Environmental Study S5

Monitoring Program for the Montara Well Release Timor Sea: Final Report on the Nature of Barracouta and Vulcan Shoals

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Cover Photo: Barracouta Shoals – small coral isolate with associated biodiversity 25m depth.

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Executive Summary

At the request of PTTEP Australasia (Ashmore Cartier) Pty. Ltd. (the company), a pilot survey of benthic environments at two submerged shoals, Barracouta and Vulcan, located 55 km and 27 km west and south-west respectively of the Montara Well Head Platform, was conducted by Australian Institute of Marine Science (AIMS) in April, 2010. The objective of this preliminary work was to assist the company and the Commonwealth Government (through the responsible agency, the Department for Sustainability, Environment, Water, Population and Communities – DSEWPaC) to understand the possible scale of impact which might have occurred as a result of the uncontrolled release from the Montara well head, and to understand the variability of community composition within the shoals and between these two adjacent shoals. This would provide the company with information that could be used to design a more detailed and spatially comprehensive study to detect possible impacts in the event that the Banks and Shoals component (S5) of the Montara Monitoring Plan developed by the company and DSEWPaC was formally triggered.

This survey had a high discovery component, since the habitats on these two shoals had not been investigated before.

In summary, extensive survey sampling across the plateau areas of Barracouta and Vulcan shoals in April 2010 - conducted 4 months after uncontrolled flow from the Montara H1 well had been stopped, revealed that: (a) both contained diverse biological communities (b) there were pronounced differences within and especially between the two shoals in the relative abundance of dominant groups and (c) there were no obvious signs of a major, recent disturbance. This study, however, was not designed to detect any smaller or more localized impacts, nor could it determine if any other shoals in the region have been impacted from the oil release at the Montara platform.

The cause of the pronounced variability observed between Barracouta and Vulcan Shoals is unknown, but could be related to disturbance events such as hurricanes, bathymetry, or to the biology of the dominant organisms (i.e. founder events, clonal reproduction, larval dispersal etc). While the variability precludes extrapolation of the benthic condition recorded for the two shoals to others in the region, sampling strategies are suggested (based on the present study) to accommodate this variability and to be able to better characterise the other banks and shoals in the Timor Sea.

A series of video transects and still images was captured across the plateau areas of each shoal, allowing the nature of the biological communities to be characterized. This report documents the field sampling achieved and the general nature of the seabed habitats, together with results from broadscale and finer scale analysis of the seabed image data.

The shoals rise steeply from 100-200 m depths on the outer continental shelf and begin to flatten out into a plateau at around 40-50 m depth. The plateau areas of each shoal cover several square kilometers at 20-30m depths. Both shoal plateau areas are similar in size, in the range of 10-15 km^2, with Vulcan slightly larger than Barracouta Shoal. Occasional higher ground rises to within approximately 10 m of the sea surface. The available bathymetry, in the form of Australian

mariners' charts, proved to be indicative only, so the location and depth of the shoals were based on soundings acquired during the cruise.

On the shoal plateaus, there is adequate light to support many photosynthetic organisms. Consequently, the upper shoal areas have the potential to support benthic primary producer habitat (BPPH). Extensive video survey sampling across the general plateau areas, in depths of 15-50 m, and subsequent analysis of biota from fine scale seabed images found this to be the case, with the major habitat types recorded being dominated by varying amounts of photosynthetic organisms, typically algae, hard coral or seagrass.

Although direct sampling and traditional taxonomic characterization of the biota was not undertaken, the analysis of video and still images indicate that these shoals support highly diverse ecosystems. They provide a variety of carbonate substrates, along with fine scale topographic complexity and support communities typically seen on many coral reefs.

Spatial variability was noted at all scales; within transect, within shoal and between shoals. On both shoals extensive rubble and rock fields were common and tended to support plants and smaller invertebrates. These rubble fields were interspersed with lesser areas of consolidated, low relief reef, patches of coarse sand and isolated coral outcrops. Both shoals supported reef building corals, seagrass and algae, particularly the calcareous green algae *Halimeda* spp. However, there were also significant differences between Barracouta and Vulcan in both the presence and absence of some important organisms and their relative abundance. Barracouta Shoal supported abundant algae, especially *Halimeda*, and very little seagrass. A very extensive and likely monoclonal field of soft coral, preliminarily identified as *Nephthea* sp. covered a significant proportion of the western margin of the shoal. In contrast, Vulcan Shoal was particularly notable for an extensive and lush field of the seagrass *Thallasodendron ciliatum* that was not seen on Barracouta.

A number of potential shoal-type habitats have been identified, solely on available bathymetry, within 100 km of the Montara platform site. The results reported here provide some guidance for future sampling, if it is decided to conduct a detailed assessment of possible impact from the Montara well release.

Our analysis of statistical power indicates that for shoals of similar size and bathymetry to Barracouta and Vulcan, an initial survey program of 30-40 transects at each shoal should deliver well characterized habitats and the ability to make comparisons on the abundance and distribution of dominant biota within and between the shoals. Nonetheless, it should be noted that if a monitoring program is considered, there is a large variation, depending on location and habitat type, in the power of this type of sampling to detect changes through time. In this study, the power analyses show that in order to detect changes in abundance of 20% for dominant biota in space or time, 3-9 transects in selected major habitat types would suffice, but in some locations power is much lower. If a particular location was thought to need monitoring then, if it was highly variable or the organisms of interest were low in abundance, alternative sampling methods with greater spatial precision would be needed. Consequently a monitoring program design would depend on the question and the biota of interest. For example algae, which were more widely and evenly distributed, require less sampling intensity than the more patchily distributed corals or less commonly observed sponges.

Background

The Montara Well Head Platform (MWHP) uncontrolled release (21 August – 3 November 2009) 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' (IMCRA 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 km^2 area is also referred to as the Oceanic Shoals (OSS) meso-scale region within the IMCRA classification (IMCRA 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 (IMCRA 2006) and have a floral and faunal composition similar to the emergent oceanic reef systems. However, due to the remoteness of the meso-region most of the banks and shoals are either unstudied or poorly characterized. The lease operator PTTEP Australasia (Ashmore Cartier) Pty Ltd (PTTEPAA) requested a preliminary assessment of benthos on the tops of Barracouta and Vulcan Shoals, two submerged shoals within 100 km of the MWHP (see Figure 1), that were likely to lie under the area covered by some components of the Montara spill. The purpose of this survey was to provide preliminary data as a pilot study to aid in planning, should a broader assessment of the numerous shoals in the region be required as a result of a formal triggering of component S5 of the Montara Monitoring Plan, (PTTEPAA 2009).

Methods

Location

Barracouta Shoal, 124 2.011 E 12 32.837°S lies approximately 55 km west of the MWHP site and chart AUS314 indicates the shallowest depth is 10.2m. Vulcan Shoal, 124 16.986 E 12 48.217°S, lies approximately 27 km south-west of Montara West Atlas rig site and chart AUS 314 indicates the shallowest depth is 9.5 m (see Fig. 1).

These two shoals are poorly described, with limited available bathymetric data and no biological descriptions. Both shoals are somewhat elliptical in outline, with the long axis running approximately east-west. They have similar dimensions across the plateaux areas, when measured at the nominal 50 m depth contour, with Barracouta 5.0 km long x 2.4 km wide and Vulcan 6.4 km long x 2.6 km wide,. Consequently these shoals provide 12-16 km^2 of substrate at depths which, based on AIMS observations elsewhere in the region, could potentially support light dependent benthic communities.

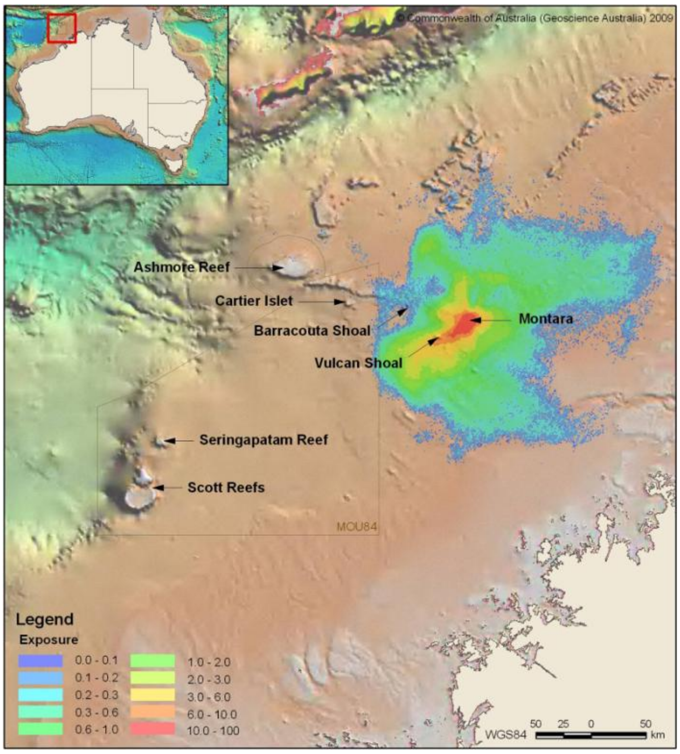

Figure 1. Location of study sites in relation to modeled relative exposure map of the oil spill.Image of the spill developed by Asia-Pacific ASA in another of the independent studies triggered under the monitoring plan developed by the company and DSEWPaC and released by the agency. This is a relative 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 spill 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 modeling.

Field sampling

The tops of Barracouta and Vulcan Shoals were surveyed using towed video and still camera imagery. A minimum of 15 tows was desired for each shoal. 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).

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 (Fig. 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 distance of about 500 m or more has been 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 (Fig. 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. The location of each transect was nominal, in the absence of any guiding habitat information and somewhat poor bathymetry from the available charts (AUS 314 Timor Sea, Sahul Banks navigation chart).

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.

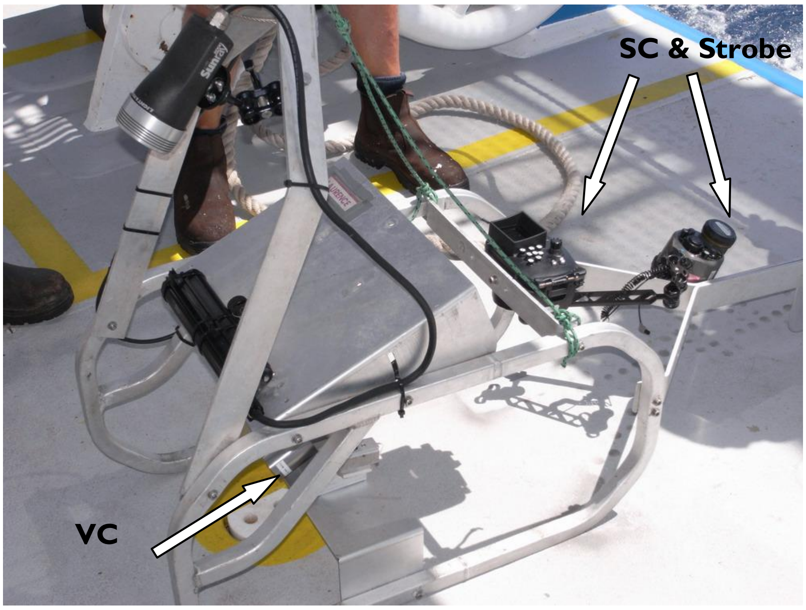

Figure 2. Towed body used for all transect surveys. A forward facing video camera (VC) provides live images to the ship, allowing the towed body to be "flown" just above the seabed while marine scientists classify the habitats. Positioned at the rear of the towed body a high resolution still camera (SC) with strobe takes downward facing, detailed images of the seabed every 5 seconds, for use in later analyses.

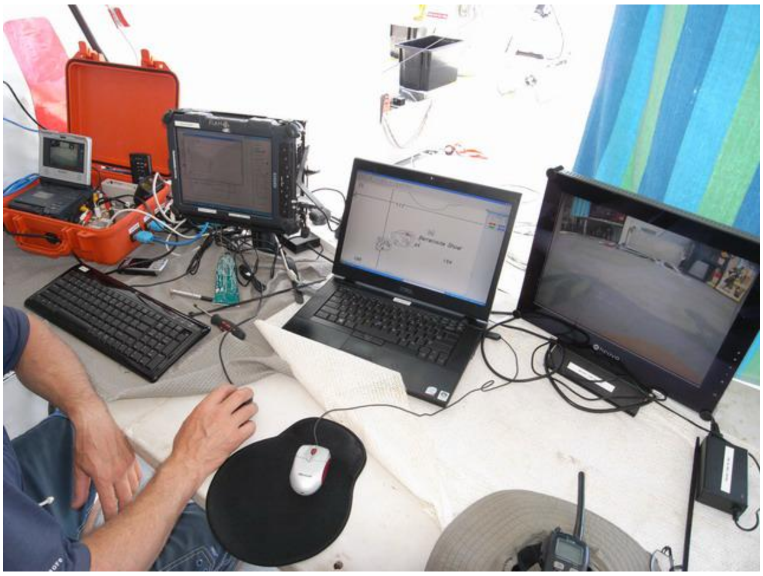

Figure 3. The AIMS towvid system in use on board the research vessel RV Solander during the survey. Live video is classified directly into a computer, with the observer keying in the appropriate classification from a variety of pre-programmed major habitat types, along with the associated data on position and depth. The video and this associated data are also recorded to tape and archived.

Data analysis

The AIMS Towvid program exports the data in a simple text format, as three comma separated values (CSV) files. The first of these is formatted to be imported directly into access for subsequent data management and storage. The second contains the header information, whilst the third is formatted for direct import into ArcGIS and includes a layback calculation to account for the angle and the distance of the towed body behind the boat. All the AIMS towvid observations for each transect were imported into ArcGIS directly for subsequent analysis and visualisation. Each point observation, recorded at 2 second intervals along the transect, was colour coded according to the dominant benthic group recorded by the observer, then displayed accordingly to create a colour coded transect classification. This broadscale classification was overlaid on a background map of the shoal bathymetry derived from the AUS 314 chart (see Figs. 8 and 9). This type of visualisation allows for rapid assessment of any major spatial patterns of the dominant benthos and can be useful in identifying general features, such as large areas of unusual habitat, transition between different types of habitat or general zones where particular benthic groups such as corals, algae or seagrass predominate.

The semi-qualitative nature of the broadscale classification has limitations, particularly as only the most dominant benthic group is recorded. This is particularly constraining in complex mixed habitats, as significant but minor components of the biota are not represented in the real-time classifications, leading to potential bias and loss of detail, and no quantitative information is provided on the mixture of biota that are present. Furthermore, when classifying according to dominant benthic groups the abundance of the major groups is only relative, with somewhat arbitrary divisions between low, medium and high density estimates assigned by the observer in real time. Nonetheless, the rapid acquisition of broad scale data does facilitate initial characterization of habitat patterns and aid in selecting subsets of more detailed imagery from the still camera for finer scale analysis and rapid reporting (see Heyward et al. 2010). A fine scale analysis of the relative abundance of key biota is desirable in order to better understand the complexity of habitats and allow better spatial discrimination within and between the shoals. This type of analysis is best done using high quality still images, which allow reliable characterization of different biota at a high taxonomic resolution. In this study, a spatially standardized subset of the still images from each survey transect has been used to provide a fine scale analysis of the biota.

There were 21 survey transects at Barracouta Shoal and 20 at Vulcan Shoal (Appendix 2). While the preliminary report (Heyward et al. 2010) drew on data from the towed video and more detailed image analysis from a small subset of transects, in this report the analyses have focused on the quantitatively more robust and detailed dataset obtained from a full analysis of still images from all transects. This consists of point intercept data from a spatially standardized set of still photos, approximately 10m apart, collected along all transects for each shoal.

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 the OSS60 meso-scale bioregion (Heyward et al. 1997, Heyward and Rees

1999), a sub sampling interval of 10 m along each selected transect was chosen to minimize the chance of autocorrelation between sequential images. This resulted in groups of 35-42 images per transect being further analyzed. Consequently approximately 800 images were analyzed at each of these shoals.

In each image the relative abundance of key biota, such as corals, algae or seagrass were quantified using point-intercept software CPCe (Version 3.4, Kohler and Gill 2006); and sampling 20 points per image. The classification scheme used is attached as Appendix 1. A stratified random sampling protocol was used (see Fig. 7), with the data for each image being saved to Microsoft Excel. The images and analytical data used for this report, along with associated position and depth information for each image is attached as Appendix 3, (see included DVD)

Cluster analysis and heatmaps

Comparison of similarities in the abundance of major biological groups between shoals and between transects within each shoal was undertaken, using a bootstrapped cluster analysis of the entire still photo transect data, to identify distinct habitats. This is a fairly conservative method but highlights major habitat groups on each shoal. The cluster analysis (complete linkage) was based on Hellinger transformed distance matrix (see Legendre and Gallagher 2001) of the major benthic groups, which is an ecologically meaningful transformation appropriate for community composition data.

The resulting cluster shows groupings between transects at various levels of similarity. To aid interpretation of these patterns, each cluster has also been expressed in association with a heatmap, labeled with correlation statistics (R-sq) for each major benthic group's influence on an individual transect. This provides a visual tool with which to quickly identify transects or groups of transects which group together because of one or more of the major benthic groups. In the heat map matrix, the cells have been coloured coded from dark red, which is low or no correlation, to yellow/white which is highly correlated.

