	0.98	1.11	0.66	T1
Pom_australis	2.74	3.3	1.2	1.52	1.8	NT
Pom_nagasakiensis	0.84	0.39	0.46	0.45	-2.3	NT
Pom_semicirculatus	0.07	0.08	1.22	1.63	1.19	NT
Pri_microlepidotus	0.18	0.62	3.44	5.12	2.59	NT
Pte_chrysozona	5.16	2.25	0.44	0.42	-1.14	NT
Pte_marri	8.15	12.42	1.52	1.95	1.06	NT
Pte_trilineata	4.08	6.87	1.68	2.22	1.24	NT
Sca_flavipectoralis	0.07	0.08	1.22	1.5	0.65	NT
Sca_schlegeli	0.2	0.25	1.22	1.31	0.92	NT
Sco_monogramma	0.65	0.66	1.01	1.07	0.45	NT
Sco_queenslandicus	0.1	0.39	3.87	6.15	3.52	NT
Ser_lalandi	0.51	0.33	0.65	0.64	-1.02	NT
Ser_rivoliana	0.11	0.09	0.83	0.89	-0.2	NT
Sig_argenteus	2	1.22	0.61	0.72	-1.16	NT
Suf_fraenatum	0.27	0.63	2.33	2.69	4.89	NT
Sym_nematophorus	0.21	0.13	0.63	0.6	-1.45	NT
Tae_meyeni	0.06	0.05	0.92	0.94	-0.1	NT
Tha_lunare	0.81	0.3	0.37	0.4	-3.29	NT
Zan_cornutus	0.2	0.09	0.46	0.55	-2.23	NT

The multivariate analyses used partial redundancy analysis to determine the relationships between species composition and biplots were used to illustrate all results. Permutation tests were used to assess the significance of the relationships. The analyses were done for the 10 targeted species and the also for all species. The redundancy models were fitted hierarchally. The order of inclusion of terms was (1) habitat, (2) location and depth and their interaction, (3) trip and (4) green/blue. Thus each effect is adjusted for previously included terms. The numerical results are shown in Table and Table 11 and the biplots in Figures 21-26 and Figures 33-34.

All terms in the model for the 10 species of targeted fish were significant, with the strongest effects being zoning (green/blue) and habitat (Figure, Figure). The effect of zoning on the community of targeted fish is clear with all species either favouring or being neutral to the zoning (Figure). The effects of location (north-south), depth and trip were more moderate. (Figure, Figure). There was also evidence of a somewhat stronger zoning difference between northern reefs compared to southern reefs.

All terms in the model for all 93 species were significant, with the strongest effects being location (north-south) and habitat (Figure, Figure). The effect of zoning was weaker than for the targetted species, with species favouring both zonings (Figure). For the community of all fish the patterns reflect the preferences to and against the zoning (Figure). The effects of habitat, location, depth and trip vary across the species and show clear patterns for all these factors (Figure, Figure and Figure).

Table 10. Permutation tests for the ten most abundant targeted species.

	DF	SS	MS	F	R2	Pr(>F)
Habitat	3	39.79	13.26	9.06	0.112	<0.001
NS	1	10.69	10.69	7.31	0.030	<0.001
SD	1	9.02	9.02	6.17	0.025	<0.001
NS.SD	1	6.55	6.55	4.48	0.018	<0.001
Trip	1	5.68	5.68	3.88	0.016	0.003
GB	1	19.53	19.53	13.36	0.055	<0.001
GB.NS	1	6.74	6.74	4.61	0.019	<0.001
Residuals	176	257.38	1.46		0.724	
Total	185	355.41				

Table 11. Permutation tests for all species.

	DF	SS	MS	F	R2	Pr(>F)
Habitat	3	203.49	67.8	7.18	0.093	<0.001
NS	1	96.62	96.6	10.24	0.044	<0.001
SD	1	36.08	36.0	3.82	0.016	<0.001
NS.SD	1	46.42	46.4	4.92	0.021	<0.001
Trip	1	25.42	25.4	2.69	0.011	<0.001
GB	1	53.51	53.5	5.67	0.024	<0.001
GB.NS	1	54.21	54.2	5.74	0.024	<0.001
Residuals	176	1660.57	9.4		0.763	
Total	185	2176.36				

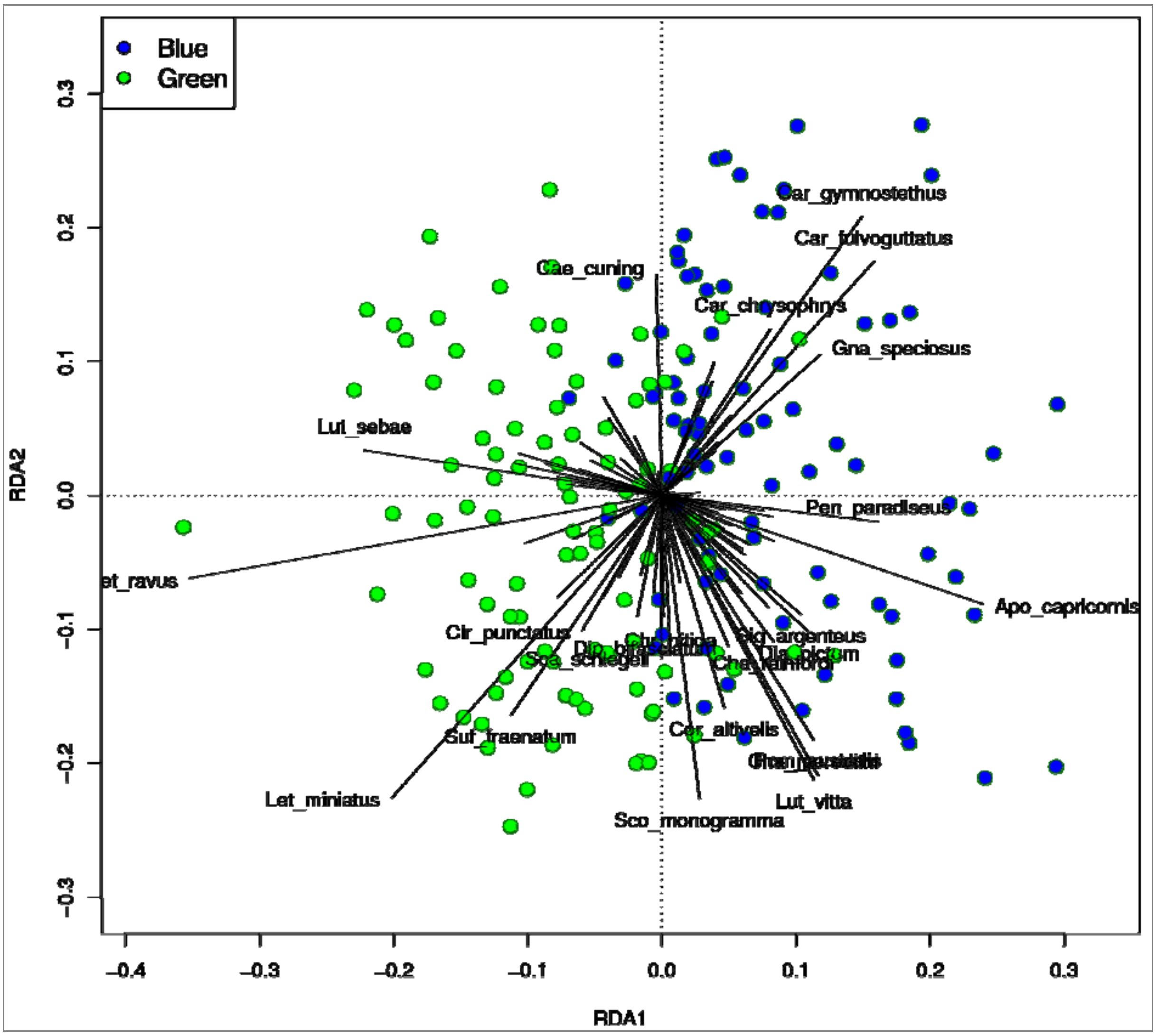


Figure 33. Influence of zoning on all species: redundancy analysis principal components biplot showing the effects of zoning (blue-green) on the species composition of the species occurring at ten or more sites. The effects are adjusted for trip, north-south, depth and habitat. The 25% longest species vectors are labeled on the plot. Unlike the case of the targeted species, individual species favour either green or blue sites.

(A key to abbreviations used for species names is provided in Appendix 10.)

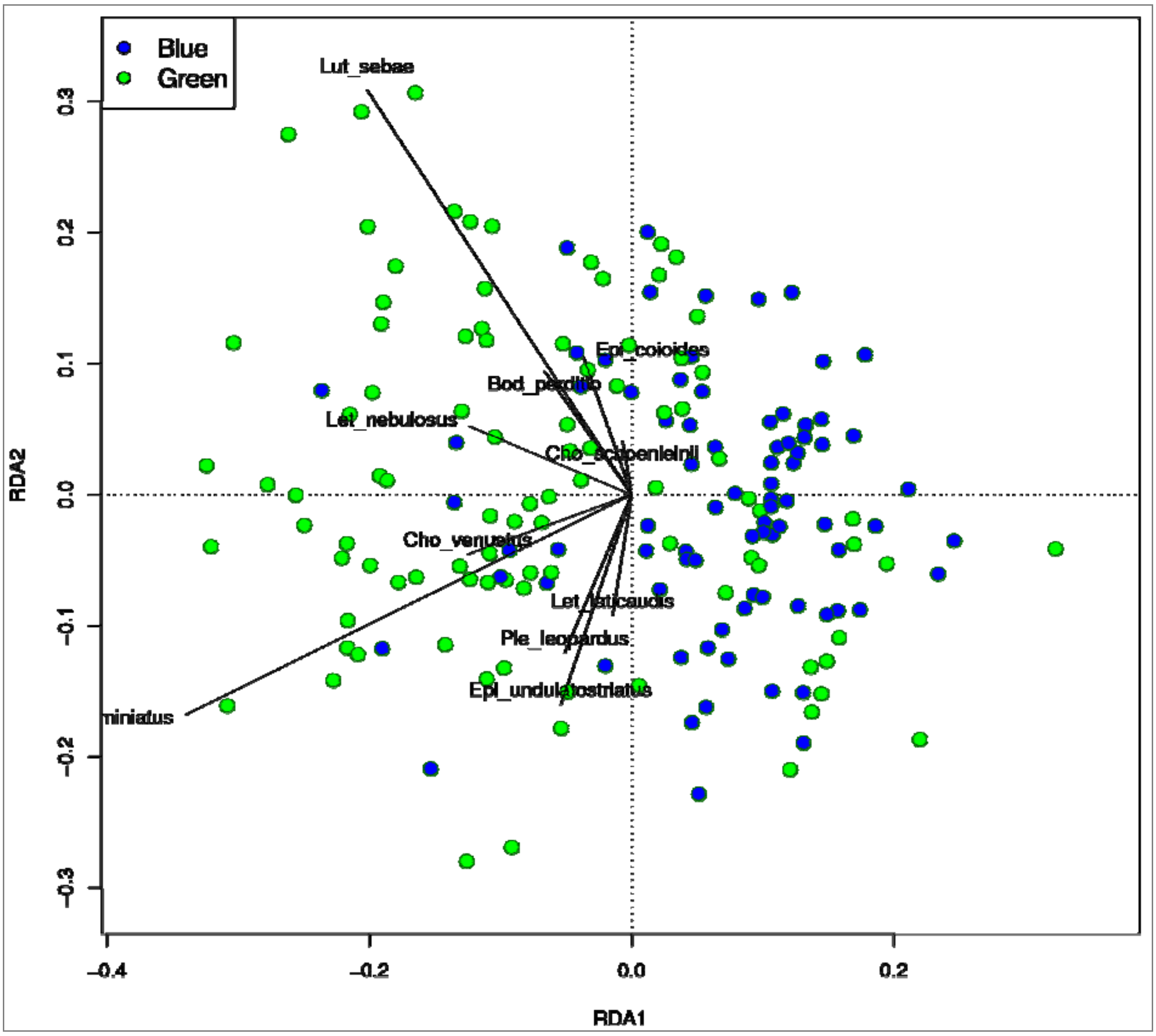


Figure 34. Influence of zoning on highly sought after species: redundancy analysis principal components biplot showing the effects of zoning (blue-green) on the species composition of the species occurring at ten or more sites. The effects are adjusted for trip, north-south, depth and habitat. There are clearly higher abundances of most species at the green sites.

(A key to abbreviations used for species names is provided in Appendix 10.)

Graphical comparison of target species abundances

The five highly sought after species shown in the statistical analyses to be significantly more abundant ($p<0.05$) in the green zone relative to the blue zone are presented graphically in Figure 35. The orders of magnitude in abundance of these species varied, with the most common being red emperor (*Lutjanus sebae*), red throat emperor (*Lethrinus miniatus*) and venus tuskfish *(Choerodon venustus)* expected to dominate the catches of fishers on these shoals. Golden spot hogfish (*Bodianus perditio)* and spangled emperor *(Lethrinus nebulosus)* although found to be in significantly greater abundance on the green zoned shoals, were considerably less abundant overall in the survey, with an average of less than one individual per BRUVS deployment at all sites.

