

Montara: Barracouta East, Goeree and Vulcan Shoals Survey 2013



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Executive Summary

- ❖ From the 21st August to the 3rd November 2009, there was an uncontrolled release of gas, condensate and crude oil from the Montara Well head platform (MWHP) into the Timor Sea. A plan to monitor the effects of this release was produced in October of that year by the lease operator PTTEP Australasia (Ashmore Cartier) Pty. Ltd (hereafter PTTEPAA) and the Department of Sustainability, Environment, Water, Population and Communities, (DSEWPoC); Monitoring Plan for the Montara Well Release Timor Sea; PTTEPAA 2009.
- ❖ The benthic communities on Barracouta East and Vulcan Shoals, two submerged shoals within 100 km of the MWHP and within the area predicted to be impacted by the release were surveyed in 2010. These surveys provided an initial set of data for benthic habitats to aid in planning for a broader assessment of other banks and shoals in the region.
- ❖ Triggering of the S5 component of the Montara Monitoring Plan (PTTEPAA 2009) led to a more comprehensive study of nine shoals and banks in 2011 that described physical characteristics, benthic and fish assemblages and sediment hydrocarbon levels. These were selected to be representative of a gradient of high, medium and low exposure to the release and ranged from <3 to ~150 km away from the MWHP.
- ❖ This study, incorporating new survey data collected in 2013, updates information on three (Barracouta East Shoal; (BAE), Goree Shoal; (GOE), and Vulcan Shoal; (VUL) of the nine banks and shoals included in the 2011 surveys. The former (BAE) of these was considered to have had low exposure to the uncontrolled release, while both the latter were closer to the well head and had relatively higher potential exposure, although surveys of hydrocarbons in the sediment and modeled hours of exposure suggested that the exposure of GOE to the uncontrolled release was somewhat lower than that of VUL.
- ❖ The aim of the present study was to characterize multi-year changes in benthic and fish assemblages between successive surveys in 2010, 2011 and 2013 on these three shoals. This information extends understanding of biodiversity patterns on these shoal features in space and time, with the aim of better understanding natural variability versus possible anthropogenic effects. Changes potentially correlated with exposure to the uncontrolled release in 2009 that were identified in the 2011 survey, notably loss of seagrasses at Vulcan Shoal and variations in the patterns of fish diversity, abundance and size among shoals were particular foci for the study.
- ❖ In order to facilitate comparisons, the same techniques and wherever possible key deployment sites used in the 2011 surveys on each shoal were also used in the present study. Shoals were surveyed using towed video and still camera transects for benthos and stereo Baited Remote Video Systems (BRUVS™®) for fish communities.

Benthic assemblages

- ❖ Benthic environments on shoals were composed of ca 25-42% of living macro-epibenthic organisms, which were diverse communities dominated by algae, sponges, and hard and soft corals. These communities were interspersed with rubble, sand, and consolidated reef.
- ❖ Most biota have shown declines in relative cover between 2011 and 2013 surveys and an increase in macro algae, sand/silt, and rubble. The broad spatial scale of these declines

suggests that a major scouring event or events, possibly a large storm, has created this result.

- ❖ Seagrass meadows lost from Vulcan Shoal between 2010 and 2011 surveys had not recovered in 2013. We recorded < 1 % cover of seagrass on this shoal. The seagrass remnants seen on Vulcan Shoal in the 2011 survey, notably fibrous rhizomes embedded in sand and rubble areas across the central and northern plateau areas, were further reduced, consistent with physical disturbance such as sediment removal or burial.
- ❖ A soft coral habitat (predominantly a mono-specific community of *Nephthea* sp.) that was present on the western side of Barracouta East Shoal in both 2010 and 2011 surveys was absent in 2013. The absence of this unusual biological community in 2013 provides further evidence of disturbance. *Nephthea* sp. originally provided the appearance of an extensive meadow, with the animals growing on loose sandy and rubble areas. Although disease, predation or natural life cycle fluctuations cannot be ruled out, it is possible this species had propagated across the area using asexual budding, coming to dominate the rubble area. Its loss may reflect the ease with which the underlying unconsolidated substrate can be removed by a storm.
- ❖ There was little variation in the structure of benthic assemblages among the three shoals, although variation in cover between years was high. This highlights the importance of long-term monitoring of these dynamic communities, which provides a baseline of natural change, to which any anthropogenic impacts could be compared in future.

Fish assemblages

- ❖ A total of 6692 fishes and sharks were identified, representing 43 families and 262 species from 72 BRUVS™ deployments at the three shoals (24 per shoal). These included 147 individuals of five species of sharks and 25 individuals of three species of rays with the remaining 97% of sightings being teleost fishes. Six sea snakes were also recorded.
- ❖ Many BRUVS™ deployments, although targeting the same locations using surface GPS co-ordinates, sampled/encountered different habitats than those recorded in the 2011 survey. We accounted for these changes by predicting expected values of species richness (SR), total abundance (TA) and size (adjFL) as a function of the relationships between habitat and fish assemblages we observed in the 2011 survey using linear regression. These expected values, based upon the results of the 2011 study, were then compared to observed values from the 2013 surveys.
- ❖ At BAE (the shoal that received relatively low exposure to the uncontrolled release of hydrocarbons), there was a significant increase in SR, TA and a shift to smaller individuals in the assemblage.
- ❖ At GOE, (the shoal that received the second highest exposure to the release), we observed values of SR, TA and adjFL consistent with those predicted for the habitat types sampled in 2013.
- ❖ At VUL, (the shoal that received the highest exposure), there were decreases in SR and TA relative to habitat and no change in mean sizes of fish within the assemblage.
- ❖ Overall, composition of fish assemblages changed between the two surveys at all three shoals, but these changes were relatively small compared to the among-shoal variation in assemblage structure recorded during the survey in 2011
- ❖ At all three shoals, numbers of *Triaenodon obesus*, (the whitetip reef shark), were significantly

lower than those predicted based on habitat. The extent of these declines differed among reefs and was correlated with exposure of the shoal to the release. However, changes in abundance of the whitetip reef sharks were not consistent with changes in numbers of other common reef sharks on these shoals, suggesting that correlations with release exposure may have occurred by chance.

- ❖ There was a decline in numbers of sea snakes from 50 sightings in the 2011 survey to only 6 sightings in the 2013 survey. Similar changes in abundance of sea snakes have been recorded on other reefs in the region that have not been exposed to an uncontrolled release of hydrocarbons.

Interpretation and Recommendations

- ❖ The results highlight that these submerged shoal features continue to support an abundant and diverse biota, but a biodiversity demonstrating significant quantitative variability over just a few years. Interpretation of patterns in benthos and fish assemblages and their attribution to any effect of the uncontrolled release is hampered by a lack of temporal and spatial understanding that would allow surveys to separate variability in assemblage structure occurring at regional scales (>100 km) from any effect of an uncontrolled release of hydrocarbons.
- ❖ Since no pre-release baseline data exists, any patterns we recorded do not necessarily imply causality with the release event in 2009.
- ❖ Given the considerable shift in area of unconsolidated sediment on the shoals between 2011 and 2013, which can potentially affect the distributions of benthic biota and fishes, repetition of a subset of the multibeam sampling completed in 2011 is recommended for future work. This would enable a better estimation of the spatial extent and quality of habitat loss and gain on the shoals and assist with interpreting observed changes in fish assemblages.
- ❖ Interpretation of trends at any given shoal will be improved as more extensive regional baselines are established to monitor benthic habitats and fish assemblage structure. The observations made in this study also indicate that monitoring of the physical oceanographic environment on and near shoals and an ability to sample at greater frequency and intensity both between and within shoals will be valuable approaches to understanding these dynamic systems

1. Introduction & Background

1.1 Monitoring background

Between the 21st August and the 3rd November 2009, loss of control from the Montara H1 well resulted in the release of gas, condensate and crude oil from the Montara reservoir through the Montara Well head platform (MWHP) into the Timor Sea. On the 9th October 2009, the lease operator PTTEP Australasia (Ashmore Cartier) Pty. Ltd (hereafter PTTEPAA) and the Department of Sustainability, Environment, Water, Population and Communities, DSEWPoC) released a Monitoring Plan for the Montara Well Release Timor Sea (PTTEPAA 2009).

In 2010, PTTEPAA requested a preliminary assessment of benthos on the tops of Barracouta and Vulcan Shoals, two submerged shoals within 100 km of the MWHP that were likely to lie under the area covered by some components of the Montara uncontrolled release. The purpose of the survey was to provide preliminary monitoring data to aid in planning for a broader assessment of the numerous shoals in the region, should it be required as a result of a formal triggering of component S5 of the Montara Monitoring Plan (PTTEPAA 2009).

A subsequent broad study of nine shoals in 2011, as outlined in the Monitoring Plan, was carried out to quantify physical characteristics, identify and characterise the benthic and fish communities, estimate the potential exposure to surface oil and dispersed oil, and identify any obvious damage to the associated communities. The objectives were addressed by examining the attributes of nine banks and shoals ranging from <3 to ~150 km away from the MWHP, and selected to represent a gradient of high, medium and low exposure to the hydrocarbons released. Surveys were undertaken on (a) sediment hydrocarbon levels, (b) shoal bathymetry using multi-beam swath mapping, and (c) benthic habitat and fish community composition.

1.2 Existing environmental information

The Montara Well Head Platform (MWHP) uncontrolled release occurred within the North West Shelf marine biogeographic province defined within the 'Integrated Marine and Coastal Regionalization of Australia (IMCRA): ecosystem-based classification scheme for marine and coastal environments' (Commonwealth of Australia 2006). Within the province there are many submerged and emergent reefs and cays along the outer edge of the continental shelf extending from the Lydoch and Troubadour Shoals in the Arafura Sea (north of Darwin) to the Rowley Shoals north-west of Broome. This 246,404 km² area is also referred to as the Oceanic Shoals (OSS) meso-scale region within the IMCRA classification (Commonwealth of Australia 2006). The limits of this region are nominated as lying between 18° South and 119° East, and 10° 30' South and 131° East. The banks and shoals of the OSS may have once constituted an intermittent barrier reef prior to being buried by rising sea levels (Commonwealth of Australia 2006) and have a floral and faunal composition similar to emergent oceanic reef systems.

Early survey data from shoals in the central part of this bioregion in the mid-1990s (Heyward *et al.* 1997) noted the abrupt bathymetry of the shoals and found that high diversity ecosystems could be found there. A number of shared biological features and habitat types were reported, but also

marked differences between individual shoals were found. The offshore waters in this region tend to be clear, enabling some phototrophic species, such as algae and corals, to thrive even at depths of 50 m or more in places. As many submerged shoals may rise to within 15-50 m of the sea surface, shallower habitats exposed to adequate sunlight have at least the potential to support a diverse floral and faunal composition similar to the emergent oceanic reef systems.

The 2010 and 2011 surveys for PTTEPAA confirmed that the seabed on the flat, plateau-like areas of the shoal tops were in fact dominated by benthic primary producers, including varying amounts of algae and hard corals, interspersed with sand and rubble patches. The benthic communities and fish faunas of the shoals were both diverse and varied within and between shoals. The biota on these shoals was typical of shallow tropical reef systems elsewhere; the biota included many coral and algal species, which likely mirror regional coral reef diversity (such as Ashmore and Cartier Reefs and the Scott Reef complex). Furthermore, fish fauna were found to be more diverse than seen on the Great Barrier Reef on equivalent seabed features. The shoal habitats also provide an additional regional reservoir of megafauna, such as sharks and sea snakes, hitherto typically associated with the emergent reefs.

Prior to the 2011 survey, there were no obvious signs of major disturbances to the benthic biota on the shoals, with one exception. At Vulcan Shoal, located closest to the MWHP, a significant loss of seagrass was apparent in 2011 when compared with data from the 2010 surveys, six months after the uncontrolled release. Sediment samples confirm that Vulcan Shoal, which lies 33 km from the MWHP, had hydrocarbons present and this exposure, while low, was higher than other shoals in this study. Sensitivity of some seagrass species to hydrocarbons, more so in the presence of dispersants, has been reported in the general literature. However, as the 2010 survey found the seagrass in excellent apparent health, a highly delayed effect from the uncontrolled release resulting in a change sometime between 6-16 months afterward seems unlikely. In contrast the hard corals on Vulcan Shoal were normal in appearance and had not decreased in abundance during the same period, suggesting that the cause of the seagrass loss was either selective to seagrass or perhaps physical in nature and mostly affecting loosely attached biota. A storm or other source of strong seabed shear forces, scouring the seagrass and other loosely attached organism present on rubble and gravel substrate, might have been responsible.

The 2011 survey also found that there was little evidence to suggest that recent major changes to fish communities had occurred; analyses showed that depth and aspect were the main predictors of the observed patterns in fish and also benthic data, rather than exposure to hydrocarbons from the Montara well head. However, there was an apparent decrease in overall diversity (5-10%), total abundance (5-30%) and increases in mean size (2-10%) for fishes at those shoals closest (within 50 kms) to the Montara well head platform. While these results do not exclude a potential effect of exposure to hydrocarbons and dispersants on the fish communities, the observed variations between shoals appear to be dominated by natural processes.

The combined results of the 2010 and 2011 surveys (Heyward *et al.* 2010 & 2012) provide a baseline for monitoring of specific shoals and a valuable resource for future shoal studies throughout the region. The Montara work highlighted the need for an improved understanding of the spatial and temporal variability the shoals biological communities might display. A number of striking patterns in benthic and fish communities resulting from these surveys prompted a further assessment of three of the previously surveyed shoals (Vulcan, Barracouta East, and Goeree) to assess long-term post

impact benthic and fish community composition at the shoals. The results from the latest survey in 2013 are presented within this report.

1.3 References

- Commonwealth of Australia (2006) A Guide to the Integrated Marine and Coastal Regionalisation of Australia Version 4.0. Canberra: Department of the Environment and Heritage.
<http://www.environment.gov.au/coasts/mbp/publications/imcra/pubs/imcra4.pdf>
- Heyward, A, Pincerratto, E & Smith L (1997) eds. Big Bank Shoals of the Timor Sea: An Environmental Resources Atlas. BHP Petroleum- AIMS joint publication. BHP Petroleum, Melbourne. pp 115.
- Heyward et al (2010) Monitoring Program for the Montara Well Release Timor Sea: Final Report on the Nature of Barracouta and Vulcan Shoals. Report prepared by the Australian Institute of Marine Science for PTTEP Australasia (Ashmore Cartier) Pty. Ltd. August 2010. pp49. Available: <http://www.environment.gov.au/coasts/oilspill/publications/pubs/banks-shoals-report.pdf>
- Heyward A, Jones R, Meeuwig J, Burns K, Radford B, Colquhoun J, Cappel M, Case M, O'Leary R, Fisher R, Meekan M, and Stowar M (2012) Monitoring Study S5 Banks & Shoals, Montara 2011 Offshore Banks Assessment Survey. Report for PTTEP Australasia (Ashmore Cartier) Pty. Ltd. Australian Institute of Marine Science, Townsville. (253 pp.).
- PTTEPAA (2009) Monitoring plan for the Montara Well release Timor Sea. Document Number: PTTEPAA 04 / Interwoven #142768. Prepared for PTTEPAA and DEWHA by Wardrop Consulting, Victoria, Australia.
<http://www.environment.gov.au/coasts/publications/pubs/montara-monitoring-plan.pdf>

2. Benthic community assessment for Barracouta, Vulcan, and Goeree Shoals

2.1 Introduction

The initial Montara Study (S5 2010 survey) of two submerged shoals in the region of the Montara well head platform (MWHP), Vulcan and Barracouta Shoals, found that both supported diverse biological communities across their shallow plateau areas (Heyward *et al.* 2010). In areas down to 40 m, bare sand and rubble were ubiquitous components of the benthos, but interspersed with abundant primary producers, dominated by algae, corals and seagrass. More than 50% of the seabed on both shoals was covered with benthic life. Barracouta Shoal supported abundant algae, especially *Halimeda*, although seagrass cover was sparse. The western margin of the shoal presented an extensive and likely monoclonal field of soft coral, preliminarily identified as *Nephthea* sp.. In contrast, Vulcan Shoal was particularly notable for an extensive and lush field of the seagrass *Thalassodendron ciliatum* that was not seen on Barracouta.

The follow up survey in 2011 extended field sampling to include a further seven banks and shoals, using previously adopted methods of towed video and still photography, as well as multibeam acoustic swath mapping to characterise habitats, and BRUVS™ to establish fish communities around each shoal / bank. The 2011 survey provided comparable benthic community results to the initial survey, except that there was a significant loss of seagrass from Vulcan Shoal (11.3% in 2010 – 2.4 % in 2011), which was the closest shoal from the Montara platform uncontrolled release of hydrocarbons. The reason for this loss of seagrass between surveys is speculative at present, although hydrocarbons in the sediment were highest at this shoal compared to the other eight shoals surveyed, albeit in low concentrations overall in the region (Heyward *et al.* 2012). There also appeared to be a slight increase in algae and concomitant decrease in coral cover at Barracouta Shoal, which may be in part due to an increase in sampling in the 2011 survey.

One of the additional shoals surveyed in 2011 was Goeree Shoal, which is situated at a similar distance from the MWHP to Vulcan Shoal (ca 32 km). At 35.5 m nominal mean depth, Goeree is slightly deeper than Vulcan (nominal mean depth 29.7 m), although Goeree is about 4 times smaller than Vulcan. However, both shoals have similar benthic habitat compositions, which are dominated by algae and abiotic material (Heyward *et al.* 2012).

The current survey carried out in April 2013 was designed to gain insights into how benthic and fish communities might have changed in the subsequent two years after the 2011 survey. To do this, three shoals were revisited, which were Vulcan, Barracouta East, and Goeree. It was envisaged that these surveys would provide detailed benthic information on current seagrass status at Vulcan Shoal, as well as an assessment of other benthic cover patterns through time, and among shoals. As Goeree Shoal was not surveyed in 2010, comparisons can only be made between 2011 and 2013 patterns; however Vulcan and Barracouta East Shoal comparisons were possible for all three survey periods.

2.2 Methods

Vulcan, Barracouta, and Goeree Shoals are situated within 50 km of the Montara Well Head Platform (MWHP) (Figure 2.1). Each shoal was surveyed using a combination of towed video and still camera transects for benthos and deployed baited video (BRUVS™) for fish communities (Chapter 3). Benthic sampling was spaced to provide broad representative samples across each of the three shoals, which was comparable to sampling in previous surveys (Figures 2.4-2.6).

2.2.1 Benthic habitat characterisation

The sessile biota and seabed substrate on the top of each shoal were surveyed down to maximum depths of approximately 60 m using towed video and still camera imagery as previously reported (Heyward *et al.* 2010 & 2012). The 60 m depth contour typically occurred just below the upper shoal rims, often at depths around 40 m, as the substrate curved rapidly from the more horizontal shoal plateau regions in the 20-45 m depth range to the steeply sloping shoal sides. Discontinuing sampling as depths approached 60 m ensured that the shallower horizontal portion of each shoal plateau was adequately sampled, while avoiding inefficiencies and difficulties associated with sampling deeper, steeply sloping areas on the shoal sides. Previous AIMS research on the Timor Sea shoals indicated that habitats in less than 60 m were most likely to support diverse communities associated with benthic primary producer habitat. These shallower shoal regions were also closest to the sea surface where hydrocarbons were most likely.

The AIMS towvid system comprises a towed camera platform sending a live camera feed to a vessel-based image classification system (see Colquhoun *et al.* 2007, Fry *et al.* 2008; Heyward *et al.* 2010). The towed platform supports a forward facing video camera with lights, together with a downward-facing high resolution still camera and strobe system programmed to take sequential still images at fixed time intervals (Figure 2.2). The towed platform was deployed over the stern of the vessel, maintained within a meter of the seabed and towed at 1-2 knots (1.5 nominal) until a minimum distance of about 1.5 km, and up to 2.1 km was covered in a continuous line transect. On the vessel, a computer-based towvid program manages collation of position, depth, and operator-derived habitat classification data, which is captured in real time as an operator interprets the live video feed and then archived for subsequent spatial analysis (Figure 2.3). At the completion of a transect the tow platform was retrieved to the vessel deck, still camera images downloaded and the camera systems serviced as required while the vessel steamed to the next transect station. Priority was given to surveying the shallow plateau regions of each shoal, identified by monitoring the live soundings, which tended to drop away quickly beyond 30-40 m depths. The location of each transect was nominal but designed to provide coverage across and along each shoal plateau region.

2.2.2 Still photo analysis

The still photo images for all transects were geo-referenced, based on corrected tow platform position data and time code synchrony, prior to being sub sampled at a standardized spatial separation then grouped for detailed point-intercept analysis. Based on previous experience of benthic habitats in this bioregion (Heyward *et al.* 1997, Heyward and Rees 1999; Heyward *et al.* 2010), a sampling interval between sequential images of 10 m along each transect was sought. Actual image spacing achieved varied from 6-10 m. The number of images collected and used in the analysis was proportional to the size of the shoal and total length of towvid transect conducted. After

sorting and discarding poor quality photos, a sample totalling 7,974 images taken from all shoals was selected for detailed analysis in the current survey.

Images of the seabed were analysed using a point intercept approach with the AIMS Reefmon software (Jonker *et al.* 2008). Reefmon is a benthic classification system developed by AIMS for the long-term monitoring (LTM) on the Great Barrier Reef. Consequently all images were analysed using the Reefmon database system, with five overlaid points classified per photo. The benthos under each superimposed point was identified to the highest possible taxonomic classification and/or morphotype.

Photo level point intercept data, analysed as described above, were obtained for each transect from each shoal. Data from below 50 m were discarded so that the depth range of the data from all shoals was equivalent (see Heyward *et al.* 2010 & 2012). Analysing the data at the photo level using presence/absence of categories in a logistic model proved to be too computationally intensive. Furthermore, different numbers of points were analysed for individual images among years, which could potentially cause biases in the estimates of percent cover. Because the transects from survey years 2011 and 2013 were very large (covering 1.42 km on average), they were divided into sub-transects such that their average length was similar to those used in 2010 (500 m+). This created a dataset with a total of 137 sub-transects in 2011 (Vulcan 57 Baraccouta East 48 & Goeree 32) and 126 in 2013 (Vulcan 49 Baraccouta East 47 & Goeree 30), and 41 (Vulcan 20 & Barracouta 21) transects for 2010. Each transect had at least 200 individual point categories within major benthic categories and a range of finer scale subcategories. Image analysis was carried out by a range of experienced benthic image scorers, and these were compared for consistency and precision.

For each transect the percent cover of benthic variables was calculated. Variables occurring frequently enough for analysis included three coarse-scale benthic categories: total algal cover, total hard coral cover, and total cover of sponges (Table 2.1). At a finer taxonomic scale we also examined the total cover of Acroporidae and Pocilloporidae (Scleractinia), coralline algae, and Ascidians (represented overwhelmingly by the small photosynthetic ascidian *Lissoclinum* sp., see Heyward *et al.* 2010) (Table 2.2). Changes in benthic composition among sample years and the three shoals were examined using pie charts. Additional multivariate and univariate analyses were carried out as described below (Section 2.2.4).

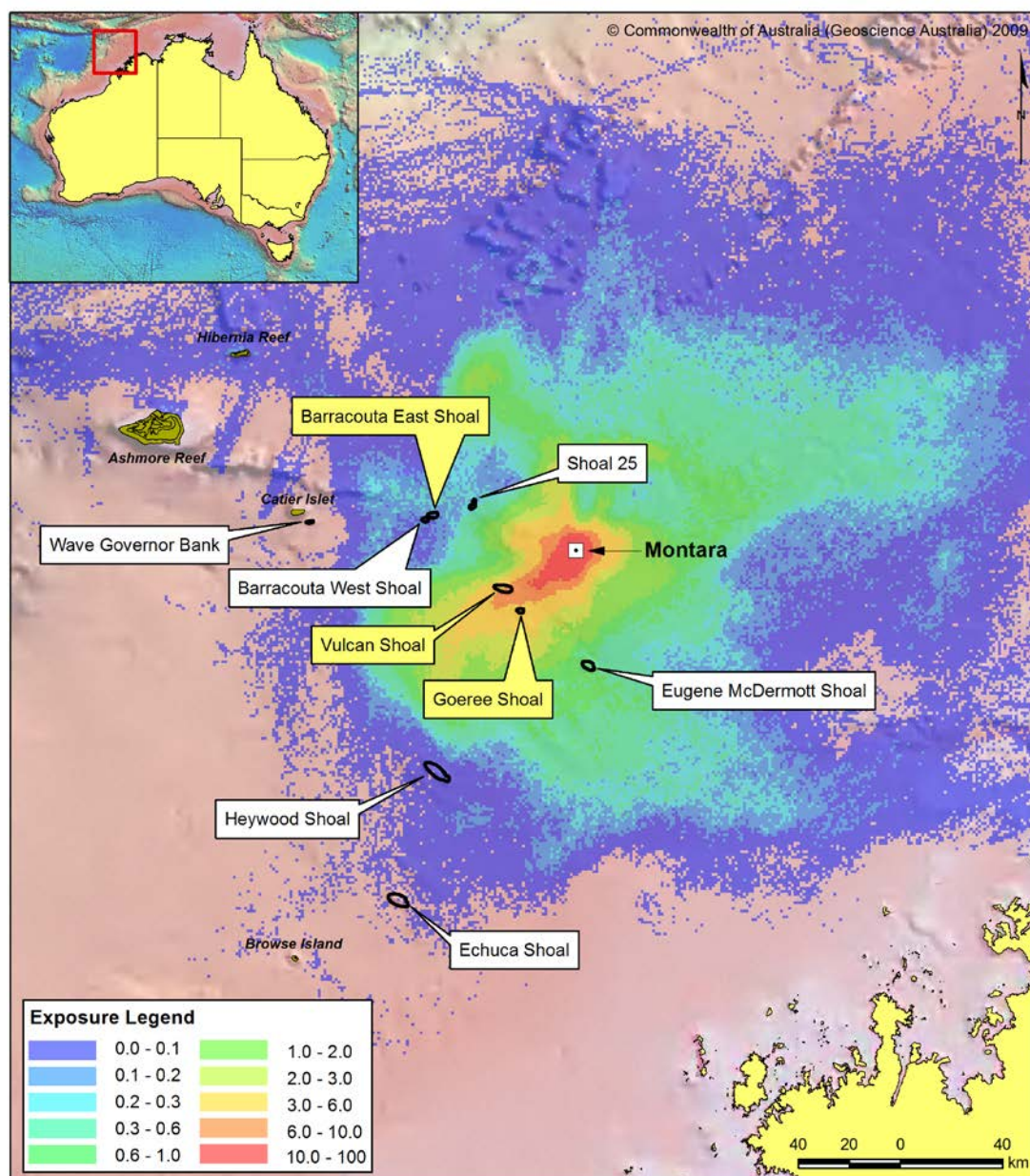


Figure 2.1. Location of Vulcan and Barracouta Shoal study sites surveyed between 2010 - 2013 in relation to modelled relative exposure map of the oil spill in 2009. Image of the spill developed by Asia-Pacific ASA in another of the independent studies triggered under the monitoring plan developed by the company and DSEWPaC and released by the agency. This is a relative exposure map representing up to 99.9% of occurrences of visible surface oil associated with the Montara incident. It is important to note that the area shown does not represent the extent of any oil slick observed at any time during the uncontrolled release incident. It is a summation of the area within which isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling. Note: Shoal names shown in yellow were revisited in the current survey.

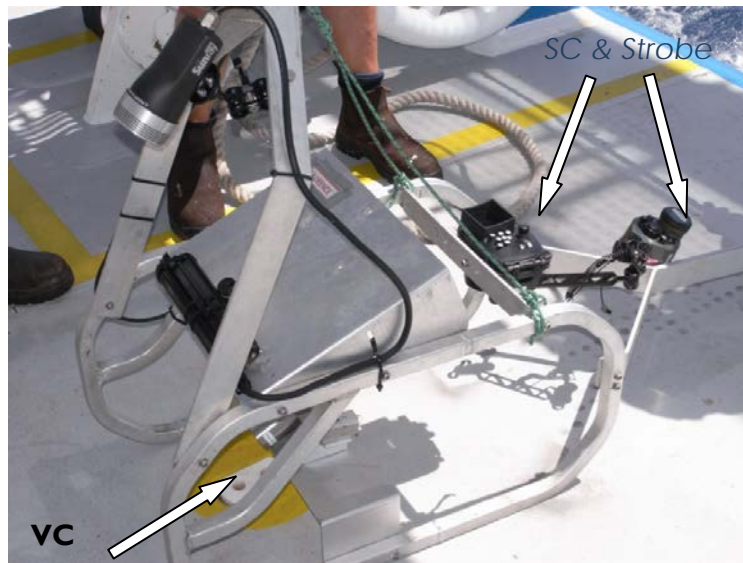


Figure 2.2. Towed body used for all transect surveys. A forward facing video camera provides live images to the ship, allowing the towed body to be “flown” just above the seabed while marine scientists classify the habitats. Positioned at the rear of the towed body a high resolution still camera with strobe takes downward facing, detailed images of the seabed every 5 seconds, for use in later analyses.



Figure 2.3. The AIMS towed video (Towvid) system in use on board the research vessel RV Solander during the survey. Live video is classified directly into a computer, with the observer keying in the appropriate classification from a variety of pre-programmed major habitat types, along with the associated data on position and depth.

Table 2.1: Major Benthic categories used for analysis of the Montara Benthic image analysis data.

Major Categories		Benthic groups and categories included and/or description
A	Algae	Articulated calcareous algae and Halimeda; Foliose algae; Brown (includes <i>Hydroclathrus</i> spp.), green and red algae (other than rhodoliths); Rhodoliths; Chrysocystis; Any other algae described as macroalgae
CR	Consolidated Reef	Consolidated substrate; Reefal substrate; Turf and crustose corraline algae (algal turf community); Filamentous algae
DHC	Dead Hard Coral	Recently dead hard coral (older dead hard coral is generally covered in algal turf community and included with Consolidated Reef)
HC	Hard Coral	All Scleractinian hard corals, covering a range of genera including: Acropora, Anacropora, Astreopera, Isopora, Montipora (Acroporidae); Coeloseris, Gardineroseris, Leptoseris, Pachyseris, Pavona (Agariciidae); Turbinaria (Densrophyllidae); Euphyllia & Physogura (Euphyllidae); Cyphastrea, Diploastrea, Echinopora, Favia, Favites, Goniastrea, Leptoria, Montastrea, Oulophyllia, Platygyra (Faviidae); Ctenactis, Diasteris, Fungia, Halomitra, Herpolitha (Fungiidae); Merulina (Merulinidae); Acanthastrea, Cyanarina, Lobophyllia, Scolymia, Symphyllia (Mussidae); Galaxea (Oculinidae); Echinophyllia and Oxypora, Mycedium, Pectinia (Pectiniidae); Pocillopora, Seriatopora, Stylophora (Pocilloporidae); Alveopora, Goniopora, Porites (Poritidae); Coscinaraea, Psammocora (Siderastreidae).
SC	Soft Coral	Cladiella, Klyxum, Lobophytum, Sarcophyton, Sinularia (Alcyoniidae); Briareum (Briareidae); (Clavularia) Cluvariinae; Junceella (Ellisellidae); Heliopora coerulea (Heloporidae); Gorgonia, Rumphella (Gorgoniidae); Isis hippuris (Isidae); Capnella, Dendronephthya, Lemnalia, Paralemnalia (Neptheidae); Xenia Tubipora (Tubiporidae); (Xeniidae);
SD	Sand/Silt	Bioturbates sand and silt, sand, silt, coarse sand
SG	Seagrass	All seagrasses
SP	Sponge	All sponges
UN	Unconsolidated Substrate	Rubble, rocks, shells/skeletal rubble, stones
OT	Other	Bryozoans, hydroids, urchins, zoanthids, ascidians, anemones, annelids, crinoids, holothurians, corallimorphs, starfish, gastropods, millipora

Table 2.2: Benthic categories and sub-categories used for analysis of the Montara Benthic still image analysis data.