Power analysis

A power analysis was conducted to determine the optimal number of transects required to detect change a 20 % change in major benthic cover with a confidence level of 95%. This was conducted using high resolution still photos for coral, algae, soft coral, sponge, other, seagrass and abiotic substrate (i.e. groups that can occur with point cover estimates greater than 10%). The 20 % threshold with 95% confidence was used as it's commonly adopted as a benchmark for benthic cover change (reviewed in Quinn and Keough 2002).

This analysis was conducted based on consecutive pair runs (Quinn and Keough 2002; Dupont 2008; Zar 1998). The benthic cover data derived from photos taken at 10 meter intervals along each transect. Each analysis was run for n=300 (n equaling number of photos). In this study we analyzed ~35-40 photos per transect, so an "n" of 300 approximates 9 transects of nominal 500 m length.

Assumptions of the analysis were:

1. Both shoal plateaus contain several major and somewhat distinct and discreet habitat types (defined by cluster analysis, the types are different for each shoal)
2. The transect with photos identified are and adequate and representative sample of cover for each substrate group on each shoal.
3. Projection of sample size beyond n=300 assumes the coefficient of the slope remains constant (with no asymptote) until power is equal to 1.
4. Poisson distribution of errors.

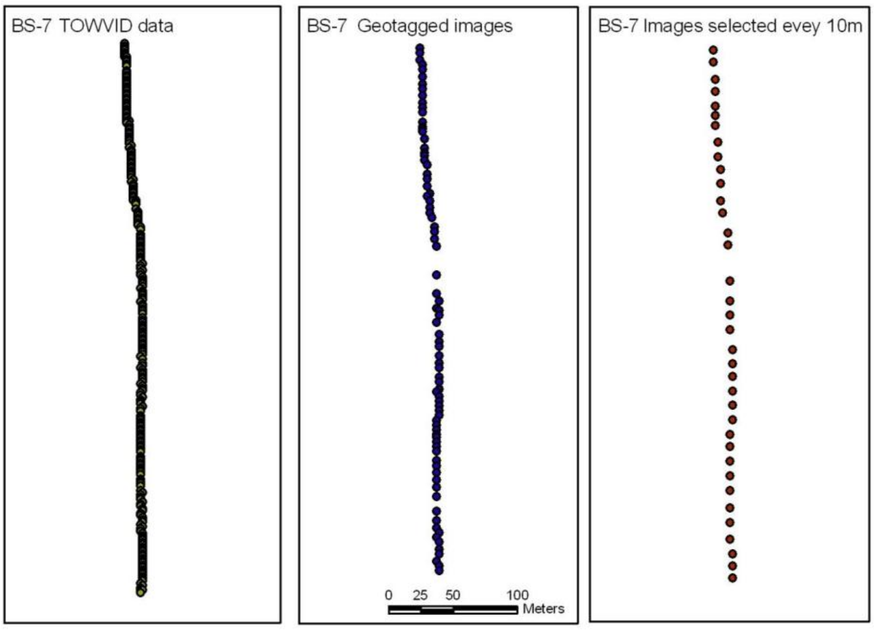

Figure 4. Example of the towvid transect still image sub-sampling approach – the georeferenced transect track plot is show on the left. The time-based position data from the track file is used to georeference the associated still images taken along the track (middle image). For the analyses in this report a subset of images at a nominal spacing of 10m along the transect is then selected (right hand image) and used for point intercept analyses of benthic cover (see Fig.5 below).

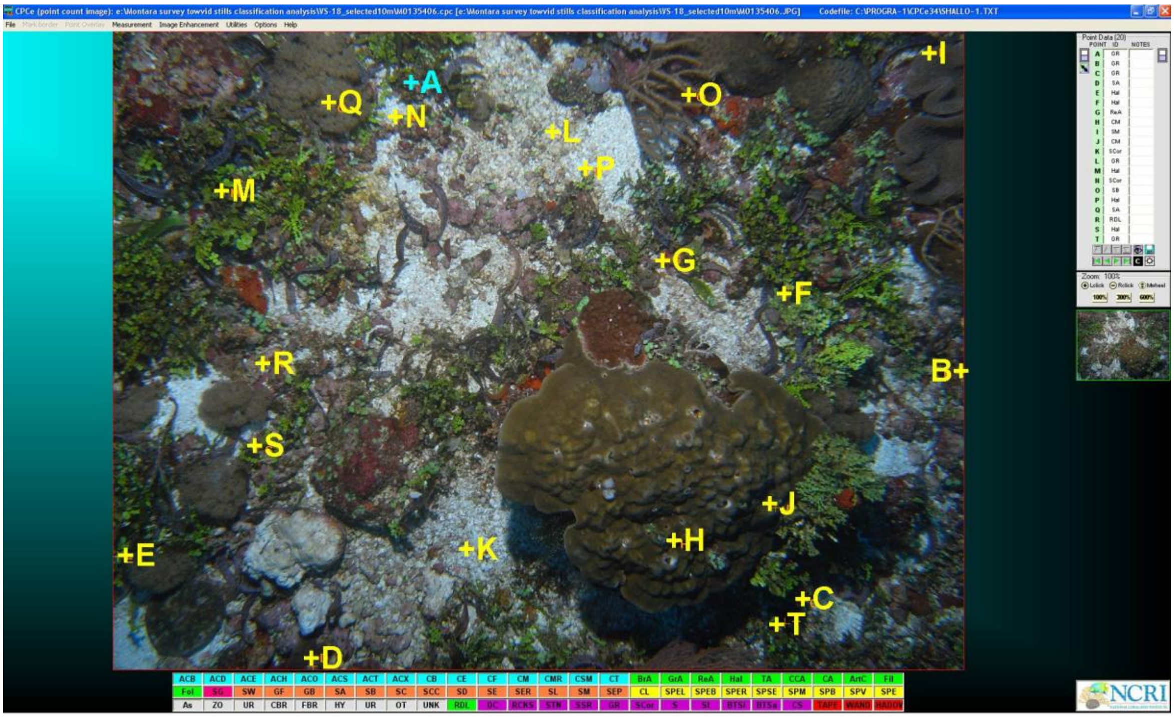

Figure 5. Fine scale image analysis - individual still photos at 10m spacing were analysed for percent cover of dominant organisms using a stratified random point intercept protocol, with 20 points per image (yellow letter symbols which change to blue once classified). The classification scheme applied is included as Appendix 1.

Results

Rough seas prevented deployment of any vessel tender and subsequent capture of additional drop camera stills, with heaving of the main ship also leading to three tow cable breakages during the survey. Nonetheless an adequate number of tow transects, delivering both video and still images were completed. In total, 20 tows of 500m+ were captured at Vulcan Shoal and 21 tows at Barracouta Shoals. These tows produced real-time habitat observations (6978, Barracouta; 6826, Vulcan) based on video observation, associated with location and depth. These data when integrated into ArcGIS and colour coded for major habitat types indicated that the broad central plateau areas of both shoals supported a mixed benthic community, in which there was considerable spatial variability at 10-100m scales along each transect, but where bare substrate was common, algae or seagrass could be important in many areas and corals were patchy and localized (see Figs. 6 and 7). In addition, each tow captured in the order of 80 high resolution stills, with the exception of 1 tow where battery failure disabled a camera and another where some incident, probably an impact on the tow platform due to heavy weather, disabled the still camera mid-tow. In addition, a short series of panoramic drop camera images were obtained from the RV Solander at the conclusion of each shoal survey.

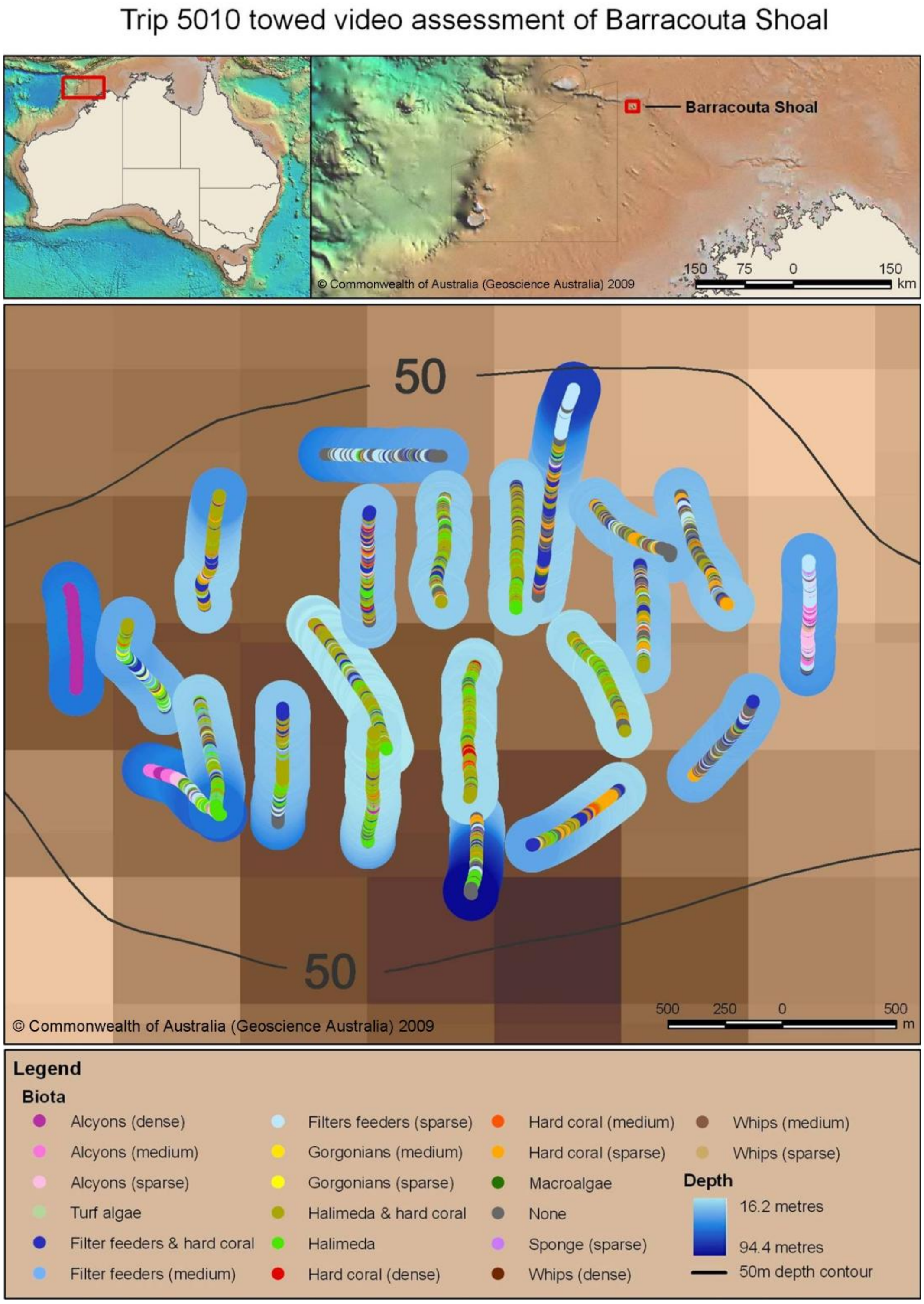

Figure 6. Barracouta Shoal -Location of survey transects and initial habitat classification of epibenthos, based on towvid data, for the top of Barracouta Shoal. This shoal has a ubiquitous presence of low to medium density calcareous green alga *Halimeda*, with some patchy but occasionally dense live coral. A very extensive field of soft coral on the western margin is a noteworthy feature. The 50m contour line shown is nominal, based on overlay of the data on the bathymetry shown in chart AUS 314.

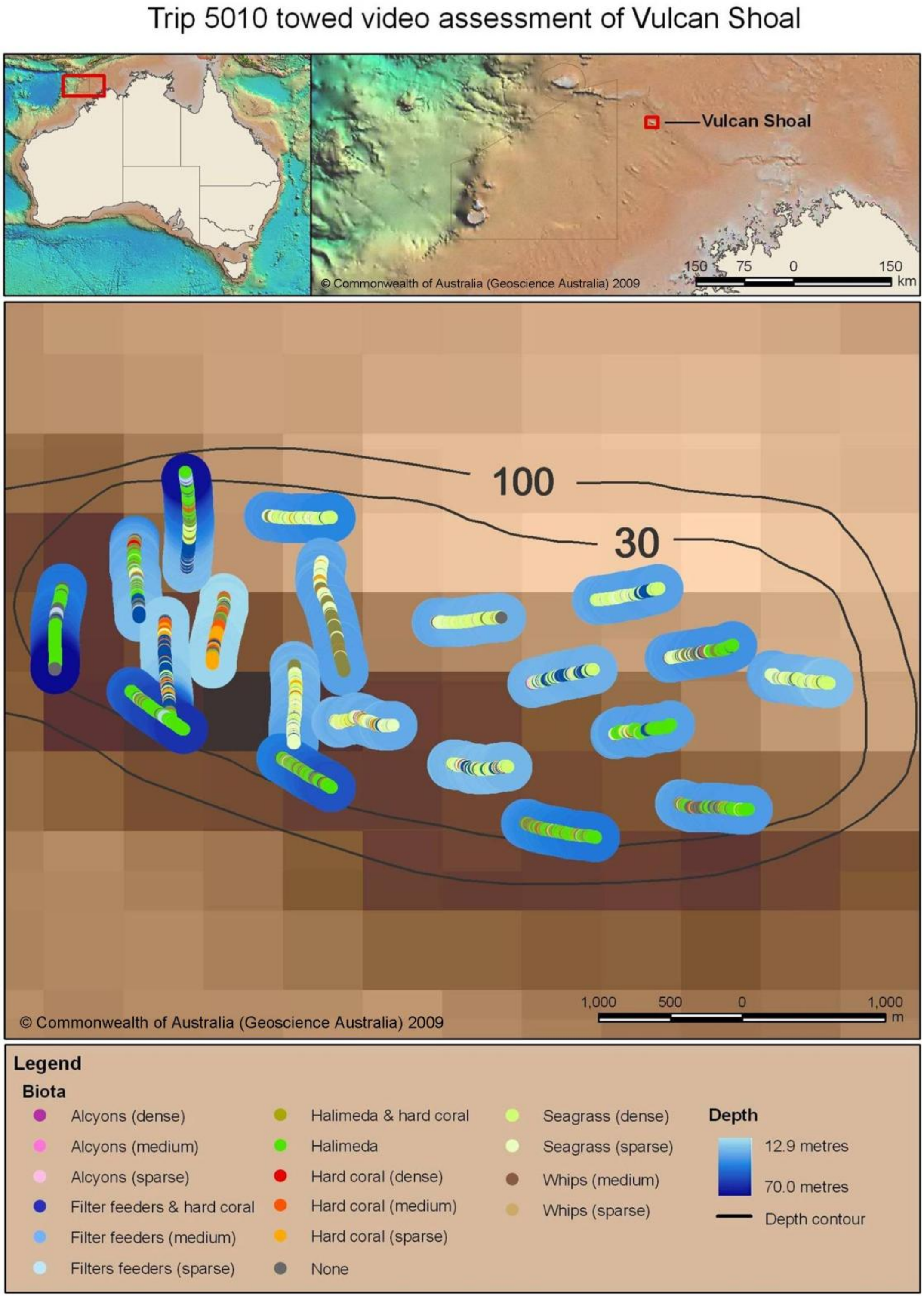

Figure 7. Vulcan Shoal - Location of survey transects and initial habitat classification of epibenthos, based on towvid data, for the top of Vulcan Shoal. This shoal has an extensive presence of low to medium density seagrass with some moderate to high density live coral around the shallower ground towards the western end. The 100 m depth contour line shown is nominal, based on overlay of the data and bathymetric from chart AUS314.

Broad scale characterization of habitat types from video

Both shoals have abrupt bathymetry, rising steeply from the surrounding shelf to horizontal plateaux areas mostly 20-30 m deep, but with occasional elevated areas. The outer rim areas slope more quickly at 40-50 m before plunging steeply to >100 m. This survey concentrated on an assessment of the shoal plateaux. Shoal substrate types could be broadly summarised as small patches of coarse sand, extensive fields of rubble and rocks (Fig. 15), limited areas of low relief consolidated reef (Figs. 13 and14) and occasional isolated rock or live coral outcrops (Fig. 16). Both shoals had very similar major classes of substrate, although proportions varied between the shoals, with Barracouta having more than twice as much consolidated low relief reef substrate (21%) as Vulcan (8%), but also more sand dominated areas (3% vs1%) (see Fig. 8). The substrate on both Barracouta and Vulcan was predominantly rubble and stones mixed with coarse sand (59-70% cover respectively, see Figs. 8 and 15) of varying density, covered in smaller plants and invertebrates. Coarser rocky (>250mm), or low relief (<1m) reef areas with isolated consolidated lumps, made up the bulk of the remaining area. Phototrophic benthos typical of tropical coral reef areas was predominant (Figs. 12-19). Areas exclusively dominated by dense hard coral were relatively rare, representing less than 1% of total observations and occurring in small patches, but low to moderate density hard coral habitat was very common, especially mixed with other biota. Coral was present as the sole dominant organism type in <10% of towed video observations on either shoal, but occurred mixed with *Halimeda* or filter feeders in 47% of observations on Barracouta Shoal and 34% of observations on Vulcan Shoal (Table 1). There was a notable and ubiquitous presence of *Halimeda*, with variable abundance especially throughout the rubble regions. The seagrass *Thalassodendron ciliatum* was also present on both shoals, although insignificant on Barracouta while being a feature of Vulcan and the dominant organism in 36% of observations. This was not evenly distributed, with an extensive meadow of dense grass at the eastern end of Vulcan Shoal representing particularly strong presence of this plant. This spatially dominant feature was mirrored by a similar extensive patch of soft coral on the western end of Barracouta Shoal. No signs of bleaching or recent mortality were observed in the stony corals.