The highly sought after species whose abundance were *not* significantly different between the blue and green zoned sites are shown graphically in Figure. The most common of these species was common coral trout (*Plectropomus leopardus*), followed by Maori cod (*Epinephelus undulatostriatus*). Estuary cod (*Epinephelus coiodes*), grass emperor (*Lethrinus laticaudis*) and black spot tuskfish (*Choerodon schoenleinii*) were less abundant, all averaging less than one individual per BRUVS deployment across all sites.

Ten other species considered to be ‘highly sought after reef dwelling species’ (Appendix 5) did not meet the abundance critera (i.e. species occurring in at least 10 BRUVS samples throughout the entire survey) considered necessary for meaningful comparison between shoals and were therefore excluded from these analyses.

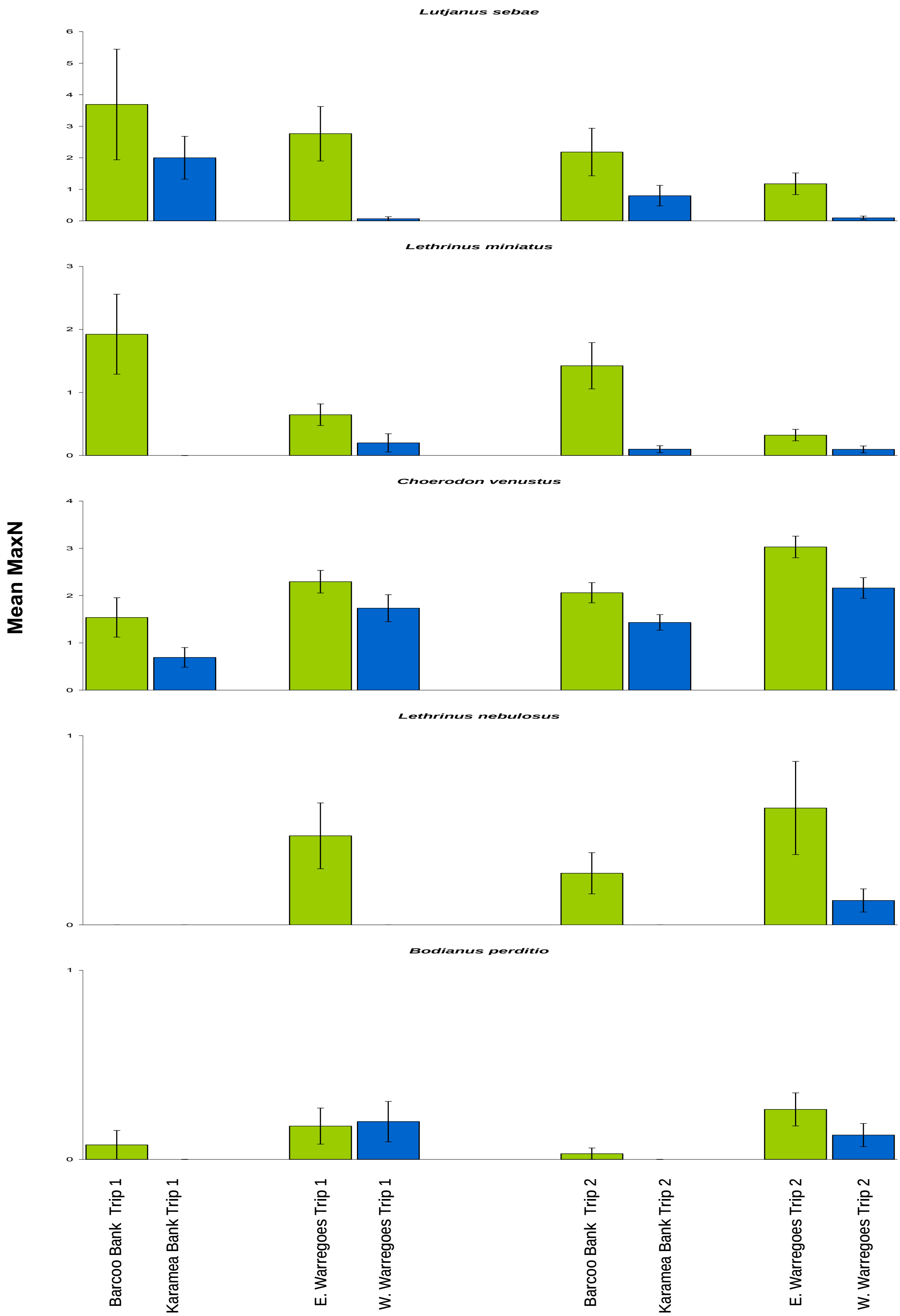


Figure 35. Mean MaxN for highly targeted species. The abundance of all these species is significantly greater in the green zone sites relative to the blue zone sites (P<0.05) when factors of site, location, trip, depth and habitat are considered. Error bars indicate s.e.m.

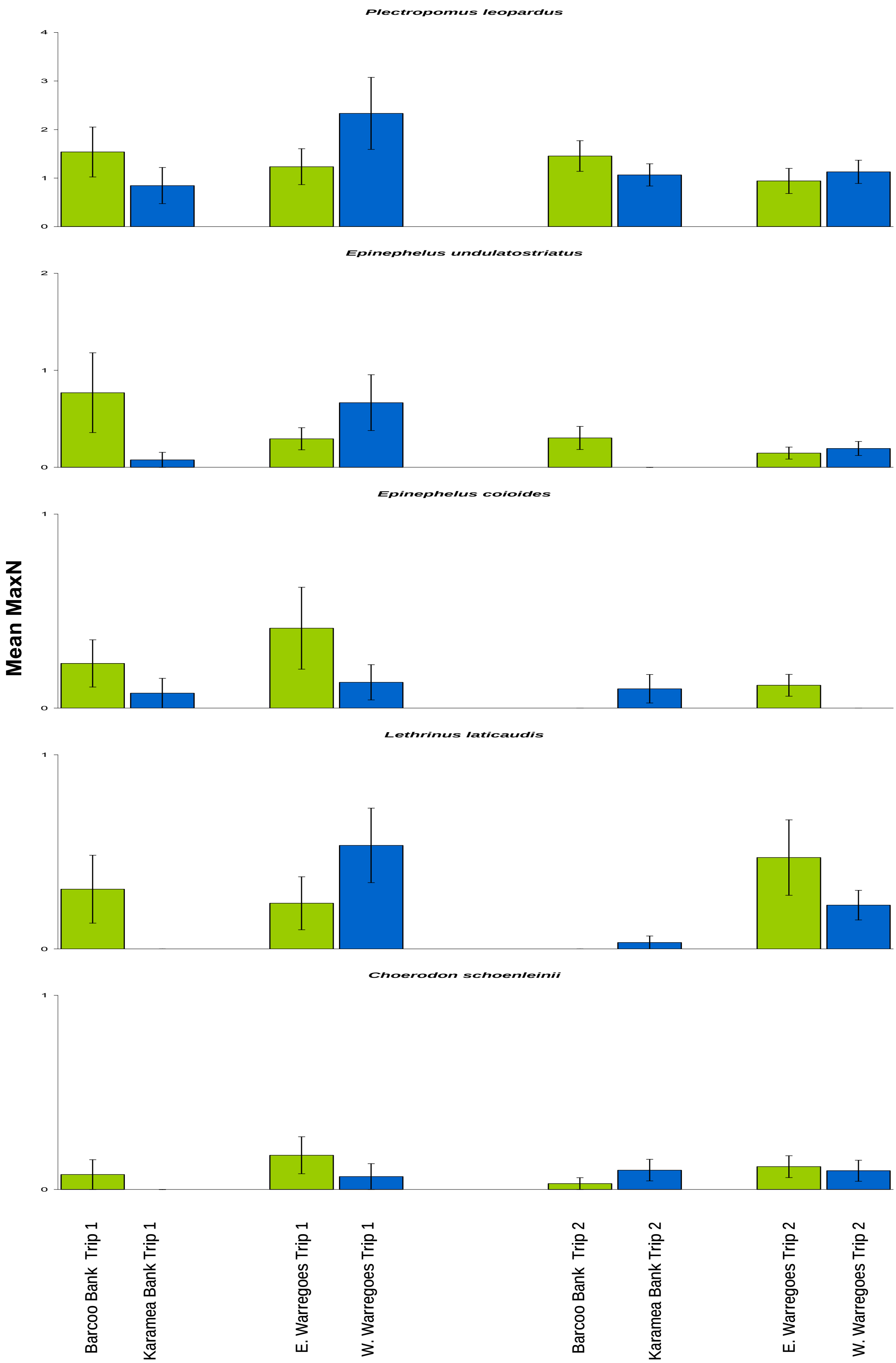


Figure 36. Mean MaxN for highly targeted species. The difference in abundance in the green zone sites relative to the blue zone sites for these species is non significant (P>0.05) when factors of site, location, trip, depth and habitat are considered. Error bars indicate s.e.m.

Discussion

The deep water shoals surveyed in this study proved to be some of the richest and most abundant fish habitats yet surveyed using BRUVS in the Great Barrier Reef Marine Park. This richness, combined with distinctive faunal associations (e.g. the influence of sub-tropical fauna in the southern-most shoals) and high biomass of species targeted by line fishers clearly demonstrates the importance of these habitats to biodiversity conservation and fisheries sustainability in the region.

The shoals selected for the study were found to be comparable and relatively discrete structures lending themselves well to the pair-wise comparison of zoning effects. They contrasted markedly in structure with some other deepwater shoal habitats that have been surveyed in other regions of the Great Barrier Reef Marine Park (e.g. Speare and Stowar 2007), which are diffuse areas of outcropping hard substratum.

There was strong evidence that the abundance of the species most targeted by recreational and commercial line fishers were, on average, approximately two times greater on the shoals closed to fishing (green zones) relative to those open to fishing (blue). While the responses to zoning of the most targeted species varied in magnitude, they all showed increases. Five of these species – red emperor (*Lutjanus sebae*), red-throat emperor (*Lethrinus miniatus*), Venus tuskfish (*Choerodon venustus*), spangled emperor (*Lethrinus nebulosus*) and golden spot hogfish (*Bodianus perditio*) showed statistically significant increases ($P<0.05$). The consistency of the response of these target fishes both individually and when aggregated strongly suggests an effect of zoning evident only in the abundance of the most highly targeted reef associated species. This observation is a somewhat predictable response in the fish community given that mortality due to fishing of targeted species is likely to be greater in the areas open to fishing than in comparable areas closed to fishing (e.g. Russ *et al.* 2008).

The present study found varying differences in the abundance of non-targeted species aligned with the zoning of the shoals. As the analyses showed no obvious trend with respect to fishing, functional groups or habits, this result is thought to reflect natural variability in species abundance rather than the effect of zoning on these species. The observation that the zoning response is *not* consistent across all species reinforces the conclusion that a zoning effect *is* being observed on the most targeted species – as it can be hypothesised that differences in the *entire* community would be expected if non-zoning factors were confounded with with the effects of zoning (i.e. a type 1 error). The detection of effects of zoning on non-targeted species remains more problematic than detecting effects on targeted species because the responses of different species are difficult to predict within the complexity of ecological interactions among species. Ongoing monitoring of these (and possibly additional) shoals would add to the robustness of the study in regard to detecting of zoning effects on the non-targeted species.

The generality of the effect of zoning in the present study should not be overstated. The present study was based on a limited number of shoals (four) and therefore conclusions about the effects of zoning on these habitats, either regionally, or throughout the Great Barrier Reef Marine Park, is not advised. Further study, with an expanded sampling programme including more shoals, would be required for such a generalization to be made. The results presented here, do however, contribute to a growing body of scientific evidence that indicates that the abundance and/or biomass of selected target species is often enhanced within areas closed to fishing relative to comparable areas open to fishing (e.g. Evans *et al.* 2006, Mapstone *et al.* 2004, Russ *et al.* 2008, Watson *et al.* 2007, Williamson *et al.* 2004). The present study is the first from the Great Barrier Reef Marine Park region to report increased abundance in relation to zoning of fish species in deeper water habitats not readily surveyed by underwater visual census techniques.

Major factors that contribute to uncertainty in assessing and understanding the effects of zoning on these fish communities include:

- Paucity of knowledge of site-specific fishing effort, catch composition and mortality of by-catch by the recreational and commercial fishing sectors (both legitimate and illegal).
- Complex movements and variable life histories of the fish species that often span zoning boundaries.
- Limited knowledge of edge effects in relation to zoning boundaries, connectivity among shoal habitats, and how they affect fish populations.
- The difficulty of linking habitat variables to fish community on appropriate spatial scales.

Dealing with this uncertainty demands robust statistical designs for studying effects of zoning on fish communities. The present study has been informative in developing recommendations for future sampling designs using BRUVS for the ongoing monitoring of effects of zoning on inter-reef shoals and other deepwater habitats. These recommendations appear at the end of this discussion.