Sub- Categories		Benthic groups and categories included and/or description
Algae	Halimeda	Mostly Halimeda spp, small amounts of other unidentified Articulated calcareous algae
	Macroalgae	Foliose algae; Brown (includes hydroclathrus spp.), green and red algae; Rhodoliths; Chrysocystis; Any other algae described as macroalgae
	Rhodolith	Rhodolith
Hard Coral	Acropora - branching	Branching forms of Acropora
	Acropora - digitate and corymbose	Digitate and corymbose forms of the Acropora
	Acropora - tabulate	Tabulate Acropora
	Branching	all non-Acrpora branching Scleractinian corals. Includes genera such as Anacropora, Porites and Seriatopora
	Encrusting	Encrusting growth forms, including both Acropora and non-Acropora Scleractinian corals. Includes genera such as Astreopora, Cyphastrea, Echinopora, Favia, Galaxea, Goniastrea, Hydrophora, Isopora, Merulina, Montipora, Mycedium, Pavona, Pectinia, Platygyra, Porites, Psammocora, and Turbinaria
	Foliose	Foliose growth forms, including both Acropora and non-Acropora Scleractinian corals; Includes genera such as Echinophyllia, Echinopora, Leptseris, Merulina, Montipora, Oxypora, Pachyseris, Pavona and Turbinaria
	Massive	Massive growth forms, including both Acropora and non-Acropora Scleractinian corals. Includes genera such as: Acanthastrea, Aleveopora, Astreopora Coeloseris, Coscinareaea, Cyphastrea, Diploastrea, Euphyllia, Favia, Favites, Gardineroseris, Goniastrea, Goniopora, Hydriophora, Leptoria, Lobophyllia, Montastrea, Montipora, Oulophyllia, Physogyra, Platygyra, Porites, Psammocora, Symphyllia and Turbinaria
	Solitary	all solitary corals including members of the Ctenactis, Cynarina, Diseris, Fungia, Halmotra, Herpolitha, Polyphylla and Scolymia
	Submassive/columnar	Submassive and columnar growth forms, including both Acropora and non-Acropora Scleractinian corals; Includes members of the Acropora, Coscinareaea, Cyphastrea, Faviidae, Galaxea, Goniopora, Isopora, Montipora, Pavona, Pocillopora, Porites, Psammocora and Stylophora
Soft Coral	Gorgonian	Members of the Gorgoniidae family
	Soft coral	All other non gorgonian soft corals
Sponge	Sponge - encrusting	Encrusting growth forms
	Sponge - erect/branching	Erect growth forms. Includes branching, foliaceous, stalked, erect laminar and erect simple types
	Sponge - massive	All massive-like sponges, including both simple and hollow massive, barrel or ridgelike and cup and vase shaped sponges
Other	Ascidian	(represented overwhelmingly by the small photosynthetic Ascidian Lissoclinum sp., see Heyward <i>et al.</i> 2010)
	Other organisms	all other non-ascidian animals, including: Bryozoans, hydroids, urchins, zoanthids, anemones, annelids, crinoids, holothurians, corallimorphs, starfish, gastropods, millipora

2.2.3 Data management

All data were collated in digital format and archived on the AIMS server. Position and depth data derived from the ship's navigation package were associated with all field sampling. Towvid position, depth and habitat classification data were transferred in Microsoft Access database structure. Associated video files, were recorded to analogue mini DV tapes and archived also in avi format. Still photos associated with each towvid transect were recorded in jpeg format and are georeferenced. Metadata for all sampling is included in Appendix 2.1.

2.2.4 Statistical analyses

Multivariate analysis of community composition across shoals and among sampling periods

For all multivariate analyses the percent cover for each benthic category was Logn ($x+1$) transformed, then used to construct Bray-Curtis similarity matrices. The logarithmic transformation of the benthic data ensured that some account was taken of the rare categories and to down-weight the contribution of the more dominant categories (Clarke and Warwick 2001).

A principle coordinates analysis (PCO) using the function “pco” in the package “ecodist” (Goslee & Urban 2007) was used to examine differences in community structure among shoals and sampling years. The “vf” function in this package was used to find the maximum correlation of the individual variables with the configuration of transects in ordination space. Permutational Multivariate Analysis of Variance tests (function “adonis” in the package “vegan”; Anderson 2001; McArdle and Anderson 2001) were used to explore statistical differences in community composition between shoals, sampling year and their interaction. Pair-wise post-hoc comparisons were used to determine which levels of each factor were significantly different. Community dispersion (heterogeneity) among factors was tested using Permutational analysis of multivariate dispersions (function “betadisper” from package “vegan”; Anderson 2006) using Bray-Curtis as a distance measure. This function implements Marti Anderson's PERMDISP2 procedure for the analysis of multivariate homogeneity of group dispersions (variances).

Univariate analysis of community composition across shoals and among sampling periods

Spatial and temporal trends were examined using generalised linear (GLM) and generalised linear mixed models (GLMMs) and related methods. Such models are akin to conventional Analysis of Variance Methods (ANOVA; Underwood 1997) but were implemented in R using a range of packages (e.g. “glm”, “lmer”) that allow greater flexibility in the statistical design and implementation, using log-likelihood estimation. R also has the advantage of automation of various analyses across a large range of response variables. Separate univariate analyses were conducted for all the major categories as well as the fine-scale subcategories for various benthic groups.

The main effects of shoal and sampling year, their interaction, and their relative importance were explored using “glm” function from the “stats” package in R. For each response variable five competing models were fitted, including an intercept only model (no effect of shoal or sampling year), a shoal only model, a sampling year only model, a shoal and sampling year model (main effects

only) and a shoal by sampling year model (full interaction). All five models were compared using the Bayesian Information Criterion (BIC) and the model with the lowest BIC value was selected as the “Best model”. BIC is a measure of goodness of fit of the models similar to Akaike’s Information Criterion (AIC, Burnham and Anderson 2002) but is more conservative (will favour simpler models) than AIC as sample size gets large, thereby it has less tendency to “overfit”. To simplify output, only the R^2 values for the best model are shown. As we were also interested in exploring the sampling year variation within each shoal, we also fitted a generalized linear mixed effects model (GLMM) using the function “lmer” from the “lme4” package (Bates *et al.* 2011). For the mixed effects model the random effect of sampling year was entered as nested within shoal (shoal | sampling year) and the parameter estimate for this random effect was extracted for each shoal and expressed as a proportion of the mean value (coefficient of variation).

To partition the overall variability between shoal and sampling year, the “hier.part” function of the “hier.part” package was used (Walsh & Mac Nally, 2013). This function calculates goodness of fit measures for the entire hierarchy of models using all combinations of (N) independent variables and then applies the hierarchical partitioning algorithm of Chevan and Sutherland (1991) to return a simple table listing each variable, its independent contribution (I) and its conjoint contribution with all other variables (J).

2.3 Results

2.3.1 Habitat classification

All shoals had a large proportion of seabed covered with life, ranging from *ca* 25-42%, with the remainder composed of sand/silt or unconsolidated rock (Figures 2.4-2.6). A combination of turf or filamentous algal covered consolidated reef or various types of other algae were the most abundant life form, often followed by hard coral and sponges (Figures 2.4-2.6).

Most major coral families were represented on all shoals, with encrusting growth forms being the most common across all shoals, followed by massives, sub-massive / columnar and branching *Acropora* (Figure 2.7). The most common category of algae across all shoals was ‘turf / coralline / consolidated reef’ (Figure 2.8). Seagrass was only present on Vulcan Shoals, which was predominant in the 2010 survey (Figure 2.8). Soft coral cover was highest at Barracouta East, whereas cover of ascidians was highest at Vulcan and Goeree Shoals (Figure 2.9). Encrusting forms of sponges were relatively common across all three shoals (Figure 2.9).

Vulcan Benthic Categories

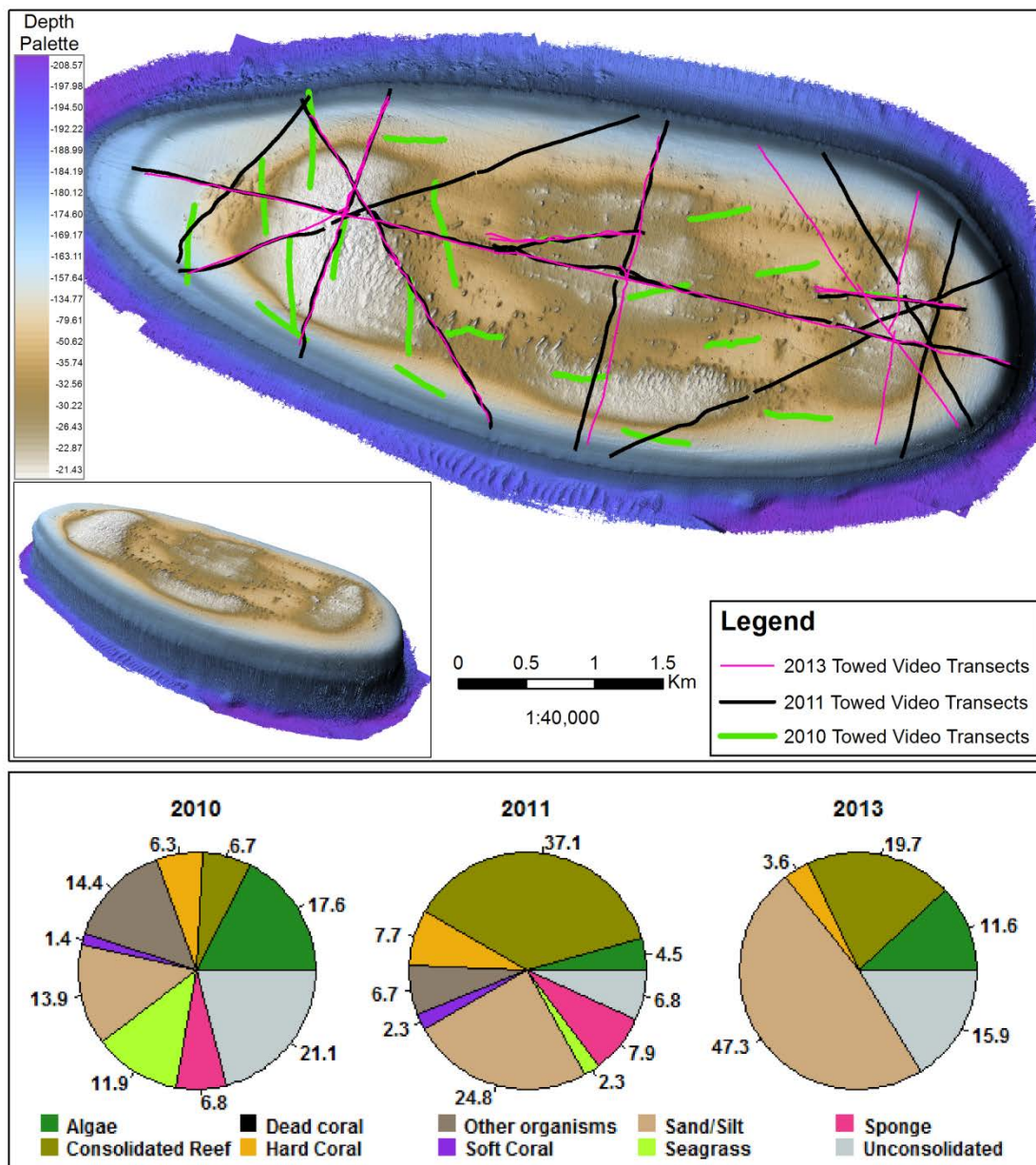


Figure 2.4. Map of towed video transects at Vulcan Shoal for the three surveys and relative percentages of major benthic community categories.

Barracouta East Benthic Categories

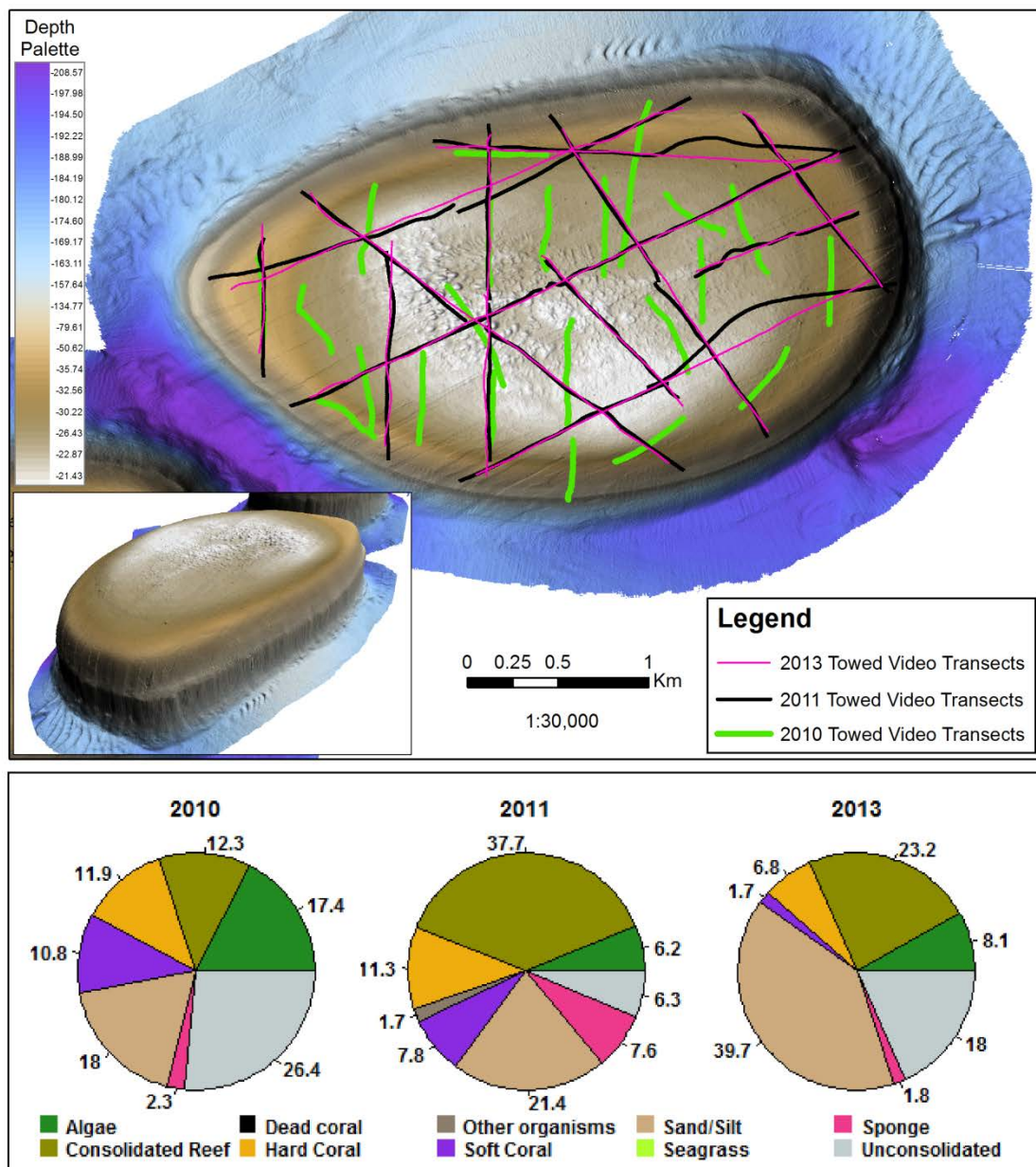


Figure 2.5. Map of towed video transects at Barracouta East Shoal for the three surveys and relative percentages of major benthic community categories.

Goeree Benthic Categories

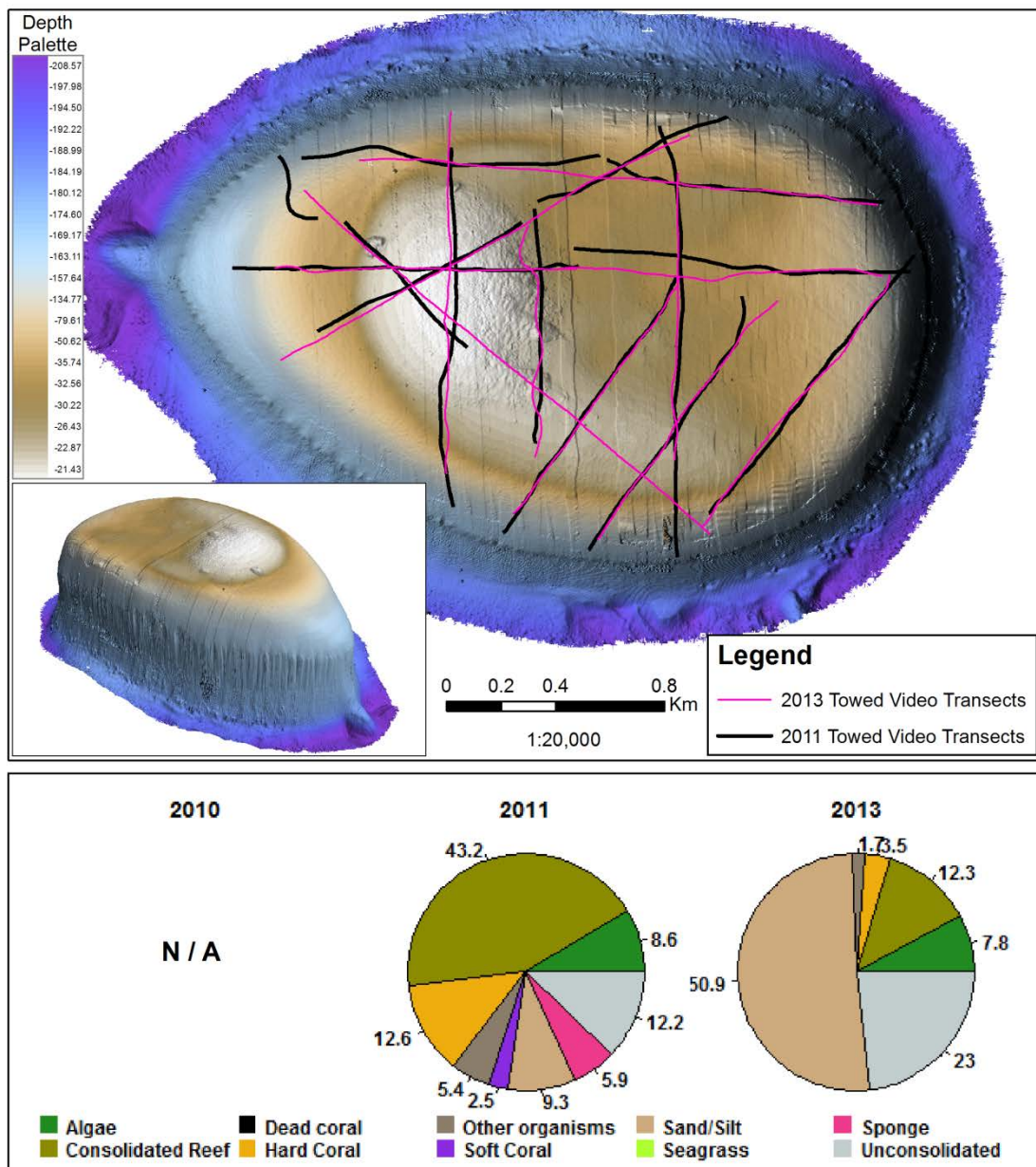


Figure 2.6. Map of towed video transects at Goeree Shoal for the two surveys and relative percentages of major benthic community categories.

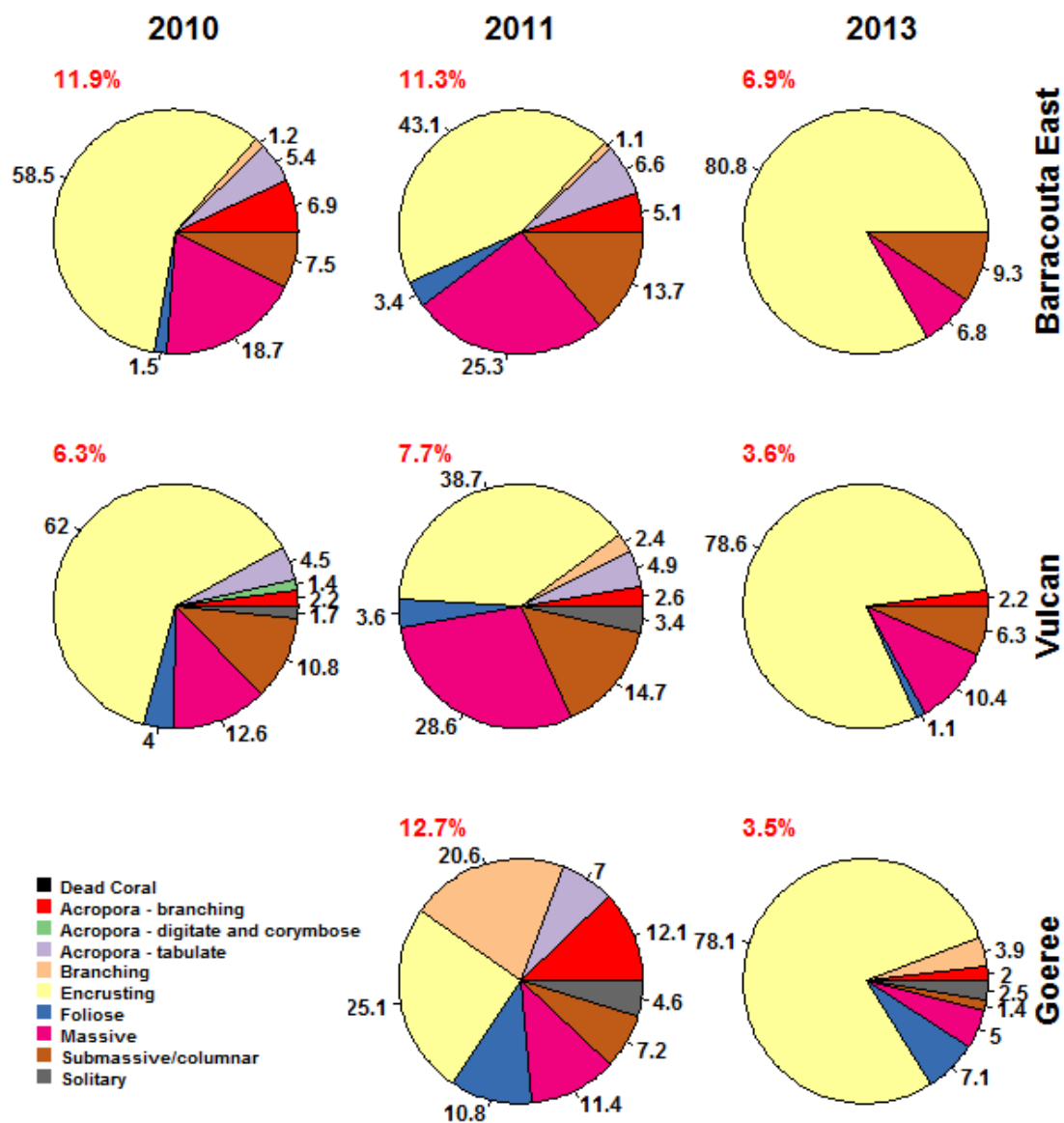


Figure 2.7. Relative hard coral composition for major taxonomic/morphological categories on all shoals, for each survey year. Categories are shown when they were > 1 % of the cover across all transects. Total mean coral cover for each shoal is shown in red, adjacent to each pie diagram. Coral cover at each shoal relative to other major benthic groups is provided in Figures 2.4-2.6.

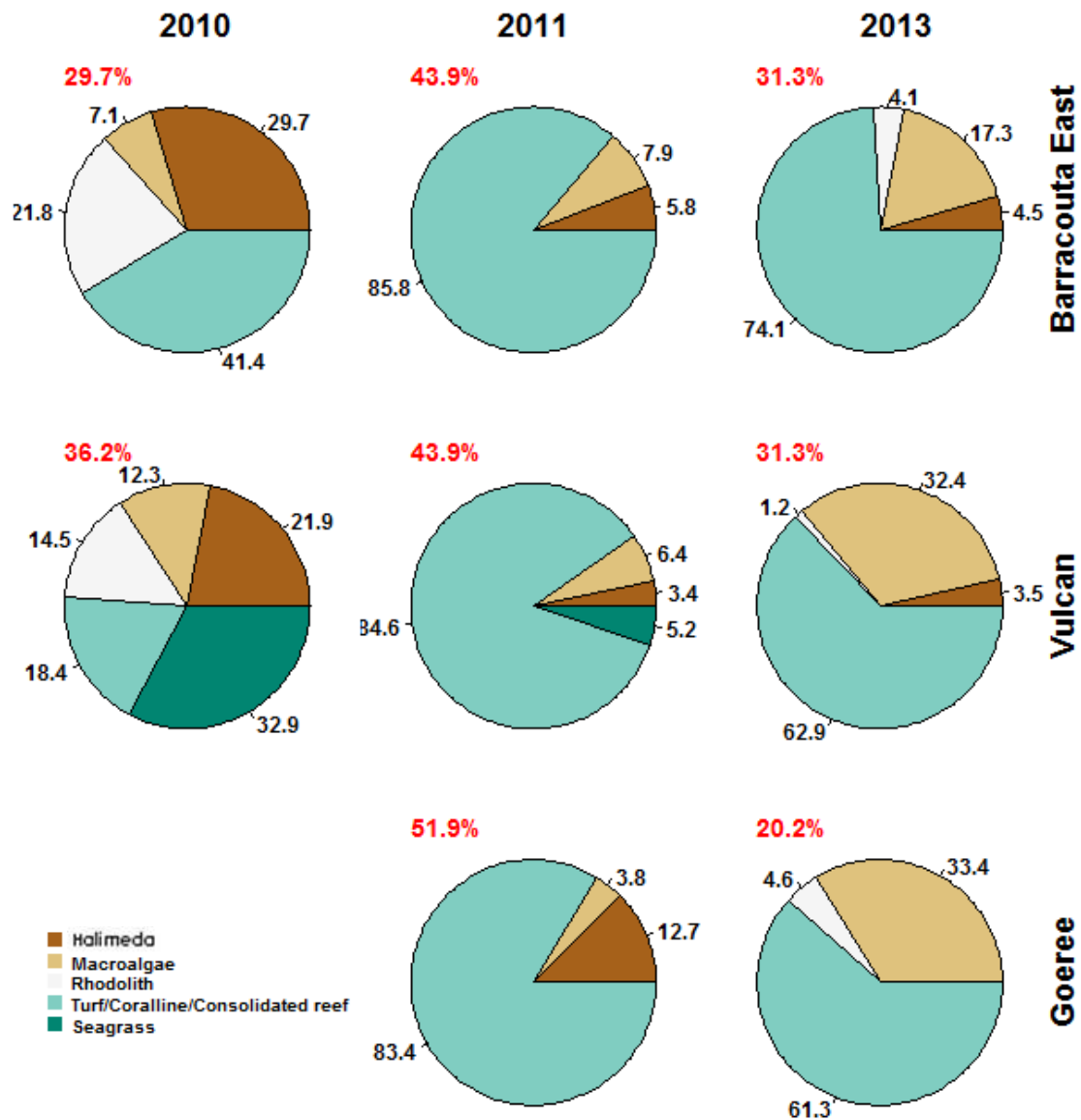


Figure 2.8. Relative composition for major algal categories, consolidated reef (including turf and encrusting coralline algae), and seagrass on all shoals, for each survey year. Categories are shown when they were > 1 % of the cover across all transects. Total mean coral cover for each shoal is shown in red, adjacent to each pie diagram. The cover of each major category relative to other major benthic groups is provided in Figures 2.4-2.6.

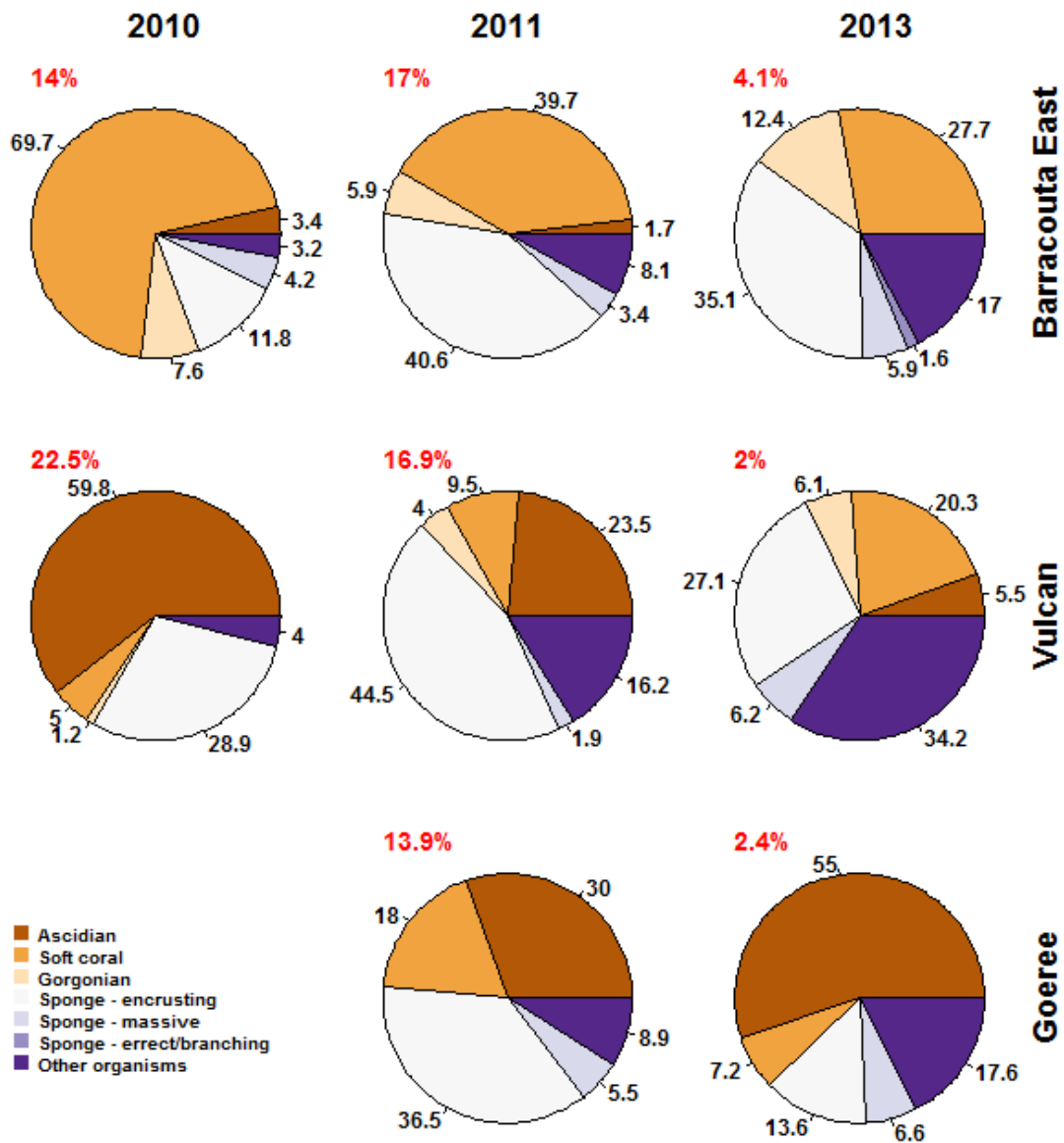


Figure 2.9. Relative composition of ascidians, soft corals, major sponge morphological categories and other organisms on all shoals. Categories are shown when they were > 1% of the cover across all transects. Total cover at each shoal relative to other major benthic groups is provided in Figures 2.4-2.6.

2.3.2 Multivariate analyses of community composition across shoals and among sampling periods

The two shoals surveyed in 2010, 2011, and 2013, Barracouta and Vulcan, showed changes in benthic cover across years. A dramatic change was observed at Vulcan Shoal, where the dense and extensive seagrass meadows seen in 2010 were gone in 2011, with only a field of rhizomes remaining (Figure 2.10). The latest survey in 2013 showed no signs of this seagrass meadow recovering. This highly significant change in seagrass cover may reflect a natural disturbance or a differential effect of the uncontrolled release, as the corals seemed healthy and slightly more abundant. In 2010, mean seagrass cover at Vulcan Shoal was healthy in appearance and cover was 11.3%, reduced to 2.4% in the 2011 survey, which was composed nearly entirely of leafless rhizomes. Another notable change was the disappearance of a large area of soft coral from the western end of Barracouta East Shoal, of which this taxa comprised > 10 % of cover for the shoal in 2010.

