National Environmental Research Program

MARINE BIODIVERSITY hub

Theme 1 Project 2

Analysis of Approaches for Monitoring Biodiversity in Commonwealth Waters
- Field work report

Althaus, F., Barrett, N., Dambacher, J. M., Davies, P., Ferrari, R., Ford, J., Hayes, K. R., Hill, N., Hosack, G., Hovey, R., Huang, Z., Hulls, J., Ingleton, T., Jordan, A., Kendrick, G., Kool, J., Lawrence, E., Leeming, R., Lucieer, V., Malcolm, H., Meyer, L., Monk, J., Nichol, S., Peel, D., Perkins, N., Siwabessy, J., Sherlock, M., Martin, T., Tran, S. M. , Walsh, A., Williams, A.

May 2016

Australian Government
Department of the Environment

MUSEUMVICTORIA

CHARLES DARWIN UNIVERSITY

Australian Government

UTAS

CSIRO

Australian Government
Geoscience Australia

The University of Western Australia
Achieving International Excellence

Australian Institute of Marine Science

Enquiries should be addressed to:
Keith Hayes
keith.hayes@csiro.au

Copyright

Acknowledgement

This work was undertaken for the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Research Program (NERP). NERP Marine Biodiversity Hub partners include the Institute for Marine and Antarctic Studies, University of Tasmania; CSIRO Wealth from Oceans National Flagship, Geoscience Australia, Australian Institute of Marine Science, Museum Victoria, Charles Darwin University and the University of Western Australia.

Important Disclaimer

Contents

List of Figures – *Executive Summary*

List of Figures

List of Tables

EXECUTIVE SUMMARY

The overall objective of this project was to contribute to a blue-print for a sustained national environmental monitoring strategy for monitoring biodiversity in the Commonwealth Marine Areas. The approach would apply to Key Ecological Features (KEFs) and the Commonwealth Marine Reserve (CMR) Network, focusing initially on the Southeast Marine Region. CMRs and KEFs are large, remote and poorly known, so this project focussed on identifying flexible, statistically robust approaches to survey design and data collection that could result in comprehensive descriptions of the surveyed area and at the same time provide a statistical baseline for future repeat surveys in the same area. Given the conservation status and values of these areas, non-destructive sampling tools were prioritized, including remote sensing using acoustics (e.g. multibeam) that provide information on seafloor characteristics (bathymetry, hardness and texture), and direct observation using video and camera stills, taken by towed units, autonomous units or baited units. The final report is of necessity highly technical, reporting on the design and analytical issues addressed by this project. This executive summary is designed to provide an overview of the project and highlight the key findings relevant to policy makers and managers, omitting most of the technical detail. Readers interested in technical detail are referred to the main body of this report or the many research papers resulting from this work that are listed at the end of this summary.

Three field programs were undertaken. The largest survey was for the Flinders Commonwealth Marine Reserve (CMR) located offshore, northeast of Tasmania. This provided a baseline of the continental shelf, in the multiple use zone of this reserve, on which future monitoring can be built, and provides an initial characterization of the upper slope areas in the same zone of this CMR. A smaller survey targeted at known shelf reefs features in the Solitary Islands Marine Park (SIMP) and Solitary Islands Marine Reserve (SIMR) was designed to address specific sampling issues including: extending State-based research to this Commonwealth KEF, comparing autonomous and towed platforms for capturing video imagery, and examining statistical issues associated with the use of baited underwater remote videos (BRUVs). The third survey in the KEF east of the Houtman-Abrolhos islands was an exploratory survey designed to identify whether coral-kelp and other shelf reef communities in the State MPA extended into this KEF, and explore whether seabird diet could be used as a reliable indicator of pelagic ecosystem health.

In most cases, these surveys used a probabilistic, spatially balanced design known as a Generalized Random Tessellation Stratified (GRTS) design. GRTS has a number of benefits over other survey design methods, notably:

- It is a flexible sampling approach that can accommodate multiple survey objectives and changes to a planned survey because of, for example, adverse weather conditions, gear failure or a reduction in available funds.

- It provides unbiased estimates of habitats and biota in surveyed regions, thus it provides a suitable basis for establishing initial baselines with associated estimates of uncertainty.
- It can readily accommodate future repeat surveys and hence provides a suitable basis for establishing trends in the condition of critical habitat or the biomass (for example) of indicator species.
- It is a probabilistic sampling method and it can therefore be used to infer the status and trends of habitats and biota across an entire region, such as a multiple use zone within a CMR, without having to invoke additional statistical modelling and associated assumptions.

GRTS designs have been used by the United States National Parks Service for many years but to our knowledge, these surveys represent the first time they been employed in the marine environment. The three surveys were designed to demonstrate the power of this flexible, balanced sampling design for establishing robust baselines that can be built on in future monitoring and for exploring new areas for which little comprehensive data exist.