The biota was very diverse, particularly in the more structurally complex rocky and low relief reef areas, where moderate to high cover of algae, corals and filter feeders was frequently encountered (see Figs. 13 and 14). On both shoals multiple transects were typified by a mix of algae, hard corals and filter feeders. Calcareous red and green (*Halimeda*) algae were the dominant plants on Barracouta Shoal, while on Vulcan Shoal a mix of algae featured, with *Halimeda* also important and the stemmed seagrass *Thalassodendron cilatum* common (Fig. 17). In addition a small photosynthetic ascidian, nominally *Lissoclinum* sp., made an important contribution to the overall benthic community and was a dominant component in a few places (Fig. 19)

Bare sand or rubble patches were a very important component of these shoals, but the majority of survey transects across the central plateaux encountered moderate to high levels of benthic life. There was some indication of higher levels of bare substrate, particularly sand, on those tows that ventured s into slightly deeper water off the edges of the shoal plateaux. Barracouta Shoal had more bare sand but also consolidated low-relief, or reef-like, substrate than Vulcan Shoal (Fig. 8 and Table 1). These consolidated areas supported a richer coral community and generally

were covered with macroscopic invertebrates or encrusting red algae, interspersed with algae, particularly *Halimeda*. Large coral outcrops higher than 1m were rare, although occasionally encountered (see Fig. 12). The most abundant biota were organisms which are dependant on light, such as the various algae, corals, and seagrass. Filter feeders, such as sponges and soft corals, were in general a lesser component, although small upright soft corals were widely distributed and had a spectacular presence with the large field of *Nepthea* on the western end of Barracouta Shoal.

The extensive rubble fields, mainly consisting of golf-ball to tennis-ball sized stones and rhodoliths*, are an important habitat. Organisms that can utilised this substrate , such as seagrass, the small ascidian *Lissoclinum*, the calcareous alga *Halimeda* and some soft corals, may form an important component of the habitat. It is not clear if asexual propagation or highly localised and intense recruitment is responsible for the dense patches of these biota.

* - rhodoliths are unattached red algal which have an outer layer, of varying thickness, of crustose coralline algae. As these are moved around by currents they may rotate, allowing the encrusting algae to grow on a new surface. Continual turnover of the stone and deposition of calcareous material on all sides gradually builds up the size of a rhodolith.

Table 1. Dominant benthic groups at Barracouta and Vulcan Shoals –classification of major biotic groups based on real-time towvid data from all transect tows shown in Figs. 6 and 7.

Benthos Key	*Barracouta Shoal* Total % towed video line intercept	*Vulcan Shoal* Total % towed video line intercept
Alcyons D	4.73%	0.05%
Alcyons M	2.12%	0.03%
Alcyons S	2.16%	1.10%
Algae T/M	0.07%	0.00%
Bioturb	0.00%	0.02%
Fil&Hcoral	11.29%	12.36%
Filters M	2.12%	0.20%
Filters S	9.86%	1.44%
Gorg M	0.09%	0.00%
Gorg S	0.37%	0.00%
Hal&Hcoral	27.80%	15.54%
Hali D	13.16%	21.43%
Hcoral D	0.47%	0.83%
Hcoral M	1.78%	2.64%
Hcoral S	5.26%	2.89%
Macroalgae	0.03%	0.00%
None	18.11%	5.64%
Sgrass D	0.00%	19.52%
Sgrass S	0.00%	16.11%
Sponge S	0.04%	0.00%
Whips D	0.10%	0.00%
Whips M	0.33%	0.02%
Whips S	0.10%	0.19%
Total	100.00%	100.00%

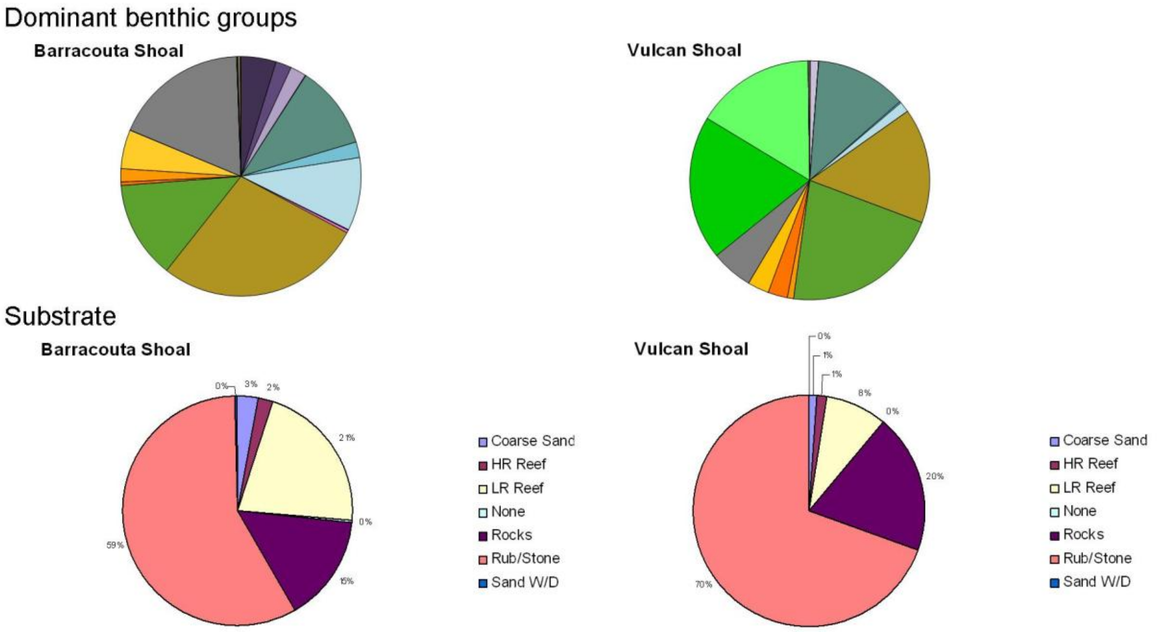

Figure 8. Dominant substrate groups at Barracouta and Vulcan Shoals –classification of substrate based on real-time towvid data from all tows shown in Figs. 6 and 7. HR Reef= high relief reef, LR Reef=low relief reef <1m high.

Quantitative broadscale patterns from point intercept analysis

In comparison to towed video classification, point intercept data from post-processed still images is much slower to acquire, but it provides an opportunity to extract more detail on the variety of biological attributes and delivers robust measures of abundance and associated levels of variation. In this analysis of the transect still images a classification table discriminating 15 types of coral and 11 types of algae was applied (see Appendix 1 Table 1a). The raw classification data, in the order of 15,000 points per shoal, has been used in all statistical analyses, but has been aggregated into major biological groups at transect and shoal level for presentation of broad scale patterns. The complete raw data results and individual images, along with associated position and depth data are included as 3a & 3b in the companion DVDs.

The mean abundance of the major benthic groups such as, Coral, Algae, Soft coral, Seagrass and Sponges are shown for each survey transect on the individual shoals (Figs. 9 and 10, Tables 2 and 3). Three additional data groups, Other, Indeterminate and Abiotic captured most remaining biotic and abiotic categories. "Other" records a mixed group of other organism, including ascidians and bryozoans. "Indeterminate" (Indet) captures data points in the analysis which, due to inadequate image quality, could not be assigned to any category with confidence. Points under which bare substrate, devoid of any obvious biota was discernible were recorded as "Abiotic". Most points could be assigned to one of the major biological categories or to Abiotic, although on average around 3% of points remained as Indeterminate (see Appendix 1, Table 1a for the full list of classifications).

On Barracouta Shoal most transects contained low to moderate levels of most of the major biological groups (Fig. 9), although transects 10 and 14 were strongly dominated by soft coral and abiotic habitat respectively. The abiotic habitat type, largely rubble and areas of bare coarse sand, were the major component of all transects with the exception of transect 10, which represents the extensive and dense field of *Nepthea* soft coral at the western edge of the shoal (see Fig. 12). Algae of several types, mostly green and red forms, were present on all transects and typically occupied 20-30% of the substrate, while hard corals were much less ubiquitous, but covered close to 20% of the seabed on 6 of the 21 transects (Table 2). Soft corals and sponges were widespread but progressively less important in general in terms of abundance.

On Vulcan Shoal, bare sand and rubble substrate, classified as Abiotic, was similarly the most significant category overall, but less dominant than on Barracouta (Fig. 10). Overall biological coverage was higher on Vulcan Shoal, with the ubiquitous presence of algae augmented by large amounts of the seagrass *Thallasodendron ciliatum*. This tropical seagrass was recorded on almost all transects, rivalling or exceeding the abundance of algae on 6 of the 20 transects and being the dominant biological group on 2 transects with in excess of 36% cover (see Table 3). Hard coral was widespread, recorded on all transects, but frequently at levels below 5% cover. Only two transects exceeded 10% coral cover, supporting 14% & 23% cover. Soft corals were greatly diminished in abundance on Vulcan compared to Barracouta Shoal, with some recorded on all transects but typically at mean levels of <2%. This mirrors the sort of levels seen for sponges on Barracouta, whereas on Vulcan Shoal sponges were a much more important group, with many transects supporting 5-10% cover of sponges and 4 close to 12-13% (Tables 2 and 3). A peculiar additional component recorded on almost all transects at Vulcan Shoal, was the strong presence

of a small green ascidian, most likely *Lissoclinum pliatum*, which was the major organism contributing to the "Other" category in Table 3.

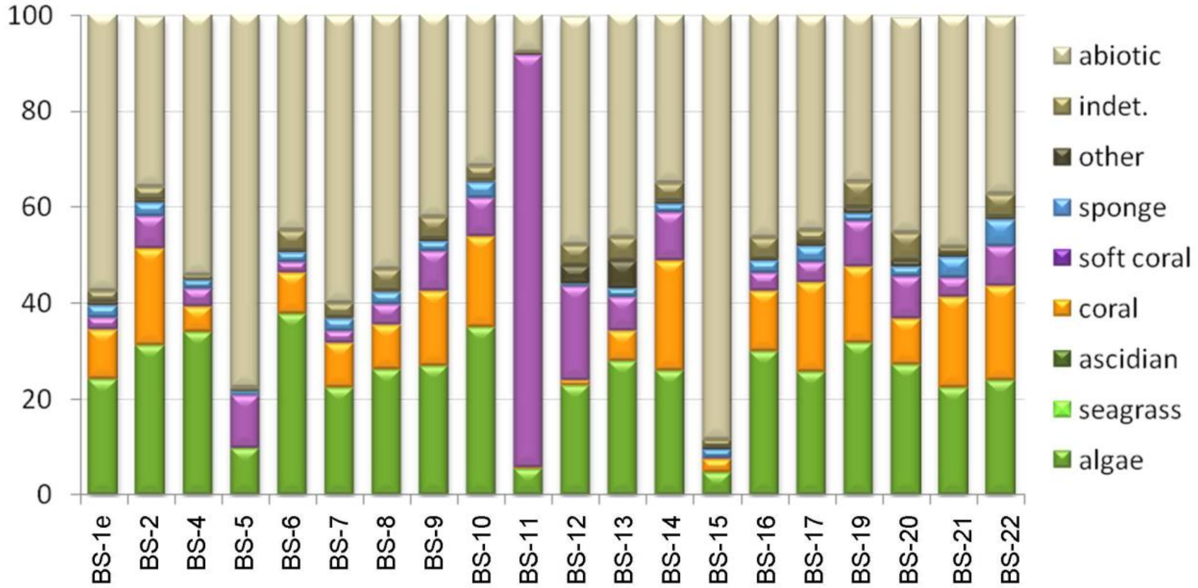

Figure 9. Barracouta Shoal – comparison of mean abundance, expressed as a percent of total benthic cover, for major benthic categories on each survey transect.

Table 2. Barracouta Shoal - Mean abundance values for Figure 9 above, expressed as a percent of total benthic cover, of major benthic categories for each survey transect. Data used to calculate these means, including calculated standard errors, are included in 3 on the accompanying DVD.

Barracouta Shoal										
Transect	Latitude	Longitude	algae	seagrass	hard coral	soft coral	sponge	other	indet.	abiotic
BS-1e	-12.53992	124.03725	24.16	0.00	10.42	2.43	2.56	0.62	2.37	57.30
BS-2	-12.54698	124.02938	31.36	0.00	20.02	6.78	2.65	0.53	2.86	35.38
BS-4	-12.54965	124.04418	33.91	0.00	5.31	3.75	1.72	0.16	0.94	54.22
BS-5	-12.54495	124.04743	9.88	0.00	0.00	10.95	0.95	0.24	0.36	77.62
BS-6	-12.54158	124.04040	37.67	0.00	8.67	2.17	2.00	0.33	4.17	45.00
BS-7	-12.54448	124.04088	22.40	0.00	9.45	2.29	2.56	0.40	2.83	59.92
BS-8	-12.55423	124.03432	26.29	0.00	9.15	4.33	2.50	0.33	4.49	52.75
BS-9	-12.55065	124.02668	27.02	0.00	15.48	8.33	2.02	0.48	4.52	42.14
BS-10	-12.54310	124.03002	34.96	0.00	18.84	8.17	3.18	0.23	3.06	31.44
BS-11	-12.54530	124.01850	5.59	0.00	0.29	85.59	0.00	0.29	0.29	7.94
BS-12	-12.55113	124.02252	22.84	0.00	1.17	19.47	0.44	3.95	4.10	47.58
BS-13	-12.54715	124.02130	27.92	0.00	6.25	7.08	1.67	5.83	4.86	46.39
BS-14	-12.54218	124.02390	25.91	0.00	22.81	10.19	1.66	0.44	3.77	34.88
BS-15	-12.53840	124.03022	4.88	0.00	2.77	0.33	1.55	0.55	1.55	88.24
BS-16	-12.54162	124.03597	30.00	0.00	12.63	3.63	2.50	0.25	4.63	46.38
BS-17	-12.54715	124.03938	25.70	0.00	18.54	4.22	3.45	0.64	2.43	44.76
BS-19	-12.55165	124.03023	31.63	0.00	15.88	9.53	1.52	1.20	5.25	34.94
BS-20	-12.55018	124.02387	27.17	0.00	9.58	8.68	2.14	1.24	5.64	44.76
BS-21	-12.54217	124.03305	22.51	0.00	18.86	4.01	4.14	0.73	1.34	48.18
BS-22	-12.54897	124.03405	23.87	0.00	19.56	8.40	5.52	0.55	4.64	36.91

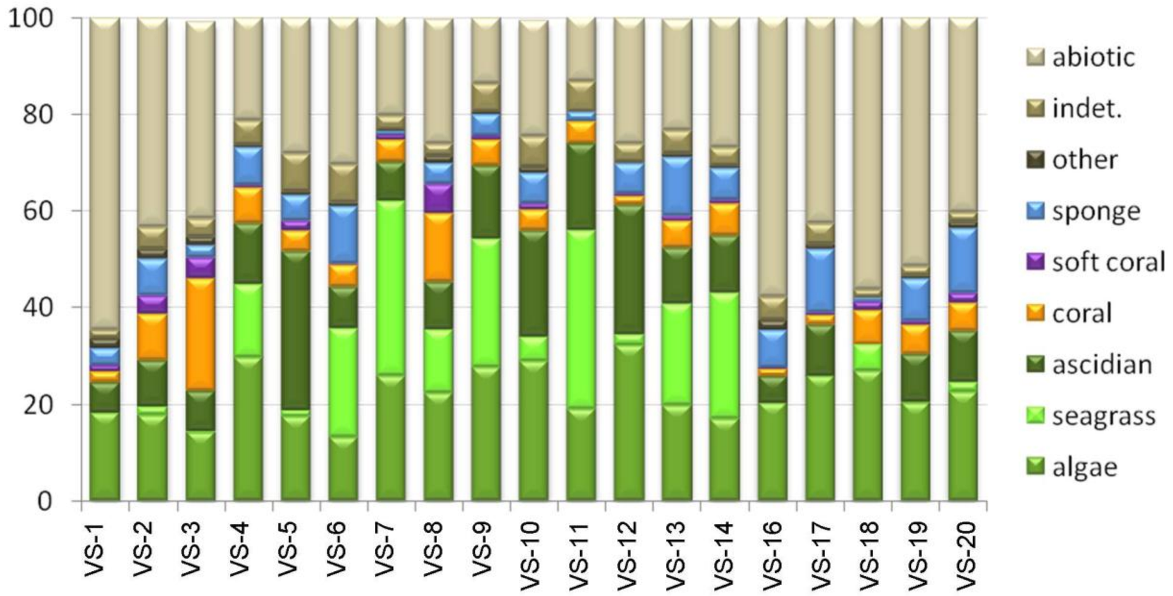

Figure 10. Vulcan Shoal – Comparison of mean abundance, expressed as a percent of total benthic cover, for major benthic categories on each survey transect

Table 3. Vulcan Shoal - Mean abundance values for Figure 10 above, as a percent of total benthic cover, of major benthic categories for each survey transect. Data used to calculate these means, including calculated standard errors, are included in Appendix 3 on the accompanying DVD.