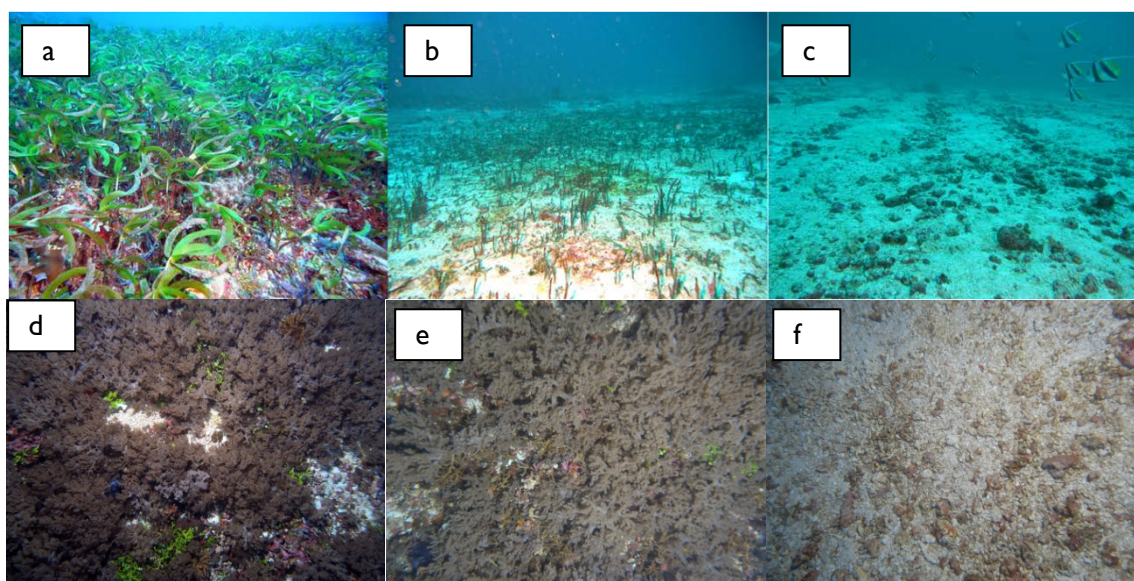


Figure 2.10 – Still images of a seagrass area from surveys at Vulcan in: a) 2010, b) 2011, c) 2013, and soft coral at the western end of Barracouta East in d) 2010, e) 2011, and f) 2013.

There was very little difference in the community structure among shoals, with a PCO based on the major benthic types and their subcategories indicating substantial overlap within each sampling year (Figure 2.11a). Permutational manova indicated that shoal explains only 4% of the variability among transects (Table 2.3). There was, however, a considerable difference in community structure among years (Figure 2.11b), with year explaining nearly 18% of the variability among transects (Table 2.3). While significant, the interaction between year and shoal explained minimal variation (Table 2.3). All three shoals showed consistent changes in community structure among years (Figure 2.11b). For both shoals sampled in 2010 (Vulcan & Barracouta) there was a substantial change from 2010 to 2011 along PCO2 (dashed green lines, Figure 2.11b). This shift appears to be driven largely by a decrease in unconsolidated substrate, articulate calcareous algae (*Halimeda*), seagrass and rhodoliths (Table 2.4). There was a second shift in community structure along PCO1 between 2011 and 2013 that was consistent among all three shoals (solid green lines, Figure 2.11b). The change from 2011 to 2013 represents substantial losses in all the hard coral subcategories, sponges, soft coral and consolidated substrate, and an increase in sand/silt, unconsolidated substrate and macroalgae (Table 2.4).

Pairwise post-hoc comparisons show clearly that, overall, the among year variation within shoals is much higher than among shoal variation within years (R^2 values range from 0.19 to 0.50, Table 2.5). The lowest among year variation occurred for Barracouta East, with the highest value (greatest difference in community structure) occurring for the for 2010/2011 comparison (0.32, Table 2.5). Substantial differences in benthic structure occurred among all years for both Vulcan and Goeree, with R^2 values ranging from 0.40-0.50 (Table 2.5).

In contrast to among year comparisons, between shoal variation was much lower (all $R^2 < 0.25$, Table 2.5). The greatest difference was between Barracouta East and Vulcan for 2010 (Table 2.5). Overall, among shoal differences were lowest among all shoals in 2013 (Table 2.5), suggesting quite homogeneous communities in this final survey year.

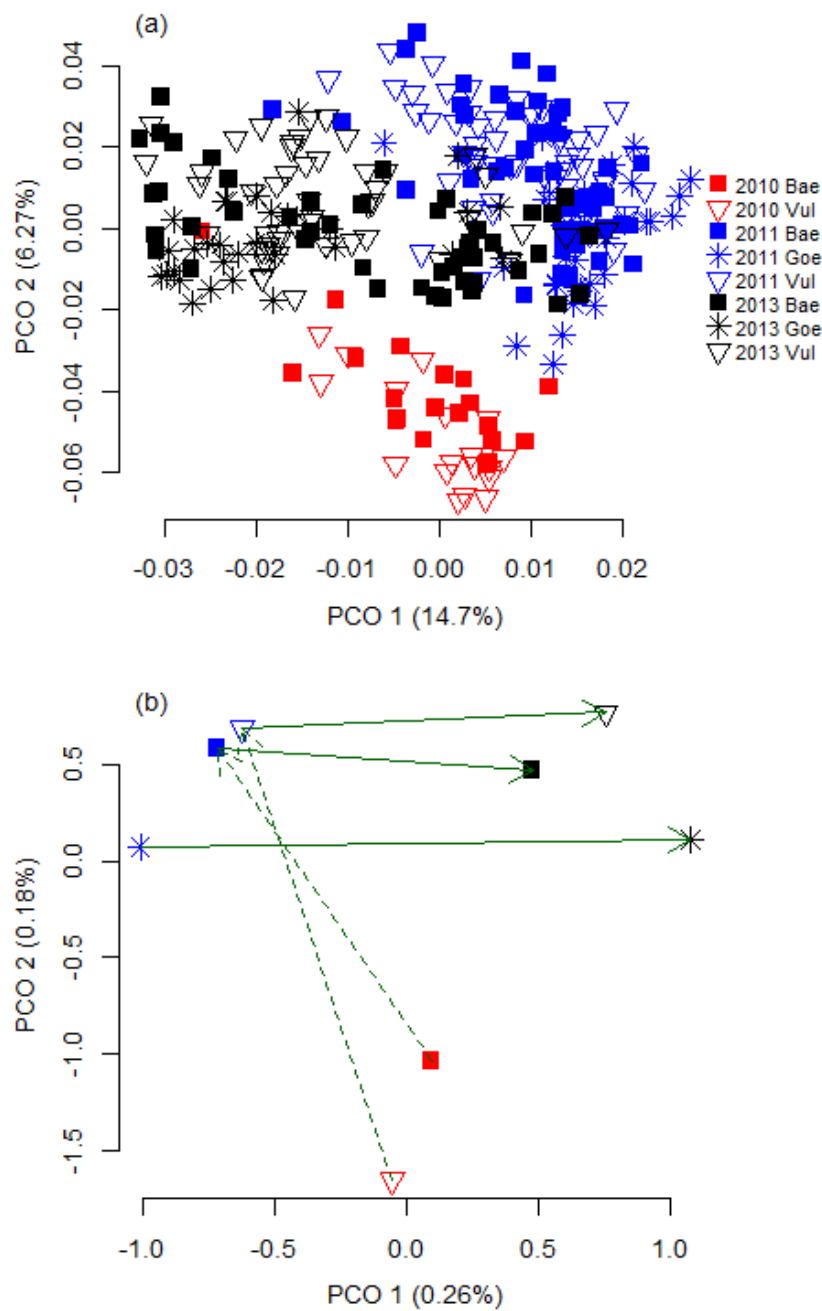


Figure 2.11: Principle co-ordinates ordination based on the major categories and subcategories of benthic types for three shoals (Barracouta East, Vulcan and Goeree) for 2010, 2011 and 2013. The upper plot shows the PCO based on transect level data, and the lower plot a PCO based on the shoal/year means. Note Goeree was not sampled in 2010.

Table 2.3. Permutation manova results for Year, Shoal and their interaction, based on the major benthic categories and their subcategories.

	Df	SumsOfSqs	MeanSqs	F.Model	R ²	Pr(>F)
Year	1	5.986415	5.986415	74.77782	0.179777	0.001
Shoal	2	1.380964	0.690482	8.624988	0.041472	0.001
Year:Shoal	2	2.315136	1.157568	14.45948	0.069526	0.001

Table 2.4. Maximum correlation of the individual variables (r) with the ordination space, and individual scores for both PCO 1 and PCO 2, for the principle coordinates analysis of community structure based on shoal / year means of the major benthic categories and their subcategories (Fig 2.10). Strong positive correlations are shown in green and strong negative correlations are shown in red.

Major category*	subcategory	r	PCO 1 score	PCO 2 score
CR	Turf/Coralline/Consolidated reef	0.99	-0.79	0.61
SD	Sand/silt	0.99	0.89	0.46
A	Halimeda	0.93	-0.51	-0.86
UN	un-consolidated substrate	0.93	0.78	-0.63
A	Rhodolith	0.92	0.19	-0.98
HC	Acropora - tabulate	0.89	-0.99	-0.16
SP	Sponge - errect/branching	0.88	-1	0
HC	Submassive/columnar	0.87	-1	0.06
A	Macroalgae	0.85	0.94	0.34
SP	Sponge - encrusting	0.85	-1	-0.1
SP	Sponge - massive	0.77	-1	-0.04
DHC	Dead Coral	0.76	-0.96	0.28
HC	Massive	0.76	-1	0.03
OT	Other organisms	0.76	-0.91	0.42
OT	Ascidian	0.73	-0.41	-0.91
SG	Seagrass	0.71	-0.16	-0.99
HC	Acropora - branching	0.69	-0.99	-0.15
HC	Acropora - digitate and corymbose	0.69	-0.98	-0.19
HC	Foliose	0.67	-1	0
HC	Solitary	0.67	-1	0.07
HC	Branching	0.58	-1	0.05
SC	Soft coral	0.46	-0.85	-0.53
HC	Encrusting	0.38	-0.17	-0.99
SC	Gorgonian	0.35	-0.99	-0.15

*major category codes as defined in Table 2.1.

Table 2.5. R^2 values from adonis (PERMANOVA) pairwise post-hoc comparisons, showing the explained variation among years within shoals (a), and the variation among shoals within years (b).

a. Among year comparison, within shoals			
	2010/2011	2010/2013	2011/2013
Barracouta East	0.315774	0.19193978	0.23129
Vulcan	0.4419424	0.46264114	0.404861
Goeree			0.497788
b. Among shoal comparison, within years			
	Barracouta / Vulcan	Barracouta / Goeree	Vulcan / Goeree
2010	0.2540921		
2011	0.0718026	0.13524202	0.169998
2013	0.0450691	0.09091354	0.065894

2.3.3 Univariate analysis of community composition across shoals and among sampling periods

For the major benthic categories the best explanatory models included the effects of sampling year alone, or shoal and sampling year either as main effects, or as an interaction (Table 2.6). For the majority of major benthic categories, as well as their subcategories, variability among sampling years was far greater than the variability seen among shoals (Table 2.6). Algae, consolidated reef, dead hard coral and sand/silt all had a strong year only effect, with the best model selected by BIC only including sampling year as a fixed effect, with variance partitioning indicating that > 62.9% of explained variation can be attributed to year (Table 2.6). For all shoals algae was highest in 2010, dropped off considerably in 2011 and then regained cover slightly in 2013 (Table 2.6, Figure 2.12).

Consolidated reef showed the opposite pattern, with lowest values in 2010, a substantial increase in 2011, and a slight decline in 2013 (Table 2.6, Figure 2.12). Dead coral was relatively low across all shoals for all sampling years, with highest values recorded in 2011 (Figure 2.12). Sand/silt was lowest in 2010, rose slightly in 2011 and then increased markedly in 2013 (Figure 2.12). Hard coral, soft coral and unconsolidated reef were best characterised by a model incorporating both year and shoal, but with little evidence of an interaction (Table 2.6). Hard coral and soft coral showed similar patterns, with high values in 2010, a slight decline in 2011, and a further decline in 2013 (Figure 2.12). Barracouta East shoal had the greatest coverage of both soft coral and hard coral, and also showed the greatest declines (Figure 2.12). Unconsolidated substrate was initially quite high in 2010, dropped off dramatically in 2011, and then increased again in 2013 (Figure 2.12). Overall it appears that Goeree has slightly higher cover of unconsolidated substrate than the other two shoals (Figure 2.12).

Seagrass, sponges and other organisms showed evidence of a significant interaction between shoal and sampling year (Figure 2.12). For seagrass this interaction is driven by the fact that it was only present in substantial abundance at Vulcan in 2010, before declining dramatically in 2011, and leading to a complete absence in 2013 (Figure 2.12). This is reflected by the fact that seagrass has an extremely high among year variation at Vulcan, with no among year variation at the other two shoals (Figure 2.12). The interaction for sponges is driven by the fact that Barracouta East had very low

coverage in 2010, and increased to be in line with Vulcan and Goeree in 2011 (Figure 2.12). All three shoals showed a subsequent decline between 2011 and 2013 (Fig 2.12).

The finer scale subcategories within the hard coral benthic group showed varying responses among years and shoals (Table 2.7, Figure 2.13). While most categories showed higher sampling year variation, six categories had greater levels of variation among shoals, including; branching, encrusting and foliose non-Acropora corals, solitary corals, gorgonians and other soft corals (Figure 2.13). The null model was selected for digitate and corymbose Acropora, as well as solitary corals, suggesting little effect of sampling year or shoal for these groups (Table 2.7). Encrusting corals showed a slight shoal effect, but no effect of year, with higher values recorded at Barracouta east (Table 2.7).

Tabulate Acropora and submassive / columnar corals of all types showed an effect of year, with both subcategories having a substantial decline in 2013 (Table 2.7). Significant shoal and year effects (but no interaction) were observed for foliose and massive growth forms, with both categories again showing a decline from 2011 to 2013 (Table 2.7, Figure 2.13). Interaction models were selected for both Acropora and non-Acropora branching corals, both of which had much greater values at Goeree than either Vulcan or Barracouta East, and declines across all years since 2010 resulting in very low cover at all shoals in 2013 (Table 2.7, Figure 2.13).

All algae groups showed a strong effect of year, with Halimeda and macroalgae also having a significant interaction between sampling year and shoal (Table 2.7, Figure 2.14). Patterns of change, however varied considerably, with Macroalgae increasing in 2013, Halimeda decreasing through time, with Rhodoliths showing their greatest decline between 2010 and 2011, with little subsequent recovery at any shoal (Figure 2.14). Both gorgonian and other soft corals were best characterised by an interaction between shoal and sampling year, with shoal explaining slightly greater levels of variation (Table 2.7). Soft corals of both subcategories were highest at Barracouta East shoal in 2010, and show a steady decline over time to the low values observed at the other two shoals (Figure 2.14). All sponge categories varied more with sampling year than among shoals (Table 2.7). Erect / branching sponges were very low in coverage throughout, with no strong temporal or spatial patterns (Figure 2.14). Encrusting sponges showed a significant interaction, with much higher coverage at Vulcan than Barracouta East in 2010, with both shoals increasing and converging to a similar coverage in 2011, with a subsequent decline of all shoals in 2013 (Figure 2.14). Massive sponges had substantial shoal and sampling year effects with Barracouta East and Goeree having higher coverage, with all shoals decreasing to quite low coverage in 2013 (Table 2.7, Figure 2.14). Ascidians (*Lissoclinum* sp.) were in very low abundance in all years at Barracouta East, and relatively high abundance in 2010 at Vulcan, with subsequent declines in 2011 and again in 2013 (Figure 2.14).

Table 2.6. Shoal and sampling year effect univariate analysis results for the percentage cover of the major benthic categories. Shown are the best models for each category examined, the total R^2 explained by the best model, year level random variation (for each shoal), and the outcome of variance partitioning between shoal and depth. The full output with corresponding BIC values for model selection is quite large thus only the selected best model is shown, with the corresponding adjusted R^2 value. Bae = Barracouta East, Vul = Vulcan, and Goe = Goeree.

Response variable	Best Model	R^2	Random Variation among years (coefficient of variation)			Variance Partitioning	
			Bae	Vul	Goe	Shoal	Year
Algae	Year	0.30	0.5	0.2	0.2	1.1	98.9
Consolidated reef	Year	0.46	0.4	0.5	0.1	1.0	99.0
Dead hard coral	Year	0.04	1.7	3.9	1.2	37.2	62.9
Hard coral	shoal+Year	0.18	0.2	0.2	0.4	30.5	69.5
Other	shoal*Year	0.57	0.3	5.1	6.5	42.7	57.3
Soft coral	shoal+Year	0.14	12.9	9.4	10.4	52.8	47.2
Sand/silt	Year	0.35	0.4	0.4	0.2	2.4	97.6
Seagrass	shoal*Year	0.39	0.0	0.0	272.3	37.0	63.0
Sponge	shoal*Year	0.49	1.2	1.1	0.9	3.6	96.5
Unconsolidated reef	shoal+Year	0.45	0.8	0.4	0.2	10.9	89.1

Table 2.7. Shoal and sampling year effect univariate analysis results for the percentage cover of the benthic subcategory variables. Shown are the best models for each category examined, the total R^2 explained by the best model, year level random variation (for each shoal), and the outcome of variance partitioning between shoal and depth. The full output with corresponding BIC values for model selection is quite large thus only the selected best model is shown, with the corresponding adjusted R^2 value. Bae = Barracouta East, Vul = Vulcan, and Goe = Goeree.

Response variable		Best Model	R^2	Random Variation in year (standard deviation/mean)			Variance Partitioning	
				Bae	Vul	Goe	Shoal	Year
Hard coral	Acropora - branching	shoal*Year	0.3	4.9	8.9	4.1	46.9	53.1
	Acropora - digitate & corymbose	Null	0.0	1.4	1.0	0.5	16.0	84.0
	Acropora - tabulate	Year	0.1	4.4	0.9	2.4	15.3	84.7
	Branching	shoal*Year	0.2	0.0	24.9	1.1	71.9	28.2
	Encrusting	shoal	0.1	0.0	0.4	0.4	83.3	16.7
	Foliose	shoal+Year	0.2	2.5	8.7	0.7	56.6	43.4
	Massive	shoal+Year	0.2	8.4	4.5	2.5	13.7	86.4
	Submassive/ columnar	Year	0.1	0.7	0.6	0.4	22.1	77.9
	Solitary	Null	0.0	0.0	6.5	2.5	51.4	48.6
	Algae	shoal*Year	0.5	0.9	0.7	0.2	7.8	92.3
Soft coral	Halimeda	shoal*Year	0.3	0.5	0.4	1.0	14.4	85.6
	Macroalgae	Year	0.6	-9.0	-0.9	-1.8	4.2	95.8
	Rhodolith	shoal+Year	0.1	10.8	7.4	9.3	51.4	48.6
Sponge	Soft coral	shoal+Year	0.2	3.3	4.3	2.3	68.5	31.5
	Gorgonian	shoal*Year	0.5	2.1	1.6	1.7	5.6	94.4
	encrusting	shoal+Year	0.1	2.0	0.7	1.3	34.7	65.3
Other	massive	Null	0.0	0.3	0.7	0.1	14.6	85.4
	Erect/branching	shoal*Year	0.6	0.0	37.2	35.6	40.6	59.4
	Ascidian	shoal+Year	0.2	0.9	0.1	1.4	25.6	74.4
Other	Other organisms							

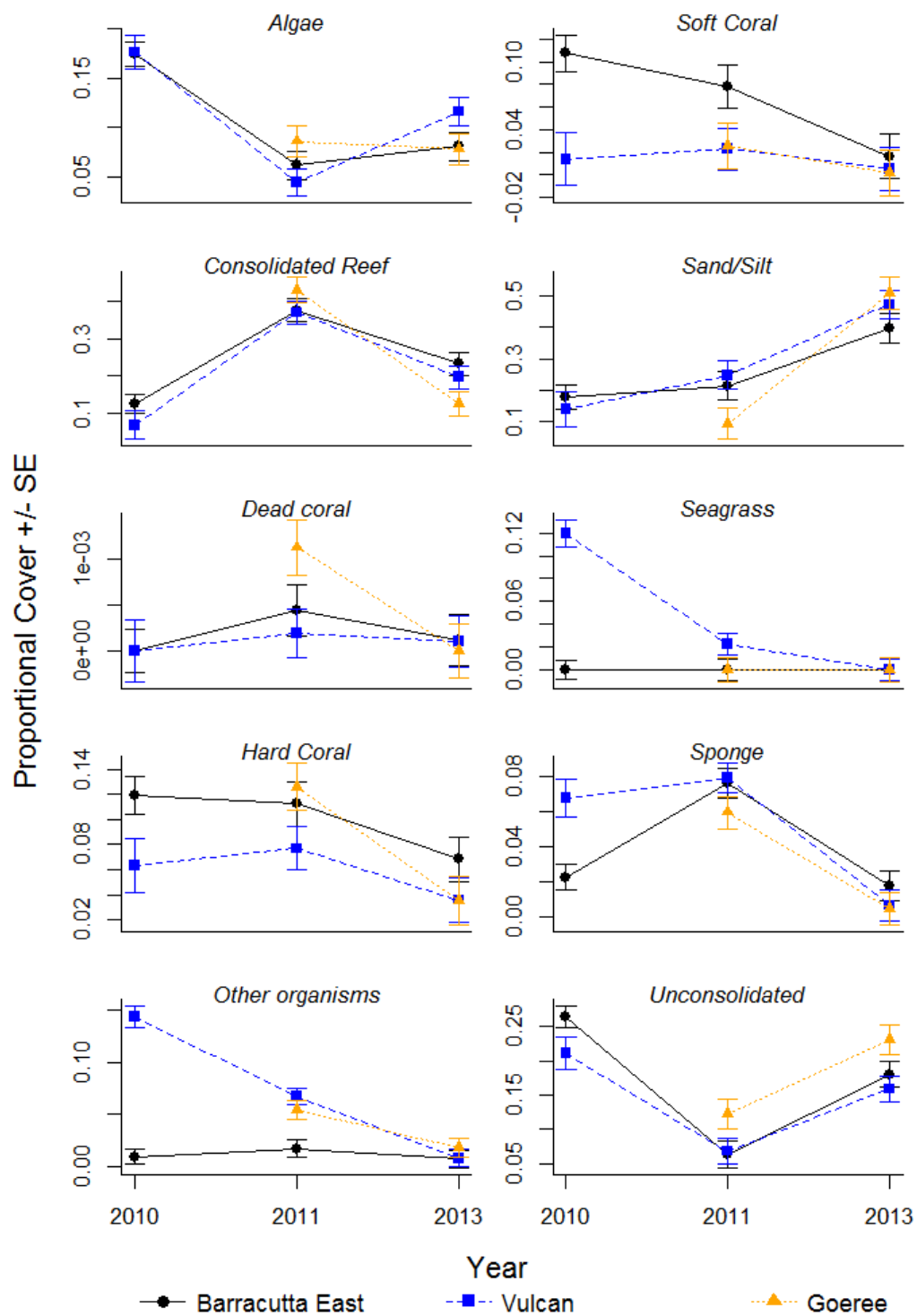


Figure 2.12. Mean cover (±se) across each shoal and sampling year for the 10 major benthic categories. Means and standard errors obtained from estimated parameters from GLM.

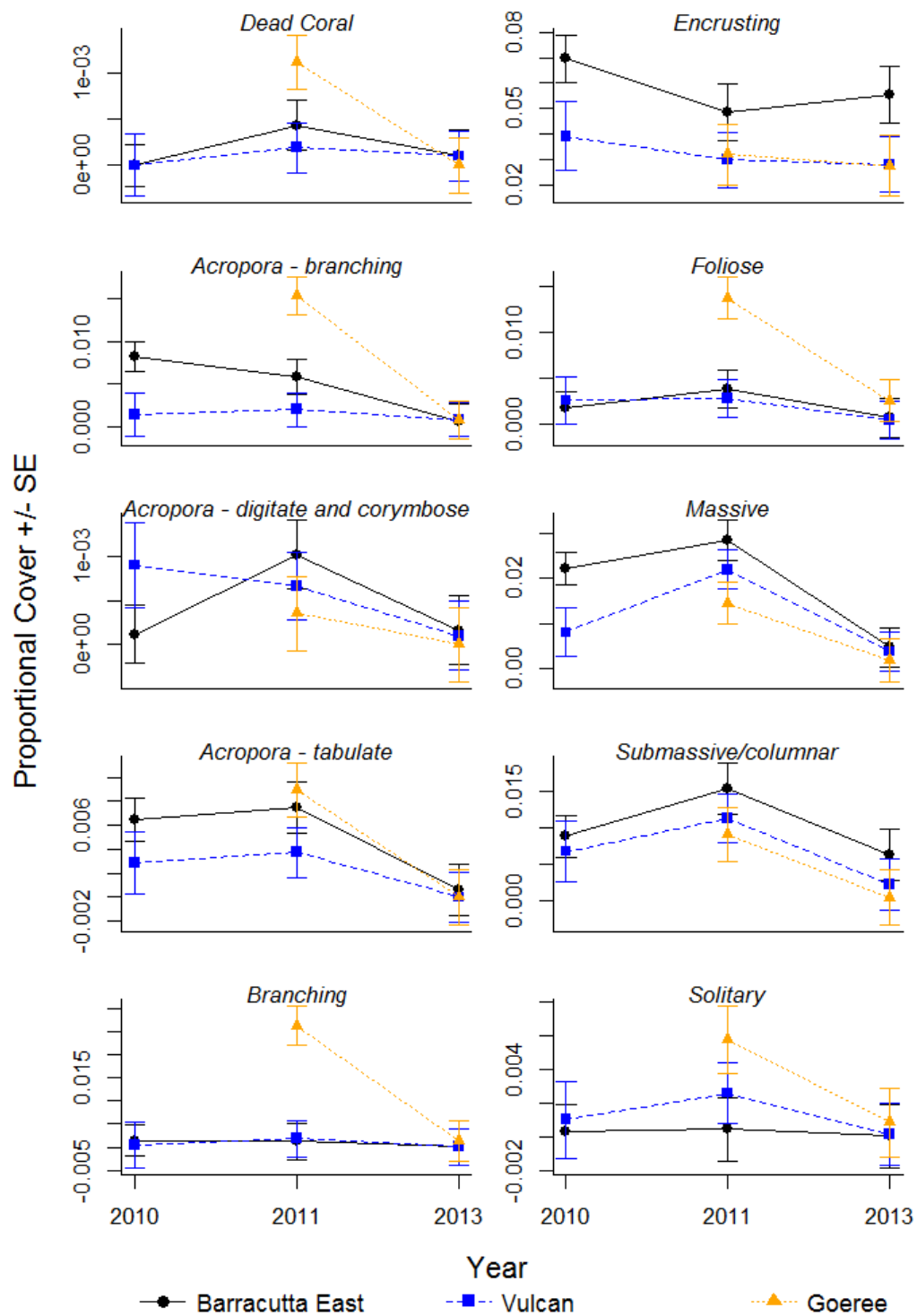


Figure 2.13. Mean cover (±se) across each shoal and sampling year for the 10 hard coral subcategories. Means and standard errors obtained from estimated parameters from GLM.

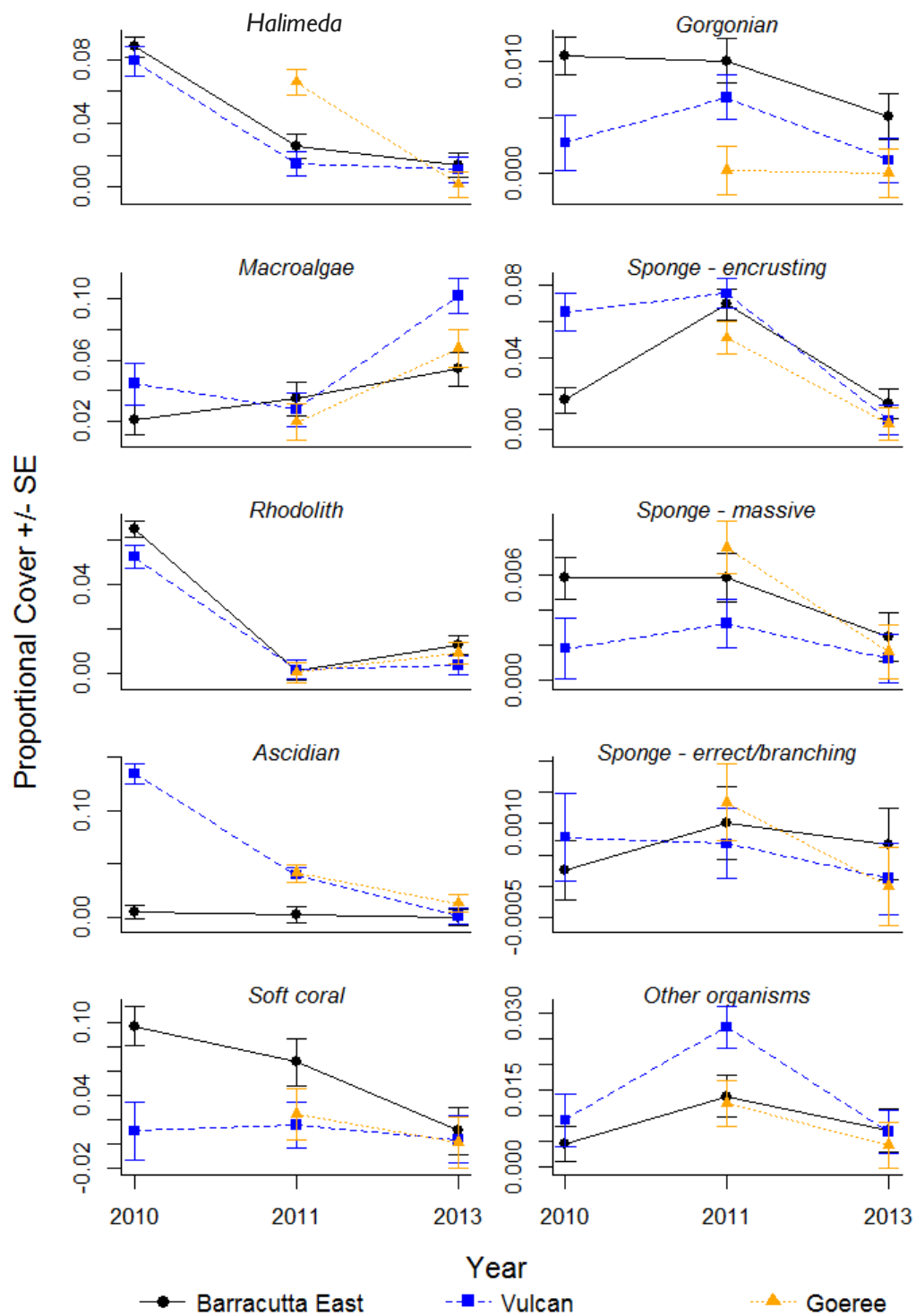


Figure 2.14. Mean cover (±se) across each shoal and sampling year for the remaining 10 non-hard coral subcategories. Means and standard errors obtained from estimated parameters from GLM.

2.4 Discussion

The benthic communities present on all shoals resurveyed exhibited a high percentage of living organisms (60 – 80%), which were dominated by algae, sponges, hard coral, and soft coral. These diverse communities of biota were interspersed with large areas of sand / silt, and consolidated and unconsolidated reef. There was little variation in community structure among shoals; the community structure being typical of shallow tropical reef systems studied elsewhere, with many coral and algal species shared between the shoals and also emergent coral reefs in this region. Coral communities were dominated by encrusting forms, as well as massive and sub-massive forms, all of which are resistant to pressures that are common in this region, such as storms, cyclones, and bleaching events (e.g., Smith *et al.* 2008 & Gilmour *et al.* 2013a). Soft corals are present on all shoals although in low abundance and predominantly from the genus *Nephthea*. Macro algae and turf algae were common across all shoals, although *Halimeda* was only found on Vulcan and Barracouta East.