The present study demonstrates the potential of BRUVS for routinely and non-intrusively monitoring both targeted and non-targeted fish populations in deepwater habitats of the Great Barrier Reef Marine Park. This utility extends to assessing the performance of the management plans and for ongoing monitoring to meet objectives of biodiversity conservation and fisheries sustainability. Continuation (and ideally expansion) of this monitoring program will provide indications of longer term temporal trends in the fish communities on these shoals, and increase the generality of the conclusions that can be made regarding the influence of zoning on both targeted species and the whole fish community on deep water shoals.

Recommendations for future sampling

1. Expansion of the study – increasing generality of results

The inference of the regional effects of zoning that can be drawn from the present study is limited by the small number of shoals (four) included in the study. Increasing the number of shoals in the sampling design would be most beneficial in strengthening the confidence and generality of conclusions that can be made about the effects of zoning on shoals of the southern region of the Great Barrier Reef Marine Park. Ideally, this would entail expansion of the paired design to include more pairs of differently zoned shoals matched by cross-shelf distance, along-shelf distance, distance from zoning boundaries, depth range, spatial extent etc. Significant research and consultation with fishers is required for this to determine the locations and nature of additional shoals within the southern Great Barrier Reef Marine Park region. Mapleston *et al.* (2006) provide significant summaries to aid this endeavour.

2. Frequency of sampling

There was some evidence for seasonality in abundance and composition of the fish community. Thus it would be preferable to conduct ongoing sampling at a similar time of year annually, suggested to coincide with 'trip2' of the present study. While multi-seasonal sampling might be suggested by the apparent seasonality of the data, with limited resources it would be preferable to expand an annual sampling program spatially (incorporate more shoals) rather than undertake more regular sampling.

3. Stratification

The patchiness of habitats and their associated fish communities on small spatial scales revealed by the analysis of repeated BRUVS deployments in this study indicated that it is not readily possible to stratify sampling by habitat when deploying BRUVS from the surface. Future stratification of sampling should be based broadly on depth, corresponding to the different fish habitats on the 'top' and at the 'base' of the shoals. The habitat variables determined from the video footage during processing would be incorporated into statistical analyses post hoc.

4. Spatial replication

The level of sampling effort on each shoal spatially within the present study was considered adequate. If additional resources were available there would be greater benefits in sampling additional shoals rather than increasing sampling effort within shoals.

5. Temporal replication

Repeated sampling of the same deployment sites was found to be problematic due to the imprecision of redeployment of BRUVS. Thus the recommendation for future sampling is to randomize deployment effort and focus on spatial rather than temporal replication. Where a temporal component to sampling is necessary (due to the limited number of BRUVS in the fleet) the temporal separation of sets nearby to one-another should be maximized to avoid possible satiety effects. The samples would then be treated as independent in subsequent analyses, as in the present study.

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Appendices

Appendix 1 – Species List: Karamea Bank		
Acanthuridae	*Acanthurus*	*olivaceus*
Acanthuridae	*Acanthurus*	*xanthopterus*
Acanthuridae	*Naso*	*annulatus*
Acanthuridae	*Naso*	*brevirostris*
Acanthuridae	*Naso*	*tuberosus*
Acanthuridae	*Prionurus*	*maculatus*
Acanthuridae	*Prionurus*	*microlepidotus*
Apogonidae	*Apogon*	*doederleini*
Balistidae	*Abalistes*	*stellatus*
Balistidae	*Sufflamen*	*fraenatum*
Caesionidae	*Caesio*	*cuning*
Caesionidae	*Pterocaesio*	*chrysozona*
Caesionidae	*Pterocaesio*	*trilineata*
Carangidae	*Carangoides*	*chrysophrys*
Carangidae	*Carangoides*	*coeruleopinnatus*
Carangidae	*Carangoides*	*dinema*
Carangidae	*Carangoides*	*fulvoguttatus*
Carangidae	*Carangoides*	*gymnostethus*
Carangidae	*Gnathanodon*	*speciosus*
Carangidae	*Scomberoides*	*tol*
Carangidae	*Seriola*	*dumerili*
Carangidae	*Seriola*	*rivoliana*
Chaetodontidae	*Chaetodon*	*aureofasciatus*
Chaetodontidae	*Chaetodon*	*lineolatus*
Chaetodontidae	*Chaetodon*	*melannotus*
Chaetodontidae	*Chaetodon*	*rainfordi*
Chaetodontidae	*Chelmon*	*rostratus*
Chaetodontidae	*Coradion*	*altivelis*
Chaetodontidae	*Coradion*	*chrysozonus*
Chaetodontidae	*Heniochus*	*acuminatus*
Cheilodactylidae	*Cheilodactylus*	*vestitus*
Dasyatidae	*Taeniura*	*meyeni*
Echeneidae	*Echeneis*	*naucrates*
Ephippidae	*Platax*	*orbicularis*
Ephippidae	*Platax*	*teira*
Grammistidae	*Diploprion*	*bifasciatum*
Haemulidae	*Diagramma*	*pictum*
Haemulidae	*Plectorhinchus*	*flavomaculatus*

Appendix 1 – Species List: Karamea Bank		
Hemiscylliidae	*Chiloscyllium*	*punctatum*
Labridae	*Bodianus*	*mesothorax*
Labridae	*Choerodon*	*fasciatus*
Labridae	*Choerodon*	*graphicus*
Labridae	*Choerodon*	*monostigma*
Labridae	*Choerodon*	*schoenleinii*
Labridae	*Choerodon*	*venustus*
Labridae	*Choerodon*	*vitta*
Labridae	*Cirrhilabrus*	*punctatus*
Labridae	*Labroides*	*dimidiatus*
Labridae	*Leptojulis*	*cyanopleura*
Labridae	*Pseudolabrus*	*guentheri*
Labridae	*Suezichthys*	*devisi*
Labridae	*Thalassoma*	*lunare*
Lethrinidae	*Gymnocranius*	*audleyi*
Lethrinidae	*Lethrinus*	*atkinsoni*
Lethrinidae	*Lethrinus*	*genivittatus*
Lethrinidae	*Lethrinus*	*laticaudis*
Lethrinidae	*Lethrinus*	*miniatus*
Lethrinidae	*Lethrinus*	*ravus*
Lutjanidae	*Lutjanus*	*adetii*
Lutjanidae	*Lutjanus*	*carponotatus*
Lutjanidae	*Lutjanus*	*malabaricus*
Lutjanidae	*Lutjanus*	*russelli*
Lutjanidae	*Lutjanus*	*sebae*
Lutjanidae	*Lutjanus*	*vitta*
Lutjanidae	*Pristipomoides*	*multidens*
Lutjanidae	*Symphorus*	*nematophorus*
Mullidae	*Parupeneus*	*heptacanthus*
Mullidae	*Upeneus*	*filifer*
Nemipteridae	*Pentapodus*	*aureofasciatus*
Nemipteridae	*Pentapodus*	*nagasakiensis*
Nemipteridae	*Pentapodus*	*paradiseus*
Nemipteridae	*Pentapodus*	*vitta*
Nemipteridae	*Scolopsis*	*Monogramma*
Pinguipedidae	*Parapercis*	*nebulosa*
Pinguipedidae	*Parapercis*	*xanthozona*
Pomacanthidae	*Chaetodontoplus*	*duboulayi*
Pomacanthidae	*Chaetodontoplus*	*meredithi*
Pomacanthidae	*Pomacanthus*	*semicirculatus*

Appendix 1 – Species List: Karamea Bank		
Pomacanthidae	*Pomacanthus*	*sexstriatus*
Pomacentridae	*Chromis*	*nitida*
Pomacentridae	*Pomacentrus*	*australis*
Pomacentridae	*Pomacentrus*	*nagasakiensis*
Rhynchobatidae	*Rhynchobatus*	*djiddensis*
Scaridae	*Scarus*	*schlegeli*
Scombridae	*Scomberomorus*	*queenslandicus*
Serranidae	*Cephalopholis*	*boenak*
Serranidae	*Cromileptes*	*altivelis*
Serranidae	*Epinephelus*	*areolatus*
Serranidae	*Epinephelus*	*coioides*
Serranidae	*Epinephelus*	*fasciatus*
Serranidae	*Epinephelus*	*merra*
Serranidae	*Epinephelus*	*undulatostriatus*
Serranidae	*Plectropomus*	*laevis*
Serranidae	*Plectropomus*	*leopardus*
Siganidae	*Siganus*	*argenteus*
Siganidae	*Siganus*	*corallinus*
Siganidae	*Siganus*	*punctatus*
Sparidae	*Argyrops*	*spinifer*
Sphyraenidae	*Sphyraena*	*jello*
Sphyrnidae	*Sphyrna*	*mokarran*

Appendix 2 – Species List: Barcoo Bank

Acanthuridae	*Acanthurus*	*dussumieri*
Acanthuridae	*Acanthurus*	*olivaceus*
Acanthuridae	*Acanthurus*	*xanthopterus*
Acanthuridae	*Naso*	*annulatus*
Acanthuridae	*Naso*	*brevirostris*
Acanthuridae	*Naso*	*tuberosus*
Acanthuridae	*Naso*	*unicornis*
Balistidae	*Abalistes*	*stellatus*
Balistidae	*Sufflamen*	*fraenatum*
Blenniidae	*Aspidontus*	*taeniatus*
Caesionidae	*Pterocaesio*	*chrysozona*
Caesionidae	*Pterocaesio*	*marri*
Caesionidae	*Pterocaesio*	*trilineata*
Carangidae	*Carangoides*	*chrysophrys*
Carangidae	*Carangoides*	*coeruleopinnatus*
Carangidae	*Carangoides*	*fulvoguttatus*
Carangidae	*Carangoides*	*gymnostethus*
Carangidae	*Caranx*	*ignobilis*
Carangidae	*Decapterus*	*russelli*
Carangidae	*Gnathanodon*	*speciosus*
Carangidae	*Pseudocaranx*	*dentex*
Carangidae	*Selaroides*	*leptolepis*
Carangidae	*Seriola*	*dumerili*
Carangidae	*Seriola*	*lalandi*
Carangidae	*Seriola*	*rivoliana*
Carangidae	*Seriolina*	*nigrofasciata*
Carcharhinidae	*Carcharhinus*	*albimarginatus*
Carcharhinidae	*Carcharhinus*	*amblyrhynchos*
Carcharhinidae	*Carcharhinus*	*plumbeus*
Carcharhinidae	*Galeocerdo*	*cuvier*
Carcharhinidae	*Triaenodon*	*obesus*
Chaetodontidae	*Chaetodon*	*flavirostris*
Chaetodontidae	*Chaetodon*	*kleinii*
Chaetodontidae	*Chaetodon*	*lineolatus*
Chaetodontidae	*Chaetodon*	*melannotus*
Chaetodontidae	*Chaetodon*	*rainfordi*
Chaetodontidae	*Chaetodon*	*vagabundus*
Chaetodontidae	*Chelmon*	*rostratus*
Chaetodontidae	*Coradion*	*altivelis*
Chaetodontidae	*Coradion*	*chrysozonus*

Appendix 2 – Species List: Barcoo Bank

Chaetodontidae	*Forcipiger*	*longirostris*
Chaetodontidae	*Heniochus*	*acuminatus*
Chaetodontidae	*Parachaetodon*	*ocellatus*
Cheilodactylidae	*Cheilodactylus*	*vestitus*
Dasyatidae	*Dasyatis*	*kuhlii*
Dasyatidae	*Taeniura*	*meyeni*
Echeneidae	*Echeneis*	*naucrates*
Grammistidae	*Diploprion*	*bifasciatum*
Haemulidae	*Diagramma*	*pictum*
Hemiscylliidae	*Chiloscyllium*	*punctatum*
Holocentridae	*Sargocentron*	*rubrum*
Labridae	*Bodianus*	*perditio*
Labridae	*Cheilinus*	*Fasciatus*
Labridae	*Choerodon*	*cephalotes*
Labridae	*Choerodon*	*graphicus*
Labridae	*Choerodon*	*schoenleinii*
Labridae	*Choerodon*	*venustus*
Labridae	*Choerodon*	*vitta*
Labridae	*Cirrhilabrus*	*punctatus*
Labridae	*Halichoeres*	*prosopeion*
Labridae	*Labroides*	*dimidiatus*
Labridae	*Leptojulis*	*cyanopleura*
Labridae	*Suezichthys*	*devisi*
Labridae	*Thalassoma*	*lunare*
Lethrinidae	*Gymnocranius*	*audleyi*
Lethrinidae	*Lethrinus*	*atkinsoni*
Lethrinidae	*Lethrinus*	*genivittatus*
Lethrinidae	*Lethrinus*	*laticaudis*
Lethrinidae	*Lethrinus*	*miniatus*
Lethrinidae	*Lethrinus*	*nebulosus*
Lethrinidae	*Lethrinus*	*Ravus*
Lethrinidae	*Lethrinus*	*rubrioperculatus*
Lutjanidae	*Lutjanus*	*adetii*
Lutjanidae	*Lutjanus*	*carponotatus*
Lutjanidae	*Lutjanus*	*russelli*
Lutjanidae	*Lutjanus*	*sebae*
Lutjanidae	*Lutjanus*	*vitta*
Lutjanidae	*Pristipomoides*	*multidens*
Lutjanidae	*Symphorus*	*nematophorus*
Monacanthidae	*Aluterus*	*scriptus*
Monacanthidae	*Cantherhines*	*dumerilii*