Vulcan Shoal										
Transect	Latitude	Longitude	algae	seagrass	hard coral	soft coral	sponge	other	indet.	abiotic
VS-1	-12.80192	124.25575	18.14	0.00	2.35	1.11	3.60	8.31	1.94	64.27
VS-2	-12.79908	124.26085	17.85	1.66	9.42	3.99	7.54	11.64	4.55	43.13
VS-3	-12.80028	124.26633	14.29	0.18	23.08	4.21	2.75	10.07	3.66	40.66
VS-4	-12.79528	124.27117	29.68	14.96	7.36	0.50	7.98	12.97	4.99	21.32
VS-5	-12.80125	124.27302	17.58	1.25	4.11	2.00	5.36	33.54	7.86	28.05
VS-6	-12.80688	124.27080	13.14	22.60	4.60	0.39	11.83	9.07	7.88	30.35
VS-7	-12.80180	124.28162	25.70	36.18	4.63	0.85	0.97	8.28	2.92	20.34
VS-8	-12.80527	124.28732	22.32	13.01	14.03	6.12	4.21	11.61	2.42	25.77
VS-9	-12.80018	124.29163	27.60	26.41	5.39	0.79	4.47	15.64	5.78	13.80
VS-10	-12.80382	124.29610	28.75	5.09	4.45	1.15	6.36	23.28	6.23	23.92
VS-11	-12.80558	124.30305	18.87	36.94	4.35	0.16	1.94	18.06	6.29	13.39
VS-12	-12.80883	124.29247	32.01	2.35	1.76	0.44	6.31	27.02	3.82	26.14
VS-13	-12.80792	124.27500	19.63	21.05	5.41	1.00	12.23	12.38	4.84	23.04
VS-14	-12.81113	124.28232	16.98	25.88	6.47	0.94	6.33	12.67	3.64	26.82
VS-16	-12.80753	124.26217	20.29	0.00	1.47	0.29	7.94	7.50	4.71	57.79
VS-17	-12.81143	124.27157	25.68	0.15	2.11	0.45	13.14	11.63	4.23	42.30
VS-18	-12.81502	124.28715	26.71	5.66	7.11	1.71	0.66	0.00	1.84	56.32
VS-19	-12.81350	124.29700	20.17	0.24	5.93	0.95	8.78	10.32	2.25	51.01
VS-20	-12.79508	124.26413	22.54	1.93	5.80	2.01	13.20	12.00	2.09	40.26

After aggregating the fine scale data for each shoal, it is clear that the broad scale benthic communities have marked differences in the relative contributions of the major groups. While bare areas (Abiotic) are very significant on both shoals (Fig. 11), the biological cover exceeds 50%. Taken as a whole these shoals both support rich benthic communities, dominated by primary producers. Of these, the plants are overwhelmingly important, in particular the calcareous green alga *Halimeda* and various encrusting red algae. In addition, seagrass makes a major contribution to the benthic habitats of Vulcan Shoal and is a key point of difference with Barracouta Shoal (see Fig. 11), although traces amounts were also seen there. The two shoals differed in the comparative abundance of sponge, soft coral and hard coral. The presence of extensive dense soft coral at the western end of Barracouta was mirrored by the dense seagrass meadows across the north-east of Vulcan.

Mean hard coral cover at Barracouta Shoal was 11%, almost twice that of Vulcan Shoal. While both shoals had single transects supporting up to 23% live coral (Tables 2 and 3), Barracouta had many more with similar abundance, suggestive of a more extensive coral zone. The greater coral cover on Barracouta Shoal was associated with more abundant consolidated substrate, in the form of low relief reef (Fig. 8). This coral community was also more diverse, with a greater array of Acroporid morphotypes recorded (Fig. 11).

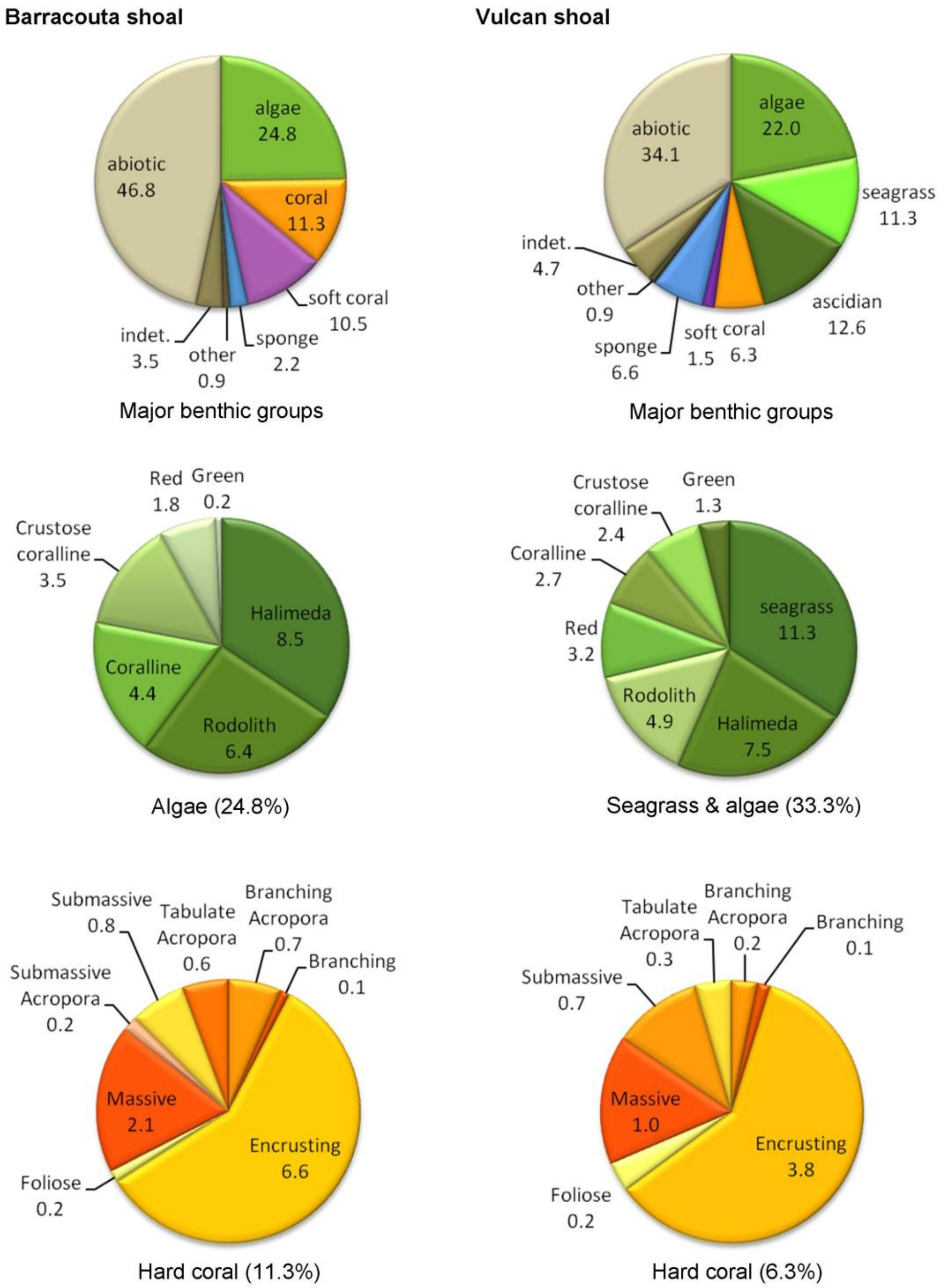

Figure 11. Barracouta and Vulcan Shoals- major benthic groups- comparative abundance estimates of major benthic groups, expressed as mean percent cover of the seabed. These data are based on the complete point intercept analysis of photos on all transects surveyed on each shoal (n≈ 15,000 per shoal).

Examples of common habitat types

Figure 12. Barracouta Shoal: soft coral field with coral bommie in the background. This small species of soft coral, a provisional *Nephthea* species, extended as a dense cover over hectares at the western shoal margin.

Figure 13. Barracouta Shoal: coral-*Halimeda*-filter feeder mixed habitats were frequently encountered on rocky and low relief reef areas.

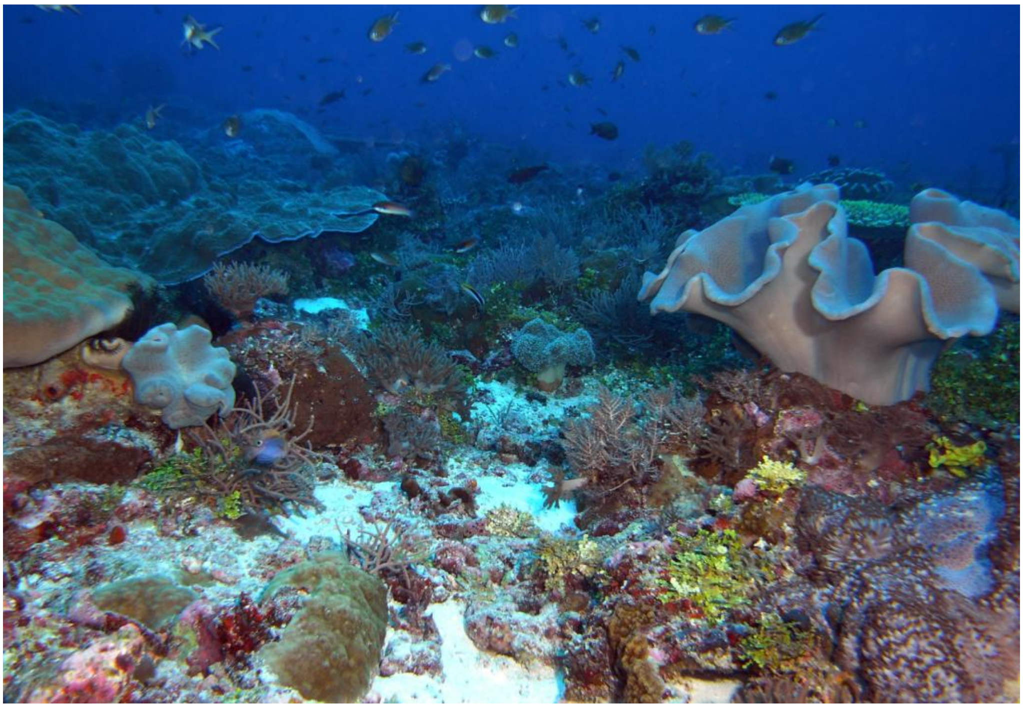

Figure 14. Barracouta Shoal – low relief consolidated reef and broken rock areas could support very diverse biota.

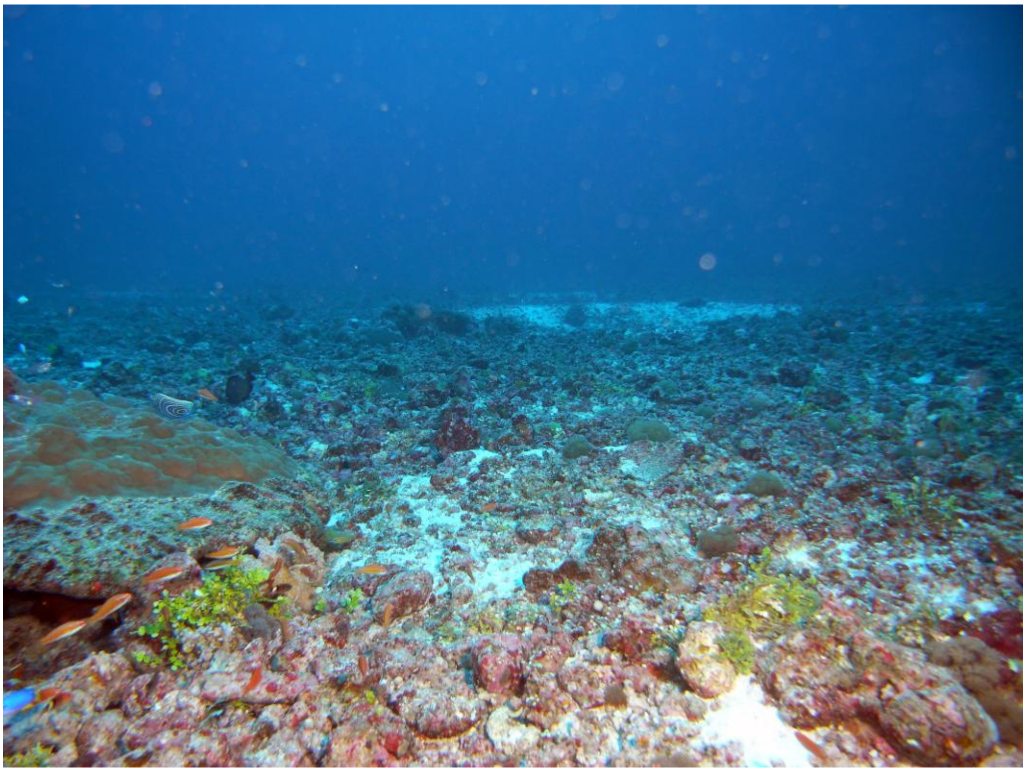

Figure 15. Barracouta Shoal –extensive rubble zones were encountered, with encrusting red algae commonly forming fields of rounded rhodoliths, which were intersperse with *Halimeda* and occasional bare sand patches.

Figure 16. Barracouta Shoal –isolated outcrop amidst coarse sand and rubble. Sandy patches were found across the shoal plateau but appeared to be more common and extensive towards the rim areas in 40m depths.

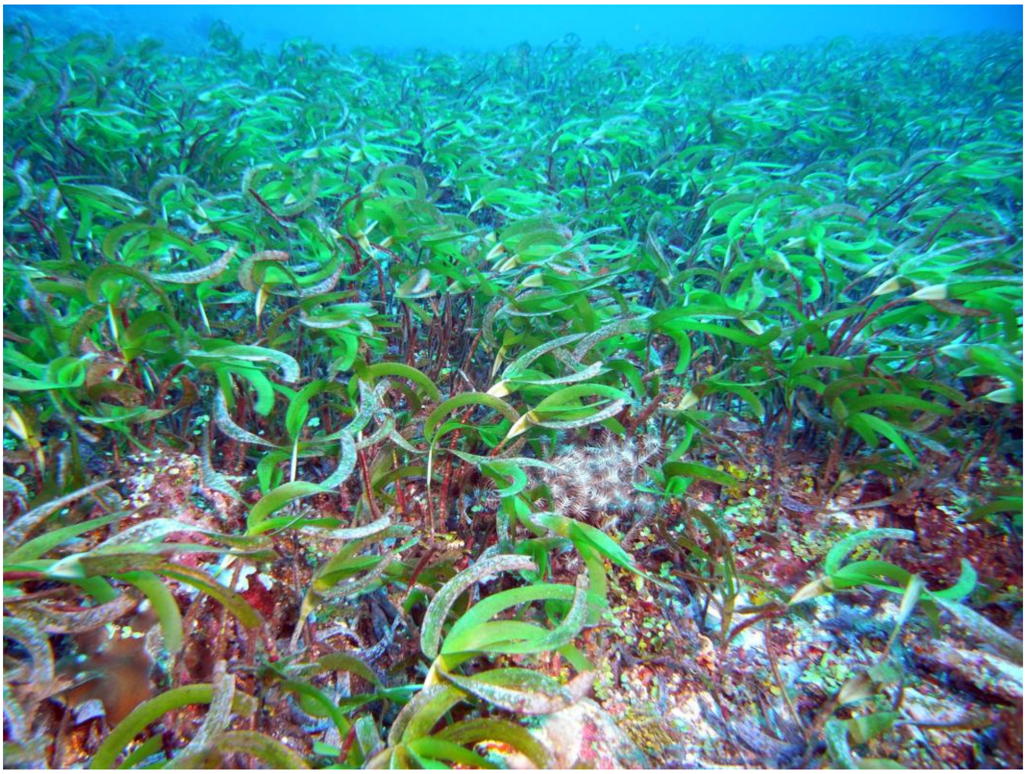

Figure 17. Vulcan Shoal – dense seagrass *Thalassodendron ciliatum* was a notable feature on parts of this shoal.