Flinders CMR

Habitat Classification

The GRTS approach used in the first phase of the Flinders CMR survey provided the following estimates for coverage of different habitat types on the shelf (see Figure A, reported figures are for hand digitisation of multi-beam sonar data): hard ground (1.1% with confidence intervals of 0.0% to 2.2%); mixed ground (21.8% with confidence interval of 15.7% to 27.9%) and soft ground (77.1% with confidence interval of 70.8% to 83.4%).

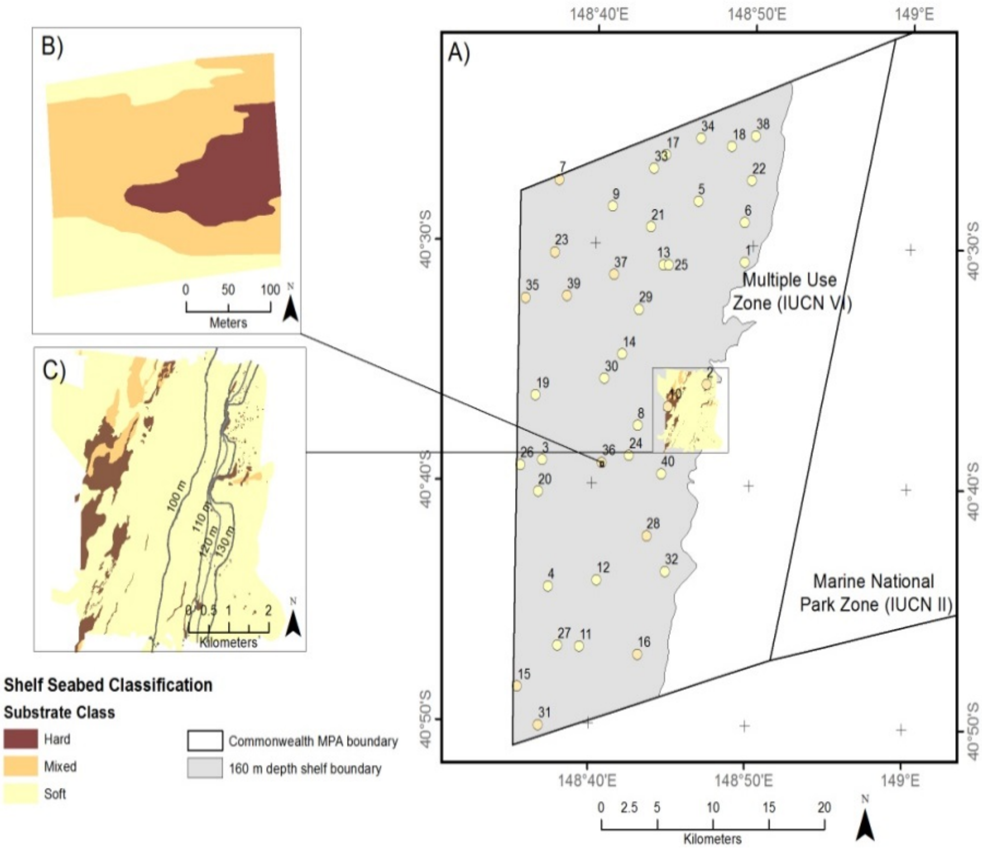


Figure A - Summary of the habitat classification of the 40 GRTS sites based on the drop camera survey and the multibeam sonar survey, illustrating the capacity of this approach to provide comprehensive habitat descriptions of unsurveyed areas where resources would not support a complete census.

Hard ground habitats were prioritised in the second phase of the survey because hard ground provides the exposed substrate needed for larger marine invertebrates to anchor and grow, and these larger attached marine invertebrates are more amenable to monitoring and are more vulnerable to anthropogenic physical disturbance. Mixed and soft habitats were sampled at a lower frequency to ensure that the surveys provided a comprehensive baseline including all known habitat types.

The GRTS approach was contrasted with continuous mapping of a particular area with multibeam sonar and an Autonomous Underwater Vehicle (AUV) (Figure B). The advantage of choosing an area to be mapped continuously is that we obtain a very detailed picture of the habitat across this area. The disadvantage of this approach, however, is that the area is selected judgementally (not probabilistically) and thus the information collected within this area cannot be extended to a wider area without additional statistical modelling and assumptions about the structure of these models, and the extent to which the selected area is representative of the CMR as whole.