Appendix 2 – Species List: Barcoo Bank

Mullidae	*Parupeneus*	*cyclostomus*
Mullidae	*Parupeneus*	*heptacanthus*
Mullidae	*Parupeneus*	*multifasciatus*
Mullidae	*Parupeneus*	*spilurus*
Mullidae	*Upeneus*	*filifer*
Muraenidae	*Gymnothorax*	*favagineus*
Muraenidae	*Gymnothorax*	*javanicus*
Nemipteridae	*Nemipterus*	*furcosus*
Nemipteridae	*Nemipterus*	*hexodon*
Nemipteridae	*Nemipterus*	*theodorei*
Nemipteridae	*Pentapodus*	*aureofasciatus*
Nemipteridae	*Pentapodus*	*nagasakiensis*
Nemipteridae	*Pentapodus*	*paradiseus*
Nemipteridae	*Scolopsis*	*bilineata*
Nemipteridae	*Scolopsis*	*margaritifer*
Nemipteridae	*Scolopsis*	*monogramma*
Pinguipedidae	*Parapercis*	*xanthozona*
Pomacanthidae	*Chaetodontoplus*	*duboulayi*
Pomacanthidae	*Chaetodontoplus*	*meredithi*
Pomacanthidae	*Pomacanthus*	*semicirculatus*
Pomacanthidae	*Pomacanthus*	*sexstriatus*
Pomacentridae	*Acanthochromis*	*polyacanthus*
Pomacentridae	*Amblyglyphidodon*	*aureus*
Pomacentridae	*Chromis*	*nitida*
Pomacentridae	*Dascyllus*	*trimaculatus*
Pomacentridae	*Pomacentrus*	*amboinensis*
Pomacentridae	*Pomacentrus*	*australis*
Pomacentridae	*Pomacentrus*	*chrysurus*
Pomacentridae	*Pomacentrus*	*coelestis*
Pomacentridae	*Pomacentrus*	*nagasakiensis*
Rhynchobatidae	*Rhynchobatus*	*djiddensis*
Scaridae	*Chlorurus*	*sordidus*
Scaridae	*Scarus*	*flavipectoralis*
Scaridae	*Scarus*	*niger*
Scaridae	*Scarus*	*schlegeli*
Scombridae	*Scomberomorus*	*queenslandicus*
Scorpaenidae	*Pterois*	*volitans*
Serranidae	*Cephalopholis*	*boenak*
Serranidae	*Cephalopholis*	*miniata*
Serranidae	*Cromileptes*	*altivelis*
Serranidae	*Epinephelus*	*areolatus*

Appendix 2 – Species List: Barcoo Bank

Serranidae	*Epinephelus*	*coioides*
Serranidae	*Epinephelus*	*fasciatus*
Serranidae	*Epinephelus*	*undulatostriatus*
Serranidae	*Plectropomus*	*leopardus*
Serranidae	*Plectropomus*	*maculatus*
Serranidae	*Pseudanthias*	*rubrizonatus*
Siganidae	*Siganus*	*argenteus*
Siganidae	*Siganus*	*corallinus*
Siganidae	*Siganus*	*punctatissimus*
Siganidae	*Siganus*	*punctatus*
Sparidae	*Argyrops*	*spinifer*
Sphyraenidae	*Sphyraena*	*jello*
Tetraodontidae	*Canthigaster*	*valentini*

Appendix 3– Species List: West Warregoes		
Acanthuridae	*Acanthurus*	*albipectoralis*
Acanthuridae	*Acanthurus*	*auranticavus*
Acanthuridae	*Acanthurus*	*dussumieri*
Acanthuridae	*Acanthurus*	*mata*
Acanthuridae	*Acanthurus*	*olivaceus*
Acanthuridae	*Acanthurus*	*xanthopterus*
Acanthuridae	*Ctenochaetus*	*striatus*
Acanthuridae	*Naso*	*annulatus*
Acanthuridae	*Naso*	*brevirostris*
Acanthuridae	*Naso*	*lituratus*
Acanthuridae	*Naso*	*tuberosus*
Acanthuridae	*Naso*	*unicornis*
Acanthuridae	*Paracanthurus*	*hepatus*
Acanthuridae	*Prionurus*	*microlepidotus*
Acanthuridae	*Zebrasoma*	*scopas*
Apogonidae	*Apogon*	*capricornis*
Apogonidae	*Apogon*	*exostigma*
Apogonidae	*Apogon*	*notatus*
Aulostomidae	*Aulostomus*	*chinensis*
Balistidae	*Abalistes*	*stellatus*
Balistidae	*Balistoides*	*conspicillum*
Balistidae	*Odonus*	*niger*
Balistidae	*Sufflamen*	*chrysopterum*
Balistidae	*Sufflamen*	*fraenatum*
Blenniidae	*Aspidontus*	*taeniatus*
Caesionidae	*Caesio*	*cuning*
Caesionidae	*Pterocaesio*	*chrysozona*
Caesionidae	*Pterocaesio*	*marri*
Caesionidae	*Pterocaesio*	*trilineata*
Carangidae	*Carangoides*	*chrysophrys*
Carangidae	*Carangoides*	*fulvoguttatus*
Carangidae	*Carangoides*	*gymnostethus*
Carangidae	*Caranx*	*ignobilis*
Carangidae	*Gnathanodon*	*speciosus*
Carangidae	*Pseudocaranx*	*dentex*
Carangidae	*Seriola*	*lalandi*
Carangidae	*Seriola*	*rivoliana*
Carangidae	*Seriolina*	*nigrofasciata*
Carcharhinidae	*Carcharhinus*	*albimarginatus*

Appendix 3– Species List: West Warregoes		
Carcharhinidae	*Carcharhinus*	*amblyrhynchos*
Carcharhinidae	*Carcharhinus*	*leucas*
Carcharhinidae	*Triaenodon*	*obesus*
Chaetodontidae	*Chaetodon*	*aureofasciatus*
Chaetodontidae	*Chaetodon*	*auriga*
Chaetodontidae	*Chaetodon*	*flavirostris*
Chaetodontidae	*Chaetodon*	*guentheri*
Chaetodontidae	*Chaetodon*	*kleinii*
Chaetodontidae	*Chaetodon*	*lineolatus*
Chaetodontidae	*Chaetodon*	*lunulatus*
Chaetodontidae	*Chaetodon*	*plebeius*
Chaetodontidae	*Chaetodon*	*rainfordi*
Chaetodontidae	*Chaetodon*	*speculum*
Chaetodontidae	*Chaetodon*	*trifascialis*
Chaetodontidae	*Chaetodon*	*unimaculatus*
Chaetodontidae	*Chelmon*	*rostratus*
Chaetodontidae	*Coradion*	*altivelis*
Chaetodontidae	*Coradion*	*chrysozonus*
Chaetodontidae	*Forcipiger*	*longirostris*
Chaetodontidae	*Heniochus*	*acuminatus*
Chaetodontidae	*Parachaetodon*	*ocellatus*
Cheilodactylidae	*Cheilodactylus*	*vestitus*
Dasyatidae	*Dasyatis*	*kuhlii*
Dasyatidae	*Taeniura*	*meyeni*
Echeneidae	*Echeneis*	*naucrates*
Ephippidae	*Platax*	*orbicularis*
Ephippidae	*Platax*	*teira*
Fistulariidae	*Fistularia*	*commersonii*
Ginglymostomatidae	*Nebrius*	*ferrugineus*
Grammistidae	*Diploprion*	*bifasciatum*
Haemulidae	*Diagramma*	*pictum*
Haemulidae	*Plectorhinchus*	*flavomaculatus*
Haemulidae	*Plectorhinchus*	*gibbosus*
Hemiscylliidae	*Chiloscyllium*	*punctatum*
Holocentridae	*Sargocentron*	*melanospilos*
Labridae	*Bodianus*	*diana*
Labridae	*Bodianus*	*perditio*
Labridae	*Cheilinus*	*fasciatus*
Labridae	*Cheilinus*	*undulatus*
Labridae	*Choerodon*	*cephalotes*

Appendix 3– Species List: West Warregoes		
Labridae	*Choerodon*	*schoenleinii*
Labridae	*Choerodon*	*venustus*
Labridae	*Cirrhilabrus*	*punctatus*
Labridae	*Coris*	*dorsomacula*
Labridae	*Coris*	*picta*
Labridae	*Coris*	*pictoides*
Labridae	*Halichoeres*	*prosopeion*
Labridae	*Labroides*	*dimidiatus*
Labridae	*Leptojulis*	*cyanopleura*
Labridae	*Suezichthys*	*devisi*
Labridae	*Suezichthys*	*gracilis*
Labridae	*Thalassoma*	*lunare*
Lethrinidae	*Gymnocranius*	*audleyi*
Lethrinidae	*Lethrinus*	*genivittatus*
Lethrinidae	*Lethrinus*	*laticaudis*
Lethrinidae	*Lethrinus*	*miniatus*
Lethrinidae	*Lethrinus*	*nebulosus*
Lethrinidae	*Lethrinus*	*ravus*
Lethrinidae	*Lethrinus*	*rubrioperculatus*
Lethrinidae	*Monotaxis*	*grandoculis*
Lutjanidae	*Lutjanus*	*adetii*
Lutjanidae	*Lutjanus*	*bohar*
Lutjanidae	*Lutjanus*	*carponotatus*
Lutjanidae	*Lutjanus*	*erythropterus*
Lutjanidae	*Lutjanus*	*lemniscatus*
Lutjanidae	*Lutjanus*	*quinquelineatus*
Lutjanidae	*Lutjanus*	*russelli*
Lutjanidae	*Lutjanus*	*sebae*
Lutjanidae	*Lutjanus*	*vitta*
Lutjanidae	*Symphorus*	*nematophorus*
Monacanthidae	*Aluterus*	*scriptus*
Monacanthidae	*Cantherhines*	*dumerilii*
Mullidae	*Parupeneus*	*barberinoides*
Mullidae	*Parupeneus*	*barberinus*
Mullidae	*Parupeneus*	*cyclostomus*
Mullidae	*Parupeneus*	*heptacanthus*
Mullidae	*Parupeneus*	*multifasciatus*
Mullidae	*Parupeneus*	*spilurus*
Myliobatididae	*Aetobatus*	*narinari*
Nemipteridae	*Pentapodus*	*aureofasciatus*

Appendix 3– Species List: West Warregoes		
Nemipteridae	*Pentapodus*	*nagasakiensis*
Nemipteridae	*Pentapodus*	*paradiseus*
Nemipteridae	*Scolopsis*	*bilineata*
Nemipteridae	*Scolopsis*	*monogramma*
Pinguipedidae	*Parapercis*	*clathrata*
Pinguipedidae	*Parapercis*	*xanthozona*
Pomacanthidae	*Centropyge*	*bicolor*
Pomacanthidae	*Centropyge*	*tibicen*
Pomacanthidae	*Chaetodontoplus*	*meredithi*
Pomacanthidae	*Pomacanthus*	*imperator*
Pomacanthidae	*Pomacanthus*	*semicirculatus*
Pomacentridae	*Acanthochromis*	*polyacanthus*
Pomacentridae	*Amblyglyphidodon*	*aureus*
Pomacentridae	*Amphiprion*	*clarkii*
Pomacentridae	*Chromis*	*nitida*
Pomacentridae	*Dascyllus*	*reticulatus*
Pomacentridae	*Dascyllus*	*trimaculatus*
Pomacentridae	*Pomacentrus*	*australis*
Pomacentridae	*Pomacentrus*	*nagasakiensis*
Pomacentridae	*Pristotis*	*jerdoni*
Rachycentridae	*Rachycentron*	*canadum*
Rhynchobatidae	*Rhynchobatus*	*djiddensis*
Scaridae	*Cetoscarus*	*bicolor*
Scaridae	*Scarus*	*flavipectoralis*
Scaridae	*Scarus*	*schlegeli*
Scombridae	*Scomberomorus*	*commerson*
Scombridae	*Scomberomorus*	*queenslandicus*
Serranidae	*Cephalopholis*	*boenak*
Serranidae	*Cephalopholis*	*miniata*
Serranidae	*Cromileptes*	*altivelis*
Serranidae	*Epinephelus*	*areolatus*
Serranidae	*Epinephelus*	*coioides*
Serranidae	*Epinephelus*	*fasciatus*
Serranidae	*Epinephelus*	*quoyanus*
Serranidae	*Epinephelus*	*undulatostriatus*
Serranidae	*Plectropomus*	*laevis*
Serranidae	*Plectropomus*	*leopardus*
Serranidae	*Plectropomus*	*maculatus*
Siganidae	*Siganus*	*argenteus*
Siganidae	*Siganus*	*corallinus*