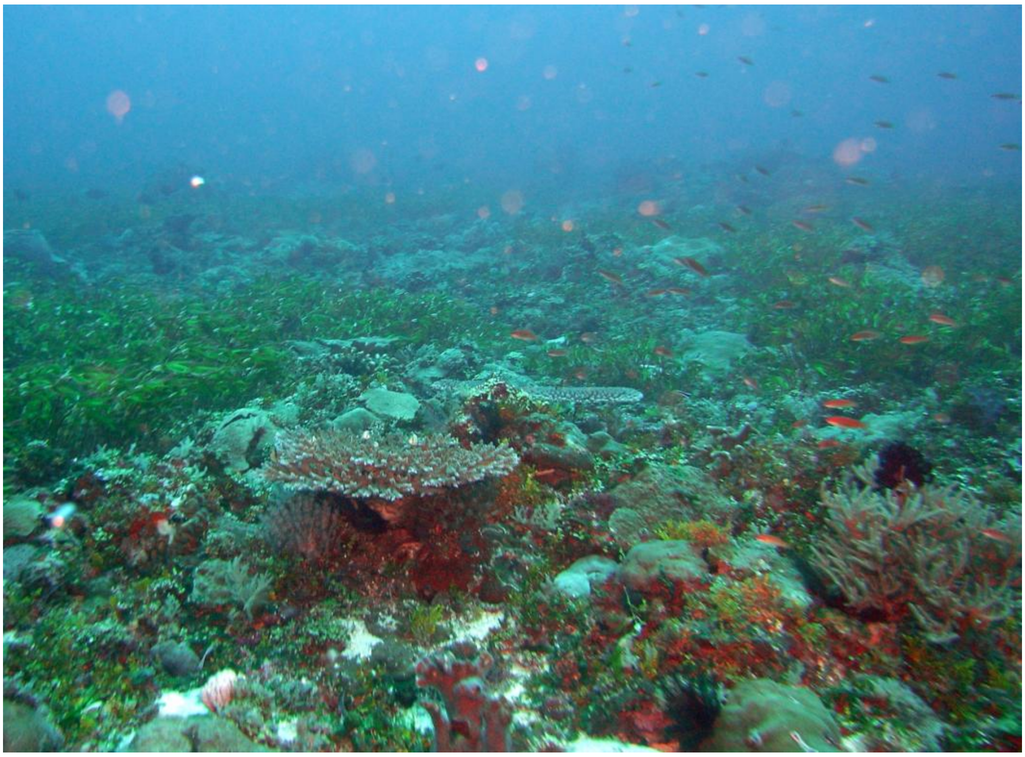

Figure 18. Vulcan Shoal –seagrass, algae and corals were encountered mixed together in a number of locations.

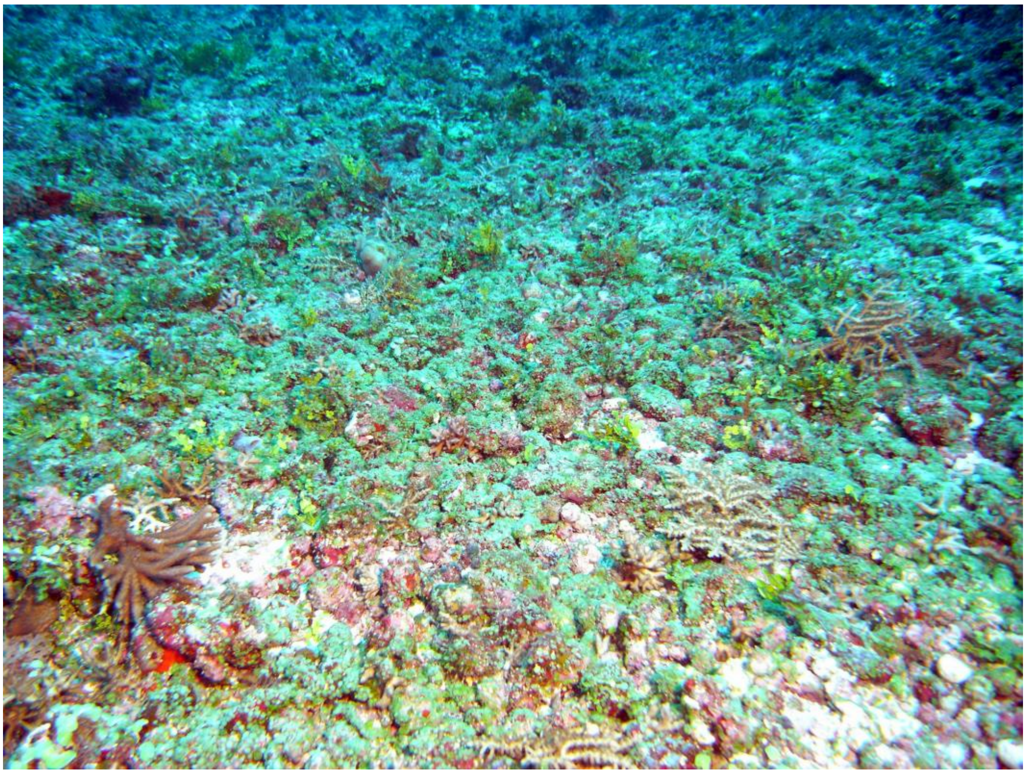

Figure 19. Vulcan Shoal - A small photosynthetic ascidian, very similar in appearance to *Lissoclinum bistratum* Sluiter, mixed with the calcareous green alga *Halimeda*. This ascidian was abundant and formed dense patches on some parts of Vulcan Shoal, possibly due to very localized recruitment

Fine scale patterns and patchiness

While it is clear that there are differences in major benthic groups at transect and whole shoal scales, spatial variability was also a persistent feature within each survey transect. It was rare to find even the dominant biological group remaining unchanged over more than 10 m intervals, and subdominant components of the community were continually changing at even finer scales.

Figures 20 and 21 prove an illustration of the sorts of spatial variability in major biological groups encountered at 10m intervals along four transects at each of the two shoals. These transects were selected as representative of four broader habitat types, including highly dominated ones such as the soft coral meadow on Barracouta Shoal or seagrass field on Vulcan Shoal (Fig. 20, BS-11; Fig. 21, VS-11) to more complex mixed communities (Fig. 20 BS-7; Fig. 21, VS-3). It is clear that most habitats at scales of tens of metres, have quite variable contributions from the major biological groups, but that those groups present tend to be recorded more often than not in sequential images along the 500 m transect.

The similarity between these benthic communities were explored with cluster analyses of all transect point intercept data. A bootstrapped analysis, indicated two very robust groups of transects at Barracouta Shoal (Fig. 22), which consisted of three deeper transects located towards the outer shoal rim (Fig. 24) that had above average amounts of soft coral and very little hard coral (Fig. 23). Of the remaining large group of 18 transects, distributed across the main plateau area of the shoal, a further group of transects was associated with areas where algae were slightly more important (BS-4,6,13) versus more abundant hard and soft corals. The comparative importance of these major benthic biotic groups is provided in the Barracouta Shoal heatmap (Fig. 23). There is some suggestion from these analyses that the slightly shallower transects located around the central apex of the shoal contain the most hard and soft coral (see Fig. 24). Transects coded Blue and Green in Figure 24 have equivalent amounts of algae (26-28%), but the Blue transects, which lie across most of the central plateau, have more hard and soft coral (18.8 ± 0.8% and 7.5 ± 0.8% respectively) than the surrounding Green transects (10.3 ± 0.6% and 4.3 ± 1.2% respectively). Nonetheless, as the mean transect depths are not tidally corrected and the overall shoal bathymetry is very limited the association of higher coral cover with shallower depths cannot be rigorously tested at present.

At Vulcan Shoal the cluster analysis (Fig. 25) shows two very distinct groups of transects, each containing a number of subgroups. The principal benthic group forcing this high level grouping is seagrass, which is a key component of all 8 transects in one of the major groups (see Heatmap, Fig. 26). The high seagrass group has a mean percent cover of 24.63 ± 3.09 (mean ± SE) whilst the remaining group of transects contain little seagrass (1.68 ± 0.61) and more bare substrate (43.8 ± 4.04 versus 21.85 ± 2.14). Both clusters are characterised by a similar mix of algae (6.53 ± 1.13 versus 6.15 ± 1.85), hard coral (21.74 ± 1.99 versus 22.18 ± 1.64), soft coral (1.34 ± 0.69 versus 1.66 ± 0.41) and sponge (6.25 ± 1.49 versus 6.88 ± 1.18). Consequently, the exception of the additional seagrass, this group of transects is not particularly different to the rest of the shoal in terms of other biota (Fig. 26.). However, as the seagrass is additional to these other major groups, the overall live benthic cover is higher (see Fig. 10). Consequently, the seagrass dominated transects appear to be especially rich in benthic life. These seagrass transects are

mostly located on the central and northeast areas of the shoal, with some indication that these generally lie across shallower areas (Fig. 27).

When looking at the finer detail of the cluster analysis, the seagrass dominated group (cluster 1, Fig. 27) is broken into three groups; the first characterised by relatively high seagrass cover (33.17%) and macroalgae (24%); the second by a greater presence of sponge (10.13%); and the third characterised by lower seagrass cover (14.96%) but high macroalgae (29.68%). The remaining major group, which has little seagrass (Fig.27, Cluster 2 as indicated by dotted line) is broken down into four groups; the first characterized by macroalgae (26.71%) and bare substrate (56.32%); the second characterized by ascidians (27.95%); the third by higher hard coral cover (23.08%); and the fourth by the presence of sponges (9.03%).

A final Cluster analysis, using data combined from all transects (Fig. 28), demonstrates the distinctive nature of the benthic communities on both shoals. While a few transects group most closely with those found on the other shoal, overwhelmingly the benthic communities on each shoal are coherent and more related to each other than to the adjacent shoal.

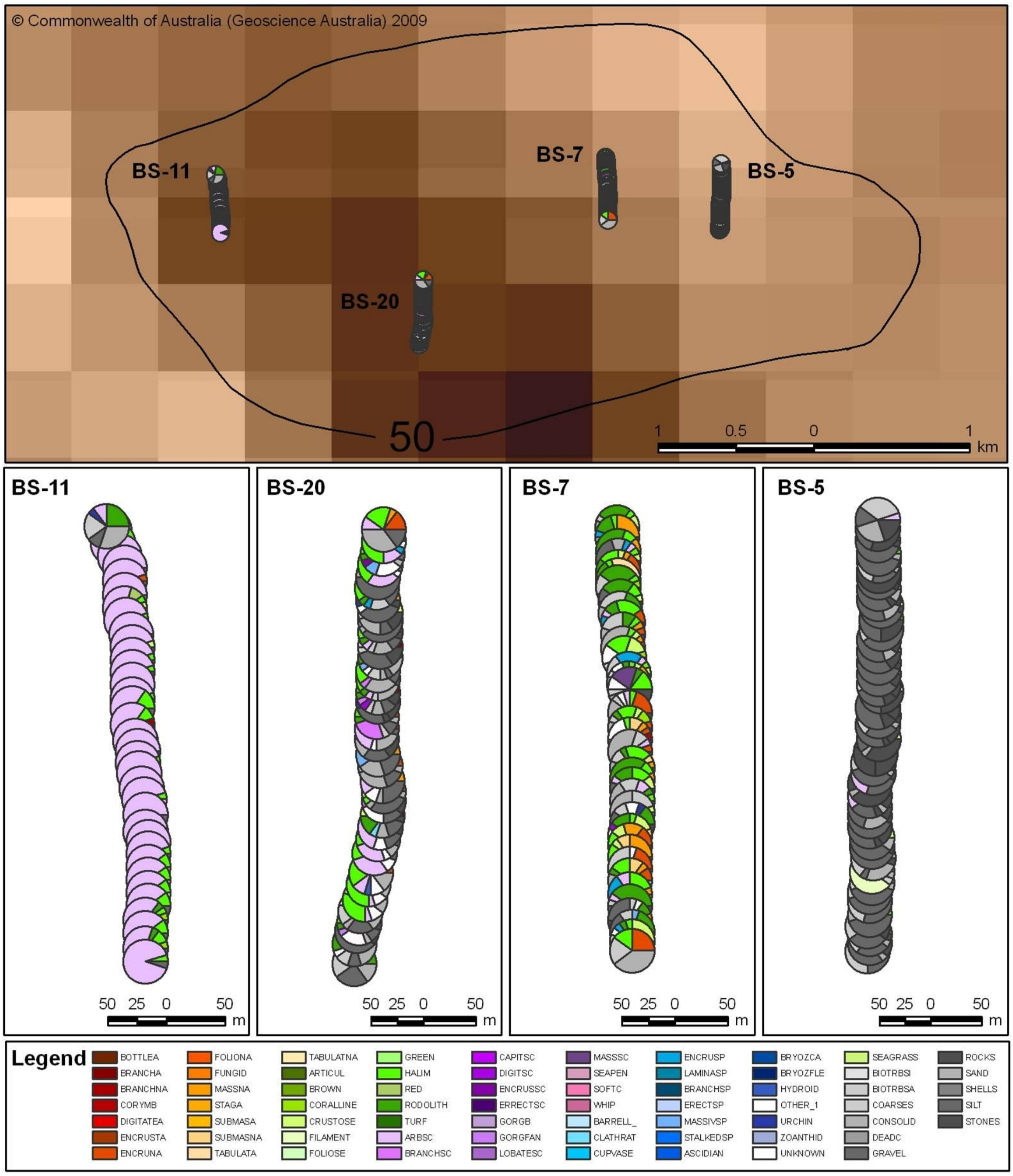

Figure 20. Barracouta Shoal - examples of fine scale patchiness and habitat heterogeneity along four transects representing different habitat types. Each pie disk summarizes the results of image analysis for an individual photoquadrat (n=35-42) at 10m intervals along the transect. Colour groups indicate hard corals (red-orange), soft corals (purple-pink), sponges (blues), plants (greens) or bare substrates (greys).

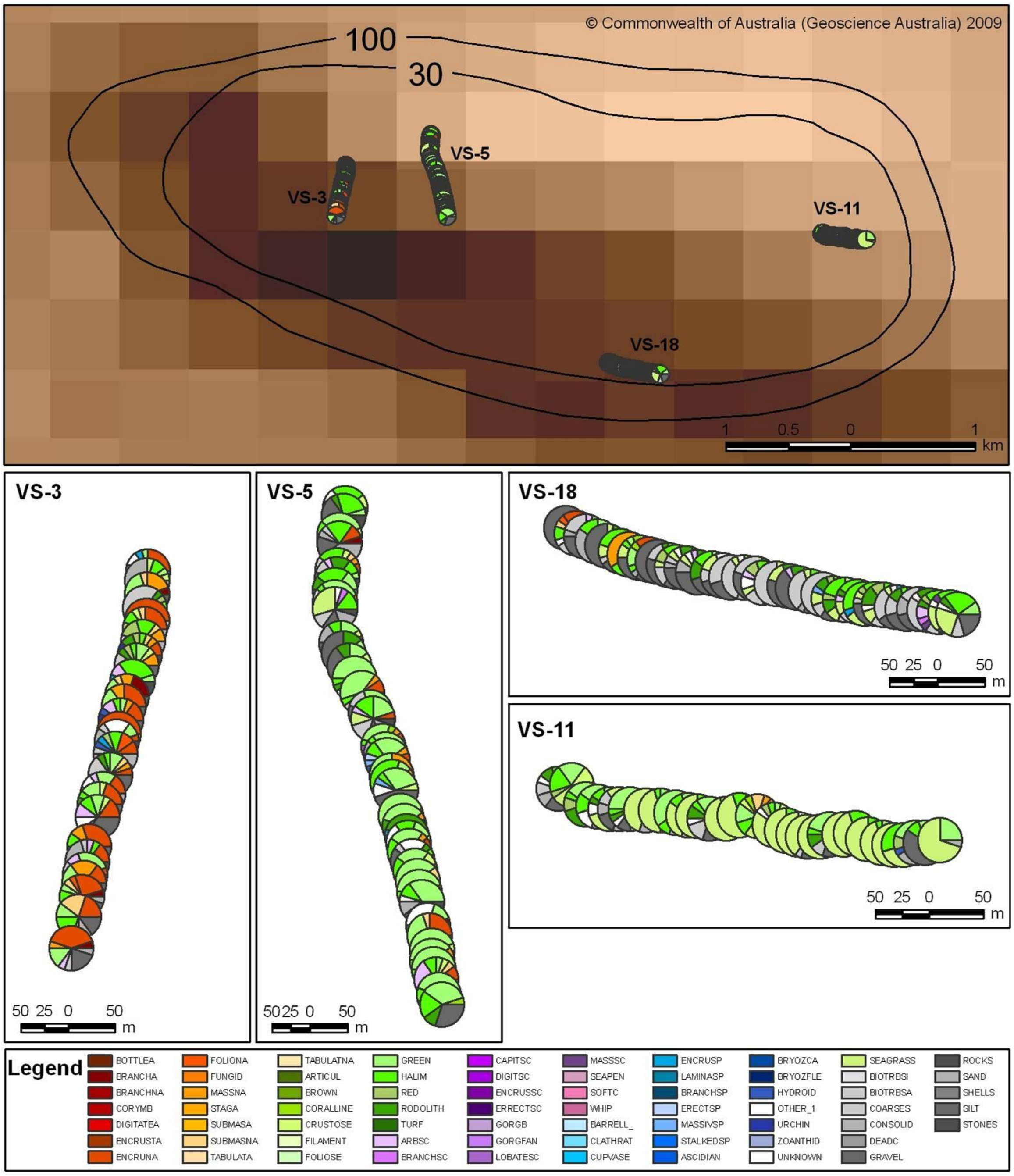

Figure 21. Vulcan Shoal – examples of fine scale patchiness and habitat heterogeneity along four transects representing different habitat types. Each pie disk summarizes the results of image analysis for an individual photoquadrat (n=35-42) at 10m intervals along the transect. Colour groups indicate hard corals (red-orange), soft corals (purple-pink), sponges (blues), plants (greens) or bare substrates (greys).