Despite limited variation in community structure among shoals in 2013, there were significant changes over time for all shoals. There was a marked increase of macro algae, along with sand / silt, and unconsolidated substrate (rubble). These increases were contrasted with significant declines in turf / coralline / consolidated reef, along with most hard coral, soft coral, and sponge categories. There was also a further decline in seagrass on Vulcan Shoal since the initial decline between 2010 and 2011 surveys (32.9% - 5.2%), which is now completely absent from the area. It is likely that the cause of the major loss of seagrass between 2010 and 2011 was either selective to seagrass, or physical in nature affecting loosely attached biota, such as a storm scouring the seagrass and other loosely attached organisms. Some species of seagrass have shown to have moderate sensitivity to hydrocarbons (e.g., Thorhaug and Marcus, 1987; Wilson and Ralph, 2010). However, as the initial survey, six months after the uncontrolled release, found the seagrass in excellent apparent health, a delayed effect from the uncontrolled release resulting in a change sometime between 6-18 months afterward seems unlikely. Of the three shoals, Barracouta East showed the least amount of change overall through time, and was also the farthest of the three shoals from the Montara Well Head Platform and, therefore, least exposed to any potential influences from the uncontrolled release of hydrocarbons in 2009. However, given that the most dramatic declines for associated biota, aside from seagrass, occurred between the two most recent sampling periods, it seems unlikely these changes are as a direct result of the residual effects of the hydrocarbon release.

There was a small range in hard coral cover among shoals that varied from 3.5 – 6.9%, which would be considered low to moderate for areas on a shallow reef in coral-dominated habitats. However, as these surveys included data across the entire shoal plateaus, the hard coral cover present may be comparable to that found on some shallow reefs, if the sampling were to include lagoonal sandy habitats. For example, a habitat survey of Ningaloo Reef Marine Park, which assessed live coral cover across the lagoonal and reef crest habitats, found the overall mean hard and soft coral cover to be only *ca* 7% of the mapped area (Kobryn *et al.* 2013). The decline in hard coral cover across shoals between 2012 and 2013 is a potentially concerning result, which might be indicative of a storm, which would also explain the increase in sand and rubble. It is surprising that there was a reduction in resilient forms (i.e massive and sub-massive), although the displacement of massive forms has been previously observed at other reefs in the region after a cyclone (e.g., Gilmour & Smith 2006). Furthermore, an increase in algae, as seen at all shoals, is also not uncommon after the reduction of coral due to a disturbance (Hughes 1994). It also seems unlikely that a reduction in coral cover was

due to a thermal anomaly such as coral bleaching, as the percentage of dead coral was $< 1\%$ at all shoals in all surveys, and there was no obvious sign of widespread stress, such as bleached or recently dead corals.

The decline in the large soft coral field that was on the western side of Barracouta East comprising *Nephtea* sp, was surprising. Soft coral cover was reduced from 10.8 % in 2010 to 1.7 % in 2013. Soft corals thrive in areas of high current flow with low wave energy, and thrive on exposed reefs at depths of 18 – 30 m on the Great Barrier Reef (GBR) (Fabricius 1997). At a mean depth of 26.8 m, Barracouta East falls within this depth range. Although found in lower relative percentages ($< 3\%$) at Vulcan and Goeree Shoals, these percentages dropped to $< 1\%$ in the most recent survey. The reason for such a marked reduction in soft coral cover, particularly at Barracouta East, is currently unknown, although dislodgement through scouring from a large storm would be consistent with the loss of other benthic groups. Despite no cyclone tracks directly passing over or near the shoals between 2011 and 2013, other areas within the region have also had considerable reductions in benthic community structure within a similar time period, such as at Scott Reef (Gilmour *et al.* 2013b). Anecdotal evidence suggests that a considerable storm passed through this region in 2012, possibly leading to the dramatic changes in benthic community structure. Frequent monsoonal storms and cyclones are characteristic of this region in summer months (Dec – Feb), and likely play a major role in structuring benthic communities (Hughes 1989).

Given the similarity in benthic communities of this region to other regions such as the Pilbara and even Ningaloo Reef (Speed *et al.* 2013), the shoal benthic communities may act as stepping stones for enhanced biological connectivity throughout both the submerged and emergent reef systems of Australia's northwest (Heyward *et al.* 2012). However, genetic connectivity has been examined for other isolated reefs in the region, which found that much of the reef fish and coral communities rely on local recruitment to sustain diversity (Underwood *et al.* 2007 & Underwood *et al.* 2012). Therefore, frequent and severe storms and cyclones predicted under climate change scenarios (Webster *et al.* 2005) may have serious implications not only for the health of local benthic communities within the shoals region, but also to other regions in the northwest.

The data collected for Vulcan and Barracouta Shoals in 2010 coupled with the nine shoals surveyed in 2011, provided a solid foundation for a regional baseline, with which current (2013) community structure was compared against. The results highlight the need for long-term community monitoring, as there is substantial temporal variation within benthic communities in this region, as has been observed previously over decadal time scales (e.g. Smith *et al.* 2008 & Gilmour *et al.* 2013a). Continued monitoring of changes in these submerged shoals in the future is required to not only better understand key processes influencing the status of their biological communities, but also to enable the discrimination between natural and any human-related impacts. The multi-model framework approach developed for this project is objective and robust, and includes a quantitative assessment of both spatial and temporal uncertainty. Furthermore, this approach provides a solid analytical basis for future monitoring and will assist in both the characterisation of additional shoals, and ongoing monitoring in the north-west bioregion.

2.5 References

- Burnham KP and Anderson DR (2002) *Model Selection and Multimodel Inference; A Practical Information-Theoretic Approach*. 2nd edition. Springer, New York.
- Colquhoun J, Heyward AJ, Rees M, Twiggs E, Fitzpatrick BM, McAllister FA, Speare PJ (2007) Ningaloo Reef Marine Park Deepwater Benthic Biodiversity Survey. Report for Western Australian Marine Science Institution (WAMSI). Australian Institute of Marine Science. 143 p.
- Fabricius, K. E. (1997). Soft coral abundance on the central Great Barrier Reef: Effects of *Acanthaster planci*, space availability, and aspects of the physical environment. *Coral Reefs* 16(3): 159-167.
- Fry G, Heyward AJ, Wassenberg T, Ellis N, Taranto T, Keesing JK, Irvine T, Stieglitz TC, Colquhoun J (2008) Benthic habitat surveys of potential LNG hub locations in the Kimberley region. Final Report for Western Australian Marine Science Institution (WAMSI). CSIRO National Research Flagships - Wealth from Oceans and Australian Institute of Marine Science. 131 p.
- Gilmour JP and LD Smith (2006). Category 5 cyclone at Scott Reef, Northwestern Australia. *Coral Reefs* 25(2): 200-200.
- Gilmour JP, Smith LD, Heyward AJ, Baird AH, Pratchett MS (2013a) Recovery of an isolated coral reef system following severe disturbance. *Science* 340: 69 – 71.
- Gilmour JP, Depczynski M, Fisher R, Radford B, Speed C (2013b) Long-term monitoring of shallow water coral and fish communities at Scott Reef. Report prepared by the Australian Institute of Marine Science for Woodside Energy Ltd.
- Heyward AJ, Pinceratto E, Smith LD (1997) Big Bank Shoals of the Timor Sea: an environmental resource atlas. Australian Institute of Marine Science & BHP Petroleum. 115 p.
- Heyward AJ, Rees M (1999) Scott Reef deeper lagoon habitat preview and recommendations for further assessment. Australian Institute of Marine Science. 14 p.
- Heyward A, Moore C, Radford B and Colquhoun J (2010) Monitoring Program for the Montara Well Release Timor Sea: Final Report on the Nature of Barracouta and Vulcan Shoals. Report prepared by the Australian Institute of Marine Science for PTTEP Australasia (Ashmore Cartier) Pty. Ltd. in accordance with Contract No.: 000/2009/10-23. (50pp.).
- Heyward A, Jones R, Meeuwig J, Burns K, Radford B, Colquhoun J, Cappel M, Case M, O'Leary R, Fisher R, Meekan M, and Stowar M (2012) Monitoring Study S5 Banks & Shoals, Montara 2011 Offshore Banks Assessment Survey. Report for PTTEP Australasia (Ashmore Cartier) Pty. Ltd. Australian Institute of Marine Science, Townsville. (253 pp.).
- Hughes TP (1989) Community structure and diversity of coral reefs: the role of history. *Ecology* 70: 275–279.
- Hughes TP (1994). Catastrophes, Phase-Shifts, and Large-Scale Degradation of a Caribbean Coral-Reef. *Science* 265(5178): 1547-1551.
- Jonker M, Johns K, Osborne K (2008) Surveys of benthic reef communities using underwater digital photography and counts of juvenile corals. Long-term Monitoring of the Great Barrier Reef. Standard Operational Procedure. No. 10. Australian Institute of Marine Science. 75 p.

- Kobryn HT, K Wouters, LE Beckley, & T Heege (2013) Ningaloo Reef: Shallow Marine Habitats Mapped Using a Hyperspectral Sensor. PLOS ONE 8(7): e70105. doi:10.1371/journal.pone.0070105
- R Development Core Team (2011) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria
- Smith LD, Gilmour JP and Heyward AJ (2008). Resilience of coral communities on an isolated system of reefs following catastrophic mass-bleaching. *Coral Reefs* **27**, 197–205
- Speed CW, RC Babcock, KP Bancroft, LE Beckley, LM Bellchambers, M Depczynski, SN Field, KJ Friedman, JP Gilmour, J-PA Hobbs, HT Kobryn, JAY Moore, CD Nutt, G Shedrawi, DP Thomson, & SK Wilson (2013) Dynamic stability of coral reefs on the west Australian coast PLoS One 8(7): e69863. doi:10.1371/journal.pone.0069863
- Thorhaug A and J Marcus (1987). Oil spill clean-up: The effect of three dispersants on three subtropical/tropical seagrasses, *Marine Pollution Bulletin* **18**(3):124-126,
- Underwood JN, LD Smith, MJH Van Oppen, & JP Gilmour (2007). Multiple scales of genetic connectivity in a brooding coral on isolated reefs following catastrophic bleaching. *Molecular Ecology* **16**(4): 771-784.
- Underwood JN, MJ Travers, JP Gilmour (2012). Subtle genetic structure reveals restricted connectivity among populations of a coral reef fish inhabiting remote atolls. *Ecology and Evolution* **2**: 666-679.
- Webster PJ, GJ Holland, JA Curry, HR Chang (2005) Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment *Science* **309**, 1844.
- Wilson KA, Westphal MI, Possingham HP and Elith J (2004) Sensitivity of conservation planning to different approaches to using predicted species distribution data. *Biological Conservation*, **22**(1):99-112.
- Wilson K and Ralph P (2010). Effects of oil and dispersed oil on temperate seagrass: scaling of pollution impacts. Final report to the Australian Maritime Safety Authority (AMSA), August 2010. University of Technology Sydney. 26p.
- Zuur AE, Ieno EN, Walker N J, Saveliev AA, and Smith GM (2009) Mixed Effects Models and Extensions in Ecology with R. Springer-Verlag New York Inc., New York/US.

Appendix 2.1. Metadata records for date, location and activities at all sample sites

Date	Technique	Site	Name	Data	Lat_start	Long_start	Depth	Comments
17/04/2013 6:07 AM	Panda Cam	Vulcan	Vul23F & Vul23D	Oblique Video & Images	-12.8019	124.2810		Position approx.
17/04/2013 6:25 AM	Towed Video	Vulcan	Vul23	Real Time Benthic Classification, Video, HD Images	-12.801759	124.275753	-23.9	
17/04/2013 7:29 AM	Towed Video	Vulcan	Vul24	Real Time Benthic Classification, Video, HD Images	-12.80506	124.297817	-21.8	
17/04/2013 8:22 AM	Towed Video	Vulcan	Vul3	Real Time Benthic Classification, Video, HD Images	-12.797551	124.25227	-41.9	
17/04/2013 9:12 AM	Towed Video	Vulcan	Vul4	Real Time Benthic Classification, Video, HD Images	-12.799467	124.264568	-16.4	
17/04/2013 9:51 AM	Towed Video	Vulcan	Vul5	Real Time Benthic Classification, Video, HD Images	-12.80261	124.276088	-22.9	
17/04/2013 10:26 AM	Towed Video	Vulcan	Vul6	Real Time Benthic Classification, Video, HD Images	-12.80447	124.287339	-21.7	
17/04/2013 11:04 AM	Towed Video	Vulcan	Vul17	Real Time Benthic Classification, Video, HD Images	-12.807607	124.298595	-24.7	
17/04/2013 11:51 AM	Towed Video	Vulcan	Vul15	Real Time Benthic Classification, Video, HD Images	-12.794422	124.287691	-41.8	
17/04/2013 12:59 PM	Towed Video	Vulcan	Vul13	Real Time Benthic Classification, Video, HD Images	-12.792163	124.269498	-44.7	
17/04/2013 1:33 PM	Towed Video	Vulcan	Vul14	Real Time Benthic Classification, Video, HD Images	-12.799626	124.266786	-19.1	
17/04/2013 2:18 PM	Towed Video	Vulcan	Vul13-1	Real Time Benthic Classification, Video, HD Images	-12.791741	124.26947	-54.8	
17/04/2013 3:02 PM	Towed Video	Vulcan	Vul16	Real Time Benthic Classification, Video, HD Images	-12.803205	124.284687	-24.1	
17/04/2013 3:53 PM	Towed Video	Vulcan	Vul19	Real Time Benthic Classification, Video, HD Images	-12.795046	124.293783	-52.8	
17/04/2013 4:39 PM	Towed Video	Vulcan	Vul20	Real Time Benthic Classification, Video, HD Images	-12.804381	124.300841	-24.5	
17/04/2013 5:19 PM	Towed Video	Vulcan	Vul22	Real Time Benthic Classification, Video, HD Images	-12.81588	124.302249	-34.8	
17/04/2013 5:48 PM	Towed Video	Vulcan	Vul21	Real Time Benthic Classification, Video, HD Images	-12.808375	124.303332	-21.2	
18/04/2013 5:45 AM	Panda Cam	Vulcan	Vul24F & Vul24D	Oblique Video & Images	-12.8057	124.305833	-21.4	
18/04/2013 6:19 AM	Towed Video	Vulcan	Vul24-1	Real Time Benthic Classification, Video, HD Images	-12.80495	124.297699	-24.2	Camera settings re-set
18/04/2013 7:41 AM	BRUVS™	Vulcan	CAM1 RIG8	Stereo Video	-12.8121149	124.307175	30.3	

18/04/2013 7:46 AM	BRUVS™	Vulcan	CAM2 RIG7	Stereo Video	-12.8079309	124.300911	21.9	
18/04/2013 7:50 AM	BRUVS™	Vulcan	CAM3 RIG6	Stereo Video	-12.8094589	124.296101	24.7	
18/04/2013 7:53 AM	BRUVS™	Vulcan	CAM4 RIG5	Stereo Video	-12.8124634	124.294405	23	
18/04/2013 7:59 AM	BRUVS™	Vulcan	CAM5 RIG4	Stereo Video	-12.8036971	124.292746	22.8	
18/04/2013 8:03 AM	BRUVS™	Vulcan	CAM6 RIG3	Stereo Video	-12.8057191	124.287161	20.6	
18/04/2013 8:10 AM	BRUVS™	Vulcan	CAM7 RIG2	Stereo Video	-12.8092293	124.283124	23.4	
18/04/2013 8:14 AM	BRUVS™	Vulcan	CAM8 RIG1	Stereo Video	-12.8109286	124.278024	23.2	
18/04/2013 9:58 AM	BRUVS™	Vulcan	CAM9 RIG1	Stereo Video	-12.8032794	124.278226	22.5	
18/04/2013 10:02 AM	BRUVS™	Vulcan	CAM10 RIG2	Stereo Video	-12.8040371	124.271736	23.8	
18/04/2013 10:06 AM	BRUVS™	Vulcan	CAM11 RIG3	Stereo Video	-12.7981615	124.270497	22.3	
18/04/2013 10:12 AM	BRUVS™	Vulcan	CAM12 RIG4	Stereo Video	-12.8090359	124.270222	23.9	
18/04/2013 10:17 AM	BRUVS™	Vulcan	CAM13 RIG5	Stereo Video	-12.8065299	124.263163	20.5	
18/04/2013 10:20 AM	BRUVS™	Vulcan	CAM14 RIG6	Stereo Video	-12.8024638	124.262963	19.3	
18/04/2013 10:26 AM	BRUVS™	Vulcan	CAM15 RIG7	Stereo Video	-12.801755	124.256124	32.9	
18/04/2013 10:30 AM	BRUVS™	Vulcan	CAM16 RIG8	Stereo Video	-12.7980307	124.253445	37.3	
18/04/2013 10:34 AM	Panda Cam	Vulcan	Vul3F & Vul3D	Oblique Video & Images	-12.798983	124.25692	-29.2	
18/04/2013 12:54 PM	BRUVS™	Vulcan	CAM17 RIG8	Stereo Video	-12.79595	124.259192	33.3	
18/04/2013 12:58 PM	BRUVS™	Vulcan	CAM18 RIG7	Stereo Video	-12.7938106	124.265536	36.1	
18/04/2013 1:03 PM	BRUVS™	Vulcan	CAM19 RIG6	Stereo Video	-12.7945019	124.274974	32.3	
18/04/2013 1:07 PM	BRUVS™	Vulcan	CAM20 RIG5	Stereo Video	-12.7955078	124.284508	35.2	
18/04/2013 1:11 PM	BRUVS™	Vulcan	CAM21 RIG4	Stereo Video	-12.796066	124.292509	41.9	
18/04/2013 1:16 PM	BRUVS™	Vulcan	CAM22 RIG3	Stereo Video	-12.7972594	124.300608	45.2	
18/04/2013 1:19 PM	BRUVS™	Vulcan	CAM23 RIG2	Stereo Video	-12.7982529	124.304163	47.3	
18/04/2013 1:25 PM	BRUVS™	Vulcan	CAM24 RIG1	Stereo Video	-12.803361	124.309585	45.1	
18/04/2013 3:15 PM	Towed Video	Vulcan	Vul23-1	Real Time Benthic Classification, Video, HD Images	-12.801706	124.275511	-25.6	Camera settings re-set
18/04/2013 3:54 PM	Towed Video	Vulcan	Vul12	Real Time Benthic Classification, Video, HD Images	-12.793383	124.263529	-37.5	
18/04/2013 4:38 PM	Towed Video	Vulcan	Vul9	Real Time Benthic Classification, Video, HD Images	-12.802566	124.269157	-21.2	
18/04/2013 5:29 PM	Towed Video	Vulcan	Vul1	Real Time Benthic Classification, Video, HD Images	-12.799616	124.26688	-17.8	

19/04/2013 6:01 AM	Panda Cam	Goeree	Goe1F & Goe1D	Oblique Video & Images	-12.881134	124.338384	-23	
19/04/2013 6:17 AM	Towed Video	Goeree	Goe7	Real Time Benthic Classification, Video, HD Images	-12.881583	124.331678	-41.9	GPS error
19/04/2013 7:28 AM	Towed Video	Goeree	Goe8	Real Time Benthic Classification, Video, HD Images	-12.881592	124.341328	-32.8	
19/04/2013 8:00 AM	Towed Video	Goeree	Goe10	Real Time Benthic Classification, Video, HD Images				
19/04/2013 8:21 AM	Towed Video	Goeree	Goe10-1	Real Time Benthic Classification, Video, HD Images	-12.882074	124.349605	-35.6	
19/04/2013 8:48 AM	Towed Video	Goeree	Goe1	Real Time Benthic Classification, Video, HD Images	-12.888831	124.338199	-43.5	
19/04/2013 9:34 AM	Towed Video	Goeree	Goe2	Real Time Benthic Classification, Video, HD Images	-12.879774	124.340955	-32.3	
19/04/2013 9:34 AM	Towed Video	Goeree	Goe3	Real Time Benthic Classification, Video, HD Images	-12.876702	124.346703	-38.5	
19/04/2013 10:23 AM	Towed Video	Goeree	Goe5	Real Time Benthic Classification, Video, HD Images	-12.884051	124.339441	-24.3	
19/04/2013 10:23 AM	Towed Video	Goeree	Goe6	Real Time Benthic Classification, Video, HD Images	-12.878476	124.332795	-42.5	
19/04/2013 11:22 AM	Towed Video	Goeree	Goe14	Real Time Benthic Classification, Video, HD Images	-12.879531	124.340998	-33.1	
19/04/2013 12:58 PM	Towed Video	Goeree	Goe11	Real Time Benthic Classification, Video, HD Images	-12.877778	124.334533	-42.1	
19/04/2013 12:58 PM	Towed Video	Goeree	Goe12	Real Time Benthic Classification, Video, HD Images	-12.878423	124.342953	-35.6	
19/04/2013 1:50 PM	Towed Video	Goeree	Goe13	Real Time Benthic Classification, Video, HD Images	-12.880932	124.353143	-49.4	
19/04/2013 2:25 PM	Towed Video	Goeree	Goe4	Real Time Benthic Classification, Video, HD Images	-12.888264	124.345779	-32.9	
19/04/2013 2:54 PM	Towed Video	Goeree	Goe9	Real Time Benthic Classification, Video, HD Images	-12.881159	124.345953	-36	
20/04/2013 7:25 AM	Panda Cam	Goeree	Goe2F	Oblique Video & Images	-12.881801	124.337344		Position approx.
20/04/2013 7:46 AM	BRUVS™	Goeree	CAM25 RIG1	Stereo Video	-12.8787217	124.333726	39.9	
20/04/2013 7:50 AM	BRUVS™	Goeree	CAM26 RIG2	Stereo Video	-12.8808849	124.335257	30.4	
20/04/2013 7:53 AM	BRUVS™	Goeree	CAM27 RIG3	Stereo Video	-12.8827926	124.333325	38.1	
20/04/2013 7:57 AM	BRUVS™	Goeree	CAM28 RIG4	Stereo Video	-12.8859587	124.334481	45.1	
20/04/2013 7:59 AM	BRUVS™	Goeree	CAM29 RIG5	Stereo Video	-12.8838764	124.336988	25.8	
20/04/2013	BRUVS™	Goeree	CAM30	Stereo Video	-12.8857095	124.337396	30.6	

8:02 AM 20/04/2013	BRUVS™	Goeree	RIG6 CAM31	Stereo Video	-12.8868393	124.339592	31.1	
8:05 AM 20/04/2013	BRUVS™	Goeree	RIG7 CAM32	Stereo Video	-12.8890874	124.340394	41.6	
8:09 AM 20/04/2013	BRUVS™	Goeree	RIG8 CAM33RIG8	Stereo Video	-12.8888346	124.343824	33.4	
9:52 AM 20/04/2013	BRUVS™	Goeree	CAM34RIG7	Stereo Video	-12.886645	124.344848	31.4	
9:55 AM 20/04/2013	BRUVS™	Goeree	CAM35RIG6	Stereo Video	-12.8846403	124.343249	33.2	
9:58 AM 20/04/2013	BRUVS™	Goeree	CAM36RIG5	Stereo Video	-12.8825159	124.340487	26.4	
10:01 AM 20/04/2013	BRUVS™	Goeree	CAM37RIG4	Stereo Video	-12.8797262	124.339919	29.8	
10:05 AM 20/04/2013	BRUVS™	Goeree	CAM38RIG3	Stereo Video	-12.8769552	124.339085	36	
10:08 AM 20/04/2013	BRUVS™	Goeree	CAM39RIG2	Stereo Video	-12.8766745	124.342957	40.3	
10:12 AM 20/04/2013	BRUVS™	Goeree	CAM40RIG1	Stereo Video	-12.8794383	124.344035	34.7	
10:15 AM 20/04/2013	BRUVS™	Goeree	CAM41RIG1	Stereo Video	-12.8878138	124.34811	33.8	
1:07 PM 20/04/2013	BRUVS™	Goeree	CAM42RIG2	Stereo Video	-12.8863387	124.35075	37.9	
1:09 PM 20/04/2013	BRUVS™	Goeree	CAM43RIG3	Stereo Video	-12.8844146	124.350054	36.4	
1:12 PM 20/04/2013	BRUVS™	Goeree	CAM44RIG4	Stereo Video	-12.882834	124.351331	39.4	
1:16 PM 20/04/2013	BRUVS™	Goeree	CAM45RIG5	Stereo Video	-12.8828912	124.346458	34.7	
1:19 PM 20/04/2013	BRUVS™	Goeree	CAM46RIG6	Stereo Video	-12.8810272	124.34856	36	
1:23 PM 20/04/2013	BRUVS™	Goeree	CAM47RIG7	Stereo Video	-12.877904	124.347577	35.6	
1:26 PM 20/04/2013	BRUVS™	Goeree	CAM48RIG8	Stereo Video	-12.8778017	124.350664	44.8	
1:30 PM 20/04/2013	BRUVS™	Goeree	CAM48RIG8	Stereo Video	-12.8778017	124.350664	44.8	
20/04/2013 5:45 AM	Panda Cam	Barracouta East	Ba8F	Oblique Video & Images	-12.547017	124.03037	-18	
21/04/2013 6:12 AM	Towed Video	Barracouta East	Bae11	Real Time Benthic Classification, Video, HD Images	-12.545075	124.029574	-21.2	
21/04/2013 7:37 AM	Towed Video	Barracouta East	Bae9	Real Time Benthic Classification, Video, HD Images	-12.549055	124.018447	-45.1	
21/04/2013 8:02 AM	Towed Video	Barracouta East	Bae1	Real Time Benthic Classification, Video, HD Images	-12.5446	124.0340	-22	
21/04/2013 8:02 AM	Towed Video	Barracouta East	Bae2	Real Time Benthic Classification, Video, HD Images	-12.550622	124.020377	-42.9	
21/04/2013 9:24 AM	Towed Video	Barracouta East	Bae3	Real Time Benthic Classification, Video, HD Images	-12.54431	124.049925	-40.1	
21/04/2013 9:24 AM	Towed Video	Barracouta East	Bae4	Real Time Benthic Classification, Video, HD Images	-12.549143	124.04015	-20.3	
21/04/2013 10:21 AM	Towed Video	Barracouta East	Bae10	Real Time Benthic Classification, Video, HD Images	-12.553655	124.025017	-47.5	

21/04/2013 10:56 AM	Towed Video	Barracouta East	Bae8	Real Time Benthic Classification, Video, HD Images	-12.539852	124.020767	-57.7	Camera fail
21/04/2013 1:04 PM	Towed Video	Barracouta East	Bae7-1	Real Time Benthic Classification, Video, HD Images	-12.546991	124.029834	-20.3	
21/04/2013 1:04 PM	Towed Video	Barracouta East	Bae8-1	Real Time Benthic Classification, Video, HD Images	-12.539641	124.020658	-62.6	
21/04/2013 2:11 PM	Towed Video	Barracouta East	Bae14	Real Time Benthic Classification, Video, HD Images	-12.536843	124.030432	-50.9	
21/04/2013 2:43 PM	Towed Video	Barracouta East	Bae18	Real Time Benthic Classification, Video, HD Images	-12.543293	124.032323	-22.5	
21/04/2013 3:22 PM	Towed Video	Barracouta East	Bae12	Real Time Benthic Classification, Video, HD Images	-12.544136	124.03859	-21.3	
21/04/2013 3:22 PM	Towed Video	Barracouta East	Bae13	Real Time Benthic Classification, Video, HD Images	-12.536578	124.033462	-44.7	
21/04/2013 4:16 PM	Towed Video	Barracouta East	Bae16	Real Time Benthic Classification, Video, HD Images	-12.544274	124.040194	-21	
21/04/2013 4:46 PM	Towed Video	Barracouta East	Bae15	Real Time Benthic Classification, Video, HD Images	-12.535799	124.042413	-42.7	
21/04/2013 5:24 PM	Towed Video	Barracouta East	Bae17	Real Time Benthic Classification, Video, HD Images	-12.53858	124.04846	-43.1	Camera fail
21/04/2013 5:28 PM	Towed Video	Barracouta East	Bae17-1	Real Time Benthic Classification, Video, HD Images	-12.538584	124.048441	-43.1	
22/04/2013 6:12 AM	Panda Cam	Barracouta East	Ba8F	Oblique Video & Images	-12.543245	124.025397	-19.8	
22/04/2013 6:31 AM	Towed Video	Barracouta East	Bae5	Real Time Benthic Classification, Video, HD Images	-12.540926	124.027722	-21.6	
22/04/2013 6:31 AM	Towed Video	Barracouta East	Bae6	Real Time Benthic Classification, Video, HD Images	-12.545501	124.016443	-39.1	
22/04/2013 8:23 AM	BRUVS™	Barracouta East	CAM49RIG8	Stereo Video	-12.5524143	124.041873	35.6	
22/04/2013 8:27 AM	BRUVS™	Barracouta East	CAM50RIG7	Stereo Video	-12.5503099	124.04387	28	
22/04/2013 8:29 AM	BRUVS™	Barracouta East	CAM51RIG6	Stereo Video	-12.5481206	124.047248	34.2	
22/04/2013 8:34 AM	BRUVS™	Barracouta East	CAM52RIG5	Stereo Video	-12.5491897	124.040303	21.2	
22/04/2013 8:37 AM	BRUVS™	Barracouta East	CAM53RIG4	Stereo Video	-12.5459679	124.042046	22.1	
22/04/2013 8:40 AM	BRUVS™	Barracouta East	CAM54RIG3	Stereo Video	-12.5451271	124.045527	24.2	
22/04/2013 8:44 AM	BRUVS™	Barracouta East	CAM55RIG2	Stereo Video	-12.5420315	124.041201	22.9	
22/04/2013 8:49 AM	BRUVS™	Barracouta East	CAM56RIG1	Stereo Video	-12.5381568	124.047271	41.1	
22/04/2013 10:28 AM	BRUVS™	Barracouta East	CAM57RIG1	Stereo Video	-12.5378428	124.043184	32.5	
22/04/2013	BRUVS™	Barracouta	CAM58RIG2	Stereo Video	-12.5377186	124.03612	33	

10:32 AM 22/04/2013	BRUVS™	East Barracouta	CAM59RIG3	Stereo Video	-12.541575	124.031498	21.9	
10:38 AM 22/04/2013	BRUVS™	East Barracouta	CAM60RIG4	Stereo Video	-12.5388508	124.025888	41.8	
10:42 AM 22/04/2013	BRUVS™	East Barracouta	CAM61RIG5	Stereo Video	-12.5426739	124.025253	20.3	
10:47 AM 22/04/2013	BRUVS™	East Barracouta	CAM62RIG6	Stereo Video	-12.5443208	124.022533	23.8	
10:49 AM 22/04/2013	BRUVS™	East Barracouta	CAM63RIG7	Stereo Video	-12.5428172	124.018608	39.4	
10:53 AM 22/04/2013	BRUVS™	East Barracouta	CAM64RIG8	Stereo Video	-12.5482908	124.019736	34.5	
10:57 AM 22/04/2013	BRUVS™	East Barracouta	CAM65RIG8	Stereo Video	-12.5473577	124.023023	22.5	
1:41 PM 22/04/2013	BRUVS™	East Barracouta	CAM66RIG7	Stereo Video	-12.5482621	124.027577	19.5	
1:44 PM 22/04/2013	BRUVS™	East Barracouta	CAM67RIG6	Stereo Video	-12.551509	124.028695	20.4	
1:47 PM 22/04/2013	BRUVS™	East Barracouta	CAM68RIG5	Stereo Video	-12.5531304	124.03033	24.1	
1:50 PM 22/04/2013	BRUVS™	East Barracouta	CAM69RIG4	Stereo Video	-12.5501804	124.03048	19.5	
1:53 PM 22/04/2013	BRUVS™	East Barracouta	CAM70RIG3	Stereo Video	-12.5458152	124.027934	19.5	
1:56 PM 22/04/2013	BRUVS™	East Barracouta	CAM71RIG2	Stereo Video	-12.5448419	124.032312	20.5	
2:00 PM 22/04/2013	BRUVS™	East Barracouta	CAM72RIG1	Stereo Video	-12.5467776	124.03499	18.7	
2:07 PM								

3. Fish community re-assessment using Baited Remote Underwater Video Stations (BRUVS™)

3.1 Background

Following the uncontrolled release of hydrocarbons from the Montara well in 2009, assessment of the potential impacts included surveys of the fish communities on the submerged shoals and banks within the area exposed to the release at various distances from the Montara well-head platform. Contrasts were made between banks and shoals of predicted high, medium and low exposure to the spill plume as a “gradient” analysis. These surveys were done in March and April 2011, 16 months after the uncontrolled release. Results were reported by Heyward *et al.* (2012).