Appendix 3– Species List: West Warregoes		
Sparidae	*Pagrus*	*auratus*
Sphyraenidae	*Sphyraena*	*jello*
Stegastomatidae	*Stegostoma*	*fasciatum*
Tetraodontidae	*Canthigaster*	*valentini*
Zanclidae	*Zanclus*	*cornutus*

Appendix 4 – Species List: East Warregoes		
Acanthuridae	*Acanthurus*	*albipectoralis*
Acanthuridae	*Acanthurus*	*auranticavus*
Acanthuridae	*Acanthurus*	*dussumieri*
Acanthuridae	*Acanthurus*	*olivaceus*
Acanthuridae	*Acanthurus*	*thompsoni*
Acanthuridae	*Acanthurus*	*xanthopterus*
Acanthuridae	*Naso*	*annulatus*
Acanthuridae	*Naso*	*brevirostris*
Acanthuridae	*Naso*	*caesius*
Acanthuridae	*Naso*	*lituratus*
Acanthuridae	*Naso*	*tuberosus*
Acanthuridae	*Naso*	*unicornis*
Acanthuridae	*Paracanthurus*	*hepatus*
Acanthuridae	*Prionurus*	*microlepidotus*
Aulostomidae	*Aulostomus*	*chinensis*
Balistidae	*Abalistes*	*stellatus*
Balistidae	*Balistoides*	*conspicillum*
Balistidae	*Odonus*	*niger*
Balistidae	*Pseudobalistes*	*flavimarginatus*
Balistidae	*Sufflamen*	*fraenatum*
Blenniidae	*Aspidontus*	*taeniatus*
Caesionidae	*Caesio*	*cuning*
Caesionidae	*Pterocaesio*	*marri*
Caesionidae	*Pterocaesio*	*trilineata*
Carangidae	*Carangoides*	*chrysophrys*
Carangidae	*Carangoides*	*fulvoguttatus*
Carangidae	*Caranx*	*ignobilis*
Carangidae	*Elagatis*	*bipinnulata*
Carangidae	*Gnathanodon*	*speciosus*
Carangidae	*Pseudocaranx*	*dentex*
Carangidae	*Seriola*	*lalandi*
Carangidae	*Seriola*	*rivoliana*
Carcharhinidae	*Carcharhinus*	*albimarginatus*
Carcharhinidae	*Carcharhinus*	*amblyrhynchos*
Carcharhinidae	*Carcharhinus*	*plumbeus*
Carcharhinidae	*Galeocerdo*	*cuvier*
Chaetodontidae	*Chaetodon*	*auriga*
Chaetodontidae	*Chaetodon*	*flavirostris*
Chaetodontidae	*Chaetodon*	*kleinii*

Appendix 4 – Species List: East Warregoes		
Chaetodontidae	*Chaetodon*	*lineolatus*
Chaetodontidae	*Chaetodon*	*lunulatus*
Chaetodontidae	*Chaetodon*	*melannotus*
Chaetodontidae	*Chaetodon*	*ornatissimus*
Chaetodontidae	*Chaetodon*	*pelewensis*
Chaetodontidae	*Chaetodon*	*plebeius*
Chaetodontidae	*Chaetodon*	*rainfordi*
Chaetodontidae	*Chaetodon*	*speculum*
Chaetodontidae	*Chaetodon*	*trifascialis*
Chaetodontidae	*Chaetodon*	*unimaculatus*
Chaetodontidae	*Chelmon*	*rostratus*
Chaetodontidae	*Coradion*	*altivelis*
Chaetodontidae	*Coradion*	*chrysozonus*
Chaetodontidae	*Forcipiger*	*longirostris*
Chaetodontidae	*Heniochus*	*acuminatus*
Chaetodontidae	*Parachaetodon*	*ocellatus*
Cheilodactylidae	*Cheilodactylus*	*vestitus*
Dasyatidae	*Himantura*	*fai*
Dasyatidae	*Pastinachus*	*sephen*
Dasyatidae	*Taeniura*	*meyeni*
Echeneidae	*Echeneis*	*naucrates*
Ephippidae	*Platax*	*orbicularis*
Fistulariidae	*Fistularia*	*commersonii*
Ginglymostomatidae	*Nebrius*	*ferrugineus*
Grammistidae	*Diploprion*	*bifasciatum*
Haemulidae	*Diagramma*	*pictum*
Haemulidae	*Plectorhinchus*	*flavomaculatus*
Haemulidae	*Plectorhinchus*	*gibbosus*
Hemiscylliidae	*Chiloscyllium*	*punctatum*
Kyphosidae	*Kyphosus*	*vaigiensis*
Labridae	*Anampses*	*caeruleopunctatus*
Labridae	*Bodianus*	*axillaris*
Labridae	*Bodianus*	*Diana*
Labridae	*Bodianus*	*mesothorax*
Labridae	*Bodianus*	*perditio*
Labridae	*Choerodon*	*gomoni*
Labridae	*Choerodon*	*schoenleinii*
Labridae	*Choerodon*	*venustus*
Labridae	*Choerodon*	*vitta*
Labridae	*Cirrhilabrus*	*punctatus*

Appendix 4 – Species List: East Warregoes		
Labridae	*Coris*	*aygula*
Labridae	*Coris*	*dorsomacula*
Labridae	*Coris*	*picta*
Labridae	*Coris*	*pictoides*
Labridae	*Gomphosus*	*varius*
Labridae	*Halichoeres*	*chrysus*
Labridae	*Halichoeres*	*hartzfeldii*
Labridae	*Halichoeres*	*melasmapomus*
Labridae	*Halichoeres*	*prosopeion*
Labridae	*Hologymnosus*	*doliatus*
Labridae	*Hologymnosus*	*longipes*
Labridae	*Labroides*	*dimidiatus*
Labridae	*Leptojulis*	*cyanopleura*
Labridae	*Oxycheilinus*	*unifasciatus*
Labridae	*Pseudolabrus*	*guentheri*
Labridae	*Suezichthys*	*devisi*
Labridae	*Suezichthys*	*gracilis*
Labridae	*Thalassoma*	*amblycephalum*
Labridae	*Thalassoma*	*lunare*
Lethrinidae	*Gymnocranius*	*audleyi*
Lethrinidae	*Gymnocranius*	*grandoculis*
Lethrinidae	*Lethrinus*	*laticaudis*
Lethrinidae	*Lethrinus*	*miniatus*
Lethrinidae	*Lethrinus*	*nebulosus*
Lethrinidae	*Lethrinus*	*ravus*
Lethrinidae	*Lethrinus*	*rubrioperculatus*
Lutjanidae	*Aprion*	*virescens*
Lutjanidae	*Lutjanus*	*adetii*
Lutjanidae	*Lutjanus*	*bohar*
Lutjanidae	*Lutjanus*	*carponotatus*
Lutjanidae	*Lutjanus*	*quinquelineatus*
Lutjanidae	*Lutjanus*	*russelli*
Lutjanidae	*Lutjanus*	*sebae*
Lutjanidae	*Lutjanus*	*vitta*
Lutjanidae	*Symphorus*	*nematophorus*
Malacanthidae	*Malacanthus*	*brevirostris*
Mobulidae	*Manta*	*birostris*
Monacanthidae	*Aluterus*	*scriptus*
Monacanthidae	*Cantherhines*	*dumerilii*
Mullidae	*Parupeneus*	*barberinoides*

Appendix 4 – Species List: East Warregoes		
Mullidae	*Parupeneus*	*barberinus*
Mullidae	*Parupeneus*	*cyclostomus*
Mullidae	*Parupeneus*	*heptacanthus*
Mullidae	*Parupeneus*	*multifasciatus*
Mullidae	*Parupeneus*	*spilurus*
Muraenidae	*Gymnothorax*	*undulatus*
Myliobatididae	*Aetobatus*	*narinari*
Nemipteridae	*Pentapodus*	*aureofasciatus*
Nemipteridae	*Pentapodus*	*nagasakiensis*
Nemipteridae	*Scolopsis*	*bilineata*
Nemipteridae	*Scolopsis*	*monogramma*
Pinguipedidae	*Parapercis*	*nebulosa*
Pinguipedidae	*Parapercis*	*xanthozona*
Pomacanthidae	*Centropyge*	*tibicen*
Pomacanthidae	*Chaetodontoplus*	*meredithi*
Pomacanthidae	*Pomacanthus*	*imperator*
Pomacanthidae	*Pomacanthus*	*semicirculatus*
Pomacanthidae	*Pomacanthus*	*sexstriatus*
Pomacentridae	*Acanthochromis*	*polyacanthus*
Pomacentridae	*Amblyglyphidodon*	*aureus*
Pomacentridae	*Chromis*	*nitida*
Pomacentridae	*Chromis*	*xanthura*
Pomacentridae	*Dascyllus*	*reticulatus*
Pomacentridae	*Dascyllus*	*trimaculatus*
Pomacentridae	*Pomacentrus*	*amboinensis*
Pomacentridae	*Pomacentrus*	*Australis*
Pomacentridae	*Pomacentrus*	*coelestis*
Pomacentridae	*Pomacentrus*	*moluccensis*
Pomacentridae	*Pomacentrus*	*nagasakiensis*
Rachycentridae	*Rachycentron*	*canadum*
Scaridae	*Cetoscarus*	*bicolor*
Scaridae	*Scarus*	*flavipectoralis*
Scaridae	*Scarus*	*oviceps*
Scaridae	*Scarus*	*schlegeli*
Scombridae	*Gymnosarda*	*unicolor*
Scombridae	*Scomberomorus*	*commerson*
Scombridae	*Scomberomorus*	*queenslandicus*
Serranidae	*Cephalopholis*	*boenak*
Serranidae	*Cephalopholis*	*miniata*
Serranidae	*Epinephelus*	*areolatus*

Appendix 4 – Species List: East Warregoes

Serranidae	*Epinephelus*	*coioides*
Serranidae	*Epinephelus*	*fasciatus*
Serranidae	*Epinephelus*	*maculatus*
Serranidae	*Epinephelus*	*undulatostriatus*
Serranidae	*Plectropomus*	*laevis*
Serranidae	*Plectropomus*	*leopardus*
Serranidae	*Variola*	*albimarginata*
Serranidae	*Variola*	*louti*
Siganidae	*Siganus*	*argenteus*
Siganidae	*Siganus*	*punctatus*
Siganidae	*Siganus*	*vulpinus*
Sparidae	*Pagrus*	*auratus*
Stegastomatidae	*Stegostoma*	*fasciatum*
Synodontidae	*Synodus*	*variegatus*
Tetraodontidae	*Feroxodon*	*multistriatus*

Appendix 5 – 'Highly sought after reef dwelling species' (T1)

Labridae	*Bodianus*	*perditio*
Labridae	*Choerodon*	*cephalotes*
Labridae	*Choerodon*	*schoenleinii*
Labridae	*Choerodon*	*venustus*
Lethrinidae	*Lethrinus*	*laticaudis*
Lethrinidae	*Lethrinus*	*miniatus*
Lethrinidae	*Lethrinus*	*nebulosus*
Lutjanidae	*Aprion*	*virescens*
Lutjanidae	*Lutjanus*	*erythropterus*
Lutjanidae	*Lutjanus*	*malabaricus*
Lutjanidae	*Lutjanus*	*sebae*
Lutjanidae	*Pristipomoides*	*multidens*
Serranidae	*Epinephelus*	*coioides*
Serranidae	*Epinephelus*	*undulatostriatus*
Serranidae	*Plectropomus*	*laevis*
Serranidae	*Plectropomus*	*leopardus*
Serranidae	*Plectropomus*	*maculatus*
Serranidae	*Variola*	*albimarginata*
Serranidae	*Variola*	*louti*
Sparidae	*Pagrus*	*auratus*