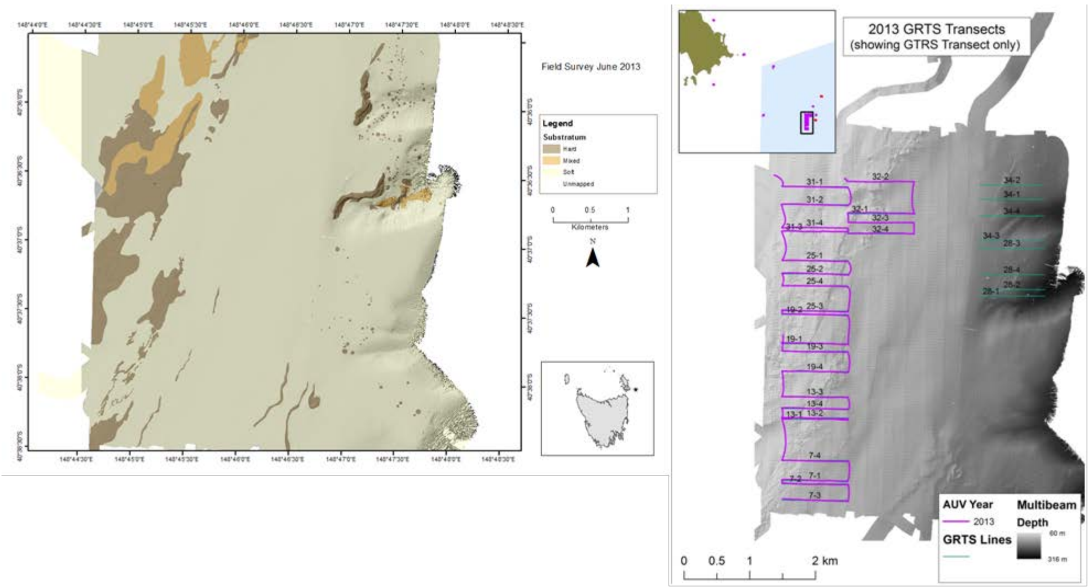


Figure B - Bathymetric map of the continuously mapped area of the Flinders CMR and resulting GRTS design for AUV sampling on the shelf and towed video on the slope.

The products from continuous mapping clearly include fine-scale detail not available from the broader GRTS survey, but this 30km2 area took approximately the same time to map, as the 774km2 of the shelf shown in Figure A. In this analysis, however, only one swath map pass of a 200m x 200m GRTS cells was undertaken, and this may have compromised the quality of the swath data. We recommend that future GRTS cells swath mapping, do two passes of larger cells (ensuring swath overlap) and this will slightly increase the time needed to complete a GRTS analysis.

Combining the swath bathymetry data collected in this project with previous multibeam data collected by CSIRO and UTAS (mainly on the slope) provides an overall picture of habitat types within the multiple use area of the Flinders CMR (Figure C).