Analyses of survey results found suggestions of a decrease in diversity (5-10%), total abundance (5-30%) and increases in mean size (2-10%) of fishes at those shoals closest (within 50 km) of the Montara well-head platform (Heyward *et al.* 2012). However, as there was no pre-existing baseline information on the fish communities associated with banks and shoals for this area these results could not be unambiguously attributed to any effect of a hydrocarbon release. The survey also found that observed variations in fish communities among shoals appeared to be principally dominated by natural processes.

In order to determine if the observations reported by Heyward *et al.* (2012) were simply a transient pattern that reflected chance events or were a more enduring phenomenon, a subset of the shoals surveyed in 2011 were resurveyed in 2013. Here, we summarise the results of this 2013 re-survey, which targeted three shoals that were chosen as representative of a range of potential exposure levels to the uncontrolled release of hydrocarbons and dispersants in 2009. These were Barracuda East (BAE), Goeree (GOE) and Vulcan (VUL). The first of these was considered to have had low exposure, while both the latter shoals had relatively high exposure, although surveys of hydrocarbons in the sediment and modelled hours of exposure suggested that the exposure of GOE to the uncontrolled release was somewhat lower than that of VUL (Heyward *et al.* 2012).

As in 2011, fish communities were sampled in 2013 using non-destructive stereo Baited Remote Underwater Video Stations (BRUVS™; Cappo *et al.* 2007b). Both the advantages (cost-effectiveness, simplicity of deployment, non-destructive sampling, versatility across depths and collection of accurate and precise length data) and biases (variation in extent and drift of bait plumes; Priede and Merrett 2006, Harvey *et al.* 2007 and collection of relative rather than absolute measures of abundance; Harvey *et al.* 2002a, Shortis *et al.* 2009, Langlois *et al.* 2010) are well-recognised. Use of the same technique as in the previous survey facilitated simple and consistent comparisons across sampling events in 2011 and 2013.

Since spatial patterns in the composition and structure of fish assemblages were described at both broad (regional; 100s of km) and fine (habitats; 10-100 m) scales for these same reefs in the report by Heyward *et al.* (2012), here we focus on comparisons of the results of the 2011 surveys with those of 2013. Analyses sought to identify any changes in species richness (SR), total abundance

(TA), mean size and assemblage structure of fish communities, as well as changes in abundance of sharks and sea snakes. The composition of habitats at each of the sampling locations was also compared across the two surveys to ensure that any changes in the fish assemblage took into account observed variability in habitats where the BRUVS™ were deployed.

3.2 Methods

3.2.1 Field sampling with stereo Baited Remote Underwater Video Systems (BRUVS™™)

As in 2011, demersal fish communities were surveyed using stereo BRUVS™ (Cappo *et al.* 2007, Harvey *et al.* 2002a; Watson 2006). A comprehensive summary of the design, use and calibration of these systems is given by Heyward *et al.* (2012) and references therein. Briefly, stereo BRUVS™ consist of two camera housings on a light frame of galvanised steel that had a pole projecting from the front side of the frame that carried a flashing diode (to synchronise video frames) and a bait bag. This bag contained one kg of crushed pilchards (*Sardinops sagax neopilchardus*) at a distance of approximately 1.2 m in front of the video housings (Figure 3.1). The frame of the BRUV was ballasted with weights for stability in currents and waves. A rope attached to surface buoys allowed the system to be retrieved after deployment (Figure 3.2).

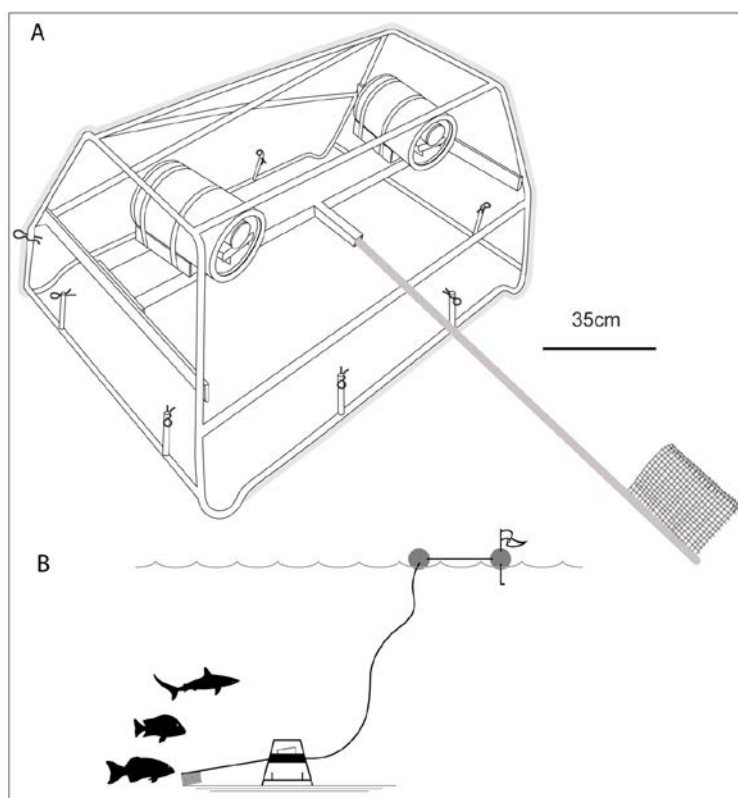


Figure 3.1. A stereo BRUVS™ unit with bait arm attached (A) showing typical deployment with bait bag touching the seabed (B).

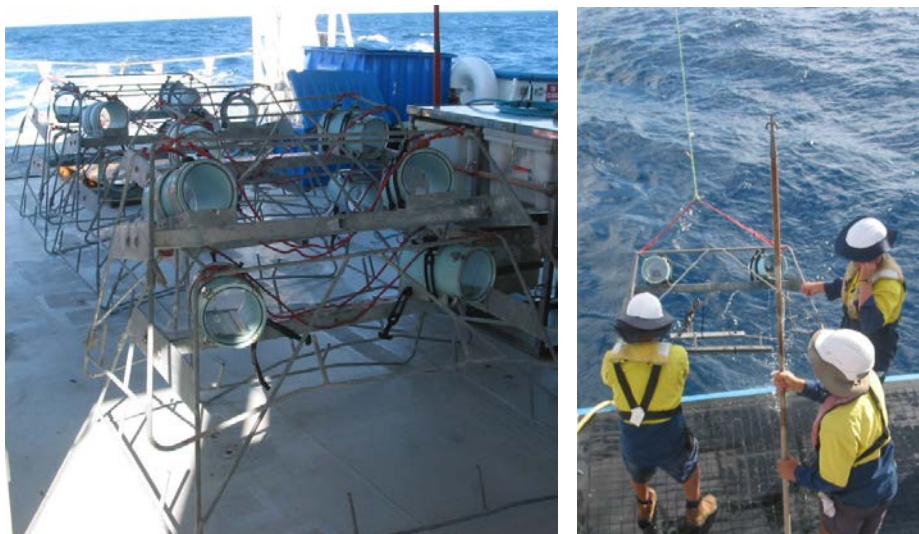


Figure 3.2. Stereo BRUVS™- units ready for deployment, and during the process of retrieval

The camera (Sony HDR-CX110E 'handycam', x 0.6 wide conversion lens) within each housing was set to record at 1920 x 1080 pixels (high definition), with focus set to infinity in manual focus mode. They recorded to a 16GB SD memory card that was downloaded upon retrieval of the BRUVS™ via Picture Motion Browser software and stored on portable hard drives in .m2ts file format.

Three shoals at varying distances from the uncontrolled release were selected for re-survey; Barracuda East (BAE) categorized as low exposure, Goeree (GOE) categorized as moderate-high exposure and Vulcan (VUL), categorized as high exposure (Table 3.1; Heyward *et al.* 2012).

The location of sampling sites for the deployment of BRUVS™ followed as closely as possible the distribution of sampling in the 2011 survey (Figure 3.3). As in the earlier survey, BRUVS™ were deployed above the 60 m depth contour, with a minimum distance of 250 m deployments. A total of 24 deployments of BRUVS™ occurred on each shoal during a single day. BRUVS™ were deployed for a minimum of 60 minutes with this deployment time based on species accumulation curves from surveys of reef fish faunas in the north-western atolls (Scott Reef) by Cappo *et al.* (2001) and the distance between deployments (250 m) avoided potential overlap of bait plumes and the movement of fish between BRUVS™ (see Cappo *et al.* 2004 for review).

Table 3.1. Shoals and banks sampled in the 2011 and 2013 surveys. Name abbreviations (Abbrev.), the number of BRUVS™ samples per shoal and bank (n) in 2011 and 2013, location (mean latitude and longitude), the linear distance (spilldist) and compass bearing from the uncontrolled release, the sediment hydrocarbon concentration [HC] with number of sediment samples in (), the minimum and maximum hours of modelled exposure (minHRS, maxHRS), the area of the shoal above 60 m depth and the mean depths of BRUVS™ samples in the 2011 and 2013 surveys.

Shoal	Abbrev.	n (2011)	n (2013)	mean latitude	mean longitude	exposure category	spilldist (km)	bearing (o)	[HC] µg/g	min HRS	max HRS	area (ha)	mean depth (2011) (m)	mean depth (2013) (m)
Barracuda East	BAE	32	24	-12.545	124.0336	Low	56.56	284.47	0.015 (4)	13	25	603	27.0	26.7
Barracuda West	BAW	24	na	-12.561	124.0067	Low	59.07	281.98	0.015 (4)	8	16	302	33.5	na
Echuca	ECH	24	na	-13.902	123.9071	Low	153.21	206.37	0.015 (4)	0.2	0.3	1266	26.1	na
Eugene McDermott	EUG	24	na	-13.075	124.5828	Medium	44.99	174.4	0.104† (1)	49	97	613	37.5	na
Goeree	GOE	24	24	-12.882	124.3427	High	31.65	222.33	0.144 (4)	424	849	320	35.5	35.3
Heywood	HEY	64	na	-13.453	124.0474	Low	101.78	211.62	0.015 (4)	3.1	6.2	3537	33.3	na
Sheldon	SHE	24	na	-12.515	124.1733	Medium	43.43	293.72	0.169 (4)	23	46	217	36.1	na
Vulcan	VUL	23	24	-12.802	124.2816	High	31.42	242.42	0.241 (4)	473	945	1299	29.7	29.5
Wave Governor Bank	WGB	16	na	-12.57	123.5983	Low	102.79	276.26	0.015‡ (0)	0	0	132	44.6	na

Baited Remote Underwater Video Stations (BRUVS)

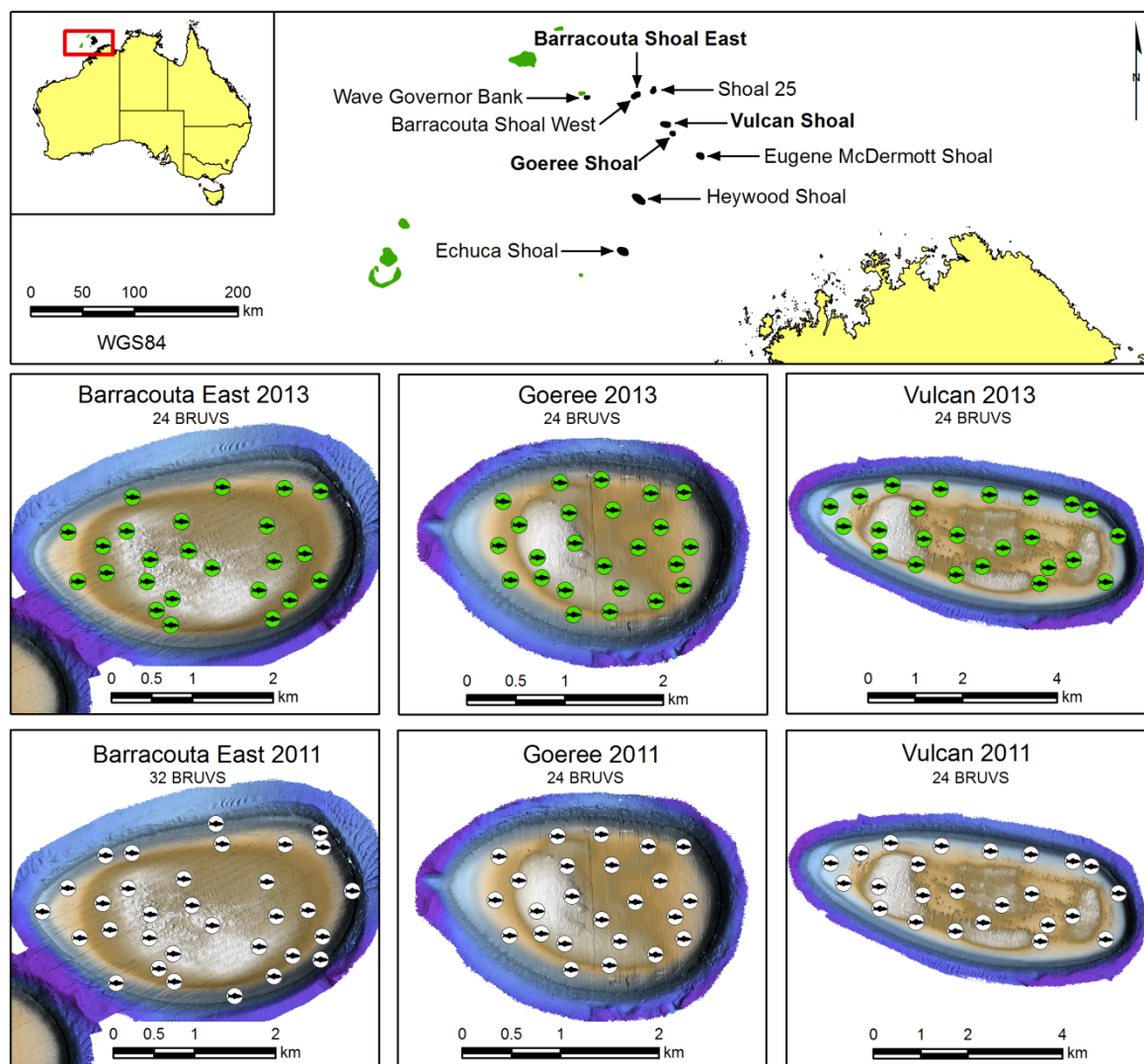


Figure 3.3. Deployment sites for stereo BRUVS™ at three shoals in 2013 surveys (upper panels) and 2011 (lower panels).

3.2.2 Data description: fish community and habitat

Two sets of data were used in the analysis. Firstly, fish communities were characterised with respect to the diversity, total abundance and size of the species observed at each deployment site. Secondly, habitat data were generated from the direct field of view of the BRUVS™. The following sections describe the methods used to generate these datasets.

Fish community structure – identity, abundance, and length:

The analysis of fish assemblages from video collected by stereo BRUVS™ followed the same protocols as those described in the report by Heyward *et al.* (2012). Briefly, for each deployment, exactly 60 minutes of bottom-time were analyzed using EventMeasure (SeaGIS Pty Ltd 2008). Individual fish were identified to the highest taxonomic level possible using available literature (Randall *et al.* 1997; Allen *et al.* 1998; Lieske and Myers 2001; Randall 2002; Allen *et al.* 2003; Allen 2004) and the UWA and AIMS image and video reference libraries. Naming of species followed the

codes and conventions of the Commonwealth codes for Australian aquatic biota (Rees *et al.* 2011). Where fishes from the same genus could not be identified to species they were labelled as *Genus* sp 1 to *n* where *n* was the total number of unknown but distinct taxa in the genus. Similarly, if a species could be recognised as unique, but not identified to either species or genus, it was labelled as *Family* sp 1 to *n*. For analysis each of these taxa were counted as a species.

As in the 2012 report, the maximum number of fish belonging to each species that were present in the field of view of the stereo BRUVS™ at one time period (*MaxN*) was used as the measure of relative abundance for analysis (Priede *et al.* 1994; Cappo *et al.* 2004). This avoided repeated counts of the same individual and provided a conservative measure of relative abundance (for reviews see Cappo *et al.* 2007; Farnsworth *et al.* 2007; Willis *et al.* 2000). Additionally, feeding activity, loss of bait bag, time elapses to *MaxN* by species, life stage of fishes and water visibility were also recorded. Length measurements (snout to fork, FL mm) of fish were made using PhotoMeasure (SeaGIS Pty Ltd 2008). These were obtained at the time when *MaxN* occurred in order to avoid repeated measures of the same individual and for accuracy and precision were limited to those individuals within a maximum distance of 8 m from the cameras (Harvey *et al.* 2002b). All fish data and still reference images were run through the QA/QC procedures used in the 2012 report prior to being incorporated into the Oracle AIMS BRUVS™ database via an Access front end.

These methods generated a multivariate dataset of fish community structure including abundance and fork length for each species. As not all individual fish were measured due to an obscured field of view (by other fishes or habitat features) or distance from the camera, missing lengths were interpolated as the mean length of conspecifics observed on the same shoal and thus referred to as adjusted fork length (adjFL). From this matrix, univariate metrics describing the fish community were estimated for each sampling station such as the total number of species (species richness; SR), total abundance of fish (TA), and mean adjusted fork length (adjFL). Univariate and multivariate attributes of the fish community were calculated at the level of individual sample stations and then as mean values for each of the three Shoals.

Habitat data

Habitat data consisted of information on the seabed composition, topography and nature of epibenthic plant and animal communities. These data were generated from the BRUVS™ field of view. Some data were also derived from previous multibeam surveys where these had been incorporated in previous fish/habitat models (i.e. profile to predict mean fish length; Heyward *et al.* 2012). This study used the standardised classification scheme for the seabed in the BRUVS™ field of view produced by Heyward *et al.* 2012 (see Table 4.2 in Heyward *et al.* 2012).

3.2.3 Statistical analyses

Descriptive statistics were derived for the 2013 survey included determination of numbers of species and families and the calculations of means and standard errors for key descriptors of the assemblage such as species richness, total abundance and size. These estimates formed the basis of comparisons to the 2011 survey.

We tested whether habitat varied between the two surveys given that re-sampling of deployment sites in 2013 was approximate rather than exact. We first excluded the six deep water deployments from BAE in 2011 as this habitat was not resampled in 2013. Differences in depth were tested using

a t-test for each shoal. Differences in habitat composition (percentage cover of each habitat type; see Heyward *et al.* 2012) were first tested using a two-way PERMANOVA including shoal (three levels: BAE, GOE, VUL) and survey (2011, 2013). While the key question was whether habitat varied between surveys at each of the shoals, the inclusion of the interaction term allowed us to determine whether any potential inter-survey changes were consistent across the shoals. Differences in habitat composition between the two surveys were then tested for each shoal using a one-way PERMANOVA with survey as the factor (Anderson 2001). Prior to the PERMANOVAs, habitat composition data were square root transformed so that common habitats did not overwhelm the analysis. Bray-Curtis similarities were then calculated given the presence of joint-zeros in the habitat data. Unrestricted permutations of the data were used given only a single factor was tested. The key test was for variation in habitat between surveys rather than between shoals. To visualise the data, a principal co-ordinates ordination (PCO) was conducted of both all samples and of the centroids of each survey and shoal.

Differences between the two surveys were also tested with respect to species richness, total abundance and adjusted mean fish length using t-tests (Zar 2010) where we calculated:

- species richness (SR) as the total number of species per deployment;
- total fish abundance (TA) as the sum of *MaxN* per deployment and;
- adjusted mean fork length (adjFL) as the sum of fork length divided by the sum of *MaxN* where the sum of fork length included estimates of fork length for individuals that were counted but lengths estimated from conspecifics (see above).

Differences in SR, TA and adjFL were tested for each shoal using simple t-tests with unequal variation on both raw and log10-transformed data. Given the strong relationships observed between the univariate attributes of the fish community (SR, TA and adjFL) and habitat identified during the first survey (Heyward *et al.* 2012), we also predicted expected values of SR, TA and adjFL as a function of observed habitat characteristics in 2013. The predictions were generated from models developed from the 2011 survey using simple linear regression (Heyward *et al.* 2012). These expected values were then compared to observed 2013 values using one-sample t-tests to determine how observed changes related to expected changes. Differences in predicted vs observed 2013 values were presented as graphs as function of habitat and as percentage differences by survey and shoal. As mean fork length was predicted to increase with increasing exposure to the oil spill (Heyward *et al.* 2012), we also tested whether the average size of species observed in both surveys varied using linear regression. Frequency distributions as a function of size class were presented as graphs by survey and shoal.

The multivariate assemblage data (abundance by species and sample) were analysed similarly to the data for habitat composition. Species abundances were square root transformed to reduce the influence of dominant species and Bray-Curtis similarities calculated given the presence of joint absences. A two-way PERMANOVA based on survey and shoal was used to test for the effect of an interaction (i.e. whether assemblage structure varied between surveys in a consistent manner among shoals). A one-way PERMANOVA with survey as the factor was then completed for each Shoal, based on unrestricted permutations of the data (Anderson 2001). To visualise the data, a principal co-ordinates ordination (PCO) was conducted of both all samples and of the centroids of each survey and shoal. Similarity percentage (SIMPER) analysis was used to determine which species

distinguished shoals between surveys. As models predicting fish assemblage structure as a function of habitat were not available (nor easily interpretable), there was no quantitative comparison of observed fish assemblage structure relative to an expected assemblage structure given the habitat. However, trends were assessed qualitatively by generating a distance-based redundancy analysis (dbRDA) that overlayed the 2013 data against all data from 2011 ($n=9$ shoals) (Legendre and Anderson 1999; McArdle and Anderson 2001).

We also considered changes in sharks and sea snakes as two iconic taxa in the region (sharks are of global concern with respect to their conservation status and sea snakes, as air breathers, may be particularly vulnerable to exposure to surface hydrocarbons). Where sufficient observations existed, we repeated the methods used to analyse univariate metrics such as SR and TA: t-tests compared abundances between the two survey periods for each shoal and expected abundances were calculated based on habitat models with one-sample t-tests comparing 2013 observed abundances with predicted abundances.

Analyses for fish sharks and sea snakes were completed in PRIMER, R and Excel as appropriate.

3.3 Results

A total of 72 BRUVS™ deployments from the three shoals (24 per shoal) were analysed for the 2013 survey. From these samples, 6692 fishes and sharks were identified, representing 43 families and 262 species. Elasmobranchs included 147 individuals of five species of sharks and 25 individuals of three species of rays. The remaining 97% of sightings were teleost fishes. Six sea snakes were also recorded. In the subset of data from the 2011 survey for these three shoals ($n=70$ deployments, excluding the “deep” samples at BAE), a total of 6854 sharks and fishes were identified, representing 39 families and 221 species. Sharks were represented by 170 individuals of seven species and rays by 34 individuals of two species. The remaining 97% of sightings were of teleost fishes and 50 sea snakes were observed across the three shoals in 2011.

The three shoals varied in exposure from low (BAE) to high, (GOE and VUL), noting that GOE had slightly lower exposure than VUL (Table 3.1). On a whole-of-shoal scale, all had similar habitats characterised by a mix of abiotic sand or gravel and calcareous reef; areas that were not bare were dominated by encrusting organisms and massive and branching corals (Heyward *et al.* 2012).

3.3.1 Comparisons between 2011 and 2013

Habitat

Because BRUVS™ were not re-deployed on the exact sites used in the earlier survey (due to windage, current flow, etc.), we first compared deployment depth and habitat composition at each shoal between the two surveys to assess variation in the placement of the BRUVS™ resulted in changes in habitat. The mean depth at which BRUVS™ were deployed in 2013 was $30.5 \text{ m} \pm 1.0 \text{ SE}$ (range 18.7-47.3 m). Sampling occurred at a slightly greater depth at GOE than at BAE and VUL but there were no significant differences in deployment depths between the two surveys for any of the shoals (Table 3.2). Habitat composition, as derived from the BRUVS™ field of view, included six abiotic classes (bedrock, boulder, calcareous reef, gravel, rubble and sand) and biotic classes: encrusting organisms (including bryozoans, hydroids, seaweeds and zoanthids), fans, *Halimeda*, hard corals (massive, branching and plate), solitary hard corals, macroalgae, soft coral, sponges and areas

bare of biota (Table 3.3). The two-way PERMANOVA indicated that habitat composition varied significantly between surveys and shoals with a significant interaction between surveys depended on shoal or was not consistent across shoals and year (Table 3.4; Figure 3.4a). The significant interaction indicated that change in habitat was not directional and consistent (Figure 3.4b). Results from one-way PERMANOVAs indicated that all shoals differed in habitat composition between the two surveys (Table 3.3). At the level of individual shoals, key changes included: (1) at BAE, a decline in cover of calcareous reef and increase in cover of sand and bare (no biota) areas; (2) at GOE, an increase in cover of calcareous reef and bare habitat with a decline in cover of *Halimeda* cover; and (3) at VUL, an increase in cover of calcareous reef and gravel and a decrease in rubble habitat, along with a decrease in the cover of bare habitat with increases in encrusting organisms and cover of hard coral (Table 3.4).

Table 3.2. Results of t-tests assuming unequal variance comparing mean depths sampled at Barracuda East (BAE), Goeree (GOE) and Vulcan (VUL) Shoals between the two surveys (2011 and 2013) where $t_{\text{CRIT}}=2.01$.

	BAE		GOE		VUL	
	2011	2013	2011	2013	2011	2013
Mean	27.0	26.7	35.9	35.3	29.7	29.5
Variance	69.4	58.0	26.6	25.9	53.0	78.5
Observations	23	24	23	24	24	24
t Stat	0.12		0.40		0.08	
P(T<=t) two-tail	0.90		0.69		0.94	

Table 3.3. Summary of mean and standard error estimates of percentage cover of abiotic and biotic categories (following Heyward et al 2012) for surveys in 2011 and 2013 of Barracuda East (BAE), Goeree (GOE) and Vulcan (VUL) Shoals.

		BAE				GOE				VUL			
		2011		2013		2011		2013		2011		2013	
	Habitat Class	Mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
abiotic	Bedrock	0	0.0	15.8	5.4	0	0.0	0	0.0	0	0.0	0	0.0
	Boulder	2.2	1.5	1.7	1.2	0	0.0	0	0.0	0	0.0	0.4	0.4
	Calcareous reef	44.3	7.0	23.3	6.1	14.8	6.9	27.5	8.5	19.6	4.9	34.2	8.1
	Gravel (2-64mm)	13.0	4.1	9.2	5.0	66.1	7.7	57.5	8.1	25.0	6.1	41.7	9.1
	Rubble	21.3	3.5	17.1	4.7	10.9	4.2	11.7	3.2	32.1	6.1	8.3	2.8
	Sand	19.1	4.4	32.9	6.3	8.3	2.9	3.3	2.1	23.3	4.0	15.4	4.6
biotic	Encrusting (bryozoans, hydroids, whips, zoanthids)	2.6	1.1	17.5	2.3	5.7	1.2	21.7	4.2	11.3	1.7	21.7	3.4
	Fans	1.3	0.7	0.4	0.4	0.4	0.4	0	0.0	0.4	0.4	0.4	0.4
	<i>Halimeda</i>	0	0.0	0	0.0	20.0	5.7	0	0.0	3.3	3.0	0	0.0
	Hard corals: massive / branching / tabular	23.5	5.6	12.9	3.0	3.0	2.6	12.9	4.3	6.3	2.5	18.8	4.9
	Hard corals: Solitary or detached	7.4	1.7	2.1	1.3	1.7	1.0	0	0.0	3.8	1.2	0	0.0
	Macroalgae	0	0.0	0.4	0.4	2.2	2.1	0	0.0	0	0.0	0.4	0.4
	None	46.5	5.4	61.7	5.2	51.7	6.7	63.8	7.8	67.5	3.7	56.3	6.9
	Soft coral	11.3	2.5	1.7	1.0	7.0	2.2	1.7	1.7	2.1	0.9	2.5	1.1
	Sponges	7.4	1.7	3.3	1.0	8.3	1.9	0	0.0	5.4	1.7	0	0.0

Table 3.4. Results of two-factor PERMANOVA testing the effects of survey (2011, 2013), shoal and their interaction on habitat composition and a one-factor PERMANOVA of survey on habitat composition for each shoal, reporting the degrees of freedom (df), sums of squares (SS), mean squares (MS), the Pseudo-F statistics and its permutationally derived p value (P(per)) and the number of permutations completed (perms).

	df	SS	MS	Pseudo-F	P(per)	perms
ALL Shoals						
Survey	1	12092	12092	9.5562	0.0001	95702
					2.00E-	
Shoal	2	26230	13115	10.365	05	95011
Survey x Shoal	2	10006	5003	3.9538	0.0035	94942
Residuals	136	1.72E+05	1265.4			
Total	141	2.20E+05				
BAE						
Survey	1	9811.1	9811.1	9.0626	0.0003	9952
Residuals	45	48717	1082.6			
Total	46	58528				
GOE						
Survey	1	11967	11967	8.0488	0.0006	9963
Residuals	140	2.08E+05	1486.8			
Total	141	2.20E+05				
VUL						
Survey	1	4594.5	4594.5	3.7279	0.0203	9947
Residuals	46	56693	1232.5			
Total	47	61288				

.6

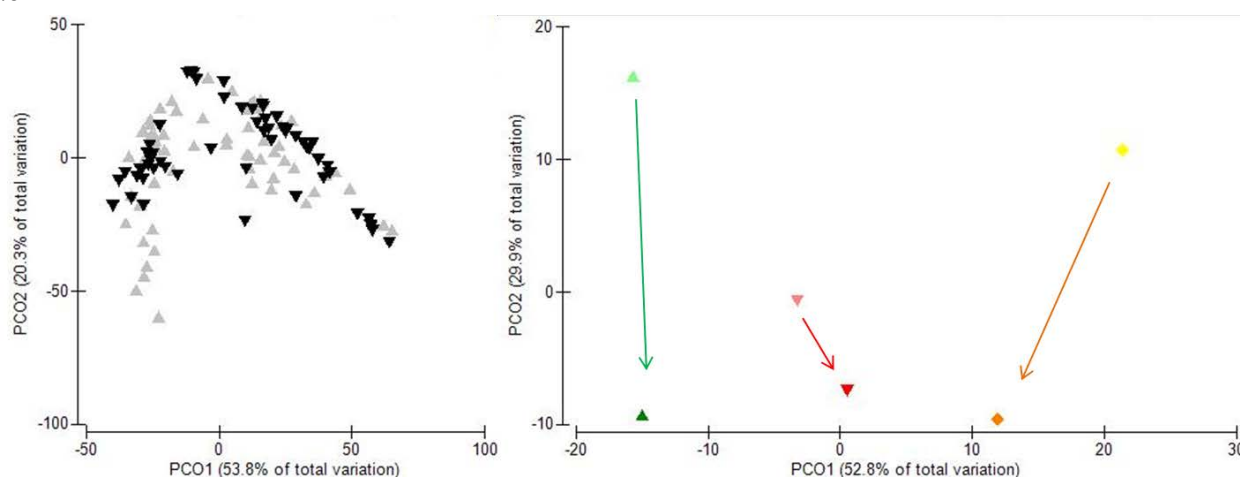


Figure 3.4. Principal coordinates ordination (PCO) demonstrating effect of survey on habitat composition for (a) all deployments in 2011 (grey) and 2013 (black), and (b) centroids of each shoal for each survey for BAE (green), GOE (orange) and VUL (red) with pale shades indicating centroids for 2011 and dark shades indicating centroids for 2013 and associated arrows indicating directional change. In both cases, PCO1 is positively associated with calcareous reef and hard coral and negatively correlated with gravel and bare habitats; PCO2 is associated positively with *Halimeda*.

We considered specific changes in the habitat variables that were most effective in predicting univariate attributes of the fish assemblage (Table 3.5). Calcareous reef was strongly ($r^2=0.77$) and positively correlated to species richness such that the decrease in cover of calcareous reef at BAE samples in 2013 (Table 3.3), would be expected to result in lower SR at this shoal. The increased cover of calcareous reef at GOE and VUL in the 2013 samples (Table 3.6) should have yielded higher values for species richness at these two shoals. Similarly, bare substrate was negatively correlated to total abundance (Table 3.5) and as such, TA should have decreased at BAE and GOE and increased at VUL. Bare substrate was also positively correlated with adjFL (Table 3.5) and as such, adjFL should have increased at BAE and GOE and decreased at VUL. See Table 3.6 for summary of changes expected simply due to changes in habitat sampled between the two surveys.