Appendix 6 – 'Sought after reef dwelling and pelagic species' (T2)		
Labridae	*Bodianus*	*perditio*
Labridae	*Choerodon*	*cephalotes*
Labridae	*Choerodon*	*schoenleinii*
Labridae	*Choerodon*	*venustus*
Lethrinidae	*Lethrinus*	*laticaudis*
Lethrinidae	*Lethrinus*	*miniatus*
Lethrinidae	*Lethrinus*	*nebulosus*
Lutjanidae	*Aprion*	*virescens*
Lutjanidae	*Lutjanus*	*erythropterus*
Lutjanidae	*Lutjanus*	*malabaricus*
Lutjanidae	*Lutjanus*	*sebae*
Lutjanidae	*Pristipomoides*	*multidens*
Serranidae	*Epinephelus*	*coioides*
Serranidae	*Epinephelus*	*undulatostriatus*
Serranidae	*Plectropomus*	*laevis*
Serranidae	*Plectropomus*	*leopardus*
Serranidae	*Plectropomus*	*maculatus*
Serranidae	*Variola*	*albimarginata*
Serranidae	*Variola*	*louti*
Sparidae	*Pagrus*	*auratus*
Carangidae	*Carangoides*	*chrysophrys*
Carangidae	*Carangoides*	*coeruleopinnatus*
Carangidae	*Carangoides*	*dinema*
Carangidae	*Carangoides*	*fulvoguttatus*
Carangidae	*Carangoides*	*gymnostethus*
Carangidae	*Caranx*	*ignobilis*
Carangidae	*Gnathanodon*	*speciosus*
Carangidae	*Pseudocaranx*	*dentex*
Carangidae	*Seriola*	*dumerili*
Carangidae	*Seriola*	*lalandi*
Carangidae	*Seriola*	*rivoliana*
Carangidae	*Seriolina*	*nigrofasciata*
Haemulidae	*Diagramma*	*pictum*
Lutjanidae	*Lutjanus*	*adetii*
Lutjanidae	*Lutjanus*	*carponotatus*
Lutjanidae	*Lutjanus*	*lemniscatus*
Lutjanidae	*Lutjanus*	*russelli*
Rachycentridae	*Rachycentron*	*canadum*
Scombridae	*Gymnosarda*	*unicolor*

Appendix 6 – 'Sought after reef dwelling and pelagic species' (T2)		
Scombridae	*Scomberomorus*	*commerson*
Scombridae	*Scomberomorus*	*queenslandicus*
Serranidae	*Epinephelus*	*fasciatus*
Sparidae	*Argyrops*	*spinifer*

Appendix 7 – 'All species considered likely to be caught by line fishing, including by-catch' (T3)

Labridae	*Bodianus*	*perditio*
Labridae	*Choerodon*	*cephalotes*
Labridae	*Choerodon*	*schoenleinii*
Labridae	*Choerodon*	*venustus*
Lethrinidae	*Lethrinus*	*laticaudis*
Lethrinidae	*Lethrinus*	*miniatus*
Lethrinidae	*Lethrinus*	*nebulosus*
Lutjanidae	*Aprion*	*virescens*
Lutjanidae	*Lutjanus*	*erythropterus*
Lutjanidae	*Lutjanus*	*malabaricus*
Lutjanidae	*Lutjanus*	*sebae*
Lutjanidae	*Pristipomoides*	*multidens*
Serranidae	*Epinephelus*	*coioides*
Serranidae	*Epinephelus*	*undulatostriatus*
Serranidae	*Plectropomus*	*laevis*
Serranidae	*Plectropomus*	*leopardus*
Serranidae	*Plectropomus*	*maculatus*
Serranidae	*Variola*	*albimarginata*
Serranidae	*Variola*	*louti*
Sparidae	*Pagrus*	*auratus*
Balistidae	*Abalistes*	*stellatus*
Balistidae	*Balistoides*	*conspicillum*
Balistidae	*Odonus*	*niger*
Balistidae	*Pseudobalistes*	*flavimarginatus*
Balistidae	*Sufflamen*	*chrysopterum*
Balistidae	*Sufflamen*	*fraenatum*
Carangidae	*Carangoides*	*chrysophrys*
Carangidae	*Carangoides*	*coeruleopinnatus*
Carangidae	*Carangoides*	*dinema*
Carangidae	*Carangoides*	*fulvoguttatus*
Carangidae	*Carangoides*	*gymnostethus*
Carangidae	*Caranx*	*ignobilis*
Carangidae	*Decapterus*	*russelli*
Carangidae	*Elagatis*	*bipinnulata*
Carangidae	*Gnathanodon*	*speciosus*
Carangidae	*Pseudocaranx*	*dentex*
Carangidae	*Scomberoides*	*tol*
Carangidae	*Seriola*	*dumerili*
Carangidae	*Seriola*	*lalandi*

Appendix 7 – 'All species considered likely to be caught by line fishing, including by-catch' (T3)

Carangidae	*Seriola*	*rivoliana*
Carangidae	*Seriolina*	*nigrofasciata*
Carcharhinidae	*Carcharhinus*	*albimarginatus*
Carcharhinidae	*Carcharhinus*	*amblyrhynchos*
Carcharhinidae	*Carcharhinus*	*leucas*
Carcharhinidae	*Carcharhinus*	*plumbeus*
Carcharhinidae	*Galeocerdo*	*cuvier*
Carcharhinidae	*Triaenodon*	*obesus*
Dasyatidae	*Dasyatis*	*kuhlii*
Dasyatidae	*Himantura*	*fai*
Dasyatidae	*Pastinachus*	*sephen*
Dasyatidae	*Taeniura*	*meyeni*
Echeneidae	*Echeneis*	*naucrates*
Ephippidae	*Platax*	*orbicularis*
Ephippidae	*Platax*	*teira*
Ginglymostomatidae	*Nebrius*	*ferrugineus*
Grammistidae	*Diploprion*	*bifasciatum*
Haemulidae	*Diagramma*	*pictum*
Haemulidae	*Plectorhinchus*	*flavomaculatus*
Haemulidae	*Plectorhinchus*	*gibbosus*
Hemiscylliidae	*Chiloscyllium*	*punctatum*
Holocentridae	*Sargocentron*	*melanospilos*
Holocentridae	*Sargocentron*	*rubrum*
Labridae	*Anampses*	*caeruleopunctatus*
Labridae	*Bodianus*	*axillaris*
Labridae	*Bodianus*	*diana*
Labridae	*Bodianus*	*mesothorax*
Labridae	*Cheilinus*	*fasciatus*
Labridae	*Cheilinus*	*undulatus*
Labridae	*Choerodon*	*fasciatus*
Labridae	*Choerodon*	*gomoni*
Labridae	*Choerodon*	*graphicus*
Labridae	*Choerodon*	*monostigma*
Labridae	*Choerodon*	*vitta*
Labridae	*Hologymnosus*	*doliatus*
Labridae	*Hologymnosus*	*longipes*
Labridae	*Oxycheilinus*	*unifasciatus*
Labridae	*Thalassoma*	*amblycephalum*
Labridae	*Thalassoma*	*lunare*
Lethrinidae	*Gymnocranius*	*audleyi*

Appendix 7 – 'All species considered likely to be caught by line fishing, including by-catch' (T3)

Lethrinidae	*Gymnocranius*	*grandoculis*
Lethrinidae	*Lethrinus*	*atkinsoni*
Lethrinidae	*Lethrinus*	*genivittatus*
Lethrinidae	*Lethrinus*	*ravus*
Lethrinidae	*Lethrinus*	*rubrioperculatus*
Lethrinidae	*Monotaxis*	*grandoculis*
Lutjanidae	*Lutjanus*	*adetii*
Lutjanidae	*Lutjanus*	*bohar*
Lutjanidae	*Lutjanus*	*carponotatus*
Lutjanidae	*Lutjanus*	*lemniscatus*
Lutjanidae	*Lutjanus*	*quinquelineatus*
Lutjanidae	*Lutjanus*	*russelli*
Lutjanidae	*Lutjanus*	*vitta*
Lutjanidae	*Symphorus*	*nematophorus*
Monacanthidae	*Aluterus*	*scriptus*
Monacanthidae	*Cantherhines*	*dumerilii*
Rachycentridae	*Rachycentron*	*canadum*
Rhynchobatidae	*Rhynchobatus*	*djiddensis*
Scombridae	*Gymnosarda*	*unicolor*
Scombridae	*Scomberomorus*	*commerson*
Scombridae	*Scomberomorus*	*queenslandicus*
Serranidae	*Cephalopholis*	*boenak*
Serranidae	*Cephalopholis*	*miniata*
Serranidae	*Cromileptes*	*altivelis*
Serranidae	*Epinephelus*	*areolatus*
Serranidae	*Epinephelus*	*fasciatus*
Serranidae	*Epinephelus*	*maculatus*
Serranidae	*Epinephelus*	*merra*
Serranidae	*Epinephelus*	*quoyanus*
Sparidae	*Argyrops*	*spinifer*
Sphyraenidae	*Sphyraena*	*jello*
Sphyrnidae	*Sphyrna*	*mokarran*
Sphyraenidae	*Sphyraena*	*jello*

Appendix 8 – 'Species considered likely to be caught by line fishing'		
Scaridae	*Cetoscarus*	*bicolor*
Scaridae	*Chlorurus*	*sordidus*
Scaridae	*Scarus*	*flavipectoralis*
Scaridae	*Scarus*	*oviceps*
Scaridae	*Scarus*	*schlegeli*
Acanthuridae	*Acanthurus*	*albipectoralis*
Acanthuridae	*Acanthurus*	*auranticavus*
Acanthuridae	*Acanthurus*	*dussumieri*
Acanthuridae	*Acanthurus*	*mata*
Acanthuridae	*Acanthurus*	*olivaceus*
Acanthuridae	*Acanthurus*	*thompsoni*
Acanthuridae	*Acanthurus*	*xanthopterus*
Acanthuridae	*Ctenochaetus*	*striatus*
Acanthuridae	*Naso*	*annulatus*
Acanthuridae	*Naso*	*brevirostris*
Acanthuridae	*Naso*	*caesius*
Acanthuridae	*Naso*	*lituratus*
Acanthuridae	*Naso*	*tuberosus*
Acanthuridae	*Naso*	*unicornis*
Acanthuridae	*Paracanthurus*	*hepatus*
Acanthuridae	*Prionurus*	*maculatus*
Acanthuridae	*Prionurus*	*microlepidotus*
Acanthuridae	*Zebrasoma*	*scopas*
Apogonidae	*Apogon*	*capricornis*
Apogonidae	*Apogon*	*doederleini*
Apogonidae	*Apogon*	*exostigma*
Apogonidae	*Apogon*	*notatus*
Aulostomidae	*Aulostomus*	*chinensis*
Blenniidae	*Aspidontus*	*taeniatus*
Caesionidae	*Caesio*	*cuning*
Caesionidae	*Pterocaesio*	*chrysozona*
Caesionidae	*Pterocaesio*	*marri*
Caesionidae	*Pterocaesio*	*trilineata*
Carangidae	*Selaroides*	*leptolepis*
Chaetodontidae	*Chaetodon*	*aureofasciatus*
Chaetodontidae	*Chaetodon*	*auriga*
Chaetodontidae	*Chaetodon*	*flavirostris*
Chaetodontidae	*Chaetodon*	*guentheri*
Chaetodontidae	*Chaetodon*	*kleinii*

Appendix 8 – 'Species considered likely to be caught by line fishing'		
Chaetodontidae	*Chaetodon*	*lineolatus*
Chaetodontidae	*Chaetodon*	*lunulatus*
Chaetodontidae	*Chaetodon*	*melannotus*
Chaetodontidae	*Chaetodon*	*ornatissimus*
Chaetodontidae	*Chaetodon*	*pelewensis*
Chaetodontidae	*Chaetodon*	*plebeius*
Chaetodontidae	*Chaetodon*	*rainfordi*
Chaetodontidae	*Chaetodon*	*speculum*
Chaetodontidae	*Chaetodon*	*trifascialis*
Chaetodontidae	*Chaetodon*	*unimaculatus*
Chaetodontidae	*Chaetodon*	*vagabundus*
Chaetodontidae	*Chelmon*	*rostratus*
Chaetodontidae	*Coradion*	*altivelis*
Chaetodontidae	*Coradion*	*chrysozonus*
Chaetodontidae	*Forcipiger*	*longirostris*
Chaetodontidae	*Heniochus*	*acuminatus*
Chaetodontidae	*Parachaetodon*	*ocellatus*
Cheilodactylidae	*Cheilodactylus*	*vestitus*
Fistulariidae	*Fistularia*	*commersonii*
Kyphosidae	*Kyphosus*	*vaigiensis*
Labridae	*Cirrhilabrus*	*punctatus*
Labridae	*Coris*	*aygula*
Labridae	*Coris*	*dorsomacula*
Labridae	*Coris*	*picta*
Labridae	*Coris*	*pictoides*
Labridae	*Gomphosus*	*varius*
Labridae	*Halichoeres*	*chrysus*
Labridae	*Halichoeres*	*hartzfeldii*
Labridae	*Halichoeres*	*melasmapomus*
Labridae	*Halichoeres*	*prosopeion*
Labridae	*Labroides*	*dimidiatus*
Labridae	*Leptojulis*	*cyanopleura*
Labridae	*Pseudolabrus*	*guentheri*
Labridae	*Suezichthys*	*devisi*
Labridae	*Suezichthys*	*gracilis*
Malacanthidae	*Malacanthus*	*brevirostris*
Mobulidae	*Manta*	*birostris*
Mullidae	*Parupeneus*	*barberinoides*
Mullidae	*Parupeneus*	*barberinus*
Mullidae	*Parupeneus*	*cyclostomus*