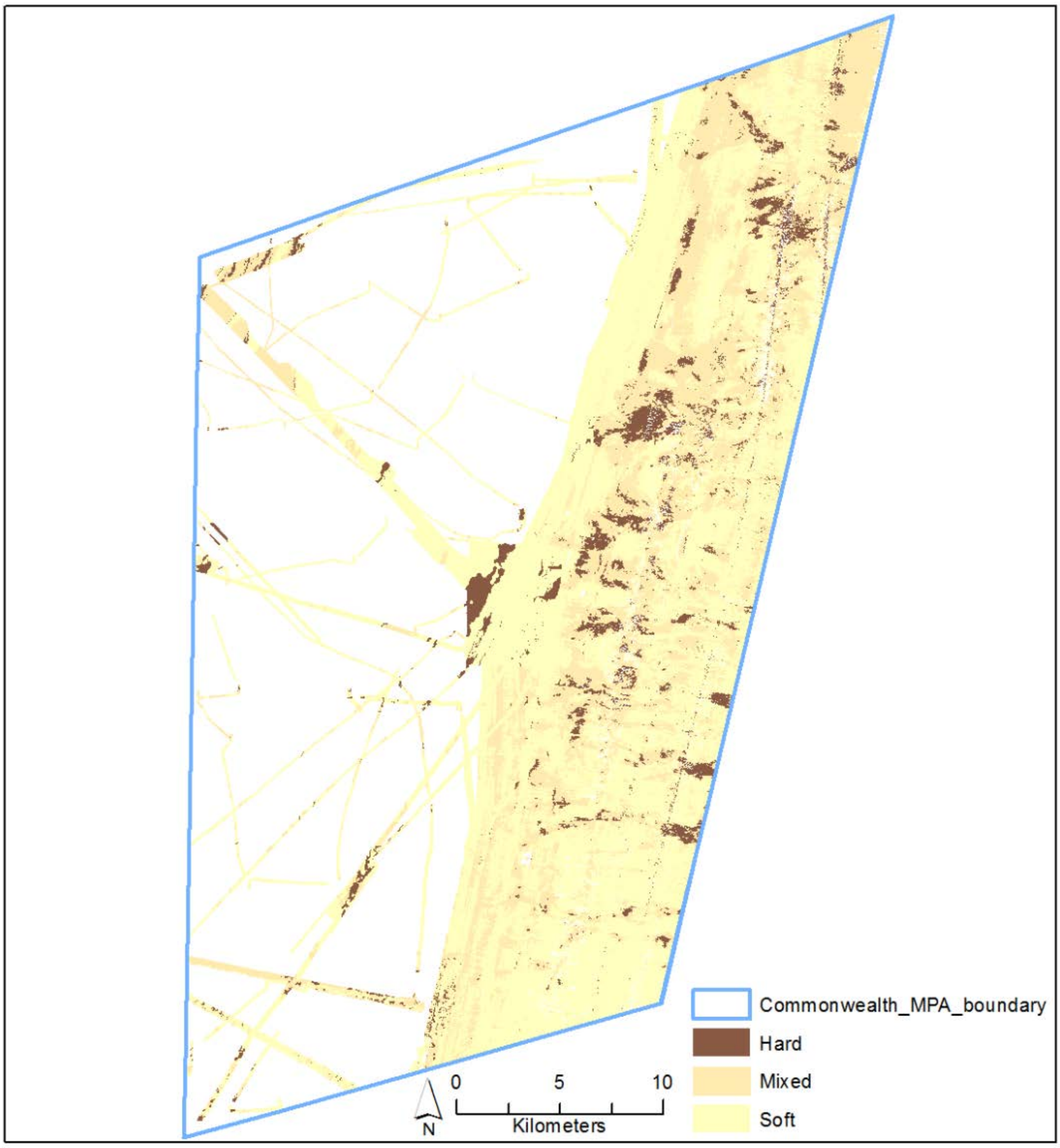


Figure C - Summary of shelf and slope habitats classifications for the multiple use zone of the Flinders CMR

The continental shelf within Flinders CMR is dominated by sandy seabed with the remainder of the benthic substrate comprised of sand-inundated low profile reef, where sand forms a thin (millimetre to decimetre scale) veneer over flat bedrock. The reefs are mostly flat features, comprising a series of slightly dipping layers of sedimentary rock that occasionally outcrop and where eroded form a 1–2 m high scarp. In the continuous mapped area, these scarps can be seen to extend ~5 km north-south as a semi-continuous feature, providing a stable rock surface for epibenthic communities of sponges and soft corals to attach. In places, the sand deposits form fields of active bedforms (sand waves, ripples) with sediment transport likely driven by a combination of strong tidal currents that sweep across the shelf and wave-generated currents, particularly during storms. We thus consider the sand veneer on reef to be ephemeral and expect that the boundaries between mapped areas of the different substrate types have the potential to shift, such that small areas of reef may be covered and uncovered over time.

Video Imagery

A total of 70 BRUV deployments was completed across the Flinders CMR shelf. Due to time and logistical constrains, shallow BRUVS were deployed in clusters of 5 based on phase 1 GRTS sites, prioritising hard ground sites. BRUVs were subsequently deployed at ‘mixed’ (8), and ‘sand’ (3) and one canyon head habitats to ensure a comprehensive description of the area. Three newly developed deep-water BRUVs that use a slow release liquefied bait to increase sampling times in this remote environment, were deployed for 12 recording periods at 500m depth on the slope.

All video and towed camera imagery collected was scored at two different levels of biological resolution:

- Broad scale: A coarse assessment of the higher level physical and biological habitat to gain an overview of the habitats and biota in the region. It quantifies the dominant and subdominant physical and biological habitat in an image;

- Fine scale: Point scoring of the substratum or biota within an image to the finest level possible (including identifiable morpho-species based on previous scoring conducted on AUV imagery in eastern Tasmania by UTA) following the CATAMI national standard to enable comparison between different areas, surveys and research agencies.

The seabed communities sampled confirm the patchy and discontinuous distribution of the reef (hard ground) on the Flinders shelf indicated in the multibeam surveys. The biological communities are dominated by sessile invertebrates such as bryozoa and sponges and to a lesser extent cnidaria. Macroalgae are only present on the shallow-mixed habitats in the northwest of the CMR, which also appears to be a previously undiscovered hotspot for sponges. The site at the edge of the continental shelf closest to a shelf-incising canyon head is also a biologically important area with relatively high proportions of bryozoans, sponges and cnidarians.

Shallow water BRUVs recorded a range of species from multiple trophic levels, including species of commercial and recreational interest, such as flathead and morwong (Hill *et al*., 2014). The majority of species, whilst found commonly along the southern or south-eastern coasts of Australia, are endemic to Australia, highlighting the global significance of this region. Species richness was greater on habitats containing some reef and declined with increasing depth (Figure D). Six assemblages with a distinct spatial pattern were observed at sites across the reserve. Many species contributed to more than one assemblage and differences in the relative abundance of species defined the differences between several assemblages. Assemblages were structured by depth and habitat type, and could be heterogeneous at relatively small scales (i.e. within a sampling cluster). The trophic breath of species in assemblages was also greater in shallow waters.