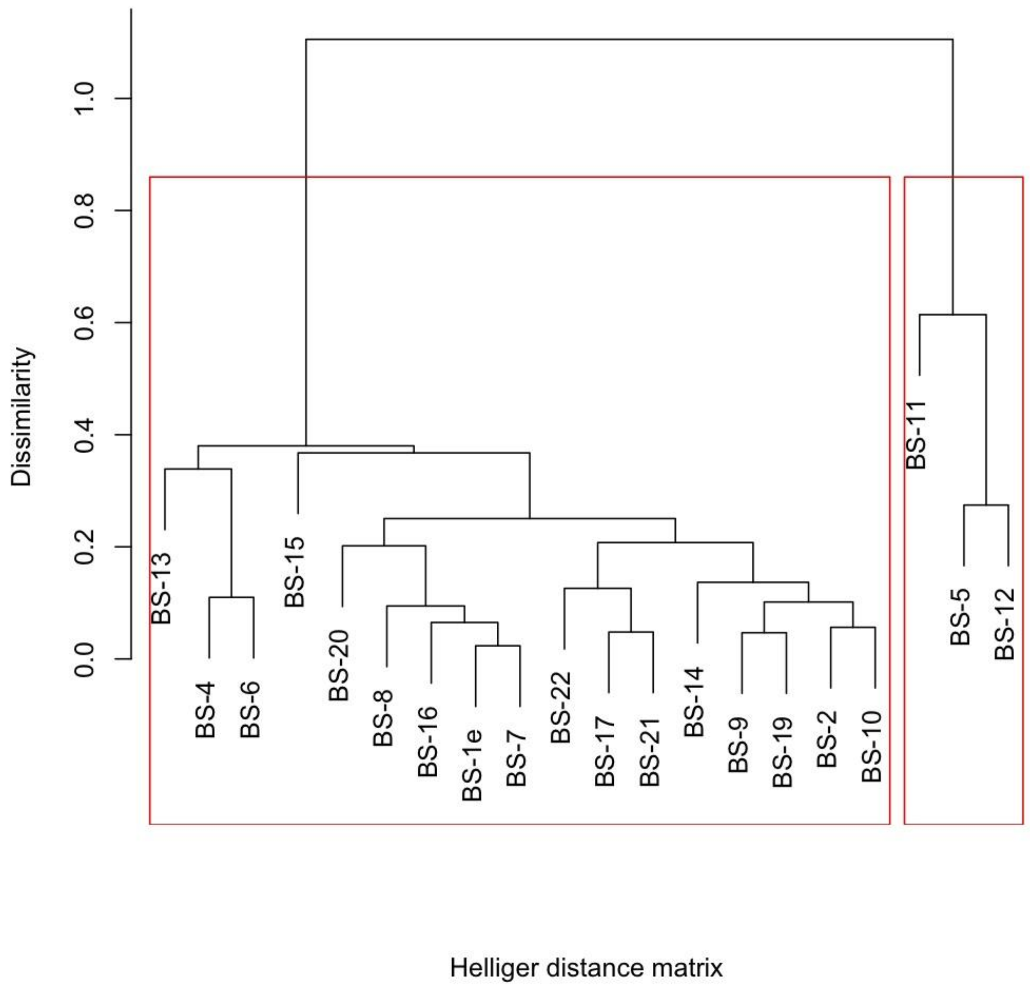

Figure 22. Cluster analysis (complete linkage) based on Hellinger transformed distance matrix for major benthic biotic groups found on Barracouta Shoal transects. Two robust groups (outlined in red) are identified using bootstrapped significance calculation. Iterations =1000.

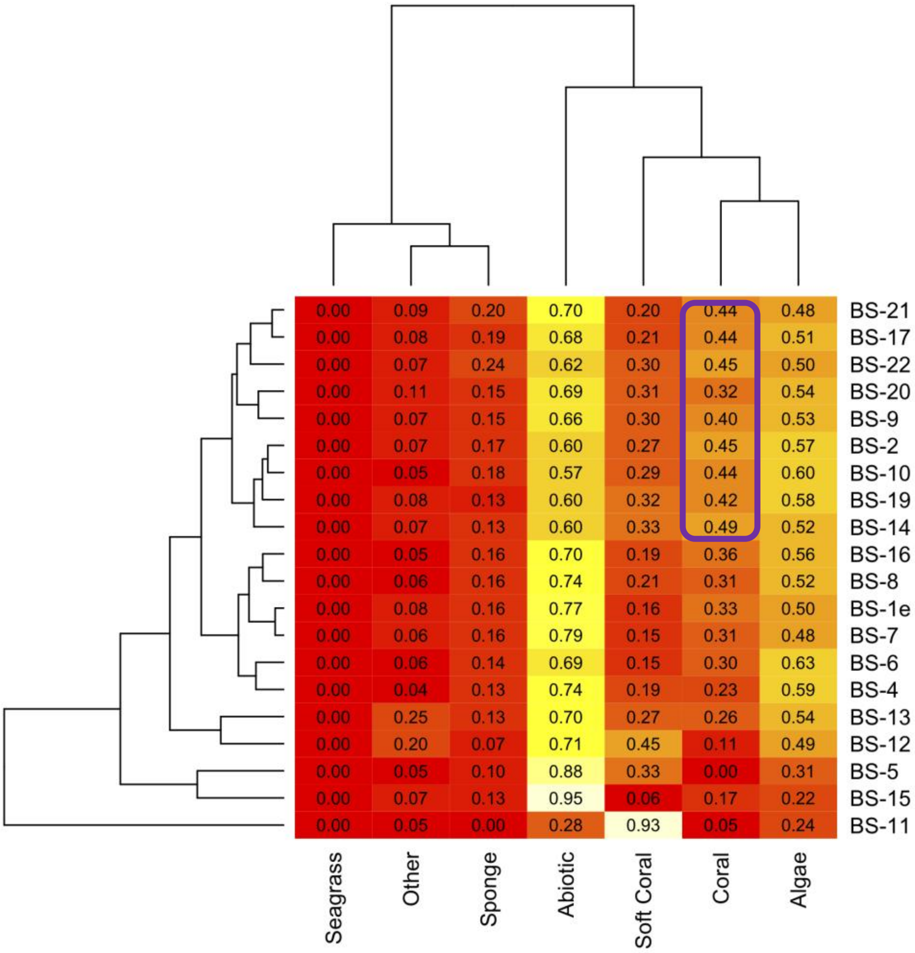

Figure 23. Barracouta Shoal - Heatmap and cluster analysis (complete linkage), row and column ordered, based on Hellinger transformed distance matrix for major benthic biotic groups found on Barracouta Shoal transects. Cell values are labeled with correlation statistic (R-sq). This cluster analysis varies slightly from the bootstrapped analysis shown in Figure 22, as it is the result of a single analysis and was not bootstrapped. It is presented here primarily to aid interpretation of which major benthic groups are influencing the grouping of transects. The lighter the colour in each box the greater the degree to which that class of benthos is associated with a particular transect. A purple box has been overlaid to indicate how this type of map can be used to clarify which major benthic group has a significant effect on the grouping. In this example the purple box highlights a group of transects with tended to contain hard coral as a significant component.

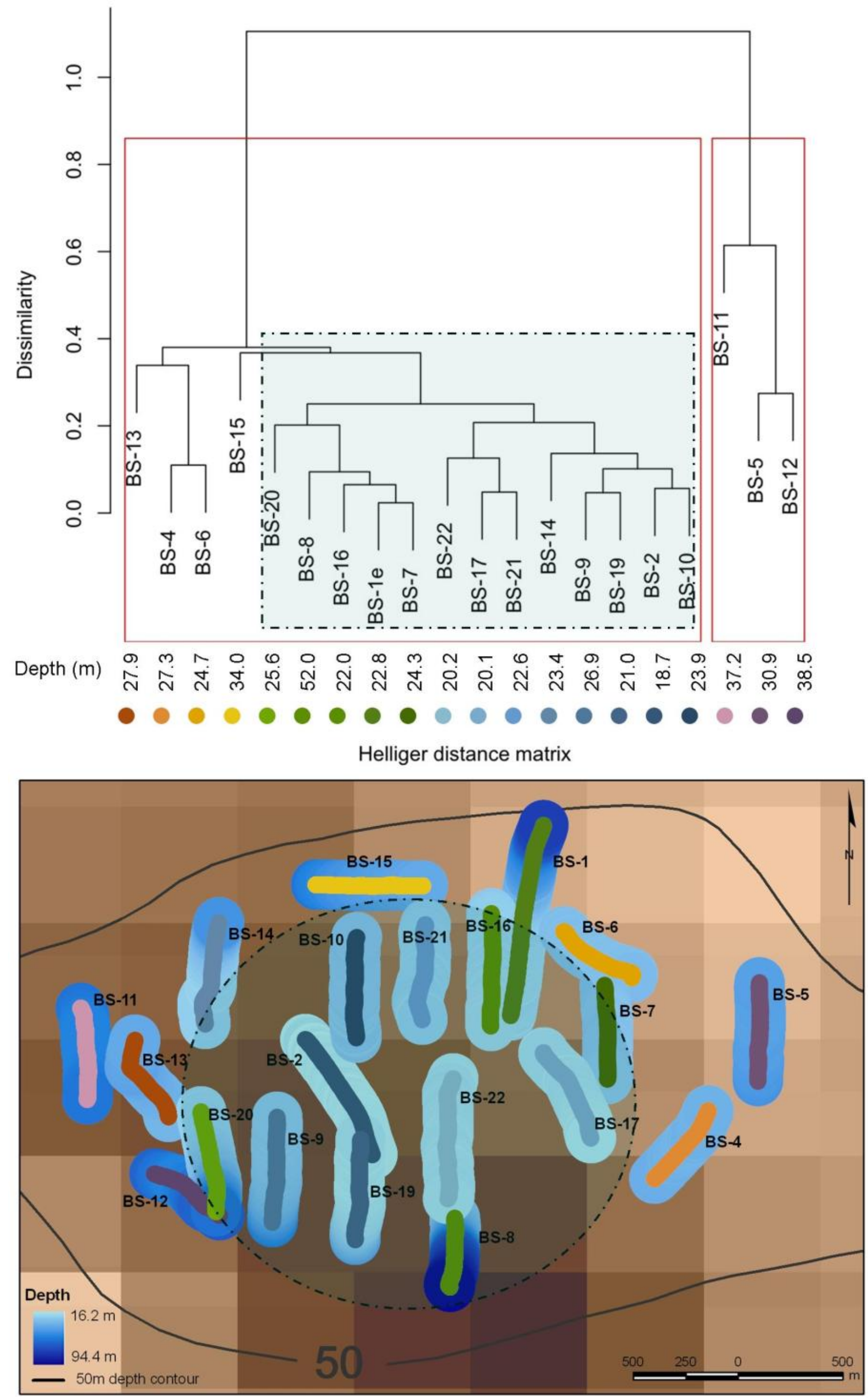

Figure 24. Barracouta Shoal - Spatial distribution of similar transects, based on cluster analysis above. Mean depth data is also shown under each transect in the cluster. The degree of similarity, using the Hellinger distance matrix, has been colour coded, with similar transect groups shown displayed in similar colour tones, e.g., blue tones versus green or yellow tones. The dotted circle encloses a mixed group of transects clustering together, as indicated by the dotted rectangle in the Hellinger matrix. This larger cluster breaks down into two subgroups, those slightly shallow transects around the central apex of the shoal, shown in blue, containing more hard and soft coral than the green transects.

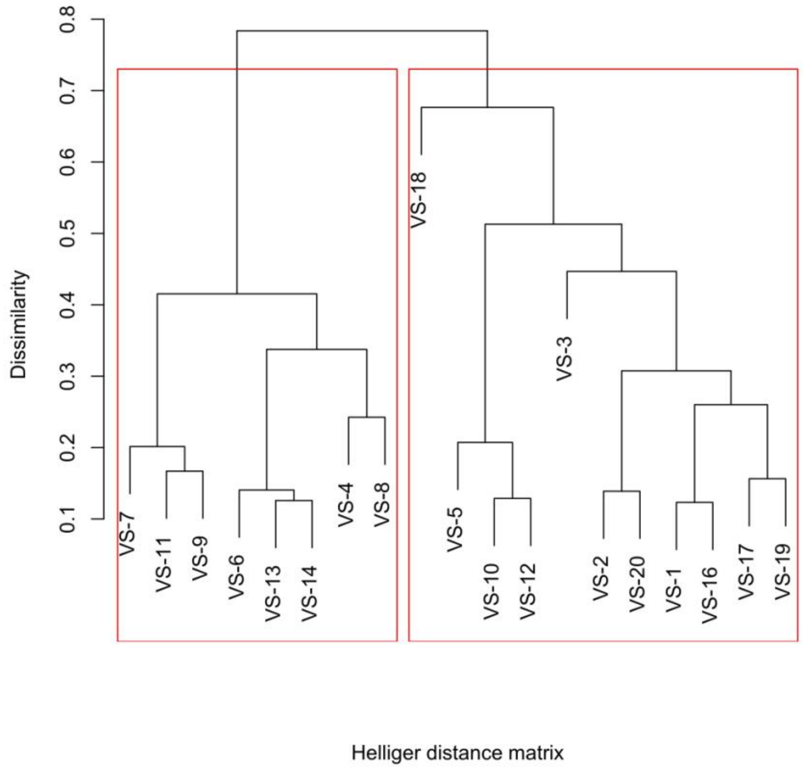

Figure 25: Vulcan Shoal - Cluster analysis (complete linkage) based on Hellinger transformed distance matrix for major benthic biotic groups found on Vulcan Shoal transects. Two robust groups (outlined in red) are identified using bootstrapped significance calculation.

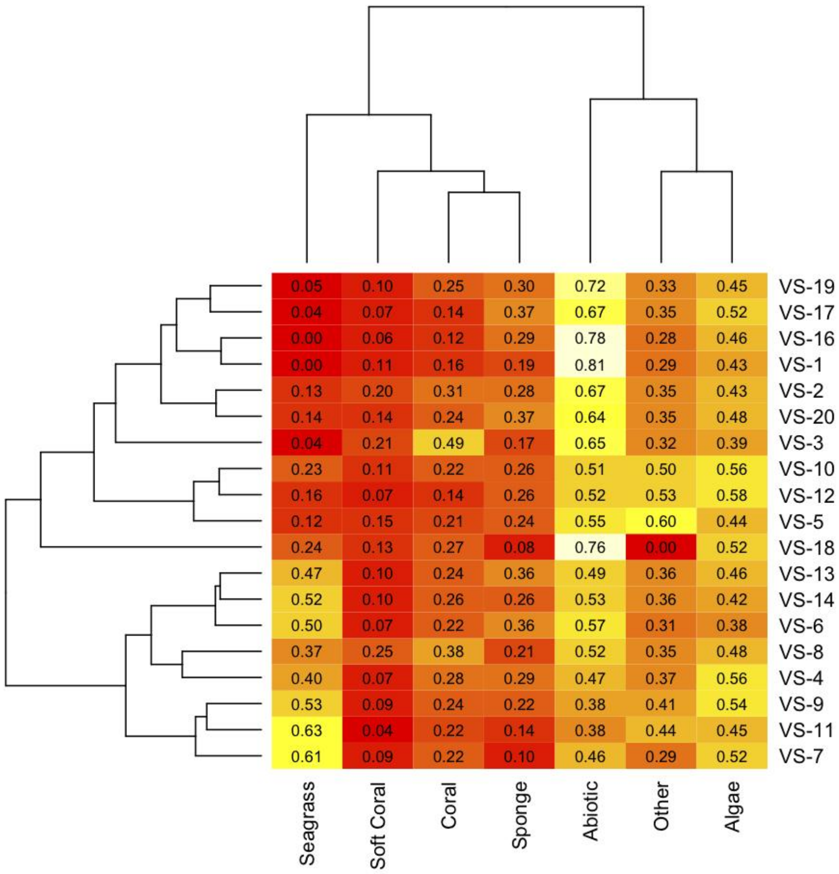

Figure 26: Vulcan Shoal - Heatmap and cluster analysis (complete linkage), row and column ordered, based on Hellinger transformed distance matrix for major benthic biotic groups found on Vulcan Shoal transects. Cell values are labeled with correlation statistic (R-sq). This cluster analysis varies slightly from the bootstrapped analysis shown in Figure 25, as it is the result of a single analysis and was not bootstrapped. It is presented here primarily to aid interpretation of which major benthic groups are influencing the grouping of transects. The lighter the colour in each box the greater the degree to which that class of benthos is associated with a particular transect.