Appendix 8 – 'Species considered likely to be caught by line fishing'		
Mullidae	*Parupeneus*	*heptacanthus*
Mullidae	*Parupeneus*	*multifasciatus*
Mullidae	*Parupeneus*	*spilurus*
Mullidae	*Upeneus*	*filifer*
Muraenidae	*Gymnothorax*	*favagineus*
Muraenidae	*Gymnothorax*	*javanicus*
Muraenidae	*Gymnothorax*	*undulatus*
Myliobatididae	*Aetobatus*	*narinari*
Nemipteridae	*Nemipterus*	*furcosus*
Nemipteridae	*Nemipterus*	*hexodon*
Nemipteridae	*Nemipterus*	*theodorei*
Nemipteridae	*Pentapodus*	*aureofasciatus*
Nemipteridae	*Pentapodus*	*nagasakiensis*
Nemipteridae	*Pentapodus*	*paradiseus*
Nemipteridae	*Pentapodus*	*vitta*
Nemipteridae	*Scolopsis*	*bilineata*
Nemipteridae	*Scolopsis*	*margaritifer*
Nemipteridae	*Scolopsis*	*monogramma*
Pinguipedidae	*Parapercis*	*clathrata*
Pinguipedidae	*Parapercis*	*nebulosa*
Pinguipedidae	*Parapercis*	*xanthozona*
Pomacanthidae	*Centropyge*	*bicolor*
Pomacanthidae	*Centropyge*	*tibicen*
Pomacanthidae	*Chaetodontoplus*	*duboulayi*
Pomacanthidae	*Chaetodontoplus*	*meredithi*
Pomacanthidae	*Pomacanthus*	*imperator*
Pomacanthidae	*Pomacanthus*	*semicirculatus*
Pomacanthidae	*Pomacanthus*	*sexstriatus*
Pomacentridae	*Acanthochromis*	*polyacanthus*
Pomacentridae	*Amblyglyphidodon*	*aureus*
Pomacentridae	*Amphiprion*	*clarkii*
Pomacentridae	*Chromis*	*nitida*
Pomacentridae	*Chromis*	*xanthura*
Pomacentridae	*Dascyllus*	*reticulatus*
Pomacentridae	*Dascyllus*	*trimaculatus*
Pomacentridae	*Pomacentrus*	*amboinensis*
Pomacentridae	*Pomacentrus*	*australis*
Pomacentridae	*Pomacentrus*	*chrysurus*
Pomacentridae	*Pomacentrus*	*coelestis*
Pomacentridae	*Pomacentrus*	*moluccensis*

Appendix 8 – 'Species considered likely to be caught by line fishing'		
Pomacentridae	*Pomacentrus*	*nagasakiensis*
Pomacentridae	*Pristotis*	*jerdoni*
Scorpaenidae	*Pterois*	*volitans*
Serranidae	*Pseudanthias*	*rubrizonatus*
Siganidae	*Siganus*	*argenteus*
Siganidae	*Siganus*	*corallinus*
Siganidae	*Siganus*	*punctatissimus*
Siganidae	*Siganus*	*punctatus*
Siganidae	*Siganus*	*vulpinus*
Stegastomatidae	*Stegostoma*	*fasciatum*
Synodontidae	*Synodus*	*variegatus*
Tetraodontidae	*Canthigaster*	*valentini*
Tetraodontidae	*Feroxodon*	*multistriatus*
Zanclidae	*Zanclus*	*cornutus*

Appendix 9 – Depth and habita categories for repeat samplings. Instances where the habitat category recorded differs between the first and second deployment are highlighted in red.

Sample 1	Sample 2 (repeat)	Distance Between Samples* (m)	Depth Difference (m)**	Habitat_Category-Sample 2	Habitat_Category-Sample 1	Time Interval (hr:min)	∆Richness	∆Total MaxN
RAPKBbA_03	RAPKBbB_15	22.9	0.3	GORGONIAN and SEAWHIP GARDEN	as before	3.02	-6	-47
RAPKBbA_04	RAPKBbB_04	9.5	0.4	GORGONIAN and SEAWHIP GARDEN	as before	3.00	-1	-204
RAPBBgC_04	RAPBBgE_05	4.0	1.7	GORGONIAN and SEAWHIP GARDEN	as before	17.82	-11	-27
RAPBBgD_01	RAPBBgF_15	16.2	2.3	CORAL DOMINATED REEF	as before	18.55	**12**	**28**
RAPBBgD_02	RAPBBgF_02	9.2	1.5	CORAL DOMINATED REEF	as before	18.55	**12**	-10
RAPBBgD_04	RAPBBgF_05	18.2	0.9	**GORGONIAN and SEAWHIP GARDEN**	**OPEN SANDY SEABED**	18.55	-11	**8**
RAPBBgD_05	RAPBBgF_25	14.1	2.3	GORGONIAN and SEAWHIP GARDEN	as before	18.55	-25	**7**
RAPBBgE_02	RAPBBgG_02	11.4	0.2	CORAL DOMINATED REEF	as before	5.38	**12**	-35
RAPBBgF_01	RAPBBgG_03	4.7	0.8	**LOW RELIEF RUBBLE FIELD**	**CORAL DOMINATED REEF**	3.12	-6	-4
RAPEWgD_02	RAPEWgF_02	1.6	0.4	LOW RELIEF RUBBLE FIELD	as before	19.45	**5**	**25**
RAPEWgD_03	RAPEWgF_03	7.0	0.4	**OPEN SANDY SEABED**	**GORGONIAN and SEAWHIP GARDEN**	19.45	**6**	-37
RAPEWgD_04	RAPEWgF_04	18.1	0.2	CORAL DOMINATED REEF	as before	19.38	-13	-34
RAPEWgD_06	RAPEWgF_06	18.5	0.1	LOW RELIEF RUBBLE FIELD	as before	19.37	-20	-71
RAPEWgE_01	RAPEWgG_01	0.0	1.4	**GORGONIAN and SEAWHIP GARDEN**	**LOW RELIEF RUBBLE FIELD**	19.92	-3	-17
RAPEWgE_02	RAPEWgG_15	7.5	1.7	LOW RELIEF RUBBLE FIELD	as before	19.90	-3	**26**
RAPEWgE_04	RAPEWgG_03	5.7	1.3	LOW RELIEF RUBBLE FIELD	as before	19.90	-6	-2
RAPEWgE_05	RAPEWgG_04	18.5	1.3	CORAL DOMINATED REEF	as before	19.88	-2	-16

RAPEWgE_15	RAPEWgG_02	6.3	4.0	GORGONIAN and SEAWHIP GARDEN	as before	19.83	-2	-20
RAPEWgE_25	RAPEWgG_05	7.9	1.7	CORAL DOMINATED REEF	as before	19.87	**6**	-71
RAPEWgF_25	RAPEWgH_01	4.7	0.1	CORAL DOMINATED REEF	as before	4.65	**2**	-980
RAPEWgG_06	RAPEWgH_03	22.4	2.4	**LOW RELIEF RUBBLE FIELD**	**CORAL DOMINATED REEF**	2.25	**6**	**46**
RAPKBbC_01	RAPKBbE_01	13.7	0.5	CORAL DOMINATED REEF	as before	95.80	-4	-27
RAPKBbC_02	RAPKBbE_02	14.9	0.0	CORAL DOMINATED REEF	as before	95.80	**6**	**91**
RAPKBbC_03	RAPKBbE_03	5.6	0.5	CORAL DOMINATED REEF	as before	95.77	**4**	-31
RAPKBbC_04	RAPKBbE_04	16.5	0.3	GORGONIAN and SEAWHIP GARDEN	as before	95.25	**2**	**18**
RAPKBbC_05	RAPKBbE_05	7.1	0.5	GORGONIAN and SEAWHIP GARDEN	as before	95.22	**1**	-15
RAPKBbC_15	RAPKBbE_15	13.4	0.6	CORAL DOMINATED REEF	as before	95.78	-2	**1**
RAPKBbD_05	RAPKBbF_05	12.0	1.8	GORGONIAN and SEAWHIP GARDEN	as before	3.03	**8**	**52**
RAPKBbD_06	RAPKBbF_06	14.5	3.3	**GORGONIAN and SEAWHIP GARDEN**	**OPEN SANDY SEABED**	2.98	**11**	**33**
RAPKBbD_15	RAPKBbF_01	3.5	1.6	CORAL DOMINATED REEF	as before	3.88	**2**	**28**
RAPWWbC_01	RAPWWbD_05	16.2	3.7	GORGONIAN and SEAWHIP GARDEN	as before	17.57	-5	-34
RAPWWbC_02	RAPWWbD_15	14.6	2.1	CORAL DOMINATED REEF	as before	17.57	-16	-99
RAPWWbC_03	RAPWWbD_04	10.0	4.8	CORAL DOMINATED REEF	as before	17.57	-3	-194
RAPWWbC_04	RAPWWbD_25	18.9	3.1	**GORGONIAN and SEAWHIP GARDEN**	**OPEN SANDY SEABED**	17.57	**4**	-27
RAPWWbC_05	RAPWWbD_03	11.1	5.3	GORGONIAN and SEAWHIP GARDEN	as before	17.55	**8**	-80
RAPWWbC_06	RAPWWbD_02	12.0	3.2	CORAL DOMINATED REEF	as before	17.55	-6	**9**
RAPWWbC_15	RAPWWbD_06	14.9	3.7	GORGONIAN and SEAWHIP GARDEN	as before	17.70	-3	**26**
RAPWWbC_25	RAPWWbD_01	4.0	3.7	CORAL DOMINATED REEF	as before	17.53	-14	-64

RAPWWbE_01	RAPWWbF_01	8.0	1.1	OPEN SANDY SEABED	as before	2.15	**1**	**3**
RAPWWbE_04	RAPWWbF_04	9.9	0.5	CORAL DOMINATED REEF	as before	2.08	-6	**148**
RAPWWbE_05	RAPWWbF_06	15.9	0.4	**LOW RELIEF RUBBLE FIELD**	**GORGONIAN and SEAWHIP GARDEN**	2.08	-4	-80
RAPWWbE_25	RAPWWbF_05	6.8	1.7	GORGONIAN and SEAWHIP GARDEN	as before	2.08	-1	-71

Appendix 10 - Abbreviations for species names used in analyses		
Abbreviation	**Genus**	**Species**
Aba_stellatus	*Abalistes*	*stellatus*
Aca_polyacanthus	*Acanthochromis*	*polyacanthus*
Aca_albipectoralis	*Acanthurus*	*albipectoralis*
Aca_auranticavus	*Acanthurus*	*auranticavus*
Aca_dussumieri	*Acanthurus*	*dussumieri*
Aca_mata	*Acanthurus*	*mata*
Aca_olivaceus	*Acanthurus*	*olivaceus*
Aca_thompsoni	*Acanthurus*	*thompsoni*
Aca_xanthopterus	*Acanthurus*	*xanthopterus*
Aet_narinari	*Aetobatus*	*narinari*
Alu_scriptus	*Aluterus*	*scriptus*
Amb_aureus	*Amblyglyphidodon*	*aureus*
Amp_clarkii	*Amphiprion*	*clarkii*
Ana_caeruleopunctatus	*Anampses*	*caeruleopunctatus*
Apo_capricornis	*Apogon*	*capricornis*
Apo_doederleini	*Apogon*	*doederleini*
Apo_exostigma	*Apogon*	*exostigma*
Apo_notatus	*Apogon*	*notatus*
Apr_virescens	*Aprion*	*virescens*
Arg_spinifer	*Argyrops*	*spinifer*
Asp_taeniatus	*Aspidontus*	*taeniatus*
Aul_chinensis	*Aulostomus*	*chinensis*
Bal_conspicillum	*Balistoides*	*conspicillum*
Bod_axillaris	*Bodianus*	*axillaris*
Bod_diana	*Bodianus*	*diana*
Bod_mesothorax	*Bodianus*	*mesothorax*
Bod_perditio	*Bodianus*	*perditio*
Cae_cuning	*Caesio*	*cuning*
Can_dumerilii	*Cantherhines*	*dumerilii*
Can_valentini	*Canthigaster*	*valentini*
Car_chrysophrys	*Carangoides*	*chrysophrys*
Car_coeruleopinnatus	*Carangoides*	*coeruleopinnatus*
Car_dinema	*Carangoides*	*dinema*
Car_fulvoguttatus	*Carangoides*	*fulvoguttatus*
Car_gymnostethus	*Carangoides*	*gymnostethus*
Car_ignobilis	*Caranx*	*ignobilis*
Car_albimarginatus	*Carcharhinus*	*albimarginatus*
Car_amblyrhynchos	*Carcharhinus*	*amblyrhynchos*
Car_leucas	*Carcharhinus*	*leucas*