Table 3.5. Summary of regression models for key dependent and independent variables, reporting the significance levels (p), coefficient of determination (r^2), mean square error (MSE) and values for predicted coefficients and their standard errors (SE) for the intercept (b0) and slope (b1). Regression models derived from data for the original 9 shoals sampled in the survey in 2011, thus each model had 8 degrees of freedom. These models were built on the modelling results of Heyward *et al.* (2012) but were reconstructed to use habitat variables available across both data sets and adjusted to exclude the deep sites originally sampled at BAE in 2011. These equations were used to generate the "expected" lines in Figures 3.5 and 3.9

Dependent Variable	Independent Variable	p	R ²	MSE	bo	SE(bo)	b1	SE(b1)
Species richness	Calcareous reef	0.0020	0.77	3.55	15.5	2.4	0.47	0.10
Total abundance	Bare	0.0012	0.80	13.3	202.4	19.5	-1.95	0.37
adjFL	Bare	0.0368	0.49	18.5	188.8	27.4	1.34	0.52
Abundance of <i>T. obesus</i>	Calcareous reef	0.0003	0.86	0.148	0.084	0.105	0.030	0.005

Table 3.6. Qualitative predicted outcomes based on habitat models for species richness (SR), total abundance (TA), adjusted mean fork length (adjFL) and the abundance of *T. obesus* (TO) based on calcareous reef (CR) and cover with no biota (Bare).

	CR=>SR	Bare=>TA	Bare=>adjFL	CR=>TO
BAE	Down	Down	Up	Down
GOE	Up	Down	Up	Up
VUL	Up	Up	Down	Up

Species richness, total abundance and size

Mean SR per deployment in 2013 varied from 24.0 (± 4.1 SE) at GOE to 25.1 (± 3.0 SE) at VUL and 35.0 (± 2.3 SE) at BAE. Based on the 2011 model, species richness was predicted to decline from 36.4 to 26.5 species per deployment at BAE, but was predicted to increase from 22.5 to 28.5 species per deployment at GOE and 24.7 to 31.6 species per deployment at VUL based on changes in sampled habitat (Figure 3.5a). There was a 32% increase of observed species per deployment relative to that predicted by habitat in 2013 and 15.7% and 20.5% declines in species per deployment for GOE and VUL respectively (Figure 3.5b). One sample t-tests ($p_{0.05(1),23}=1.71$) indicated that the observed species richness per deployment at BAE was significantly higher than expected ($p=0.0014$), not significantly different than expected at GOE ($p=0.26$) and significantly lower than expected at VUL ($p=0.036$) (Table 3.7).

Total abundance per deployment in 2013 varied from 69.4 (± 10.1 SE) individuals per deployment at VUL to 98.1 (± 20.8 SE) individuals at GOE to 111.3 (± 10.2 SE) individuals at BAE. Total abundance was strongly ($p=0.0012$) and inversely related to cover of bare habitat, explaining 80% of the variation in the number of fish per deployment in 2011 (Table 3.6). Based on the 2011 model, predicted total abundance would decline from 113.3 individuals per deployment to 83.1 individuals per deployment at BAE and from 102.9 to 78.9 individuals per deployment at GOE; in contrast, based on cover of bare habitat, individuals per deployment were predicted to increase from 71.4 to 93.9 at VUL (Figure 3.5c). These predictions represented a 35.6% and 25.7% increase in predicted total abundance per deployment for BAE and GOE respectively, and a 25.1% decline in total abundance per deployment for VUL relative to observed values in 2013 (Figure 3.5d). One sample t-tests ($p_{0.05(1),23}=1.71$) indicated that, given the sampled habitat in 2013, the observed total abundance per deployment at BAE was significantly greater than expected ($p=0.011$), not significantly different than expected at GOE ($p=0.18$), and significantly lower than expected at VUL ($p=0.011$) (Table 3.7). In 2013, adjFL per deployment varied from 184 mm (± 11.5 mm SE) at BAE to 265 (± 17.5 mm SE) at VUL to 303 mm (± 21.8 mm SE) at GOE. The adjFL was positively correlated to the cover of bare habitat, explaining 49% of the variation in adjFL per deployment in 2011 ($p=0.037$) (Table 3.6). Based on the 2011 model, predicted adjFL should have increased from 251 mm to 271 mm at BAE and from 258 mm to 274 mm at GOE, but would be expected to decline from 279 mm to 264 mm at VUL (Figure 3.5e). Relative to observed 2013 mean adjFL values, these predicted values represent a 32.0% decline in mean adjFL at BAE, a 10.4% increase in mean adjFL at GOE and a 0.6% increase at VUL (Figure 3.5f). One sample one-tail t-tests ($p_{0.05(1),23}=1.71$) indicated that the observed mean adjFL per deployment at BAE was significantly less than expected ($p<0.000001$) but not significantly different than expected at GOE ($p=0.18$) or VUL ($p=0.466$) given the observed habitat in 2013 (Table 3.7). Given that changes in mean size can occur due to either changes in species assemblage structure (higher proportions of smaller or larger species) or due to changes in individual sizes (a growth effect), we also compared the mean sizes of species in 2011 and 2013, and found that there were no significant differences between the individuals of a given species across the two surveys (Figure 3.6).

Table 3.7. One-sample t-tests ($n=24$; $t_{\text{CRIT}}=1.71$) to compare mean observed values of species richness, total abundance and adjFL with values predicted from habitat models. Where observed 2013 values are significantly different from that predicted, p-values are highlighted in red. One-tailed tests were completed as predictions were directional.

Species Richness	BAE	GOE	VUL
Predicted mean	26.5	28.5	31.6
2013 mean	35.0	23.9	24.9
	11.4	19.7	14.7
tstat	3.63	-1.15	-2.23
P(T<=t) one-tail	0.0007	0.1310	0.0180
Total Abundance	BAE	GOE	VUL
Predicted mean	82.1	78.0	92.7
2013 mean	111.3	98.1	69.4
2013 stdev	49.8	101.8	49.5
t Stat	2.77	0.92	-2.42
P(T<=t) one-tail	0.0054	0.1827	0.0119
AdjFL	BAE	GOE	VUL
Predicted mean	279.1	282.1	271.4
2013 mean	184.7	304.0	265.8
2013 stdev	56.3	106.9	85.6
t Stat	-7.52	1.37	0.10
P(T<=t) one-tail	<1.0 E-8	0.0915	0.4588
Trianodon obesus	BAE	GOE	VUL
Predicted mean	0.788	0.914	1.116
2013 mean	0.667	0.500	0.542
2013 stdev	1.049	0.978	0.779
t Stat	-0.57	-2.07	-3.64
P(T<=t) one-tail	0.2883	0.0247	0.0007

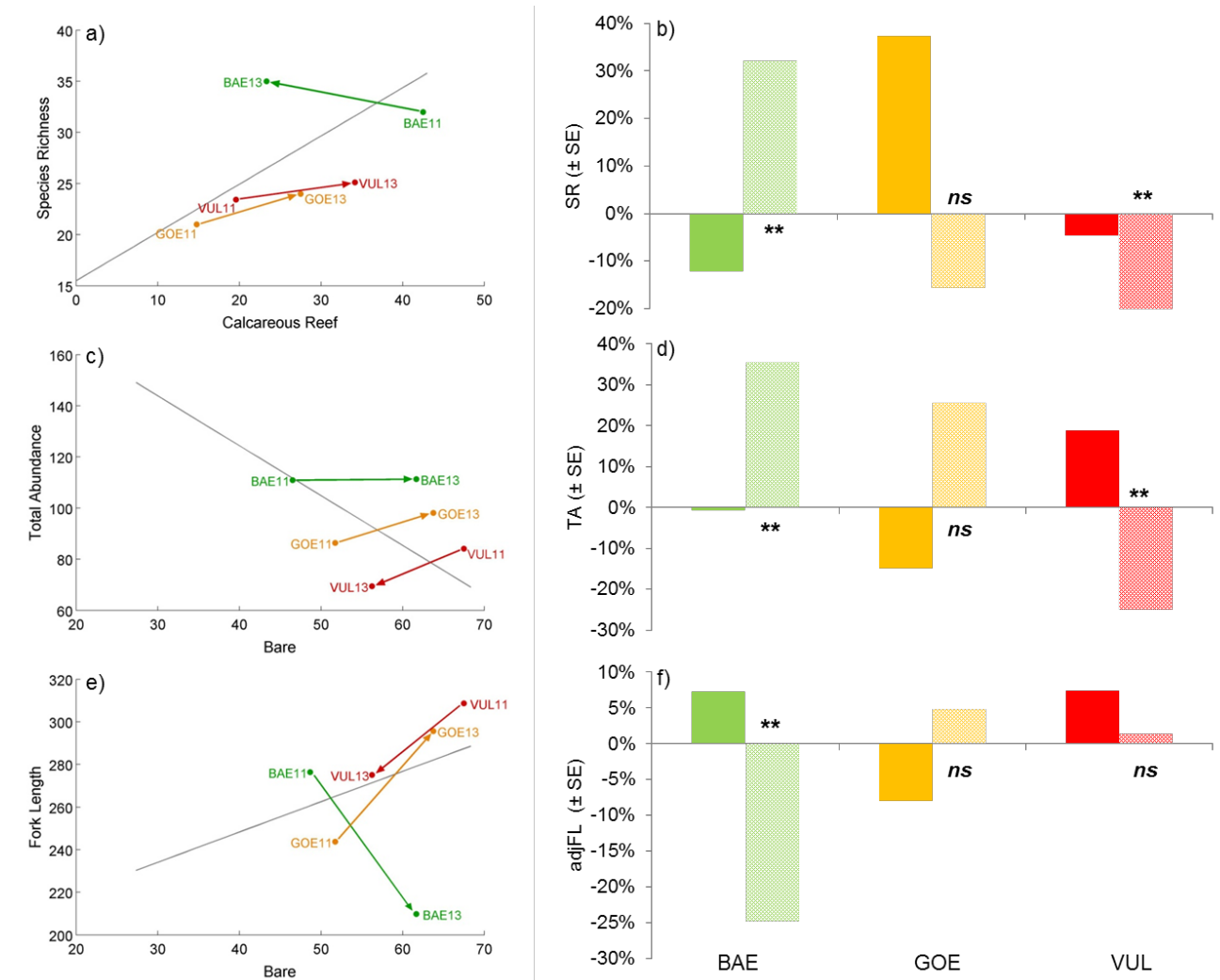


Figure 3.5. Observed 2013 outcomes relative to 2011 outcomes and predicted values (grey line) and associated estimates of percentage differences between 2011 observed and predicted values and 2013 observed and predicted values for species richness (SR) (a,b), total abundance (TA) (c,d) and adjFL (e,f). Percentage differences calculated as (observed - predicted)/predicted for each year and represent the vertical difference between the observation and the regression line.

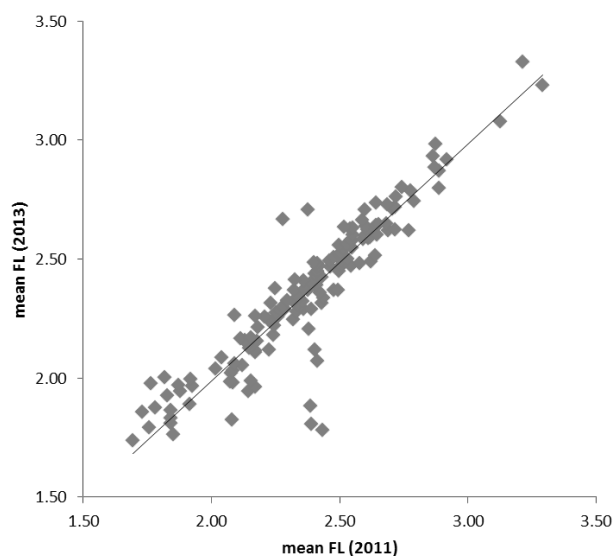


Figure 3.6. Relationship between mean fork lengths of species common to the 2011 and 2013 surveys: $\log(L_{2013}) = 1.003(\pm 0.004 \text{ SE}) - \log(FL_{2011})$; $n=152$ species; $r^2=0.997$ and $p=2.3E-194$; the slope was not significantly different from 1 and the intercept was 0.

Fish assemblage structure

There were strong effects of survey and shoal on fish assemblage structure with a significant interaction term ($p=0.036$; Table 3.8) indicating moderate differences in survey results from each shoal. One-way PERMANOVA indicated that the assemblages at each location differed between the two surveys (Table 3.8). Principal coordinates ordination of all deployments and the centroids for each shoal and survey showed consistent directional change in fish assemblage between the two surveys (Figure 3.7). A SIMPER analysis to determine which species contributed to the differences between each shoal across the two surveys indicated that even the most influential species typically only contributed on average 2% of the cumulative variation in distinguishing between the surveys for each shoal. Key species that differentiated surveys at each shoal were dominated by caragids, labrids and lethrinids (Table 3.9) but these differences did not account for changes to habitat between the two survey events. The distance-based redundancy analysis (dbRDA) based on species assemblage structure as a function of habitat for all shoals indicated that the change in species assemblage structure between surveys at the three shoals was relatively moderate for BAE, high for GOE and low for VUL (Figure 3.7). The first dbRDA axis was associated negatively with calcareous reef and positively with gravel while the second dbRDA axis was associated negatively with cover of bare habitats. For this reason we would predict that the BAE assemblage of 2013 should move positively with respect to dbRDA (declining calcareous reef cover) and negatively with respect to dbRDA axis 2 (increasing bare cover). The assemblage responded as expected with respect to calcareous reef but showed little variation in response to an increase in the bare category. At GOE the change in assemblage reflected the increases in calcareous reef and bare habitats. Despite a predicted response resulting from increased cover of calcareous reef and bare habitats assemblages at VUL showed the least change in structure.

Table 3.8. Results of two-factor PERMANOVAs that tested the effects of survey (2011, 2013), shoal (BAE, GOE, VUL) and their interaction on species composition (based on abundance) of fish assemblages and a one factor PERMANOVA of survey on composition of fish assemblages for each shoal, showing the degrees of freedom (df), sums of squares (SS), mean squares (MS), the Pseudo-F statistics and its permutationally derived p value (P(perm)) and the number of permutations completed (perms).

	df	SS	MS	Pseudo-F	P(perm)	perms
ALL Shoals						
Survey	1	18909	18909	7.0153	0.00001	91091
					1.00E-	
Shoal	2	33923	16961	6.2927	05	89407
Survey x Shoal	2	8392.4	4196.2	1.5568	0.036	88856
Residuals	136	3.67E+05	2695.4			
Total	141	4.28E+05				
BAE						
Survey	1	10019	10019	4.0817	0.00008	91121
Residuals	45	110460	2454.8			
Total	46	120480				
GOE						
Survey	1	8714.2	8714.2	3.1033	0.0024	91824
Residuals	45	1.26E+05	2808			
Total	46	1.35E+05				
VUL						
Survey	1	8568	8568	3.0376	0.0036	91736
Residuals	46	129750	2820.6			
Total	47	138320				

Table 3.9. Results of SIMPER analysis for each shoal (BAE, GOE, VUL) reporting the species that contributed to the differentiation of species assemblages between the two surveys (2011, 2013) reporting the mean and standard errors (SE) of species abundances for each survey, percentage contribution (Contrib%) to the differentiation of each species and the cumulative percentage differentiation (Cum.%).

	Change	mean (2011)	SE (2011)	mean (2013)	SE (2013)	Contrib%	Cum.%
BAE							
<i>Pomacentrus coelestis</i>	Up	7.35	2.90	23.92	3.82	4.46	4.46
<i>Odonus niger</i>	Down	16.30	3.17	8.58	2.58	3.86	8.32
<i>Cirrhilabrus</i> sp1	Down	5.48	3.24	0.00	2.38	1.86	10.18
<i>Cirrhilabrus eximius</i>	Up	1.61	0.90	4.67	1.63	1.81	11.99
<i>Lutjanus bohar</i>	Down	4.78	0.81	2.58	1.00	1.77	13.76
<i>Lethrinus amboinensis</i>	Down	2.30	0.69	0.33	0.62	1.65	15.41
<i>Naso hexacanthus</i>	Down	3.43	1.19	0.42	0.85	1.59	17
<i>Scolopsis xenochrous</i>	Up	1.35	0.43	2.42	0.53	1.56	18.57
<i>Parupeneus multifasciatus</i>	Up	1.65	0.32	2.83	0.36	1.54	20.11
<i>Lethrinus rubrioperculatus</i>	Down	6.35	1.28	6.21	1.28	1.45	21.56
GOE							
<i>Cirrhilabrus</i> sp1	Down	13.61	2.23	0.00	0.00	5.62	5.62
<i>Lethrinus rubrioperculatus</i>	Down	9.57	1.08	7.46	0.64	3.69	9.31
<i>Lethrinus atkinsoni</i>	Down	5.83	0.37	4.92	0.87	3.41	12.73
<i>Alepes vari</i>	Up	0.43	5.22	18.00	0.00	2.95	15.67
<i>Lethrinus amboinensis</i>	Down	3.52	0.84	2.29	0.17	2.89	18.57
<i>Lutjanus bohar</i>	Up	1.96	0.92	3.38	0.74	2.25	20.82
<i>Cirrhilabrus</i> sp2	Down	9.43	2.45	0.00	0.00	2.02	22.84
<i>Carangoides gymnotethus</i>	Down	1.65	0.18	0.88	0.04	2.02	24.86
<i>Cirrhilabrus temminckii</i>	Up	0.08	0.00	4.83	0.74	1.82	26.67
<i>Halichoeres zeylonicus</i>	Up	0.04	0.00	2.33	1.65	1.78	28.45
VUL							
<i>Lethrinus atkinsoni</i>	Down	12.00	1.48	5.79	1.06	4.73	4.73
<i>Pomacentrus coelestis</i>	Down	8.04	0.49	6.54	2.35	3.58	8.31
<i>Lethrinus rubrioperculatus</i>	Up	3.63	1.48	5.33	1.79	3.09	11.41
<i>Halichoeres zeylonicus</i>	Up	0.13	0.04	4.00	1.15	2.53	13.94
<i>Cirrhilabrus</i> sp1	Down	6.42	4.27	0.00	0.00	2.43	16.37
<i>Lutjanus bohar</i>	Down	2.75	0.69	1.83	1.82	2.23	18.6
<i>Carangoides gymnotethus</i>	Down	2.21	0.51	0.00	0.18	2.23	20.83
<i>Elagatis bipinnulata</i>	Down	2.46	0.52	0.58	0.11	2.03	22.86
<i>Carangoides orthogrammus</i>	Down	2.00	0.27	0.83	0.18	2.02	24.88
<i>Carcharhinus amblyrhynchos</i>	Down	1.67	0.20	1.17	0.53	1.86	26.74

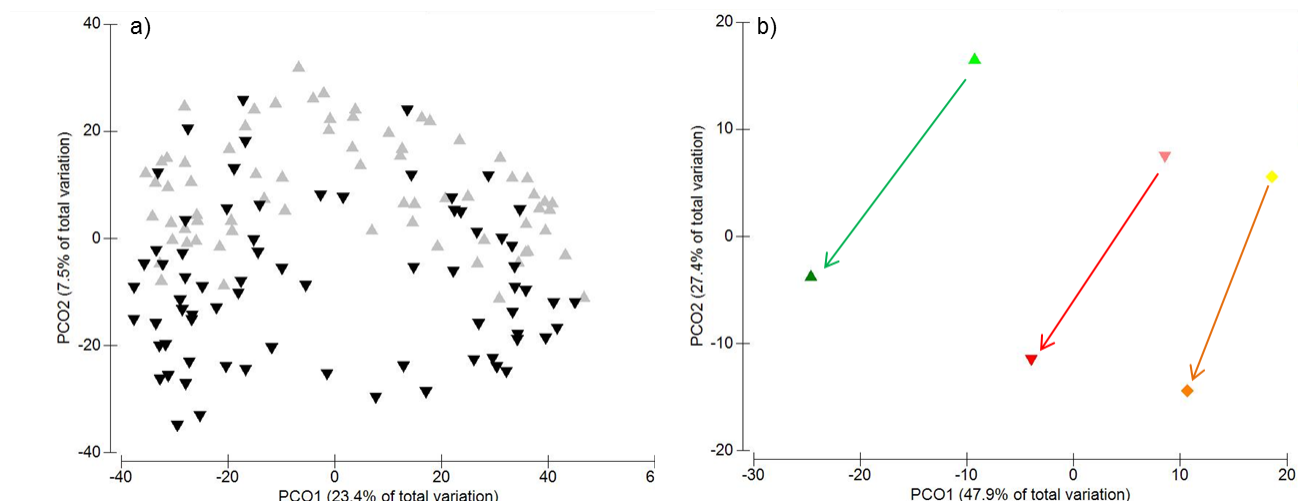


Figure 3.7. Principal coordinates ordination (PCO) showing effect of survey (2011, 2013) on the assemblage of fishes for (a) all deployments in 2011 (grey) and 2013 (black), and (b) centroids of each shoal for each survey for BAE (green), GOE (orange) and VUL (red) with pale shades indicating centroids for 2011 and dark shades indicating centroids for 2013 and associated arrows indicating directional change. See Appendix 2.1 for correlations between species and PCO axes.

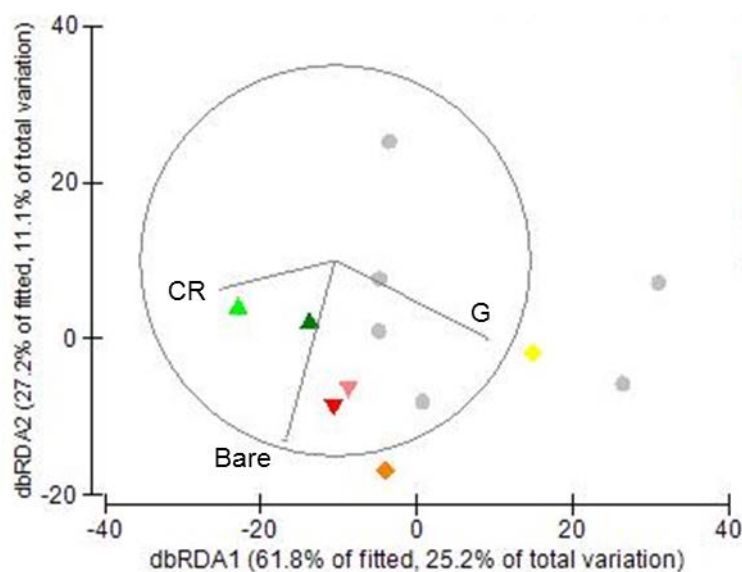


Figure 3.8. Distance-based redundancy analysis showing the relationship between species composition and habitat vectors (calcareous reef (CR), gravel (G) and bare cover) for the 6 shoals surveyed only in 2011 (grey) and for each shoal and survey for BAE (green), GOE (orange) and VUL (red) with pale shades indicating species assemblage for 2011 and dark shades indicating species assemblage for 2013 and associated arrows indicating directional change.

Variation in shark assemblages

Seven species of sharks were observed in 2011 and five species in 2013 (Table 3.10). The mean number of sharks per deployment ranged from 1.8 (± 0.47 SE) at BAE to 2.0 (± 0.39 SE) at VUL to 2.3 (± 0.69 SE) at GOE. The most common sharks in both 2011 and 2013 were *Carcharhinus amblyrhynchos* (the grey reef shark) and *Triaenodon obesus* (the whitetip reef shark), comprising more than 92% of the total numbers sighted in each survey (Table 3.10). There was a minor decrease in total number of sharks at BAE with no changes at GOE and VUL, ignoring any variations in sampled habitat. These observed changes were primarily driven by declines in *T. obesus* at all three shoals between the two surveys, offset by increases in numbers of *C. amblyrhynchos* at all three shoals (Table 3.10). In 2011, *T. obesus* was significantly and positively correlated with cover of calcareous reef (Table 3.6) such that the observed changes in calcareous reef in 2013 should have resulted in decreases in *T. obesus* at BAE and increases at GOE and VUL. Numbers of *T. obesus* were as predicted at BAE (-15%; $p=0.29$; Table 3.7) given the change in habitat but substantially lower than expected at GOE (-45%; $p=0.025$; Table 3.7) and VUL (-51%; $p=0.0007$; Table 3.7) given changes in habitat. No strong habitat relationships were detected for *C. amblyrhynchos* and total sharks in 2011, making increases in numbers of this species and general declines in total numbers of sharks difficult to interpret.

Table 3.10 Mean abundance (MaxN) of sharks per deployment by species in the 2011 and 2013 surveys for each shoal (BAE, GOE, VUL).

Species	BAE_11	BAE_13	GOE_11	GOE_13	VUL_11	VUL_13
<i>Carcharhinus albimarginatus</i>	0.000	0.000	0.000	0.000	0.125	0.000
<i>Carcharhinus amblyrhynchos</i>	1.522	1.167	0.696	1.583	1.667	1.167
<i>Galeocerdo cuvier</i>	0.000	0.000	0.000	0.042	0.042	0.167
<i>Nebrius ferrugineus</i>	0.043	0.000	0.000	0.000	0.000	0.042
<i>Negaprion acutidens</i>	0.043	0.000	0.000	0.000	0.042	0.000
<i>Sphyrna mokarran</i>	0.043	0.000	0.087	0.167	0.125	0.083
<i>Triaenodon obesus</i>	1.565	0.667	0.522	0.500	0.750	0.542

Variation in abundances of sea snakes

Numbers of sea snakes per deployment declined dramatically between the 2011 and 2013 surveys with 50 sea snakes observed in 2011 at BAE, GOE and VUL (0.71 sea snakes per deployment; $n=70$ samples) and six sea snakes observed at these same three shoals in 2013 (0.08 sea snakes per deployment; $n=72$ samples), an 88% decline (Table 3.11). In 2011, sea snake abundance varied negatively with depth and positively with cover of rubble (Heyward *et al.*, 2012). However the low numbers observed in 2013 meant that numbers could not be corrected to account for changes in habitat.

Table 3.11 Mean abundance of sea snakes (all observations and species combined) per deployment in the 2011 and 2013 surveys for each shoal (BAE, GOE, VUL).

	BAE_11	BAE_13	GOE_11	GOE_13	VUL_11	VUL_13
Total sea snakes	20	1	8	1	22	4
Sea snakes / deployment	0.87	0.04	0.35	0.04	0.92	0.17

3.4 Discussion

The rationale for the use of species richness (SR), abundance (TA) and size (adjFL) as appropriate variables to assess any impact of an uncontrolled release of hydrocarbons on the assemblages of fishes on the shoals was discussed in detail by Heyward *et al.* (2012). These authors noted that the justification relied largely on theory because for the most part, studies of oil spill effects have used a bioassay approach that focused on indicator species rather than assessing ecological impacts at the community level (Islam and Tanaka 2004). Reef fishes will vary in sensitivity to exposure to hydrocarbons among species and it would be expected that species richness should decline as the relatively susceptible species will be removed from the assemblage. Similarly, individuals within species will also vary in susceptibility and the loss of both species and individuals will result in a decline in abundance, assuming that other, more tolerant species do not increase in abundance in the interim. Smaller-bodied species should also be more sensitive to exposure (Peters 1986; Pauly 2005) because small fish have larger gill surfaces per unit body weight and greater surface area to volume ratio than large fish (Pauly 2005). Hydrocarbons and dispersants have been shown to impact gill function (Duarte *et al.* 2010; Al Hassan *et al.* 2000) and small fish also have faster metabolisms (Pauly 2005). Because smaller fish also tend to have smaller home ranges (Peters 1985) they may have less ability to avoid patches of oil and dispersant contamination than larger fish. They also tend to make up the bulk of planktivorous species on a reef and consequently may be susceptible to consumption of oil droplets distributed through the water column (Heyward *et al.* 2012).

Habitat was a key element of our comparison of the variables of SR, TA and adjFL between the 2011 and 2013 surveys. The initial survey of these shoals in 2011 highlighted the importance of habitat as a critical determinant of the structure and abundance of fish assemblages (Heyward *et al.* 2012). Although we aimed to resample the same deployment sites as those of the 2011 survey by using GPS fixes, small deviations due to current flow, windage on the vessel, the relatively limited number of deployments per shoal (24) and changes in the benthic cover between surveys resulted in many deployments sampling habitats that differed from the 2011 survey. Because of the strong dependence of assemblage structure on habitat (see Heyward *et al.* 2012 for a detailed analysis), it was essential that our study accounted for these changes. We did this by predicting expected values of SR, TA and adjFL as a function of the relationships between habitat and fish assemblages we observed in the 2011 survey (Heyward *et al.* 2012) using linear regression. These expected values, based upon the results of the 2011 study, were then compared to observed values from the 2013 surveys. The tests provided a means to determine if observed patterns were significantly different from the results of our earlier study.

Overall, these comparisons showed the following major patterns of change between survey dates in 2011 and 2013:

- (1) At BAE (the shoal that received relatively low exposure to the uncontrolled release of hydrocarbons), there was a significant increase in SR, TA and a shift to smaller individuals in the assemblage within the habitats sampled by the BRUVS™.
- (2) At GOE, (the shoal that received the second highest exposure to the release), we observed values of SR, TA and size consistent with those predicted for the habitat types that were sampled by the BRUVS™ in 2013.
- (3) At VUL, (the shoal that received the highest exposure), there were ongoing decreases in SR and TA relative to habitat and no change in mean sizes of fish within the assemblage.
- (4) Overall, composition of fish assemblages changed between the two surveys at all three shoals, but these changes were relatively small compared to the among-shoal variation in assemblage structure recorded during the survey in 2011, when nine shoals were sampled. It was unclear whether these differences reflected the changes we observed in habitats sampled by the BRUVS™, or were part of some ongoing response to the oil spill (e.g. a recovery in numbers). For example, the fish assemblage at BAE differed between surveys in a manner consistent with changes in the amount of calcareous reef, but not with changes in the amount of shoal that was bare. Similarly, the assemblage at GOE shifted between surveys in a manner consistent with changes in both calcareous reef and bare categories, while the assemblage at VUL remained the same between surveys despite observed changes in calcareous reef and bare categories. Changes in the assemblage were also very difficult to interpret, once again because they could not be clearly associated with habitat. This would have required the construction of habitat models at the scale of single species.
- (5) There was a small decline in diversity of sharks from seven to five species between surveys. At all three shoals, numbers of one of the most common sharks associated with coral reefs, *T. obesus*, (the whitetip reef shark), were significantly lower than those predicted based on habitat. These changes differed among reefs and were correlated with exposure to the release, so that numbers at BAE (relatively low exposure) displayed the smallest decline (relative to predicted values for the habitat sampled by the BRUVS™), at GOE the decline was slightly greater and the largest decline occurred at VUL, where exposure was highest.
- (6) There was a decline in numbers of sea snakes from 50 sightings in the 2011 survey to only six sightings in the 2013 survey.

Interpretation of these patterns and their attribution to any effect of the uncontrolled release is hampered by a number of factors. Foremost of these is the lack of regional baselines that would allow surveys to separate variability in assemblage structure occurring at regional scales (>100 km) from any effect of an uncontrolled release of hydrocarbons. Secondly, because no pre-release baseline data exists, our study is only correlative and any patterns do not necessarily imply causality with the release event. Thirdly, the patterns described here are from a small subsample of the original group of nine shoals surveyed in 2011 and it is possible that they are not representative of changes that occurred in this larger sample. It should be noted in this context that the earlier survey by Heyward *et al.* (2012) identified a large amount of variation in assemblage structure that occurred among nearby banks and shoals in this region.

Bearing these caveats in mind and in addition, assuming that our estimates of relative exposure of the shoals to the uncontrolled release were realistic, we found overall patterns in change were consistent with the range of exposures. These are summarised below in Table 3.12.

Table 3.12 The direction of changes (+ = increase, 0 = no change, - = decrease) in response variables (SR = species richness; TA = total abundance; adjFL = adjusted fork length, see methods; *T. obesus* - *Triaenodon obesus*, the whitetip reef shark) between the 2011 and 2013 surveys by shoal.