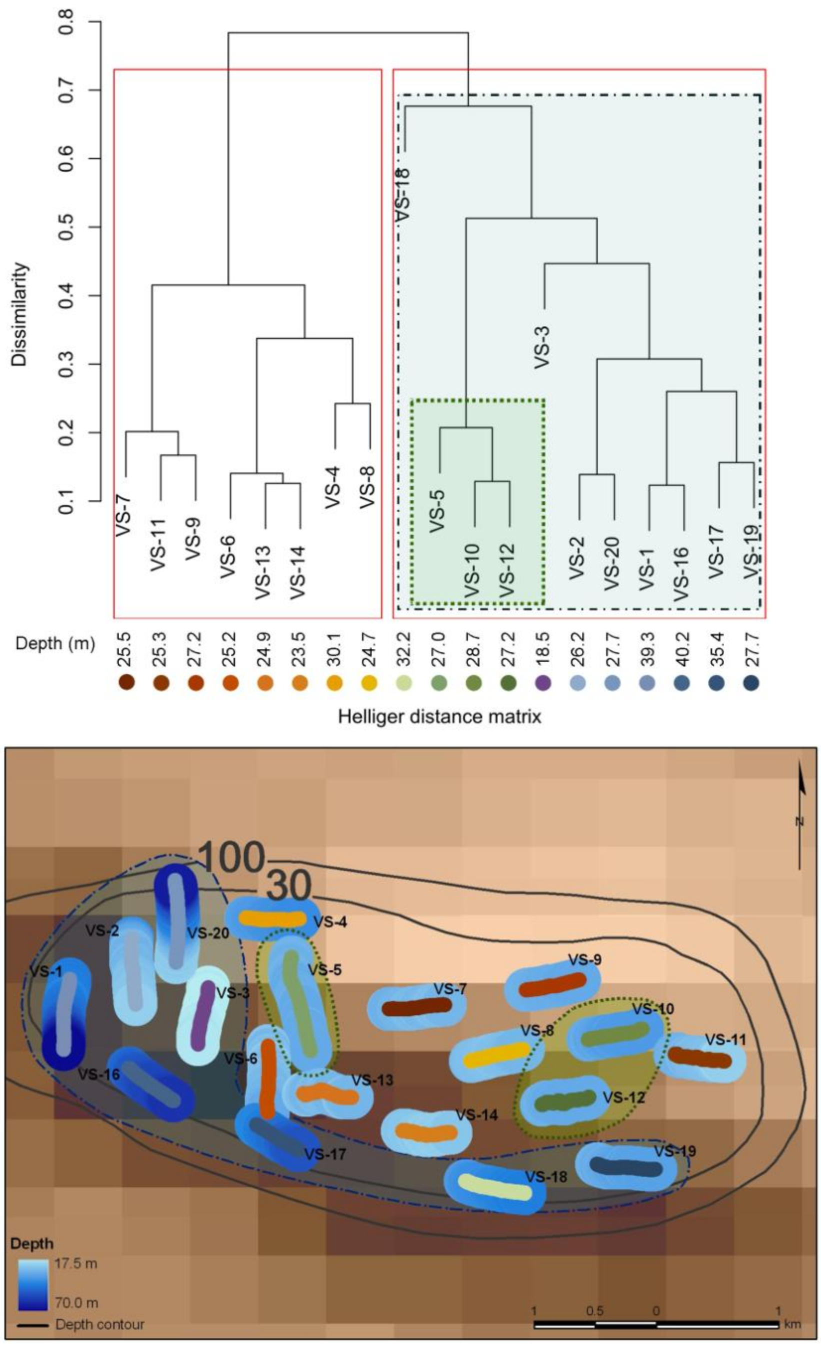

Figure 27. Vulcan Shoal - Spatial distribution of similar transects, based on cluster analysis above. Median depth data is also shown under each transect in the cluster. The degree of similarity, using the Hellinger distance matrix, has been colour coded, with similar transect groups shown displayed in similar colours, e.g. blue tones versus green or yellow tones. The dotted area encloses a group clustering together as indicated by the dotted rectangle in the Hellinger matrix. This larger cluster breaks down into three subgroups, those slightly shallow transects around the central apex of the shoal, shown in yellows and browns, containing abundant seagrass, three transitional transects, shown in green with <5% seagrass, and the remaining group along the south and west margin, shown in greys, with low seagrass and more bare substrate.

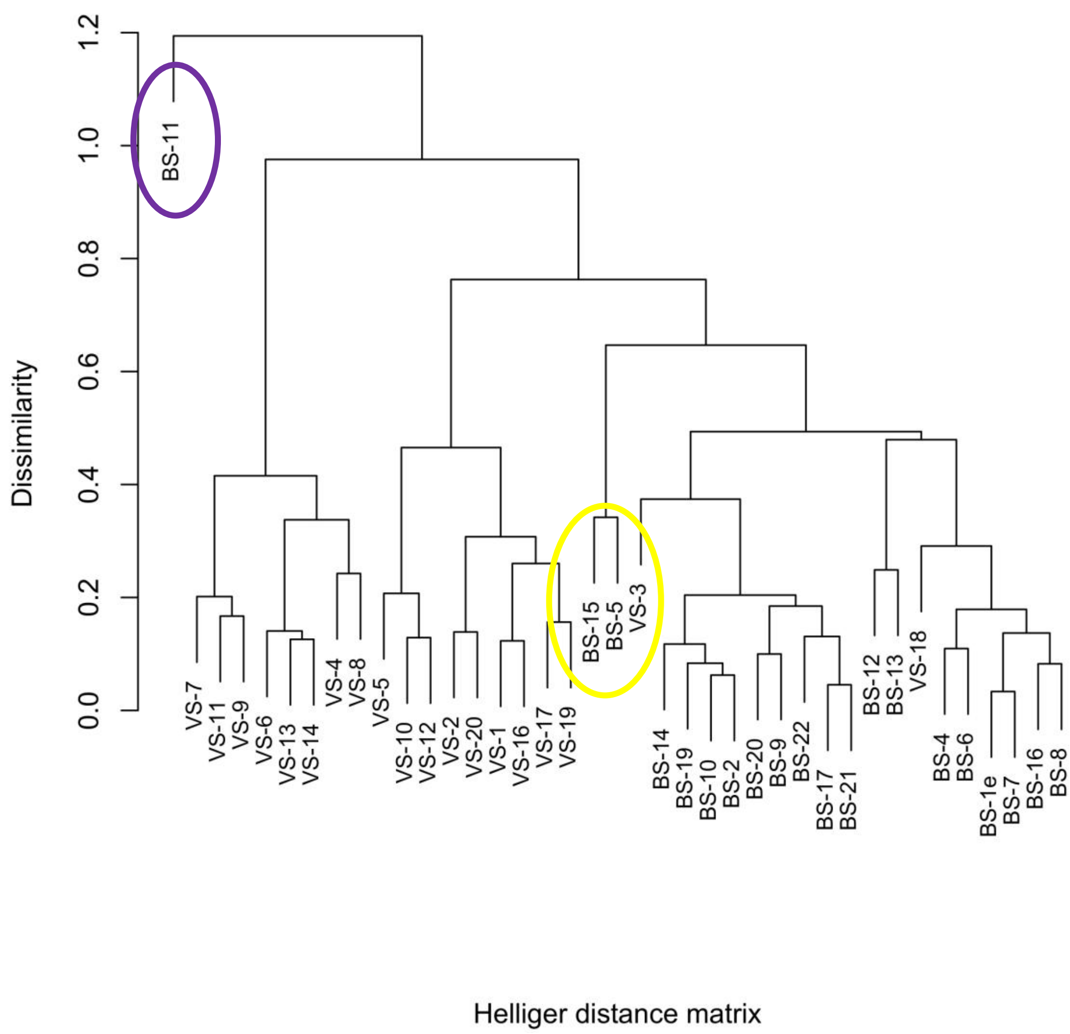

Figure 28. Barracouta and Vulcan Shoal comparison -Cluster analysis (complete linkage) based on Hellinger transformed distance matrix for major benthic biotic groups found on Vulcan Shoal transects. Two robust groups are identified using bootstrapped significance calculation. The transects on each shoal, labeled BS or VS respectively, clearly group together, based on benthic community patterns. An extreme outlier is transect BS-11, circled in purple, which represented to dense field of soft coral *Nepthea*. A small group of transects (BS-5, BS-15 and VS -3) circled in yellow are intermediate between the two shoal groups, having in common high abiotic cover, moderate soft coral and no seagrass.

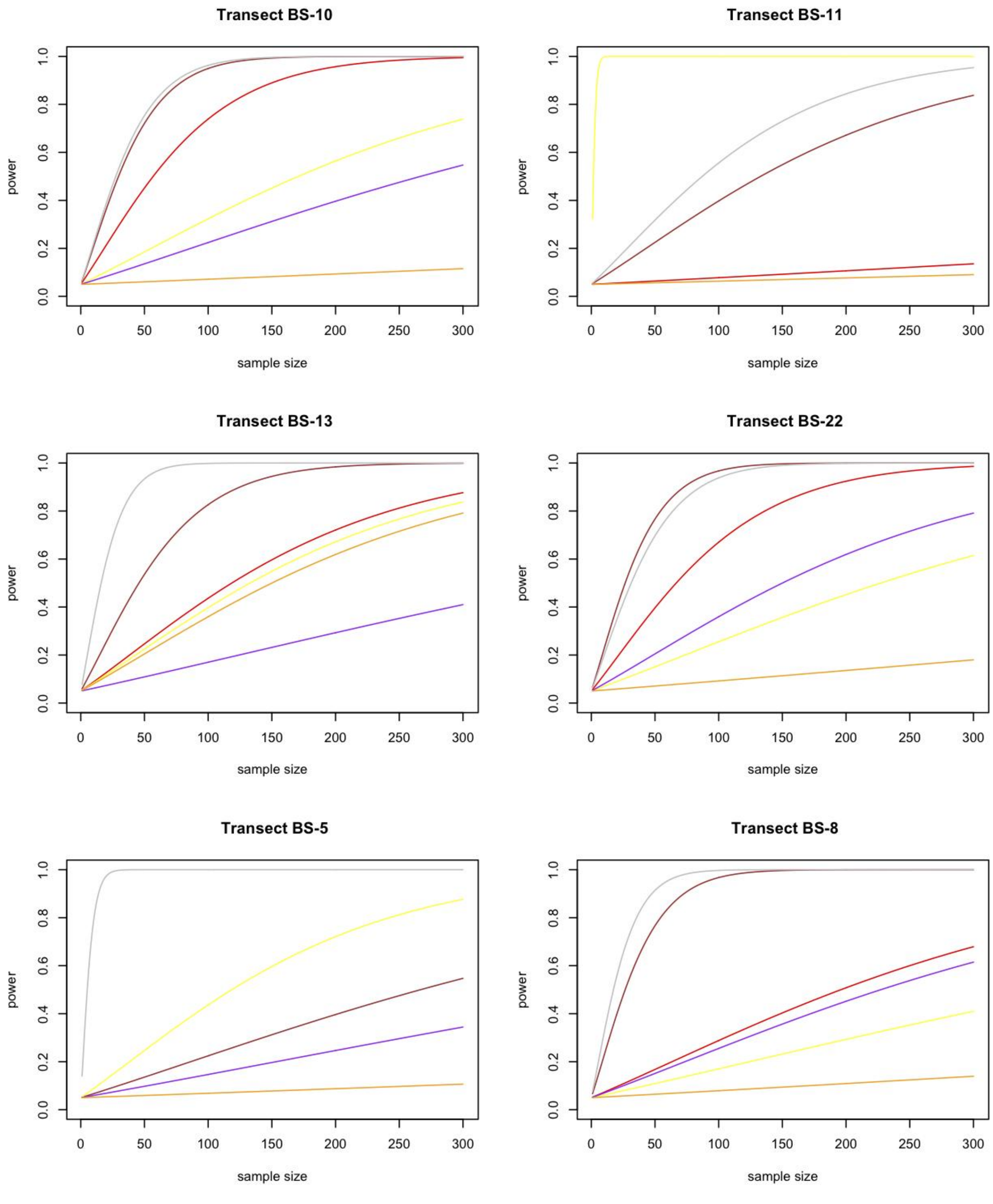

Figure 29. Barracouta Shoal - power analysis of six transects with divergent benthic coverage of major habitat groups, identified by cluster analysis. Total sample size **n** is 300 photoquadrats, equivalent to approximately 9 transects with a photo analysed every 10m. Benthic groups coral are shown in red, algae in brown, soft coral in yellow, sponge in purple, other in orange, seagrass in green and abiotic in gray.

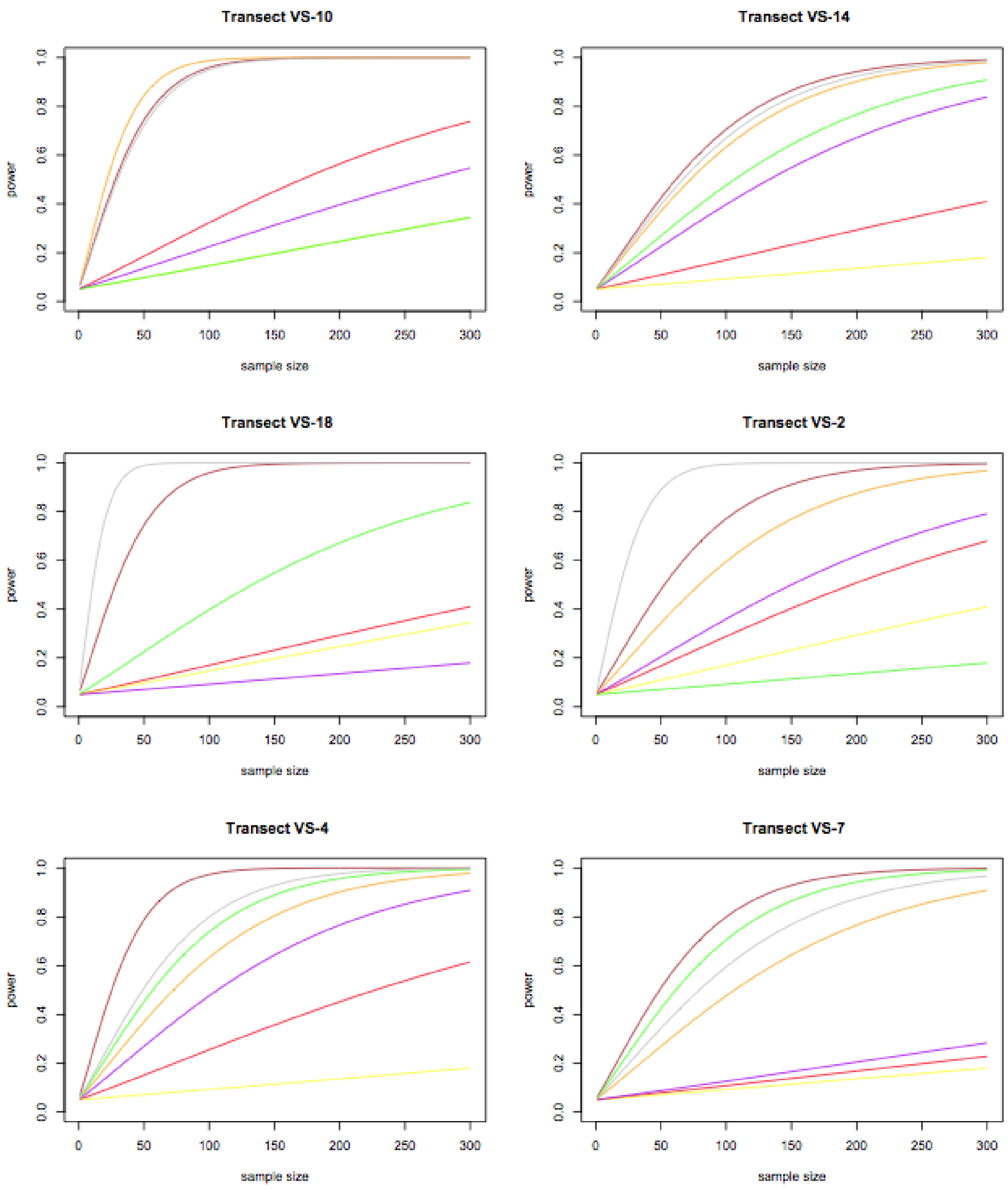

Figure 30. Power analysis of six transects from Vulcan shoal with divergent benthic coverage of major habitat groups, identified by cluster analysis. Total sample size **n** is 300 photoquadrats, equivalent to approximately 9 transects. Benthic groups coral are shown in red, algae in brown, soft coral in yellow, sponge in purple, other in orange, seagrass in green and abiotic in gray.

Power analysis

The power analysis demonstrates that the habitat variability encountered across these shoals will strongly influence the sampling effort required to detect changes in the order of 20% for major biological groups. Figures 29 and 30 provide comparison power analyses for six transects on each shoal that are representative of the range of benthic communities encountered.

It is clear that in locations where benthic cover is high and a major biotic class such as algae or soft coral is extensive, adequate power to detect a 20% change in that class of biota can be generated with just a few transects. For example the dense soft coral field on Barracouta is extremely even and just a single tow repeated in that habitat would provide enough data to detect such a level of change (see Fig. 29, transect BS-11).Nonetheless, it would be prudent to undertake triplicate tows as a minimum.

As can be seen in Figures 29 and 30, the 95% confidence level to detect a 20% change in major groups can be reached in many habitat types or benthic classes such as Abiotic and Algae on both Barracouta and Vulcan Shoal by undertaking approximately 6 transects. However, there are fewer locations where the density and evenness of distribution of significant Coral or Seagrass habitats could be surveyed with an equivalent level of power using the same number of transects and even in these areas 6 - 9 transects , equivalent to 300 photos, would be required. Consequently, for most biotic groups that occur in non-trivial amounts (i.e. 10% cover or greater) a sample size of between 6 and 9 transects per habitat type was required to estimate point cover to within 20% around mean value and with a power of 95% and allow detection in of change in point cover of 20% or greater.

Habitat groups with typically low prevalence (i.e. sponge) and/or high variability (i.e. seagrass) would require many more than 9 transects per habitat to characterize point coverage and pick up change. If this was important when estimating point coverage for this type of low prevalence of high variability groups, for example in a monitoring program, it would be necessary to revise the sampling method and sample plan to produces less variance in point cover estimates. Generally these alternative methods require much high spatial accuracy when sampling and better supporting data, such as multibeam bathymetry.