Appendix 10 - Abbreviations for species names used in analyses

Abbreviation	Genus	Species
Car_plumbeus	*Carcharhinus*	*plumbeus*
Cen_bicolor	*Centropyge*	*bicolor*
Cen_tibicen	*Centropyge*	*tibicen*
Cep_boenak	*Cephalopholis*	*boenak*
Cep_miniata	*Cephalopholis*	*Miniata*
Cet_bicolor	*Cetoscarus*	*bicolor*
Cha_aureofasciatus	*Chaetodon*	*aureofasciatus*
Cha_auriga	*Chaetodon*	*auriga*
Cha_flavirostris	*Chaetodon*	*flavirostris*
Cha_guentheri	*Chaetodon*	*guentheri*
Cha_kleinii	*Chaetodon*	*kleinii*
Cha_lineolatus	*Chaetodon*	*lineolatus*
Cha_lunulatus	*Chaetodon*	*lunulatus*
Cha_melannotus	*Chaetodon*	*melannotus*
Cha_ornatissimus	*Chaetodon*	*ornatissimus*
Cha_pelewensis	*Chaetodon*	*pelewensis*
Cha_plebeius	*Chaetodon*	*plebeius*
Cha_rainfordi	*Chaetodon*	*rainfordi*
Cha_speculum	*Chaetodon*	*speculum*
Cha_trifascialis	*Chaetodon*	*trifascialis*
Cha_unimaculatus	*Chaetodon*	*unimaculatus*
Cha_vagabundus	*Chaetodon*	*vagabundus*
Cha_duboulayi	*Chaetodontoplus*	*duboulayi*
Cha_meredithi	*Chaetodontoplus*	*meredithi*
Che_fasciatus	*Cheilinus*	*fasciatus*
Che_undulatus	*Cheilinus*	*undulatus*
Che_vestitus	*Cheilodactylus*	*vestitus*
Che_rostratus	*Chelmon*	*rostratus*
Chi_punctatum	*Chiloscyllium*	*punctatum*
Chl_sordidus	*Chlorurus*	*sordidus*
Cho_cephalotes	*Choerodon*	*cephalotes*
Cho_fasciatus	*Choerodon*	*fasciatus*
Cho_gomoni	*Choerodon*	*gomoni*
Cho_graphicus	*Choerodon*	*graphicus*
Cho_monostigma	*Choerodon*	*monostigma*
Cho_schoenleinii	*Choerodon*	*schoenleinii*
Cho_venustus	*Choerodon*	*venustus*
Cho_vitta	*Choerodon*	*vitta*
Chr_nitida	*Chromis*	*nitida*

Appendix 10 - Abbreviations for species names used in analyses		
Abbreviation	**Genus**	**Species**
Chr_xanthura	*Chromis*	*xanthura*
Cir_punctatus	*Cirrhilabrus*	*punctatus*
Cor_altivelis	*Coradion*	*altivelis*
Cor_chrysozonus	*Coradion*	*chrysozonus*
Cor_aygula	*Coris*	*aygula*
Cor_dorsomacula	*Coris*	*dorsomacula*
Cor_picta	*Coris*	*picta*
Cor_pictoides	*Coris*	*pictoides*
Cro_altivelis	*Cromileptes*	*altivelis*
Cte_striatus	*Ctenochaetus*	*striatus*
Das_reticulatus	*Dascyllus*	*reticulatus*
Das_trimaculatus	*Dascyllus*	*Trimaculatus*
Das_kuhlii	*Dasyatis*	*kuhlii*
Dec_russelli	*Decapterus*	*russelli*
Dia_pictum	*Diagramma*	*pictum*
Dip_bifasciatum	*Diploprion*	*bifasciatum*
Ech_naucrates	*Echeneis*	*naucrates*
Ela_bipinnulata	*Elagatis*	*bipinnulata*
Epi_areolatus	*Epinephelus*	*areolatus*
Epi_coioides	*Epinephelus*	*coioides*
Epi_fasciatus	*Epinephelus*	*fasciatus*
Epi_maculatus	*Epinephelus*	*maculatus*
Epi_merra	*Epinephelus*	*merra*
Epi_quoyanus	*Epinephelus*	*quoyanus*
Epi_undulatostriatus	*Epinephelus*	*undulatostriatus*
Fer_multistriatus	*Feroxodon*	*multistriatus*
Fis_commersonii	*Fistularia*	*commersonii*
For_longirostris	*Forcipiger*	*longirostris*
Gal_cuvier	*Galeocerdo*	*cuvier*
Gna_speciosus	*Gnathanodon*	*speciosus*
Gom_varius	*Gomphosus*	*varius*
Gym_audleyi	*Gymnocranius*	*audleyi*
Gym_grandoculis	*Gymnocranius*	*grandoculis*
Gym_unicolor	*Gymnosarda*	*unicolor*
Gym_favagineus	*Gymnothorax*	*favagineus*
Gym_javanicus	*Gymnothorax*	*javanicus*
Gym_undulatus	*Gymnothorax*	*undulatus*
Hal_chrysus	*Halichoeres*	*chrysus*
Hal_hartzfeldii	*Halichoeres*	*hartzfeldii*

Appendix 10 - Abbreviations for species names used in analyses		
Abbreviation	**Genus**	**Species**
Hal_melasmapomus	*Halichoeres*	*melasmapomus*
Hal_prosopeion	*Halichoeres*	*prosopeion*
Hen_acuminatus	*Heniochus*	*acuminatus*
Him_fai	*Himantura*	*fai*
Hol_doliatus	*Hologymnosus*	*doliatus*
Hol_longipes	*Hologymnosus*	*longipes*
Hyd_ornatus	*Hydrophis*	*ornatus*
Kyp_vaigiensis	*Kyphosus*	*vaigiensis*
Lab_dimidiatus	*Labroides*	*dimidiatus*
Lep_cyanopleura	*Leptojulis*	*cyanopleura*
Let_atkinsoni	*Lethrinus*	*atkinsoni*
Let_genivittatus	*Lethrinus*	*genivittatus*
Let_laticaudis	*Lethrinus*	*laticaudis*
Let_miniatus	*Lethrinus*	*miniatus*
Let_nebulosus	*Lethrinus*	*nebulosus*
Let_ravus	*Lethrinus*	*ravus*
Let_rubrioperculatus	*Lethrinus*	*rubrioperculatus*
Lut_adetii	*Lutjanus*	*Adetii*
Lut_bohar	*Lutjanus*	*bohar*
Lut_carponotatus	*Lutjanus*	*carponotatus*
Lut_erythropterus	*Lutjanus*	*erythropterus*
Lut_lemniscatus	*Lutjanus*	*lemniscatus*
Lut_malabaricus	*Lutjanus*	*malabaricus*
Lut_quinquelineatus	*Lutjanus*	*quinquelineatus*
Lut_russelli	*Lutjanus*	*russelli*
Lut_sebae	*Lutjanus*	*sebae*
Lut_vitta	*Lutjanus*	*vitta*
Mal_brevirostris	*Malacanthus*	*brevirostris*
Man_birostris	*Manta*	*birostris*
Mon_grandoculis	*Monotaxis*	*grandoculis*
Nas_annulatus	*Naso*	*annulatus*
Nas_brevirostris	*Naso*	*brevirostris*
Nas_caesius	*Naso*	*caesius*
Nas_lituratus	*Naso*	*lituratus*
Nas_tuberosus	*Naso*	*tuberosus*
Nas_unicornis	*Naso*	*unicornis*
Neb_ferrugineus	*Nebrius*	*ferrugineus*
Nem_furcosus	*Nemipterus*	*furcosus*
Nem_hexodon	*Nemipterus*	*hexodon*

Appendix 10 - Abbreviations for species names used in analyses		
Abbreviation	**Genus**	**Species**
Nem_theodorei	*Nemipterus*	*theodorei*
Odo_niger	*Odonus*	*niger*
Oxy_unifasciatus	*Oxycheilinus*	*unifasciatus*
Pag_auratus	*Pagrus*	*auratus*
Par_hepatus	*Paracanthurus*	*hepatus*
Par_ocellatus	*Parachaetodon*	*ocellatus*
Par_clathrata	*Parapercis*	*clathrata*
Par_nebulosa	*Parapercis*	*nebulosa*
Par_xanthozona	*Parapercis*	*xanthozona*
Par_barberinoides	*Parupeneus*	*barberinoides*
Par_barberinus	*Parupeneus*	*barberinus*
Par_cyclostomus	*Parupeneus*	*cyclostomus*
Par_heptacanthus	*Parupeneus*	*heptacanthus*
Par_multifasciatus	*Parupeneus*	*multifasciatus*
Par_spilurus	*Parupeneus*	*spilurus*
Pas_sephen	*Pastinachus*	*sephen*
Pen_aureofasciatus	*Pentapodus*	*aureofasciatus*
Pen_nagasakiensis	*Pentapodus*	*nagasakiensis*
Pen_paradiseus	*Pentapodus*	*paradiseus*
Pen_vitta	*Pentapodus*	*vitta*
Pla_orbicularis	*Platax*	*orbicularis*
Pla_sp	*Platax*	*sp*
Pla_teira	*Platax*	*teira*
Ple_flavomaculatus	*Plectorhinchus*	*Flavomaculatus*
Ple_gibbosus	*Plectorhinchus*	*gibbosus*
Ple_laevis	*Plectropomus*	*laevis*
Ple_leopardus	*Plectropomus*	*leopardus*
Ple_maculatus	*Plectropomus*	*maculatus*
Pom_imperator	*Pomacanthus*	*imperator*
Pom_semicirculatus	*Pomacanthus*	*semicirculatus*
Pom_sexstriatus	*Pomacanthus*	*sexstriatus*
Pom_amboinensis	*Pomacentrus*	*amboinensis*
Pom_australis	*Pomacentrus*	*australis*
Pom_chrysurus	*Pomacentrus*	*chrysurus*
Pom_coelestis	*Pomacentrus*	*coelestis*
Pom_moluccensis	*Pomacentrus*	*moluccensis*
Pom_nagasakiensis	*Pomacentrus*	*nagasakiensis*
Pri_maculatus	*Prionurus*	*maculatus*
Pri_microlepidotus	*Prionurus*	*microlepidotus*

Appendix 10 - Abbreviations for species names used in analyses		
Abbreviation	**Genus**	**Species**
Pri_multidens	*Pristipomoides*	*multidens*
Pri_jerdoni	*Pristotis*	*jerdoni*
Pse_rubrizonatus	*Pseudanthias*	*rubrizonatus*
Pse_flavimarginatus	*Pseudobalistes*	*flavimarginatus*
Pse_dentex	*Pseudocaranx*	*dentex*
Pse_guentheri	*Pseudolabrus*	*guentheri*
Pte_chrysozona	*Pterocaesio*	*chrysozona*
Pte_marri	*Pterocaesio*	*marri*
Pte_trilineata	*Pterocaesio*	*trilineata*
Pte_volitans	*Pterois*	*volitans*
Rac_canadum	*Rachycentron*	*canadum*
Rhy_djiddensis	*Rhynchobatus*	*djiddensis*
Sar_melanospilos	*Sargocentron*	*melanospilos*
Sar_rubrum	*Sargocentron*	*rubrum*
Sca_flavipectoralis	*Scarus*	*flavipectoralis*
Sca_niger	*Scarus*	*niger*
Sca_oviceps	*Scarus*	*oviceps*
Sca_schlegeli	*Scarus*	*schlegeli*
Sco_bilineata	*Scolopsis*	*bilineata*
Sco_margaritifer	*Scolopsis*	*margaritifer*
Sco_monogramma	*Scolopsis*	*monogramma*
Sco_tol	*Scomberoides*	*tol*
Sco_commerson	*Scomberomorus*	*commerson*
Sco_queenslandicus	*Scomberomorus*	*queenslandicus*
Sel_leptolepis	*Selaroides*	*leptolepis*
Ser_dumerili	*Seriola*	*dumerili*
Ser_lalandi	*Seriola*	*lalandi*
Ser_rivoliana	*Seriola*	*rivoliana*
Ser_nigrofasciata	*Seriolina*	*nigrofasciata*
Sig_argenteus	*Siganus*	*Argenteus*
Sig_corallinus	*Siganus*	*corallinus*
Sig_punctatissimus	*Siganus*	*punctatissimus*
Sig_punctatus	*Siganus*	*punctatus*
Sig_vulpinus	*Siganus*	*vulpinus*
Sph_jello	*Sphyraena*	*jello*
Sph_mokarran	*Sphyrna*	*mokarran*
Ste_fasciatum	*Stegostoma*	*fasciatum*
Sue_devisi	*Suezichthys*	*devisi*
Sue_gracilis	*Suezichthys*	*gracilis*

Appendix 10 - Abbreviations for species names used in analyses		
Abbreviation	**Genus**	**Species**
Suf_chrysopterum	*Sufflamen*	*chrysopterum*
Suf_fraenatum	*Sufflamen*	*fraenatum*
Sym_nematophorus	*Symphorus*	*nematophorus*
Syn_variegatus	*Synodus*	*variegatus*
Tae_meyeni	*Taeniura*	*meyeni*
Tha_amblycephalum	*Thalassoma*	*amblycephalum*
Tha_lunare	*Thalassoma*	*lunare*
Tri_obesus	*Triaenodon*	*obesus*
Upe_filifer	*Upeneus*	*filifer*
Var_albimarginata	*Variola*	*albimarginata*
Var_louti	*Variola*	*louti*
Zan_cornutus	*Zanclus*	*cornutus*
Zeb_scopas	*Zebrasoma*	*scopas*