The deep water BRUVs recorded 12 species of bony fish, 6 species of shark, and two undifferentiated groups (small benthic fish and jellies), despite there being no evidence that fish were attracted to the liquefied bait. Total counts over the 36 total deployments ranged from 1 (a frilled shark) to 404 (spotted trevally observed schooling in 16 deployments). Toothed and banded whiptails were the most commonly observed species, being seen in 92% and 75% of samples, respectively. The bait type and release mechanism will need to be reviewed and tested further.

The substrate along the towed stereo camera system (TSCS) on slope transects, initially targeted because they were acoustically 'hard' habitats, were subsequently founds to be dominated by sand/mud (72% of images) with some rocky outcrops where transects intersect some steeper topography. The sand/mud substrate in nearly half of all scored images, however, was found to be consolidated by a matrix of bryozoans (dead and alive) that apparently provide enough stability for settling of fixed fauna and may also confound the interpretation of multibeam backscatter data.

Biota was observed in most images selected from the slope transects. Faunal cover, however, was predominantly sparse (<20%), and dominated by a mixed category composed of bryozoan and hydroids (24% of images) followed by small ascidians (26%) and sponges (19%). Most individual organisms were found to be small with a low profile (<20 cm height or diameter). On rocky outcrops larger fauna was observed, including some bamboo and other octocorals (0.5% of images).

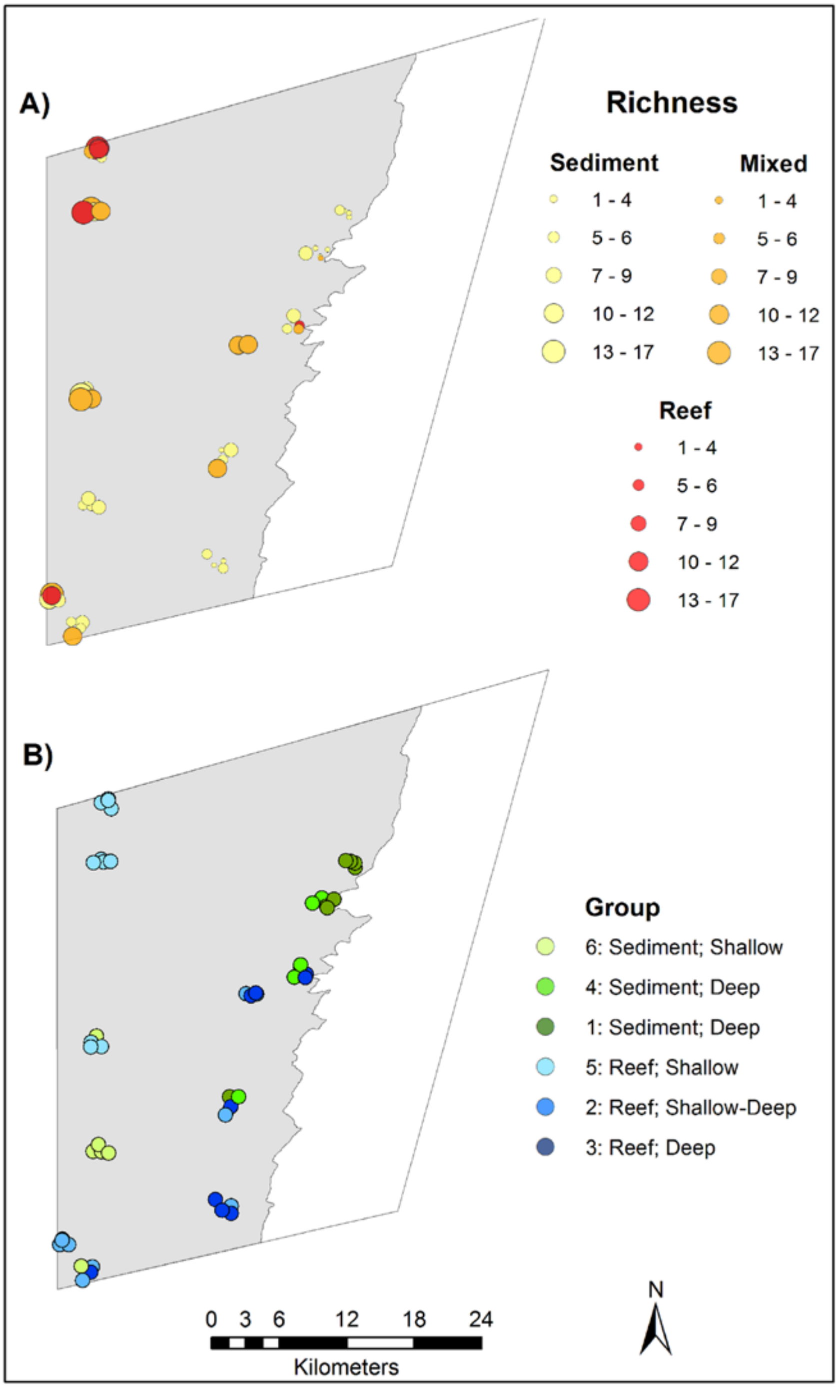


Figure D - Spatial distribution of A) species richness B) fish assemblage groups on the Flinders CMR shelf (shaded grey). Increasing size of symbols in A) indicate increasing species richness. Symbols are colour coded according to the observed substratum type in BRUV footage: yellow = sediment; orange = mixed; red = reef. Assemblages in B) are coded by colour, with predominantly sediment-associated assemblages coloured green and predominantly reef-associated assemblages coloured blue. doi:10.1371/journal.pone.0110831.g005