	BAE	GOE	VUL
SR	+	0	-
TA	+	0	-
adjFL	-	0	0
<i>T. obesus</i>	0	-	-

Positive changes occurred on the shoal with the lowest exposure and the greatest number of negative changes on the shoal with highest exposure to the uncontrolled release. One possible interpretation of these results (again, bearing in mind the caveats mentioned above) is that the shoal that had only a small exposure to the release (BAE) showed some resilience and recovered at a faster rate than the shoal that had the moderate exposure (GOE) which showed no change, while the shoal that had the greatest exposure (VUL) displayed some long-term effects of the release. However, such interpretations are complicated by a number of other factors. For example, trends in numbers of *T. obesus* were consistent with exposure and the declines in numbers of this species at the shoals with moderate and high exposure may reflect long-term effects of the release of hydrocarbons manifested through food chains (*T. obesus* is an apex predator) and expressed for this species in terms of recruitment and survivorship. Such patterns have been witnessed in other apex predators, notably killer whales (*Orcinus orca*) where mortalities linked to oil exposure were still occurring some years after the Exxon Valdez spill (Matkin *et al.* 2008). However, in our study, patterns were not consistent among species with changes in numbers of the other common reef shark in the region, *Carcharhinus amblyrhynchos* (the grey reef shark) displaying no relationship to relative exposure of the shoals to the release. This may reflect differences in ecology of the species, such that *T. obesus* may be more resident than *C. amblyrhynchos*, (Speed *et al.* 2010) or it may simply be that the pattern we observed in *T. obesus* is merely the result of a chance event.

Similar problems exist with interpretation of patterns in numbers of sea snakes. During the 2011 survey, 50 sea snakes were sighted in BRUVS™ deployments on these reefs. In the 2013 survey, only 6 were sighted, suggesting a long-term impact of the release on the survivorship and demography of these animals. Sea snakes are likely to be highly susceptible to oil spills because they must visit the surface to breathe at frequent intervals and during clean-up operations a small number of sea snakes were found dead in the area of the Montara well head platform. Biopsies indicated exposure though either ingestion of contaminated prey or direct inhalation as the likely cause of death (Gagnon and Rawson, 2010). The reduction in numbers of snakes we recorded in 2013 was unlikely to be due to emigration, since there is growing evidence for very limited dispersal in many species, with deep channels between reefs acting as barriers (Lukoschek *et al.* 2007) and recent studies showing that closely related species may move less than 2 km over periods of a number of years (Lukoschek and Shine 2012). However, sea snakes have shown major declines in abundance at other reefs in this region well before the Montara uncontrolled release. At Ashmore Reef adjacent to our study area, surveys in 1973 and 1994 recorded nine species and average numbers of 42–46 snakes day⁻¹. Surveys since 2005 mostly sighted only two species with counts averaging just 1–7 snakes day⁻¹. Five species that were abundant at Ashmore Reef are now thought to have become locally extinct (Lukoschek *et al.* 2013). The cause of these major declines in numbers is unknown. Thus, these surveys from adjacent areas show that sea snakes may undergo declines that appear to

have little to do with anthropogenic factors such as oil spills. Again, this illustrates the value of baseline data collected at regional scales.

It is also possible, however, that our analysis underestimated an effect of the uncontrolled release on the fish assemblage. Our predicted values for response variables were created from measurements taken from all nine shoals surveyed in 2011, some of which may have displayed responses to the uncontrolled release. Thus, it is possible that our predicted values for comparison with the 2013 survey results would have been lower than those likely to be calculated if we had only sampled unimpacted shoals in 2011. This situation would have effectively reduced the power of the study to detect significant change between surveys and could only have been avoided if pre-release baseline data sets had been available.

3.4.1 Recommendations

Our analysis suggests that patterns existed within the assemblage of fishes on the three shoals that were consistent with exposure to an uncontrolled release of hydrocarbons and therefore, that full recovery from this event may not yet have occurred. However, the evidence is circumstantial and tentative for the following reasons:

- (1) No pre-oil spill baselines exist that allow the clear separation of regional variability from potential impacts of the release;
- (2) The sample sizes for surveys in 2013 were limited to only three shoals that included one low exposure and two high exposure situations. This made it difficult for the study to discern general patterns in response and to clearly differentiate between natural variability in structure and effects of an uncontrolled release of hydrocarbons.
- (3) The habitat structure of the shoals was spatially and temporally heterogeneous and sampling deployments were limited, resulting variation in the types of habitat sampled between surveys.

In the future:

- 1) As more extensive regional baselines are established to monitor benthic habitats and fish assemblage structure, interpretation of trends at any given shoal will be improved
- 2) Monitoring of the physical oceanographic environment on and near shoals and the ability to sample at greater frequency and intensity both between and within shoals will be valuable approaches to understanding these dynamic systems.

3.5 References

- Al-Hassan JM, Afzal M, Rao CVN, & Fayad S (2000). Petroleum Hydrocarbon Pollution in Sharks in the Arabian Gulf. *Bulletin of Environmental Contamination and Toxicology*, 65: 391-398.
- Allen G (2004) *Marine Fishes of Tropical Australia and South-East Asia. A field guide for anglers and divers*. Western Australian Museum
- Allen G, Steene R, Allen M (1998) *A guide to angelfishes and butterflyfishes*. Odyssey Publishing, Tropical Reef Research, USA
- Allen G, Steene R, Humann P, Deloach N (2003) *Reef fish identification. Tropical Pacific*. Odyssey Publishing, USA
- Anderson MJ (2001) Permutation tests for univariate or multivariate analysis of variance and regression, *Canadian Journal of Fisheries and Aquatic Science* 58 (2001), pp. 626–639
- Cappo M, Harvey E & Shortis M (2007) Counting and measuring fish with baited video techniques – An overview. *Australian Society for Fish Biology 2006 Workshop Proceedings*, p. 101-114.
- Cappo M, Speare P & De'ath G (2004) Comparison of baited remote underwater video stations (BRUVS™) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. *Journal of Experimental Marine Biology and Ecology* 302: 123-152.
- Cappo M, Speare P, Wassenberg TJ, Harvey E, Rees M, Heyward A, Pitcher R (2001) Use of baited remote underwater video stations (BRUVS™) to survey demersal fish – how deep and meaningful? In: Harvey ES, M Cappo (eds) *Direct sensing of the size frequency and abundance of target and non-target fauna in Australian Fisheries*. 4-7 September 2000, Rottneest Island, Western Australia. Fisheries Research and Development Corporation. pp 63-71
- Duarte RM, Hondab RT, Vala AL (2010) Acute effects of chemically dispersed crude oil on gill ion regulation, plasma ion levels and haematological parameters in tambaqui (*Colossoma macropomum*). *Aquatic Toxicology* 97:134-141.
- Farnsworth KD, Thygesen UH, Ditlevsen S & King NJ (2007) How to estimate scavenger fish abundance using baited camera data. *Marine Ecology Progress Series* 350: 223-234.
- Gagnon MMG, Rawson CA (2010) Montara Well Release: Report on necropsies from a Timor Sea horned sea snake. Curtin University, Perth, Western Australia. 13p
- Harvey E, Fletcher D, Shortis M (2002a) Estimation of reef fish length by divers and by stereo-video: A first comparison of the accuracy and precision in the field on living fish under operational conditions. *Fisheries Research* 57: 255-265
- Harvey ES, Shortis MR, Stadler M and Cappo M (2002b) A comparison of the accuracy and precision of digital and analogue stereo-video systems. *Marine Technology Society Journal* 36(2): 38-49
- Harvey ES, Cappo M, Butler JJ, Hall N and Kendrick GA (2007) Bait attraction affects the performance of remote underwater video stations in assessment of demersal fish community structure. *Marine Ecology Progress Series* 350: 245-254.
- Heyward A, Jones R, Meeuwig JJ, Burns K, Radford B, Colquhoun J, Cappo M, Case M, O'Leary R, Fisher R, Meekan M, Stowar M. (2012) Montara: 2011 Offshore Banks Assessment Survey.

- Monitoring Study S5. Final Report prepared by the Australian Institute of Marine Science for PTTEP Australasia (Ashmore Cartier) Pty. Ltd. In accordance with Contract No. 000/2011/02-04. Perth 2012. 241 pp.
- Islam S, Tanaka M (2004). Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. *Marine Pollution Bulletin*, 48(7), 624-649.
- Langlois TJ, Harvey ES, Fitzpatrick BJ, Meeuwig JJ, Shedrawi G and Watson DL (2010) Cost efficient sampling of tropical and temperate fish assemblages: comparison of diver transects and baited video. *Aquatic Biology* 9: 155-168.
- Langlois TJ, Radford B, Van Niel K, Meeuwig JJ, Pearce A, Rousseaux C, Kendrick GA, and Harvey ES (2011) Consistent abundance distributions of marine fishes in an old, climatically buffered, infertile seascape. *J. Global Ecology and Biogeography*. In press
- Legendre P, Anderson MJ (1999). Distance-based redundancy analysis: testing multiple species responses in multifactorial ecological experiments. *Ecological Monographs* 69 1-24.
- Lieske E and Myers R (2001) Coral reef fishes Indo-Pacific and Caribbean. Revised Edition. HarperCollins Publishers Ltd, London
- Lukoschek V, Beger M, Ceccarelli D, Richards Z, Pratchett M (2013). Enigmatic declines of Australia's sea snakes from a biodiversity hotspot. *Biological Conservation*, 166, 191-202.
- Lukoschek V, Shine R (2012). Sea snakes rarely venture far from home. *Ecology and Evolution*, 2: 1113-1121.
- Lukoschek V, Waycott M, Marsh H (2007). Phylogeographic structure of the olive sea snake, *Aipysurus laevis* (Hydrophiinae) indicates recent Pleistocene range expansion but low contemporary gene flow. *Molecular Ecology* 16:3406-3422.
- Matkin CO, et al. (2008). Ongoing population-level impacts on killer whales *Orcinus orca* following the 'Exxon Valdez' oil spill in Prince William Sound, Alaska. *Marine Ecology Progress Series* 356: 269-281.
- McCordle BH, Anderson MJ (2011) Fitting multivariate models to community data: a comment on distance-based redundancy analysis. *Ecology* 82:290-297.
- Pauly D (1998). Tropical fishes: patterns and propensities*. *Journal of Fish Biology*, 53(sa), 1-17.
- Peters RH (1986) The ecological implications of body size. Cambridge University Press. 344 pp.
- Pinheiro JC and Bates DM (2000) Mixed-Effects Models in S and S-Plus. Springer, New York.
- Priede IG, Bagley PM, Smith A, Creasey S and Merrett NR (1994) Scavenging deep demersal fishes of the Porcupine Seabight, North-east Atlantic: observations by baited camera, trap and trawl. *Journal of Marine Biological Association of the United Kingdom* 74: 481-498
- Priede IG and Merrett NR (2006) Estimation of abundance of abyssal demersal fishes; a comparison of data from trawls and baited cameras. *Journal of Fish Biology* 49 SA: 207-216
- 'R' Development Core Team (2006) *R: A language and environment for statistical computing*. Reference Index. R Foundation for Statistical Computing: <http://cran.r-project.org/doc/manuals/refman.pdf>

- Randall JE (2002) Surgeonfishes of Hawaii and the World. Mutual Publishing and Bishop Museum Press, Hawaii
- Randall JE, Allen GR and Steene RC (1997) Fishes of the Great Barrier Reef and Coral Sea (Revised and Expanded Edition), University of Hawaii Press, Honolulu
- Rees AJJ, Yearsley GK, Gowlett-Holmes K, Pogonoski J (2010) Codes for Australian aquatic biota (on-line version). CSIRO Marine and Atmospheric Research, World Wide Web electronic publication, 1999 onwards. Available at: <http://www.cmar.csiro.au/caab/> .
- SeaGIS Pty Ltd (2008) <http://www.seagis.com.au/> Last updated January 2010
- Shortis M, Harvey E and Abdo D (2009) A review of underwater stereo-image measurement for marine biology and ecology applications. *Oceanography and Marine Biology: An Annual Review* 47: 257-292.
- Speed CW, Field IC, Meekan MG, Bradshaw CJ (2010). Complexities of coastal shark movements and their implications for management. *Marine Ecology Progress Series*, 408, 275-293.
- Watson DL (2006) Use of underwater stereo-video to measure fish assemblage structure, spatial distribution of fishes and change in assemblages with protection from fishing. PhD Thesis, School of Plant Biology, The University of Western Australia
- Willis TJ, Millar RB and Babcock RC (2000) Detection of spatial variability in relative density of fishes: comparison of visual census, angling, and baited underwater video. *Marine Ecology Progress Series* 198: 249-260.
- Zar JH (2010) Biostatistical Analysis. 5th edition. Pearson Publishers.

Appendix 3.1 Raw data of abundances (MaxN) of fishes and sharks observed during BRUVS™ surveys in 2013 and 2011 at three shoals (BAE, GOE, VUL).

Family	Species	2013			2011		
		BAE	GOE	VUL	BAE	GOE	VUL
Acanthuridae	<i>Acanthurus dussumieri</i>	0	0	1	0	1	0
Acanthuridae	<i>Acanthurus grammoptilus</i>	16	3	15	10	6	72
Acanthuridae	<i>Acanthurus leucocheilus</i>	12	3	7	12	4	5
Acanthuridae	<i>Acanthurus mata</i>	11	10	6	1	0	15
Acanthuridae	<i>Acanthurus nigricans</i>	1	2	2	2	2	2
Acanthuridae	<i>Acanthurus nigricauda</i>	2	0	2	0	0	0
Acanthuridae	<i>Acanthurus nigrofusus</i>	8	0	0	0	0	0
Acanthuridae	<i>Acanthurus olivaceus</i>	33	4	29	24	1	24
Acanthuridae	<i>Acanthurus pyroferus</i>	9	4	3	4	1	2
Acanthuridae	<i>Acanthurus thompsoni</i>	0	0	0	1	0	2
Acanthuridae	<i>Acanthurus xanthopterus</i>	2	6	0	6	0	2
Acanthuridae	<i>Ctenochaetus binotatus</i>	14	6	1	0	0	0
Acanthuridae	<i>Ctenochaetus striatus</i>	6	6	4	23	2	11
Acanthuridae	<i>Naso annulatus</i>	1	0	0	1	0	1
Acanthuridae	<i>Naso brachycentron</i>	3	10	7	6	6	6
Acanthuridae	<i>Naso brevirostris</i>	17	24	28	7	50	3
Acanthuridae	<i>Naso caesius</i>	2	2	1	6	0	1
Acanthuridae	<i>Naso fageni</i>	0	1	1	0	0	0
Acanthuridae	<i>Naso hexacanthus</i>	10	11	10	79	19	70
Acanthuridae	<i>Naso lituratus</i>	13	9	3	9	5	4
Acanthuridae	<i>Nasolopezi</i>	3	14	3	79	5	0
Acanthuridae	<i>Naso mcdadei</i>	0	0	1	0	0	0
Acanthuridae	<i>Naso minor</i>	0	0	1	1	1	0
Acanthuridae	<i>Naso thynnoides</i>	0	12	45	0	41	0
Acanthuridae	<i>Naso tonganus</i>	0	0	0	0	0	2
Acanthuridae	<i>Naso unicornis</i>	2	4	0	1	0	0
Acanthuridae	<i>Naso vlamingii</i>	4	8	8	16	6	7
Acanthuridae	<i>Paracanthurus hepatus</i>	0	0	1	0	0	0
Acanthuridae	<i>Zebrasoma scopas</i>	0	0	0	1	0	0
Apogonidae	<i>Apogon fragilis</i>	8	0	0	0	0	0
Apogonidae	<i>Apogon sp1</i>	95	0	0	0	0	0
Apogonidae	<i>Apogon sp2</i>	0	0	15	0	0	0
Aulostomidae	<i>Aulostomus chinensis</i>	0	0	2	0	0	0
Balistidae	<i>Balistapus undulatus</i>	18	14	17	5	3	5
Balistidae	<i>Balistoides conspicillum</i>	6	1	3	6	2	3

Balistidae	<i>Balistoides viridescens</i>	9	5	6	16	5	5
Balistidae	<i>Canthidermis maculatus</i>	0	0	0	1	8	1
Balistidae	<i>Melichthys vidua</i>	0	6	0	0	1	0
Balistidae	<i>Odonus niger</i>	206	49	19	375	30	64
Balistidae	<i>Pseudobalistes flavimarginatus</i>	17	5	3	2	2	2
Balistidae	<i>Pseudobalistes fuscus</i>	0	0	1	43	13	5
Balistidae	<i>Rhinecanthus rectangulus</i>	0	0	0	0	0	1
Balistidae	<i>Sufflamen bursa</i>	0	1	3	1	0	1
Balistidae	<i>Sufflamen chrysopteron</i>	25	6	13	11	0	10
Balistidae	<i>Sufflamen fraenatum</i>	11	3	4	10	6	3
Blenniidae	<i>Aspidontus taeniatus</i>	0	0	0	2	0	0
Blenniidae	<i>Ecsenius lividanalus</i>	0	0	1	0	0	0
Blenniidae	<i>Plagiotremus rhinorhynchus</i>	1	0	0	0	0	0
Blenniidae	<i>Plagiotremus tapeinosoma</i>	0	0	0	0	1	0
Caesionidae	<i>Caesio cuning</i>	0	7	0	0	95	0
Caesionidae	<i>Caesio lunaris</i>	0	0	0	31	0	0
Carangidae	<i>Alepes vari</i>	0	432	7	120	10	63
Carangidae	<i>Atule mate</i>	0	28	2	0	1	61
Carangidae	<i>Carangoides caeruleopinnatus</i>	0	5	3	0	3	1
Carangidae	<i>Carangoides ferdau</i>	0	4	6	1	6	5
Carangidae	<i>Carangoides fulvoguttatus</i>	0	2	3	0	5	1
Carangidae	<i>Carangoides gymnotethus</i>	1	21	0	7	38	53
Carangidae	<i>Carangoides oblongus</i>	0	1	0	0	0	0
Carangidae	<i>Carangoides orthogrammus</i>	2	20	20	38	29	48
Carangidae	<i>Carangoides plagiotaenia</i>	2	5	3	2	2	10
Carangidae	<i>Caranx ignobilis</i>	4	0	9	6	0	3
Carangidae	<i>Caranx lugubris</i>	0	1	0	0	0	0
Carangidae	<i>Caranx melampygus</i>	14	19	24	31	29	29
Carangidae	<i>Caranx sexfasciatus</i>	2	28	0	0	12	1
Carangidae	<i>Elagatis bipinnulata</i>	6	6	14	62	18	59
Carangidae	<i>Scomberoides lysan</i>	2	21	12	0	0	0
Carangidae	<i>Scomberoides tol</i>	0	0	0	0	0	1
Carangidae	<i>Seriola dumerili</i>	0	0	1	1	0	0
Carangidae	<i>Seriola rivoliana</i>	0	3	6	0	0	0
Carcharhinidae	<i>Carcharhinus albimarginatus</i>	0	0	0	0	0	3
Carcharhinidae	<i>Carcharhinus amblyrhynchus</i>	28	38	28	35	16	40
Carcharhinidae	<i>Galeocerdo cuvier</i>	0	1	4	0	0	1
Carcharhinidae	<i>Negaprion acutidens</i>	0	0	0	1	0	1

Carcharhinidae	<i>Triaenodon obesus</i>	16	12	13	36	12	18
Chaetodontidae	<i>Chaetodon adiergastos</i>	0	0	4	0	0	0
Chaetodontidae	<i>Chaetodon auriga</i>	6	6	1	1	2	0
Chaetodontidae	<i>Chaetodon baronessa</i>	0	0	0	1	1	0
Chaetodontidae	<i>Chaetodon ephippium</i>	2	0	0	2	0	0
Chaetodontidae	<i>Chaetodon kleinii</i>	17	5	8	21	2	7
Chaetodontidae	<i>Chaetodon lineolatus</i>	0	2	1	3	1	1
Chaetodontidae	<i>Chaetodon lunula</i>	7	0	0	3	3	1
Chaetodontidae	<i>Chaetodon lunulatus</i>	0	0	0	0	1	0
Chaetodontidae	<i>Chaetodon melannotus</i>	0	1	0	0	0	2
Chaetodontidae	<i>Chaetodon meyeri</i>	0	0	1	3	0	0
Chaetodontidae	<i>Chaetodon ornatissimus</i>	7	0	1	2	0	2
Chaetodontidae	<i>Chaetodon oxycephalus</i>	0	0	0	0	1	0
Chaetodontidae	<i>Chaetodon punctatofasciatus</i>	0	2	1	0	0	0
Chaetodontidae	<i>Chaetodon speculum</i>	1	1	0	0	0	0
Chaetodontidae	<i>Chaetodon trifascialis</i>	3	0	0	4	0	0
Chaetodontidae	<i>Chaetodon ulietensis</i>	0	0	0	2	2	0
Chaetodontidae	<i>Chaetodon vagabundus</i>	0	0	1	0	1	0
Chaetodontidae	<i>Coradion chrysozonus</i>	0	0	0	0	0	1
Chaetodontidae	<i>Forcipiger flavissimus</i>	5	1	1	4	0	1
Chaetodontidae	<i>Hemitaenichthys polylepis</i>	0	1	19	0	0	2
Chaetodontidae	<i>Heniochus acuminatus</i>	0	5	0	0	0	3
Chaetodontidae	<i>Heniochus diphreutes</i>	0	28	0	0	0	0
Chaetodontidae	<i>Heniochus monoceros</i>	0	1	0	0	0	0
Chaetodontidae	<i>Heniochus singularius</i>	4	7	3	5	3	0
Cirrhitidae	<i>Cirrhitichthys aprinus</i>	0	0	1	0	0	0
Cirrhitidae	<i>Cirrhitichthys falco</i>	0	0	1	0	0	0
Cirrhitidae	<i>Paracirrhites forsteri</i>	2	1	1	0	0	1
Dasyatidae	<i>Dasyatis kuhlii</i>	5	4	5	7	3	6
Dasyatidae	<i>Himantura fai</i>	0	0	0	0	1	0
Dasyatidae	<i>Taeniura lymma</i>	5	2	3	8	3	2
Dasyatidae	<i>Taeniura meyeni</i>	0	0	0	0	2	1
Echeneidae	<i>Echeneis naucrates</i>	4	13	8	16	4	10
Ephippidae	<i>Platax batavianus</i>	0	0	0	0	1	0
Ephippidae	<i>Platax teira</i>	2	1	0	1	1	5
Fistulariidae	<i>Fistularia commersonii</i>	1	6	1	3	1	2
Ginglymostomatidae	<i>Nebrius ferrugineus</i>	0	0	1	1	0	0
Gobiidae	<i>Amblyeleotris</i> sp1	3	0	0	0	0	0
Gobiidae	<i>Amblyeleotris</i> sp2	1	0	0	0	0	0

Haemulidae	<i>Plectorhinchus picus</i>	1	0	0	0	0	0
Haemulidae	<i>Plectorhinchus vittatus</i>	1	0	1	0	0	0
	<i>Sargocentron</i>						
Holocentridae	<i>caudimaculatum</i>	0	4	0	1	0	0
Hydrophiidae	<i>Aipysurus laevis</i>	8	4	9	0	0	0
Kyphosidae	<i>Kyphosus vaigiensis</i>	0	0	0	0	1	0
Labridae	<i>Anampses lennardi</i>	0	0	0	0	2	0
Labridae	<i>Anampses melanurus</i>	1	0	0	0	0	0
Labridae	<i>Anampses meleagrides</i>	0	1	0	0	0	0
Labridae	<i>Bodianus axillaris</i>	1	0	0	0	0	0
Labridae	<i>Bodianus diana</i>	3	2	2	2	1	0
Labridae	<i>Cheilinus trilobatus</i>	4	0	0	3	0	1
Labridae	<i>Cheilinus undulatus</i>	0	1	0	0	0	0
Labridae	<i>Cheilio inermis</i>	2	0	0	0	0	0
Labridae	<i>Choerodon jordani</i>	2	0	0	3	2	0
Labridae	<i>Cirrhilabrus exquisitus</i>	112	81	18	37	0	0
Labridae	<i>Cirrhilabrus sp1</i>	0	0	0	126	313	154
Labridae	<i>Cirrhilabrus sp2</i>	0	0	0	88	217	0
Labridae	<i>Cirrhilabrus temminckii</i>	38	116	69	0	0	0
Labridae	<i>Coris aygula</i>	0	0	0	0	1	0
Labridae	<i>Coris caudimacula</i>	1	0	0	0	4	0
Labridae	<i>Coris dorsomacula</i>	2	0	0	0	0	0
Labridae	<i>Coris gaimard</i>	2	0	1	11	0	0
Labridae	<i>Gomphosus varius</i>	1	1	0	0	0	0
Labridae	<i>Halichoeres chrysus</i>	4	0	0	4	0	0
Labridae	<i>Halichoeres hartzfeldii</i>	0	0	0	27	0	1
Labridae	<i>Halichoeres hortulanus</i>	11	11	3	3	3	1
Labridae	<i>Halichoeres nebulosus</i>	8	0	9	3	0	1
Labridae	<i>Halichoeres prosopion</i>	0	2	4	0	1	0
Labridae	<i>Halichoeres scapularis</i>	3	0	0	0	0	0
Labridae	<i>Halichoeres sp2</i>	0	0	0	0	1	0
Labridae	<i>Halichoeres sp3</i>	0	0	0	1	0	0
Labridae	<i>Halichoeres zeylonicus</i>	77	56	96	0	1	3
Labridae	<i>Hemigymnus fasciatus</i>	0	1	0	0	0	0
Labridae	<i>Hologymnosus annulatus</i>	8	2	5	0	0	0
Labridae	<i>Hologymnosus doliatus</i>	23	0	5	13	1	3
Labridae	<i>Hologymnosus rhodonotus</i>	0	2	0	0	0	0
Labridae	<i>Iniistius aneitensis</i>	0	2	4	0	0	0
Labridae	<i>Labracinus lineatus</i>	0	0	0	0	1	0
Labridae	<i>Labroides bicolor</i>	0	2	0	0	0	0

Labridae	<i>Labroides dimidiatus</i>	24	11	16	30	16	11
Labridae	<i>Leptojulis cyanopleura</i>	1	0	0	0	0	0
Labridae	<i>Macropharyngodon negrosensis</i>	1	0	1	0	0	0
Labridae	<i>Novaculichthys taeniourus</i>	2	0	2	0	0	1
Labridae	<i>Oxycheilinus digrammus</i>	6	0	2	8	1	1
Labridae	<i>Oxycheilinus orientalis</i>	0	0	1	0	0	0
Labridae	<i>Oxycheilinus</i> sp1	0	0	0	0	3	0
Labridae	<i>Oxycheilinus unifasciatus</i>	3	1	1	2	1	1
Labridae	<i>Paracheilinus flavianalis</i>	0	1	0	0	0	0
Labridae	<i>Pseudocheilinus evanidus</i>	8	4	1	0	0	0
Labridae	<i>Pseudodax moluccanus</i>	7	3	0	4	2	0
Labridae	<i>Pseudojuloides severnsi</i>	0	1	0	2	3	10
Labridae	<i>Pteragogus enneacanthus</i>	0	0	1	0	0	0
Labridae	<i>Thalassoma amblycephalum</i>	35	3	8	7	0	0
Labridae	<i>Thalassoma janseni</i>	8	0	1	5	1	0
Labridae	<i>Thalassoma lunare</i>	17	2	1	14	0	4
Labridae	<i>Thalassoma lutescens</i>	9	1	5	0	0	0
Lethrinidae	<i>Gymnocranius grandoculis</i>	10	16	13	13	25	12
Lethrinidae	<i>Gymnocranius</i> sp1	0	8	3	0	0	0
Lethrinidae	<i>Gymnocranius</i> sp2	1	0	0	0	0	0
Lethrinidae	<i>Lethrinus amboinensis</i>	8	55	6	53	81	21
Lethrinidae	<i>Lethrinus atkinsoni</i>	43	118	139	30	134	288
Lethrinidae	<i>Lethrinus erythracanthus</i>	1	2	0	3	0	0
Lethrinidae	<i>Lethrinus microdon</i>	1	0	1	0	1	0
Lethrinidae	<i>Lethrinus nebulosus</i>	0	3	0	1	5	3
Lethrinidae	<i>Lethrinus olivaceus</i>	7	7	10	30	16	22
Lethrinidae	<i>Lethrinus ravus</i>	1	0	0	21	1	0
Lethrinidae	<i>Lethrinus rubrioperculatus</i>	149	179	128	146	220	87
Lethrinidae	<i>Lethrinus</i> sp1	2	6	1	0	6	0
Lethrinidae	<i>Lethrinus xanthochilus</i>	1	0	0	0	1	0
Lethrinidae	<i>Monotaxis grandoculis</i>	8	5	25	2	1	3
Lutjanidae	<i>Aprion virescens</i>	5	1	3	11	5	4
Lutjanidae	<i>Caesio teres</i>	1	33	0	0	6	8
Lutjanidae	<i>Lutjanus bohar</i>	62	81	44	110	45	66
Lutjanidae	<i>Lutjanus fulviflamma</i>	0	3	0	0	1	2
Lutjanidae	<i>Lutjanus gibbus</i>	1	37	0	6	6	2
Lutjanidae	<i>Lutjanus kasmira</i>	2	0	0	0	2	0
Lutjanidae	<i>Lutjanus lemniscatus</i>	0	2	0	0	0	0
Lutjanidae	<i>Lutjanus rivulatus</i>	0	5	2	7	0	4

Lutjanidae	<i>Macolor macularis</i>	16	19	31	3	7	6
Lutjanidae	<i>Macolor niger</i>	0	1	4	19	6	1
Lutjanidae	<i>Paracaesio xanthura</i>	0	92	14	0	0	0
Lutjanidae	<i>Pterocaesio digramma</i>	0	0	2	93	0	39
Lutjanidae	<i>Pterocaesio marri</i>	0	0	1	0	1	0
Lutjanidae	<i>Pterocaesio sp1</i>	0	0	39	1	0	27
Lutjanidae	<i>Pterocaesio tile</i>	0	0	1	83	0	0
Lutjanidae	<i>Symphorus nematophorus</i>	0	0	2	0	1	0
Malacanthidae	<i>Hoplolatilus cuniculus</i>	0	16	1	0	1	4
Malacanthidae	<i>Hoplolatilus sp1</i>	0	0	0	0	2	0
Malacanthidae	<i>Malacanthus brevirostris</i>	15	1	3	4	4	0
Malacanthidae	<i>Malacanthus latovittatus</i>	11	4	4	10	1	0
Microdesmidae	<i>Gunnellichthys monostigma</i>	0	0	1	0	0	0
Microdesmidae	<i>Gunnellichthys pleurotaenia</i>	0	2	0	0	0	0
Microdesmidae	<i>Nemateleotris magnifica</i>	0	1	0	0	0	0
Microdesmidae	<i>Ptereleotris evides</i>	0	0	1	0	0	1
Microdesmidae	<i>Ptereleotris heteroptera</i>	9	6	12	0	0	0
Microdesmidae	<i>Ptereleotris microlepis</i>	7	1	13	0	0	0
Microdesmidae	<i>Ptereleotris sp1</i>	0	0	0	0	1	0
Monacanthidae	<i>Aluterus monoceros</i>	0	0	1	0	1	0
Monacanthidae	<i>Aluterus scriptus</i>	3	0	1	1	7	8
Monacanthidae	<i>Cantherhines dumerilii</i>	0	0	4	5	1	1
Mullidae	<i>Parupeneus barberinoides</i>	0	0	0	0	1	1
Mullidae	<i>Parupeneus barberinus</i>	4	0	0	1	1	1
Mullidae	<i>Parupeneus cyclostomus</i>	17	11	4	15	6	3
Mullidae	<i>Parupeneus multifasciatus</i>	68	16	15	38	4	19
Mullidae	<i>Parupeneus pleurostigma</i>	10	3	7	3	1	5
Muraenidae	<i>Gymnothorax flavimarginatus</i>	0	0	2	0	1	0
Muraenidae	<i>Gymnothorax sp1</i>	0	0	0	0	1	0
Muraenidae	<i>Gymnothorax undulatus</i>	0	0	1	0	1	0
Myliobatidae	<i>Manta birostris</i>	0	1	0	0	0	0
Nemipteridae	<i>Scolopsis bilineata</i>	0	2	0	0	0	0
Nemipteridae	<i>Scolopsis xenochrous</i>	58	21	44	31	16	24
Ostraciidae	<i>Lactoria cornuta</i>	0	0	0	0	0	1
Ostraciidae	<i>Ostracion cubicus</i>	1	0	1	0	0	1
Pinguipedidae	<i>Parapercis clathrata</i>	25	15	17	0	0	1
Pinguipedidae	<i>Parapercis sp1</i>	0	0	0	7	3	8
Pinguipedidae	<i>Parapercis xanthozona</i>	0	0	0	4	0	3
Pomacanthidae	<i>Apolemichthys trimaculatus</i>	29	3	5	13	10	9