Other shoals

The results of the initial survey support the idea that the submerged shoals in the Timor Sea can support diverse tropical ecosystems and in many cases, particularly where the depths are shallow enough to support phototrophic organisms, may support a typical array of coral reef primary producers and associated biodiversity. Based on general observations in this region, benthic primary producers such as algae and reef building corals can be dominant to depths of 50-60m at least. On this basis a preliminary analysis of the bathymetry around the Montara Well Head platform has identified more than 20 possible shoal features within 100km distance and >100 similar bathymetric features within 200km (Fig. 31).

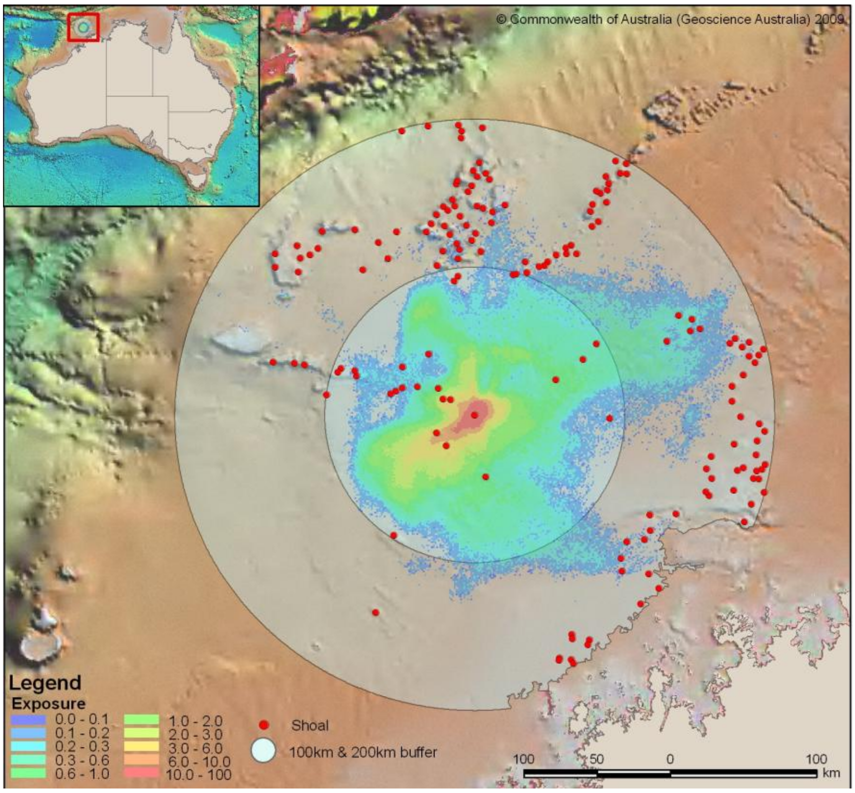

Figure 31. Potential shoal type habitat locations in the vicinity of the Montara spill. Shoals type features, indicated by red dots, were identified from the Australian hydro-geographic charts A00314, A00319 and A00320 and defined as abrupt submerged features rising from deeper than 50 meters. Depths of less than 50 meters along the coast of Australia have been excluded from the analysis. Due to much of the region being inadequately surveyed this analysis may only be used as a guide.

Discussion

Consequently our results are the first to describe these benthic communities. Both Barracouta and Vulcan Shoals support diverse biological communities across their shallow plateau areas, with many organisms typical of shallow water coral reefs. There were significant differences between the two shoals in the relative abundance of dominant groups, particularly the algae, seagrass, hard corals and soft corals.

The surveys of areas down to 40 m revealed bare sand and rubble as a ubiquitous component 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 life. To the degree measurable from image analysis, there was no evidence of major recent disturbance or mortality in the biota.

Within each shoal there were distinct habitat areas where individual organism types dominated, but there were also broad patches with mixed biota in juxtaposition. The differences in community structure between the two shoals and the fact that on Barracouta soft corals seem much more common and create a large field at one end, while on Vulcan the same can be said of seagrass, raises a number of questions about what processes are driving these patterns. The disturbance history of these plateau areas, due to passing storms, may be partly responsible, but the distribution of substrates and the ability of some organisms to self propagate or self seed to the parental shoal are also likely factors. Localised recruitment due to very limited larval dispersal has been observed a number of invertebrate species, including ascidians similar to the species observed on Vulcan Shoal (see Olson and McPherson 1987). The extensive field of soft coral at the western margin of Barracouta Shoal may be a consequence of that species, likely to be in the genus *Nepthea*, propagating asexually, as has been demonstrated through the production of runner like mechanisms in a number of soft corals (see Walker and Bull 1983 and references therein). Similar processes may have contributed to the dense patches of seagrass on Vulcan Shoal, as *T. ciliatum*, like most seagrasses demonstrates primarily vegetative growth through its rhizomes (Bandeira and Nilsson, 2001).

If future monitoring is required as part of a formally triggered component of the Montara Monitoring Plan, our analyses suggest sampling intensity of 30 - 40 tows would give adequate power to detect moderate changes in major habitats across any individual shoal. This level of effort could be reduced by targeting specific habitats of interest in more detail, but greater sampling precision, allowing a return to the exact survey transect , individual quadrat or coral, may be required in certain habitats. If so then alternative methods must be applied and could include the use of divers, ROV and AUV technologies. A number of potential shoal-type habitats have been identified, solely on available bathymetry, within 100 km of the Montara Well Head Platform. The preliminary analysis reported here, although relying on several assumptions, provides some guidance for future sampling effort. High resolution bathymetry is an additional dataset that would be highly desirable in future work, and could facilitate rigorous interpolation of habitat extent between survey points. If better bathymetry is available beforehand it would also enable more efficient sample design.

The results of this survey do not provide any insight into sub-lethal, chronic or highly localized effects on these shoals. Additionally, it is not possible to extrapolate the benthic condition recorded for these shoals to other shoals in the region. The pathways for any interaction or potential exposure that may have occurred between the Montara spill and the benthic communities of Barracouta and Vulcan Shoals may not be the same for other shoals that lie under the spill area. Similarly, given the biological differences observed between these two shoals, it is not yet possible to confidently predict what exists on the remaining unsurveyed shoals of the region. Consequently it is not clear if un-surveyed shoals under the spill support unusual or more complex biological communities with differing sensitivities.

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Appendix1

Table A1. Real-time habitat classification system for towed video TowVid analysis.

Habitat (Descriptor[1]=Dense, Medium, Sparse); (No Descriptor[2])	Substrate	Organism/Items of Interest
Sponge Garden[1]	Soft Mud	Anemone
Alcyonarian Garden[1]	Silt (Sandy-Mud)	Ascidian
Gorgonian Garden[1]	Sand	Bryozoan
Whip Garden[1]	Coarse Sand	Holothurian
Hard Coral Garden[1]	Sand Waves/Dunes	Starfish
Seagrass[1]	Rubble/Stones (<250 mm)	Crinoid
Filter-Feeders Mixed[1]	Rocks (>250 mm)	Urchin
Halimeda[2]	Low Relief Reef (<0.5 m)	Hydroid
Macroalgae[2]	High Relief Reef (0.5-2.0 m)	Clam
Algae Turf/Microphyton[2]	Bioturbated	Seapen
Halimeda/Hard Coral[2]		Rhodolith
Filter-Feeders/Hard Coral[2]		Solitary Coral

Table A2. Post-processing Coral Point Count (CPCe) analysis - abiotic and biotic classification system.

Substrate	Hard Coral	Soft Coral	Sponge	Algae & Seagrass	Other & Unknown
Consolidated Substrate	Branching Acropora	Whip	Clathrate	Rhodolith	Ascidian
Bioturbated Sand	Digitate Acropora	Gorgonian Fan	Erect Laminar	Brown	Zoanthid
Bioturbated Silt	Encrusting Acropora	Gorgonian Branching	Erect Branching	Green	Urchin
Silt	Staghorn Acropora	Arborescent	Simple Erect	Red	Calcareous Bryozoan
Sand	Corymbose Acropora	Branching	Stalked Erect	Halimeda	Fleshy Bryozoan
Coarse Sand	Submassive/columnar Acropora	Soft Coral	Solid Massives	Turf Algal Community	Hydroid
Gravel	Tabulate Acropora	Capitate	Barrel/Ridgelike Massives	Crustose Coralline	Other Organisms
Shells/Skeletal Rubble	Bottlebrush Acropora	Digitate	Cup/Vase Shape	Coralline	Unknown
Stones	Branching non-Acropora	Encrusting	Encrusters	Articulated Calcareous	
Rocks	Encrusting non-Acropora	Erect		Filamentous	
Dead Coral (Recent)	Foliose non-Acropora	Lobate		Foliose	
	Massive non-Acropora	Massive		Seagrass	
	Fungid/Solitary Coral	Sea Pen			
	Submassive/columnar non-Acropora				
	Tabulate non-Acropora				

Appendix 2.

Date	Technique	Site	Time start	Time end	Lat start	Long start	Depth start	Lat end	Long end	Depth end
16-Apr	Towvid	Bar_BS_1e	16:19:40	16:47:02	-12.5440	124.0367	21.4	-12.5358	124.0382	58
16-Apr	Towvid	Bar_BS-2	18:03:10	18:16:02	-12.5450	124.0279	18.1	-12.5500	124.0308	18.1
17-Apr	Towvid	Bar_BS-3	8:45:10	8:57:38	-12.5400	124.0424	25.8	-12.5443	124.0442	23.5
17-Apr	Towvid	Bar_BS-4	9:19:30	9:28:50	-12.5510	124.0429	28.2	-12.5481	124.0452	27.1
17-Apr	Towvid	Bar_BS-5	9:38:18	9:48:08	-12.5468	124.0473	32.8	-12.5426	124.0474	30.4
17-Apr	Towvid	Bar_BS-6	10:00:32	10:10:30	-12.5404	124.0390	25.1	-12.5424	124.0419	25.3
17-Apr	Towvid	Bar_BS-7	10:32:16	10:40:48	-12.5427	124.0408	24.7	-12.5467	124.0409	23.3
17-Apr	Towvid	Bar_BS-8	11:32:56	11:41:38	-12.5527	124.0343	24.2	-12.5557	124.0341	94.4
17-Apr	Towvid	Bar_BS-9	11:55:50	12:05:46	-12.5529	124.0265	37.6	-12.5483	124.0267	23
17-Apr	Towvid	Bar_BS-10	12:15:46	12:27:26	-12.5449	124.0301	24.2	-12.5406	124.0301	24.3
17-Apr	Towvid	Bar_BS-11	13:56:20	14:06:04	-12.5437	124.0183	38.8	-12.5476	124.0186	38.4
17-Apr	Towvid	Bar_BS-12	14:18:02	14:34:34	-12.5508	124.0214	40.9	-12.5526	124.0242	42.3
17-Apr	Towvid	Bar_BS-13	14:50:36	15:01:28	-12.5483	124.0221	26.6	-12.5450	124.0206	28.5
17-Apr	Towvid	Bar_BS-14	15:08:02	15:18:58	-12.5443	124.0236	22.2	-12.5400	124.0242	32.9
17-Apr	Towvid	Bar_BS-15	16:16:42	16:28:10	-12.5384	124.0284	38.2	-12.5384	124.0330	29.3
17-Apr	Towvid	Bar_BS-16	16:39:36	16:49:16	-12.5396	124.0359	21.9	-12.5444	124.0359	21.3
17-Apr	Towvid	Bar_BS-17	16:59:24	17:09:52	-12.5456	124.0381	20.1	-12.5493	124.0402	19.3
17-Apr	Towvid	Bar_BS-18	17:18:24	17:25:56	-12.5516	124.0399	20.6	-12.5537	124.0365	29.4
17-Apr	Towvid	Bar_BS-19	17:34:26	17:44:24	-12.5536	124.0301	30.8	-12.5493	124.0303	19.5
17-Apr	Towvid	Bar_BS-20	17:52:46	18:01:20	-12.5481	124.0234	22	-12.5524	124.0241	38.6
18-Apr	Towvid	Var_VS-1	8:54:58	9:01:24	-12.7997	124.2562	34.1	-12.8049	124.2557	70
18-Apr	Towvid	Var_VS-2	9:14:18	9:23:56	-12.7967	124.2607	32.2	-12.8015	124.2610	23.3
18-Apr	Towvid	Var_VS-3	9:35:06	9:41:06	-12.8003	124.2663	17.8	-12.8045	124.2656	19.3
18-Apr	Towvid	Var_VS-4	10:13:56	10:27:22	-12.7952	124.2691	27.7	-12.7953	124.2731	32.1
18-Apr	Towvid	Var_VS-5	10:38:18	10:48:46	-12.7981	124.2725	26.3	-12.8050	124.2739	27.4
18-Apr	Towvid	Var_VS-6	10:56:16	11:03:10	-12.8046	124.2708	25.6	-12.8095	124.2707	27.4
18-Apr	Towvid	Var_VS-7	11:15:18	11:24:54	-12.8019	124.2796	24.7	-12.8016	124.2838	25.5
18-Apr	Towvid	Var_VS-8	11:31:34	11:40:40	-12.8057	124.2857	25.2	-12.8048	124.2895	25.5
18-Apr	Towvid	Var_VS-9	11:48:46	11:58:42	-12.8005	124.2897	26.3	-12.7997	124.2936	27.6
18-Apr	Towvid	Var_VS-10	12:07:34	12:18:00	-12.8041	124.2943	27	-12.8033	124.2983	29.7
18-Apr	Towvid	Var_VS-11	14:10:48	14:21:18	-12.8052	124.3007	27	-12.8057	124.3043	23.3
18-Apr	Towvid	Var_VS-12	14:34:14	14:45:00	-12.8089	124.2909	26.5	-12.8083	124.2943	27.6
18-Apr	Towvid	Var_VS-13	14:59:22	15:09:56	-12.8081	124.2733	24.4	-12.8084	124.2769	25.6
18-Apr	Towvid	Var_VS-14	15:18:52	15:29:52	-12.8108	124.2806	24.6	-12.8110	124.2842	23.8
19-Apr	Towvid	Var_VS-15c	20:29:24	8:38:16	-12.8018	124.2626	20.4	-12.8079	124.2630	39.1
19-Apr	Towvid	Var_VS-16	8:55:52	9:04:10	-12.8062	124.2605	36.4	-12.8086	124.2638	44.1
19-Apr	Towvid	Var_VS-17	9:21:34	9:31:46	-12.8104	124.2699	32.3	-12.8123	124.2731	39.1
19-Apr	Towvid	Var_VS-18	9:54:00	10:03:40	-12.8145	124.2853	29.7	-12.8154	124.2896	34
19-Apr	Towvid	Var_VS-19	10:12:28	10:23:26	-12.8133	124.2949	26.9	-12.8137	124.2992	28.5
19-Apr	Towvid	Var_VS-20	12:30:04	12:42:26	-12.7985	124.2640	22.4	-12.7927	124.2639	57.2
19-Apr	Towvid	Bar_BS-21	17:04:16	17:14:50	-12.5401	124.0331	23.1	-12.5442	124.0329	22.5
19-Apr	Towvid	Bar_BS-22	17:21:22	17:33:34	-12.5467	124.0343	20.5	-12.5519	124.0340	19.9
17-Apr	Tripod cam	BS1	15:56:00	N/A	-12.5427	124.0175	N/A	N/A	N/A	N/A
19-Apr	Tripod cam	VS1	9:07:33	9:13:50	-12.8093	124.2644	18	N/A	N/A	N/A
19-Apr	Tripod cam	VS2	9:40:51	9:44:04	-12.8113	124.2715	12	-12.8123	124.2714	N/A
19-Apr	Tripod cam	VS3	10:09:45	10:34:53	-12.8165	124.2999	N/A	12.8165	124.2998	N/A
19-Apr	Tripod cam	VS4	10:58:00	11:01:59	-12.8069	124.3017	N/A	-12.8075	124.3022	N/A
19-Apr	Tripod cam	VS5	11:07:41	11:13:21	-12.8027	124.2981	N/A	-12.8034	124.2987	N/A
19-Apr	Tripod cam	VS6	11:26:18	11:29:40	-12.8023	124.2841	15	-12.8028	124.2843	N/A
19-Apr	Tripod cam	VS7	11:58:22	12:05:35	-12.8016	124.2659	18	-12.8021	124.2669	N/A
19-Apr	Tripod cam	VS8	12:14:45	12:21:44	-12.7982	124.2606	19	-12.7985	124.2610	N/A
19-Apr	Tripod cam	BS2	14:53:14	15:00:22	-12.5454	124.0477	29	-12.5446	124.0471	27
19-Apr	Tripod cam	BS3	15:09:27	15:16:05	-12.5418	124.0400	21	-12.5412	124.0395	22
19-Apr	Tripod cam	BS4	15:24:08	15:28:50	-12.5526	124.0393	23	-12.5521	124.0386	20
19-Apr	Tripod cam	BS5	15:36:35	15:42:27	-12.5486	124.0299	19	-12.5484	124.0285	19
19-Apr	Tripod cam	BS6	15:48:11	15:56:22	-12.5470	124.0211	25	-12.5472	124.0183	35
19-Apr	Tripod cam	BS7	16:13:40	16:19:31	-12.5414	124.0236	21	-12.5418	124.0213	28
19-Apr	Tripod cam	BS8	16:40:39	16:47:04	-12.5384	124.0301	30	-12.5374	124.0294	54
19-Apr	Tripod cam	BS9	16:28:47	16:36:10	-12.5423	124.0300	19	-12.5420	124.0298	19