Conclusions

A complete inventory of a marine reserve or zone requires that the whole reserve or zone is continuously mapped with high resolution MBES methods. We believe that this should remain the ultimate goal of any management agency. Proceeding towards this goal, however, can be facilitated using statistical approaches that can detect changes in the status or trends of key habitats and biota, on the way to achieving this goal. The importance of local substratum in structuring fish assemblages highlights the need to develop comprehensive, high resolution habitat maps for the reserve. Assembling these habitat maps for marine reserves will require a commitment to strategic mapping of the seabed using multibeam sonar, so that over time complete coverage is achieved. For the continental shelf where swath widths are small, this mapping could take years to decades. In the meantime, we recommend that management adopt representative sampling methods, such as GRTS, to provide estimates of habitat and biodiversity within reserves to underpin and support future monitoring programs.

The two approaches used in the Flinders CMR survey are complementary. The spatially balanced strategy of GRTS produced estimates (with uncertainty) of key benthic physical and biological assets across the entire 774 km2 shelf area of the Flinders CMR, with sufficient resolution to inform management planning. In contrast, the continuous mapping provided a high spatial resolution bathymetric map that better informed our understanding of the geomorphic character of a discrete area of the Flinders shelf, and associated biological monitoring at the whole of reef scale. Both approaches have their place in a successful and flexible monitoring strategy.

Any future MBES mapping in the Flinders CMR as part of a monitoring program would ideally continue GRTS-based sampling to refine estimates of overall habitat distribution, while continuing to expand the extent of continuous coverage, building upon the existing 30 km2 area, and prioritising additional areas based on knowledge obtained from GRTS-based sampling (for further details see: Lawrence et al. 2015).

Moving forward we also recommend that the utility and necessity of broad scale scoring is examined before any decision is made to use it in future surveys. Broad scale scoring enables a relatively rapid analysis of the biological communities within an image but the subsequent data (which is binned into large categories such as 20-40% coverage) complicates statistical analysis and adds uncertainty to the interpretation of the data. All of the results and analysis that were subsequently published from the Flinders survey relied on the fine scale scoring of the imagery, suggesting that the ultimate utility of the broad scale scoring is limited.

Solitary Islands KEF

The objectives of the Solitary Islands field work were:

1. Conduct multibeam sonar mapping of shelf reef features in the KEF to augment and add to the existing mapping and inventory of shelf habitats conducted the NSW Office of Environment and Heritage.

2. Trial the use of selecting AUV and TSCS transects using GRTS to achieve spatially balanced transects whose inclusion probability reflect the proportion of hard substrate that they intersect, as determined by high resolution multibeam sonar, and compare the outcomes of sampling with these two alternative approaches.

3. Use the opportunity afforded by the NSW existing BRUV monitoring programme to conduct an autocorrelation and power analysis for a specific BRUV objective (estimating the abundance of fish on shelf reefs).

The additional multi-beam sonar data collected during the Solitary Islands survey was used to develop a 3-class habitat map that clearly shows the extension of relict reef features previously mapped in state waters extending into Commonwealth waters (Figure E).

The survey was able to demonstrate the effect of selecting transects using the GRTS approach with an inclusion probability that reflects the proportion of hard substrate intersected by each transect. This is helpful because it provides a probabilistic way to determine the start of transects in a way that can reflect their desired properties, such as the proportion of hard substrate that they will intersect. This was most clearly evident in the South Solitaries site. In this case the three transects (selected with a probabilistic design) were clearly clumped into the nearly-linear reef feature in the centre of the survey frame. This effect of targeting hard substrate with a probabilistic design was less evident in a second site (the Patch) because the hard and soft substrates are more interspersed in this location.

Comparing the broad scale scoring results between the AUV and TSCS imagery, taken along the identical transects, suggests that (in this instance at least) the AUV is a much better platform: very few of the images (7 or 2% of the dataset) selected were deemed unscorable, the images record a rich diversity of macroinvertebrates and macroalgae, and the number of images with no visible biota was relatively low (33 or 10% of the dataset) and this only occurred in images taken from locations were the dominant substrate was unconsolidated mud and sand.