Pomacanthidae	<i>Centropyge bicolor</i>	19	9	2	14	6	2
Pomacanthidae	<i>Centropyge</i> sp1	0	1	0	0	0	0
Pomacanthidae	<i>Centropyge tibicen</i>	5	4	1	2	2	2
Pomacanthidae	<i>Centropyge vroliki</i>	13	1	2	6	4	1
Pomacanthidae	<i>Genicanthus lamarck</i>	0	12	1	0	4	0
Pomacanthidae	<i>Pomacanthus imperator</i>	18	9	12	23	8	16
Pomacanthidae	<i>Pomacanthus semicirculatus</i>	0	0	0	0	1	0
Pomacanthidae	<i>Pomacanthus sexstriatus</i>	1	2	0	0	0	0
Pomacanthidae	<i>Pomacanthus</i> sp1	0	0	0	0	2	0
Pomacanthidae	<i>Pygoplites diacanthus</i>	0	5	0	0	0	1
Pomacentridae	<i>Acanthochromis polyacanthus</i>	1	1	0	0	0	0
Pomacentridae	<i>Amphiprion clarkii</i>	0	0	1	0	0	0
Pomacentridae	<i>Amphiprion percula</i>	0	0	0	3	0	0
Pomacentridae	<i>Chromis cinerascens</i>	7	0	0	0	0	0
Pomacentridae	<i>Chromis fumea</i>	0	0	0	11	0	0
Pomacentridae	<i>Chromis margaritifer</i>	0	7	3	3	8	4
Pomacentridae	<i>Chromis</i> sp1	1	0	0	0	0	0
Pomacentridae	<i>Chromis weberi</i>	53	29	21	48	80	21
Pomacentridae	<i>Chromis xanthura</i>	0	6	0	0	0	0
Pomacentridae	<i>Dascyllus aruanus</i>	2	0	0	0	0	0
Pomacentridae	<i>Dascyllus reticulatus</i>	15	0	0	37	1	5
Pomacentridae	<i>Dascyllus trimaculatus</i>	18	2	21	4	0	1
Pomacentridae	<i>Neoglyphidodon melas</i>	0	2	0	0	0	0
Pomacentridae	<i>Plectroglyphidodon dickii</i>	0	0	0	3	0	0
Pomacentridae	<i>Pomacentrus coelestis</i>	574	78	157	169	27	193
Pomacentridae	<i>Pomacentrus nagasakiensis</i>	1	0	0	0	0	0
Pomacentridae	<i>Pomacentrus nigromanus</i>	0	7	0	0	0	0
Pomacentridae	<i>Pomacentrus reidi</i>	0	1	0	0	0	0
Pomacentridae	<i>Pomacentrus</i> sp1	1	0	0	0	0	0
Pomacentridae	<i>Pomacentrus vaiuli</i>	4	1	2	0	0	0
Rachycentridae	<i>Rachycentron canadum</i>	0	0	0	0	0	2
Rhynchobatidae	<i>Rhina ancylostoma</i>	0	0	0	0	0	1
Salangidae	<i>Neosalanx brevirostris</i>	2	0	0	0	0	0
Scaridae	<i>Cetoscarus bicolor</i>	0	1	0	0	0	0
Scaridae	<i>Chlorurus bleekeri</i>	36	8	4	8	17	2
Scaridae	<i>Chlorurus microrhinos</i>	1	0	0	1	0	0
Scaridae	<i>Chlorurus sordidus</i>	23	0	3	8	4	4
Scaridae	<i>Hipposcarus longiceps</i>	2	3	0	0	1	0
Scaridae	<i>Scarus forsteni</i>	10	6	3	2	2	0

Scaridae	<i>Scarus ghobban</i>	1	2	3	1	0	1
Scaridae	<i>Scarus oviceps</i>	8	3	0	5	2	5
Scaridae	<i>Scarus rivulatus</i>	1	0	0	1	1	0
Scaridae	<i>Scarus rubroviolaceus</i>	12	3	6	3	0	9
Scaridae	<i>Scarus schlegeli</i>	0	2	0	2	2	0
Scaridae	<i>Scarus</i> sp1	1	0	0	0	0	9
Scaridae	<i>Scarus</i> sp2	0	1	0	0	0	0
Scombridae	<i>Gymnosarda unicolor</i>	0	0	3	2	12	6
Scombridae	<i>Scomberomorus commerson</i>	0	0	0	1	3	1
Scombridae	<i>Scomberomorus</i> spp	3	2	6	0	0	0
	<i>Neocentropogon</i>						
Scorpaenidae	<i>trimaculatus</i>	0	4	0	0	0	0
Serranidae	<i>Aethaloperca rogaa</i>	18	4	4	13	5	2
Serranidae	<i>Cephalopholis boenak</i>	0	0	0	1	0	0
Serranidae	<i>Cephalopholis miniata</i>	2	5	0	0	0	1
Serranidae	<i>Cephalopholis sonnerati</i>	4	3	4	0	0	2
Serranidae	<i>Cephalopholis urodeta</i>	15	10	4	15	4	4
Serranidae	<i>Epinephelus fasciatus</i>	0	3	0	2	0	2
Serranidae	<i>Epinephelus fuscoguttatus</i>	1	0	0	0	0	0
Serranidae	<i>Epinephelus polyphemadion</i>	0	0	2	0	0	0
Serranidae	<i>Plectropomus laevis</i>	1	0	0	1	0	0
Serranidae	<i>Plectropomus leopardus</i>	0	0	0	0	2	5
Serranidae	<i>Plectropomus</i> sp1	0	0	1	0	0	0
Serranidae	<i>Pseudanthias hypselosoma</i>	0	0	3	0	0	0
Serranidae	<i>Pseudanthias pleurotaenia</i>	0	0	1	0	0	0
Serranidae	<i>Pseudanthias</i> sp1	0	0	1	0	0	0
Serranidae	<i>Pseudanthias</i> sp2	0	0	4	0	0	0
Serranidae	<i>Variola albimarginata</i>	3	2	0	25	4	8
Serranidae	<i>Variola louti</i>	14	8	12	8	6	6
Siganidae	<i>Siganus argenteus</i>	29	27	3	27	17	35
Siganidae	<i>Siganus fuscescens</i>	0	0	0	1	1	0
Siganidae	<i>Siganus punctatissimus</i>	0	1	0	0	0	0
Siganidae	<i>Siganus punctatus</i>	4	1	0	3	1	1
Soleidae	<i>Heteromycteris hartzfeldi</i>	0	0	0	3	0	0
Sphyrnidae	<i>Sphyrna barracuda</i>	1	0	1	0	0	1
Sphyrnidae	<i>Sphyrna jello</i>	0	1	0	0	0	0
Sphyrnidae	<i>Sphyrna mokarran</i>	0	4	2	1	2	3
Tetraodontidae	<i>Arothron caeruleopunctatus</i>	1	0	0	0	0	0
Tetraodontidae	<i>Arothron hispidus</i>	1	0	0	1	0	2
Tetraodontidae	<i>Arothron mappa</i>	0	1	0	0	0	0

Tetraodontidae	<i>Arothron meleagris</i>	0	0	0	1	0	0
Tetraodontidae	<i>Arothron nigropunctatus</i>	1	0	0	0	0	0
Tetraodontidae	<i>Arothron</i> sp1	0	0	1	1	0	0
Tetraodontidae	<i>Diodon hystrix</i>	0	0	0	0	0	1
Zanclidae	<i>Zanclus cornutus</i>	17	11	17	14	17	8

Appendix 3.2. Correlations between species and axes for principal component ordinations (PCO). Numbers in parentheses indicate percentage of total variation in the PCO explained by that axis.

All Deployments (Figure 3.7a)			By Shoal (Figure 3.7b)		
Species	PCO1 (23.4%)	PCO2 (7.5%)	Species	PCO1 (47.9%)	PCO2 (27.4%)
<i>Acanthochromis polyacanthus</i>	-0.14	-0.09	<i>Acanthurus grammoptilus</i>	0.27	0.31
<i>Acanthurus dussumieri</i>	0.00	0.05	<i>Acanthurus leucocheilus</i>	-0.77	-0.16
<i>Acanthurus grammoptilus</i>	-0.03	0.16	<i>Acanthurus nigricans</i>	-0.77	-0.16
<i>Acanthurus leucocheilus</i>	-0.53	-0.04	<i>Acanthurus olivaceus</i>	-0.92	-0.22
<i>Acanthurus mata</i>	-0.06	0.12	<i>Acanthurus pyroferus</i>	-0.77	-0.16
<i>Acanthurus nigricans</i>	-0.27	0.02	<i>Amphiprion percula</i>	-0.77	-0.16
<i>Acanthurus nigricauda</i>	-0.11	-0.03	<i>Apolemichthys trimaculatus</i>	-0.81	-0.38
<i>Acanthurus nigrofuscus</i>	-0.18	-0.27	<i>Aprion virescens</i>	-0.83	0.41
<i>Acanthurus olivaceus</i>	-0.52	-0.16	<i>Balistoides conspicillum</i>	-0.77	-0.16
<i>Acanthurus pyroferus</i>	-0.40	-0.18	<i>Balistoides viridescens</i>	-0.67	-0.43
<i>Acanthurus thompsoni</i>	-0.09	0.11	<i>Caesio cuning</i>	0.33	-0.59
<i>Acanthurus xanthopterus</i>	-0.01	0.11	<i>Carangoides gymnostethus</i>	0.57	0.18
<i>Aethaloperca rogaa</i>	-0.52	-0.09	<i>Carangoides orthogrammus</i>	0.49	0.19
<i>Aipysurus laevis</i>	-0.26	-0.25	<i>Caranx melampygus</i>	-0.55	0.64
<i>Alepes vari</i>	-0.08	0.21	<i>Carcharhinus amblyrhynchos</i>	-0.74	-0.44
<i>Aluterus monoceros</i>	0.01	0.00	<i>Cephalopholis urodeta</i>	-0.88	0.27
<i>Aluterus scriptus</i>	0.11	0.13	<i>Chaetodon kleinii</i>	-0.83	0.41
<i>Amblyeleotris sp1</i>	0.10	-0.15	<i>Chaetodon lunula</i>	-0.77	-0.16
<i>Amblyeleotris sp2</i>	-0.09	-0.13	<i>Chaetodon meyeri</i>	-0.77	-0.16
<i>Amphiprion clarkii</i>	-0.02	-0.05	<i>Chaetodon ornatissimus</i>	-0.77	-0.16
<i>Amphiprion percula</i>	-0.09	0.00	<i>Chaetodon trifascialis</i>	-0.77	-0.16
<i>Anampses lennardi</i>	-0.13	0.16	<i>Chaetodon ulietensis</i>	-0.77	-0.16
<i>Anampses melanurus</i>	-0.08	-0.08	<i>Chlorurus sordidus</i>	-0.77	-0.16
<i>Anampses meleagrides</i>	-0.09	-0.04	<i>Chromis weberi</i>	-0.29	0.68
<i>Apogon fragilis</i>	-0.05	-0.14	<i>Cirrhilabrus exquisitus</i>	-0.29	0.68
<i>Apogon sp1</i>	0.00	0.04	<i>Cirrhilabrus sp2</i>	-0.29	0.68
<i>Apogon sp2</i>	-0.05	-0.01	<i>Coradion chrysozonus</i>	-0.12	-0.47
<i>Apolemichthys trimaculatus</i>	-0.51	-0.19	<i>Ctenochaetus striatus</i>	-0.77	-0.16
<i>Aprion virescens</i>	0.04	-0.05	<i>Dasyatis kuhlii</i>	-0.70	-0.49
<i>Arothron caeruleopunctatus</i>	-0.06	0.03	<i>Echeneis naucrates</i>	0.33	-0.16
<i>Arothron hispidus</i>	-0.15	-0.03	<i>Gymnocranius grandoculis</i>	0.42	0.55
<i>Arothron mappa</i>	-0.11	-0.03	<i>Gymnosarda unicolor</i>	0.72	-0.29
<i>Arothron meleagris</i>	-0.09	0.06	<i>Halichoeres hartzfeldii</i>	-0.12	-0.47
<i>Arothron nigropunctatus</i>	-0.08	-0.05	<i>Halichoeres zeylonicus</i>	0.27	0.31

<i>Arothron</i> sp I	0.13	0.00	<i>Hologymnosus doliatus</i>	-0.97	-0.05
<i>Aspidontus taeniatus</i>	-0.04	0.04	<i>Labroides dimidiatus</i>	-0.74	0.53
<i>Atule mate</i>	0.05	0.12	<i>Lethrinus amboinensis</i>	0.36	0.63
<i>Aulostomus chinensis</i>	-0.04	0.04	<i>Lethrinus atkinsoni</i>	0.30	-0.49
<i>Balistapus undulatus</i>	-0.49	-0.16	<i>Lethrinus nebulosus</i>	0.58	0.23
<i>Balistoides conspicillum</i>	-0.39	0.05	<i>Lethrinus olivaceus</i>	-0.13	-0.47
<i>Balistoides viridescens</i>	-0.39	0.08	<i>Lethrinus rubrioperculatus</i>	0.28	0.24
<i>Bodianus axillaris</i>	-0.11	-0.09	<i>Lutjanus bohar</i>	0.09	-0.63
<i>Bodianus diana</i>	-0.20	-0.08	<i>Lutjanus rivulatus</i>	-0.70	-0.49
<i>Caesio cuning</i>	0.05	0.03	<i>Malacanthus latovittatus</i>	-0.29	0.68
<i>Caesio lunaris</i>	-0.04	0.11	<i>Naso brachycentron</i>	-0.77	-0.16
<i>Caesio teres</i>	-0.15	0.00	<i>Naso brevirostris</i>	0.33	-0.59
<i>Cantherhines dumerilii</i>	-0.17	0.11	<i>Naso hexacanthus</i>	0.04	-0.64
<i>Canthidermis maculatus</i>	0.02	0.04	<i>Naso lituratus</i>	-0.77	-0.16
<i>Carangoides caeruleopinnatus</i>	0.25	-0.01	<i>Naso vlamingii</i>	-0.12	-0.47
<i>Carangoides ferdau</i>	0.45	-0.07	<i>Oxycheilinus digrammus</i>	-0.29	0.68
<i>Carangoides fulvoguttatus</i>	0.22	-0.01	<i>Parupeneus multifasciatus</i>	-0.65	0.58
<i>Carangoides gymnostethus</i>	0.50	0.12	<i>Platax teira</i>	-0.29	0.68
<i>Carangoides oblongus</i>	0.04	0.14	<i>Pomacanthus imperator</i>	-0.83	0.41
<i>Carangoides orthogrammus</i>	0.49	0.15	<i>Pomacentrus coelestis</i>	-0.59	0.62
<i>Carangoides plagiotaenia</i>	0.21	0.14	<i>Pseudobalistes fuscus</i>	0.38	-0.55
<i>Caranx ignobilis</i>	-0.25	-0.07	<i>Sargocentron</i>		
<i>Caranx lugubris</i>	-0.05	0.15	<i>caudimaculatum</i>	-0.77	-0.16
<i>Caranx melampygus</i>	-0.31	0.31	<i>Scarus forsteni</i>	-0.77	-0.16
<i>Caranx sexfasciatus</i>	-0.11	0.20	<i>Scolopsis xenochrous</i>	0.27	0.31
<i>Carcharhinus albimarginatus</i>	0.24	-0.04	<i>Siganus argenteus</i>	-0.77	-0.16
<i>Carcharhinus amblyrhynchos</i>	-0.38	0.27	<i>Sphyrna mokarran</i>	0.11	-0.12
<i>Centropyge bicolor</i>	-0.42	-0.19	<i>Sufflamen chrysopterum</i>	-0.29	0.68
<i>Centropyge</i> sp I	0.02	-0.17	<i>Taeniura lymma</i>	-0.34	-0.59
<i>Centropyge tibicen</i>	-0.27	-0.06	<i>Thalassoma amblycephalum</i>	-0.29	0.68
<i>Centropyge vroliki</i>	-0.34	-0.21	<i>Thalassoma lunare</i>	-0.29	0.68
<i>Cephalopholis boenak</i>	-0.07	-0.01	<i>Triaenodon obesus</i>	0.07	-0.49
<i>Cephalopholis miniata</i>	-0.17	-0.01	<i>Variola albimarginata</i>	-0.70	-0.49
<i>Cephalopholis sonnerati</i>	-0.17	0.03	<i>Variola louti</i>	-0.83	0.41
<i>Cephalopholis urodeta</i>	-0.53	-0.21	<i>Zebрасoma scopas</i>	-0.77	-0.16
<i>Cetoscarus bicolor</i>	-0.09	-0.01			
<i>Chaetodon adiergastos</i>	-0.13	-0.04			
<i>Chaetodon auriga</i>	-0.20	-0.07			
<i>Chaetodon baronessa</i>	-0.14	0.06			

<i>Chaetodon ephippium</i>	-0.17	-0.16
<i>Chaetodon kleinii</i>	-0.59	-0.20
<i>Chaetodon lineolatus</i>	-0.17	0.07
<i>Chaetodon lunula</i>	-0.30	-0.04
<i>Chaetodon lunulatus</i>	-0.11	0.02
<i>Chaetodon melannotus</i>	-0.14	0.04
<i>Chaetodon meyeri</i>	-0.16	0.00
<i>Chaetodon ornatissimus</i>	-0.27	-0.14
<i>Chaetodon oxycephalus</i>	-0.11	0.02
<i>Chaetodon punctatofasciatus</i>	-0.14	-0.02
<i>Chaetodon speculum</i>	-0.14	-0.11
<i>Chaetodon trifascialis</i>	-0.18	-0.08
<i>Chaetodon ulietensis</i>	-0.13	0.09
<i>Chaetodon vagabundus</i>	-0.15	0.00
<i>Cheilinus trilobatus</i>	-0.19	0.01
<i>Cheilinus undulatus</i>	-0.10	0.07
<i>Cheilio inermis</i>	-0.11	-0.09
<i>Chlorurus bleekeri</i>	-0.33	-0.13
<i>Chlorurus microrhinos</i>	-0.09	0.02
<i>Chlorurus sordidus</i>	-0.31	-0.20
<i>Choerodon jordani</i>	-0.20	-0.03
<i>Chromis cinerascens</i>	-0.08	-0.08
<i>Chromis fumea</i>	-0.05	0.05
<i>Chromis margaritifer</i>	-0.29	0.09
<i>Chromis sp1</i>	-0.06	0.07
<i>Chromis weberi</i>	-0.36	-0.01
<i>Chromis xanthura</i>	-0.14	-0.03
<i>Cirrhilabrus exquiritus</i>	-0.25	-0.17
<i>Cirrhilabrus sp1</i>	0.20	0.30
<i>Cirrhilabrus sp2</i>	0.00	0.00
<i>Cirrhilabrus temminckii</i>	-0.06	-0.15
<i>Cirrhitichthys aprinus</i>	-0.05	-0.01
<i>Cirrhitichthys falco</i>	-0.05	-0.01
<i>Coradion chrysozonus</i>	-0.01	0.15
<i>Coris aygula</i>	-0.10	0.08
<i>Coris caudimacula</i>	0.08	-0.01
<i>Coris dorsomacula</i>	-0.07	-0.07
<i>Coris gaimard</i>	-0.26	-0.02
<i>Ctenochaetus binotatus</i>	-0.25	-0.25

<i>Ctenochaetus striatus</i>	-0.34	-0.03
<i>Dascyllus aruanus</i>	-0.03	-0.15
<i>Dascyllus reticulatus</i>	-0.22	-0.04
<i>Dascyllus trimaculatus</i>	-0.13	-0.03
<i>Dasyatis kuhlii</i>	0.01	0.10
<i>Diodon hystrix</i>	-0.04	0.14
<i>Echeneis naucrates</i>	-0.12	0.24
<i>Ecsenius lividanalais</i>	-0.09	-0.06
<i>Elagatis bipinnulata</i>	0.20	0.21
<i>Epinephelus fasciatus</i>	-0.13	0.05
<i>Epinephelus fuscoguttatus</i>	-0.08	-0.08
<i>Epinephelus polyphkadion</i>	-0.05	-0.01
<i>Fistularia commersonii</i>	-0.18	0.14
<i>Forcipiger flavissimus</i>	-0.25	-0.13
<i>Galeocerdo cuvier</i>	-0.14	0.04
<i>Genicanthus lamarck</i>	-0.17	0.02
<i>Gomphosus varius</i>	-0.15	-0.09
<i>Gunnellichthys monostigma</i>	0.07	-0.03
<i>Gunnellichthys pleurotaenia</i>	0.09	-0.04
<i>Gymnocranius grandoculis</i>	0.48	0.01
<i>Gymnocranius sp1</i>	0.15	-0.07
<i>Gymnocranius sp2</i>	0.10	0.00
<i>Gymnosarda unicolor</i>	0.13	0.30
<i>Gymnothorax flavimarginatus</i>	-0.06	0.00
<i>Gymnothorax sp1</i>	0.11	-0.01
<i>Gymnothorax undulatus</i>	-0.04	-0.01
<i>Halichoeres chrysus</i>	-0.10	-0.05
<i>Halichoeres hartzfeldii</i>	0.06	0.06
<i>Halichoeres hortulanus</i>	-0.37	-0.14
<i>Halichoeres nebulosus</i>	-0.18	-0.21
<i>Halichoeres prosopion</i>	-0.07	-0.10
<i>Halichoeres scapularis</i>	-0.10	-0.11
<i>Halichoeres sp2</i>	0.06	-0.01
<i>Halichoeres sp3</i>	-0.10	-0.03
<i>Halichoeres zeylonicus</i>	0.05	-0.40
<i>Hemigymnus fasciatus</i>	-0.11	-0.01
<i>Hemitaenichthys polylepis</i>	-0.12	-0.02
<i>Heniochus acuminatus</i>	-0.03	0.13
<i>Heniochus diphreutes</i>	-0.07	-0.03

<i>Heniochus monoceros</i>	-0.05	0.15
<i>Heniochus singularius</i>	-0.34	0.04
<i>Heteromycteris hartzfeldi</i>	-0.06	0.01
<i>Himantura fai</i>	0.13	0.04
<i>Hipposcarus longiceps</i>	-0.26	-0.05
<i>Hologymnosus annulatus</i>	-0.28	-0.21
<i>Hologymnosus doliatus</i>	-0.37	-0.26
<i>Hologymnosus rhodonotus</i>	0.08	-0.13
<i>Hoplolatilus cuniculus</i>	0.12	-0.11
<i>Hoplolatilus sp I</i>	0.08	0.04
<i>Iniistius aneitensis</i>	0.23	-0.02
<i>Kyphosus vaigiensis</i>	-0.10	0.08
<i>Labracinus lineatus</i>	0.09	0.00
<i>Labroides bicolor</i>	-0.09	-0.01
<i>Labroides dimidiatus</i>	-0.56	-0.09
<i>Lactoria cornuta</i>	0.14	-0.02
<i>Leptojulius cyanopleura</i>	-0.11	-0.09
<i>Lethrinus amboinensis</i>	0.48	-0.04
<i>Lethrinus atkinsoni</i>	-0.32	0.48
<i>Lethrinus erythracanthus</i>	-0.23	-0.05
<i>Lethrinus microdon</i>	-0.13	-0.12
<i>Lethrinus nebulosus</i>	0.22	0.13
<i>Lethrinus olivaceus</i>	-0.21	0.23
<i>Lethrinus ravus</i>	0.02	0.14
<i>Lethrinus rubrioperculatus</i>	0.46	-0.11
<i>Lethrinus sp I</i>	0.12	-0.15
<i>Lethrinus xanthochilus</i>	-0.15	-0.01
<i>Lutjanus bohar</i>	-0.41	0.34
<i>Lutjanus fulviflamma</i>	-0.16	0.03
<i>Lutjanus gibbus</i>	-0.08	0.17
<i>Lutjanus kasmira</i>	-0.11	-0.08
<i>Lutjanus lemniscatus</i>	-0.10	0.09
<i>Lutjanus rivulatus</i>	-0.18	0.15
<i>Macolor macularis</i>	-0.24	0.04
<i>Macolor niger</i>	-0.12	0.14
<i>Macropharyngodon negrosensis</i>	-0.08	-0.19
<i>Malacanthus brevirostris</i>	0.00	-0.15
<i>Malacanthus latovittatus</i>	-0.32	-0.28
<i>Manta birostris</i>	-0.11	-0.03

<i>Melichthys vidua</i>	-0.22	-0.01
<i>Monotaxis grandoculis</i>	-0.18	-0.04
<i>Naso annulatus</i>	0.01	-0.01
<i>Naso brachycentron</i>	-0.28	-0.04
<i>Naso brevirostris</i>	-0.19	0.22
<i>Naso caesi</i>	-0.11	0.01
<i>Naso fageni</i>	-0.10	-0.04
<i>Naso hexacanthus</i>	-0.15	0.31
<i>Naso lituratus</i>	-0.49	-0.13
<i>Naso lopezi</i>	-0.09	0.08
<i>Naso mcdadei</i>	-0.01	0.05
<i>Naso minor</i>	-0.16	0.10
<i>Naso thynnoides</i>	0.08	0.02
<i>Naso tonganus</i>	-0.13	0.07
<i>Naso unicornis</i>	-0.08	-0.08
<i>Naso vlamingii</i>	-0.32	0.31
<i>Nebrius ferrugineus</i>	-0.09	0.05
<i>Negaprion acutidens</i>	-0.13	0.05
<i>Nemateleotris magnifica</i>	-0.09	-0.04
<i>Neocentropogon trimaculatus</i>	-0.11	-0.01
<i>Neoglyphidodon melas</i>	-0.09	-0.01
<i>Neosalanx brevirostris</i>	-0.08	-0.18
<i>Novaculichthys taeniourus</i>	-0.13	-0.06
<i>Odonus niger</i>	-0.29	0.18
<i>Ostracion cubicus</i>	-0.13	-0.08
<i>Oxycheilinus digrammus</i>	-0.28	-0.12
<i>Oxycheilinus orientalis</i>	-0.10	-0.03
<i>Oxycheilinus sp1</i>	0.09	-0.01
<i>Oxycheilinus unifasciatus</i>	-0.25	-0.14
<i>Paracaesio xanthura</i>	-0.15	-0.03
<i>Paracanthurus hepatus</i>	-0.12	-0.05
<i>Paracheilinus flavianalis</i>	0.05	-0.03
<i>Paracirrhites forsteri</i>	-0.20	-0.09
<i>Parapercis clathrata</i>	-0.26	-0.48
<i>Parapercis sp1</i>	-0.27	0.26
<i>Parapercis xanthozona</i>	-0.14	0.13
<i>Parupeneus barberinoides</i>	-0.01	0.04
<i>Parupeneus barberinus</i>	0.10	-0.10
<i>Parupeneus cyclostomus</i>	0.00	0.08

<i>Parupeneus multifasciatus</i>	-0.58	-0.42
<i>Parupeneus pleurostigma</i>	-0.40	-0.17
<i>Plagiotremus rhinorhynchus</i>	-0.05	-0.14
<i>Plagiotremus tapeinosoma</i>	-0.10	0.08
<i>Platax batavianus</i>	-0.09	0.14
<i>Platax teira</i>	-0.20	0.09
<i>Plectorhinchus picus</i>	-0.05	0.00
<i>Plectorhinchus vittatus</i>	-0.13	-0.08
<i>Plectroglyphidodon dickii</i>	-0.18	-0.03
<i>Plectropomus laevis</i>	-0.13	-0.06
<i>Plectropomus leopardus</i>	-0.16	0.22
<i>Plectropomus sp I</i>	-0.06	-0.06
<i>Pomacanthus imperator</i>	-0.67	0.04
<i>Pomacanthus semicirculatus</i>	0.08	0.04
<i>Pomacanthus sexstriatus</i>	-0.16	0.00
<i>Pomacanthus sp I</i>	0.06	-0.01
<i>Pomacentrus coelestis</i>	-0.48	-0.30
<i>Pomacentrus nagasakiensis</i>	-0.12	-0.08
<i>Pomacentrus nigromanus</i>	-0.11	-0.01
<i>Pomacentrus reidi</i>	-0.09	-0.01
<i>Pomacentrus sp I</i>	-0.07	-0.07
<i>Pomacentrus vaiuli</i>	-0.21	-0.14
<i>Pseudanthias hypselosoma</i>	-0.05	-0.01
<i>Pseudanthias pleurotaenia</i>	-0.05	-0.01
<i>Pseudanthias sp I</i>	-0.05	-0.01
<i>Pseudanthias sp2</i>	-0.05	-0.01
<i>Pseudobalistes flavimarginatus</i>	-0.04	-0.10
<i>Pseudobalistes fuscus</i>	-0.09	0.06
<i>Pseudocheilinus evanidus</i>	-0.16	-0.26
<i>Pseudodax moluccanus</i>	-0.30	-0.18
<i>Pseudojuloides severnsi</i>	0.04	0.13
<i>Pteragogus enneacanthus</i>	-0.06	-0.13
<i>Ptereleotris evides</i>	-0.15	0.04
<i>Ptereleotris heteroptera</i>	-0.04	-0.19
<i>Ptereleotris microlepis</i>	0.08	-0.08
<i>Ptereleotris sp I</i>	0.11	0.06
<i>Pterocaesio digramma</i>	-0.15	0.15
<i>Pterocaesio marri</i>	-0.02	0.08
<i>Pterocaesio sp I</i>	-0.02	0.06

<i>Pterocaesio tile</i>	-0.14	0.01
<i>Pygoplites diacanthus</i>	-0.22	0.02
<i>Rachycentron canadum</i>	0.08	0.18
<i>Rhina ancylostoma</i>	0.06	0.12
<i>Rhinecanthus rectangulus</i>	-0.03	0.03
<i>Sargocentron caudimaculatum</i>	-0.14	0.01
<i>Scarus forsteni</i>	-0.36	-0.18
<i>Scarus ghobban</i>	-0.04	0.12
<i>Scarus oviceps</i>	-0.46	-0.09
<i>Scarus rivulatus</i>	-0.08	0.03
<i>Scarus rubroviolaceus</i>	-0.24	-0.05
<i>Scarus schlegeli</i>	-0.09	0.12
<i>Scarus sp1</i>	-0.12	0.06
<i>Scarus sp2</i>	0.05	0.07
<i>Scolopsis bilineata</i>	-0.14	0.04
<i>Scolopsis xenochrous</i>	-0.36	-0.34
<i>Scomberoides lysan</i>	-0.16	-0.03
<i>Scomberoides tol</i>	-0.11	0.06
<i>Scomberomorus commerson</i>	0.02	0.13
<i>Scomberomorus spp</i>	-0.13	0.02
<i>Seriola dumerili</i>	-0.10	0.00
<i>Seriola rivoliana</i>	0.24	-0.12
<i>Siganus argenteus</i>	0.18	0.04
<i>Siganus fuscescens</i>	0.06	0.07
<i>Siganus punctatissimus</i>	-0.09	-0.01
<i>Siganus punctatus</i>	-0.24	0.00
<i>Sphyrna barracuda</i>	-0.05	-0.06
<i>Sphyrna jello</i>	-0.05	0.15
<i>Sphyrna mokarran</i>	0.28	0.09
<i>Sufflamen bursa</i>	-0.19	-0.06
<i>Sufflamen chrysopterum</i>	-0.52	-0.34
<i>Sufflamen fraenatum</i>	0.12	0.13
<i>Symphorus nematophorus</i>	0.09	0.02
<i>Taeniura lymma</i>	-0.34	-0.01
<i>Taeniura meyeni</i>	0.06	0.09
<i>Thalassoma amblycephalum</i>	-0.23	-0.29
<i>Thalassoma janseni</i>	-0.25	-0.23
<i>Thalassoma lunare</i>	-0.30	-0.21
<i>Thalassoma lutescens</i>	-0.15	-0.09

<i>Triaenodon obesus</i>	-0.55	0.29	
<i>Variola albimarginata</i>	-0.36	0.15	
<i>Variola louti</i>	-0.51	-0.03	
<i>Zanclus cornutus</i>	-0.43	-0.01	
<i>Zebrasoma scopas</i>	-0.09	0.00	