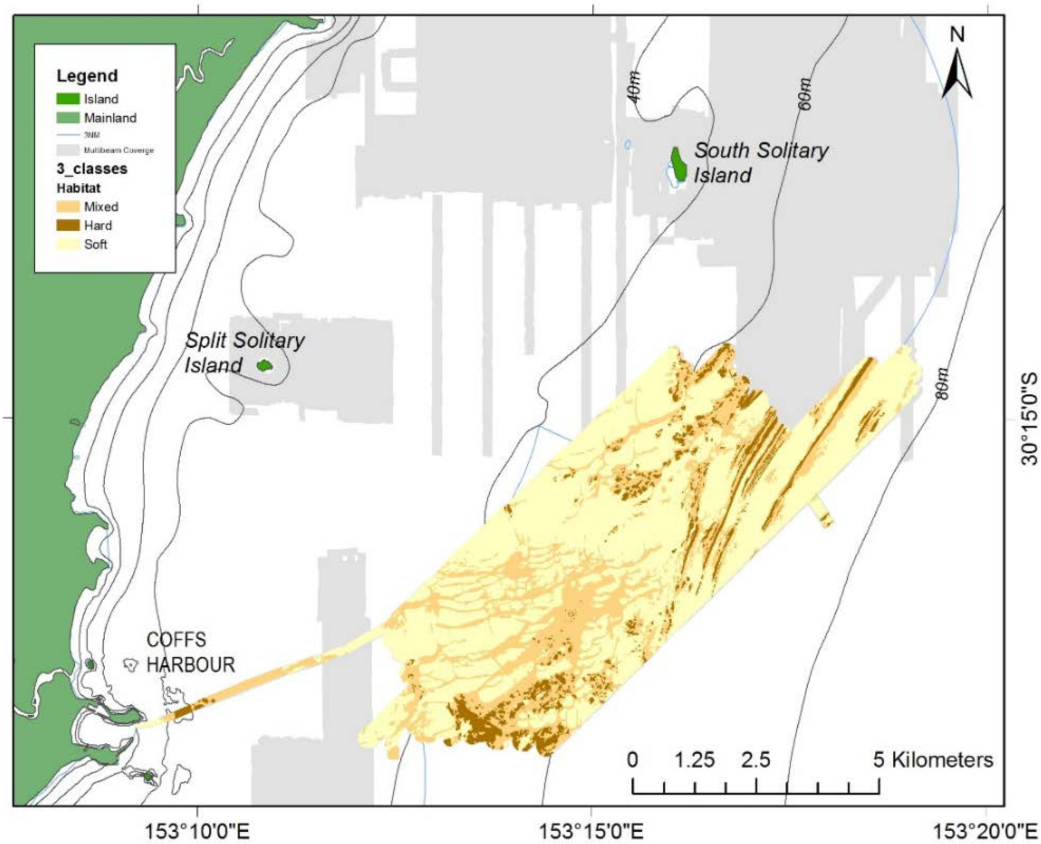


Figure E - Interpreted 3-class habitat layer based on swath bathymetry and backscatter data collected in the Solitary Islands survey. The light blue line shows the boundary between state and commonwealth waters. Swath mapping conducted during this survey clearly shows previously identified relict reef features within state waters extending into commonwealth waters.

By contrast the number of images collected by the TSCS that were deemed unscorable was much higher (77, or 16% of the dataset) and the number of images with no visible biota, again predominately (but not exclusively) from images taken over unconsolidated sand and mud, was much higher (139 or 30% of the dataset). The overall image quality was clearly much lower, and this causes a far smaller number of biota categories to be recorded. The Bryozoa and Echinoderms groups, for example, are completely absent from the TSCS data set whereas they are recorded in the AUV data set.

The results indicate that AUV imagery provides a much better picture of benthic biological communities than TSCS imagery. Future surveys should carefully consider image quality issues versus the logistical and cost implications of deploying AUVs and TSCS. If logistical constraints allow, and if the costs of deployment are similar, we recommend that AUVs are deployed in preference to TSCS.

The BRUV autocorrelation study, compared MaxN (the maximum number of individuals recorded in any of the images) and MeanN (the mean number of individuals recorded across all the images) responses using two separate models that assessed the magnitude of spatial dependence. The choice of response was found to have an important influence on the parameter estimates within these models. In particular the spatial correlation parameter for MaxN was roughly double that of MeanN, which means that the spatial dependence was stronger for MaxN than for MeanN responses. This is important because spatial autocorrelation diminishes the effective sample size of a survey and thereby inflates estimates of the variance of a sample statistics such as the mean, hence we are less certain about a sample statistic than we could be if the samples were not auto-correlated. This means that it will cost more (because more samples are needed) to obtain statistical estimates with an equivalent level of precision.

The results of the spatial auto-correlation experiment conducted during the Solitary Islands survey suggest that spatial dependence will have a greater effect on estimates of the MaxN statistic, than it will on the MeanN statistic, and this could have implications for estimates of fish abundance, or trends in abundance, derived from BRUV data. We recommend that future surveys carefully consider the spatial distribution of BRUV units, and examine the feasibility (and analysis implications) of using the MeanN statistics as well as the more traditional MaxN statistic.

Houtman-Abrolhos KEF

The objectives for the Houtman-Abrolhos KEF field work were:

1. Identify the location of coral-kelp communities and other shelf reef communities in commonwealth waters east of the Houtman-Abrolhos islands;

2. conduct multibeam sonar mapping of shelf reef features in the KEF to augment and add to the existing mapping and inventory of shelf habitats conducted in state waters by WA fisheries; and,

3. trial the application of an analysis of compound specific isotopes in samples of feathers collected from crested and sooty terns for their application as an indicator of the status of shelf reef communities in the KEF.

A drop camera survey of the KEF, using a GRTS based design (Figure F), made a number of new discoveries: (i) an extensive area of sea-grass habit was discovered s along the eastern margin of the KEF; (ii) coral-kelp communities were confirmed to be present within the KEF but are apparently restricted to its western margin, and in one instance are simply an extension of a known feature (Snapper Bank) within state jurisdictional waters around the islands; and, (iii) rich macro-invertebrate communities comprised of dense sponge gardens are scattered throughout the KEF, but particularly to the North, and are likely to contribute significantly to the KEFs biodiversity values (Figure G).

The presence of coral-kelp features in commonwealth waters was subsequently confirmed by multibeam sonar and AUV survey of six sites. The multibeam data show isolated rocky reefs surrounded by softer sediment. The shape of the reefs appears to be controlled partly by current or prevailing weather, and shallower and larger reefs show wave platforms.

Mean coral cover was highest at Site 2 (29.1% ± 4.8 s.e.), followed by Site 1 (23.1% ± 5.7 s.e.) then Site 3 (9.3% ± 3.4 s.e.). Mean macroalgae cover was highest at Site 4 (56.2% ± 5.4 s.e.), followed by Site 5 (48.9% ± 7.3 s.e.) then Site 6 (33.2% ± 5.7 s.e.). Seagrass was found at all sites, though it was more prominent at Sites 5 (9.1% ± 7.6 s.e.) and 6 (4.3% ± 3.2 s.e.), in the south-west area of the study region.

The preliminary stable isotope data gathered and analysed during Project 2 was able to distinguish the feeding niches between Sooty Terns, Bridled Terns and Crested Terns where this was previously not possible. The data suggest it would be possible to measure the trophic level for a number of important seabird species and monitor both the bird's trophic level and the base of the food web for fluctuations or trends.

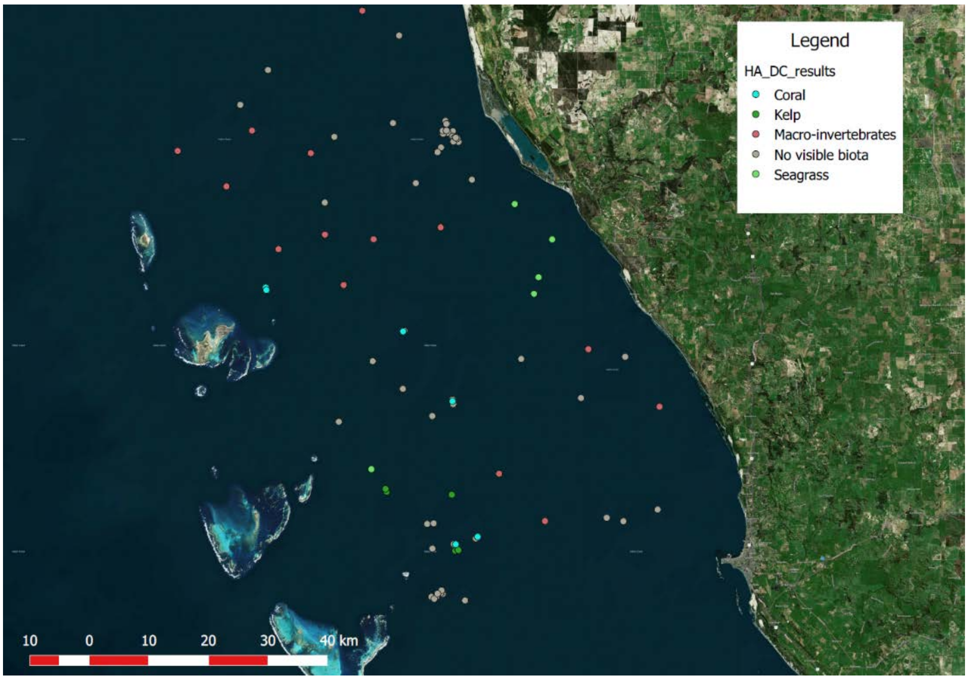


Figure F - Summary of the results of the drop camera survey in commonwealth waters east of the Houtman-Abrolhos islands showing the dominant biological community at 82 GRTS selected survey sites

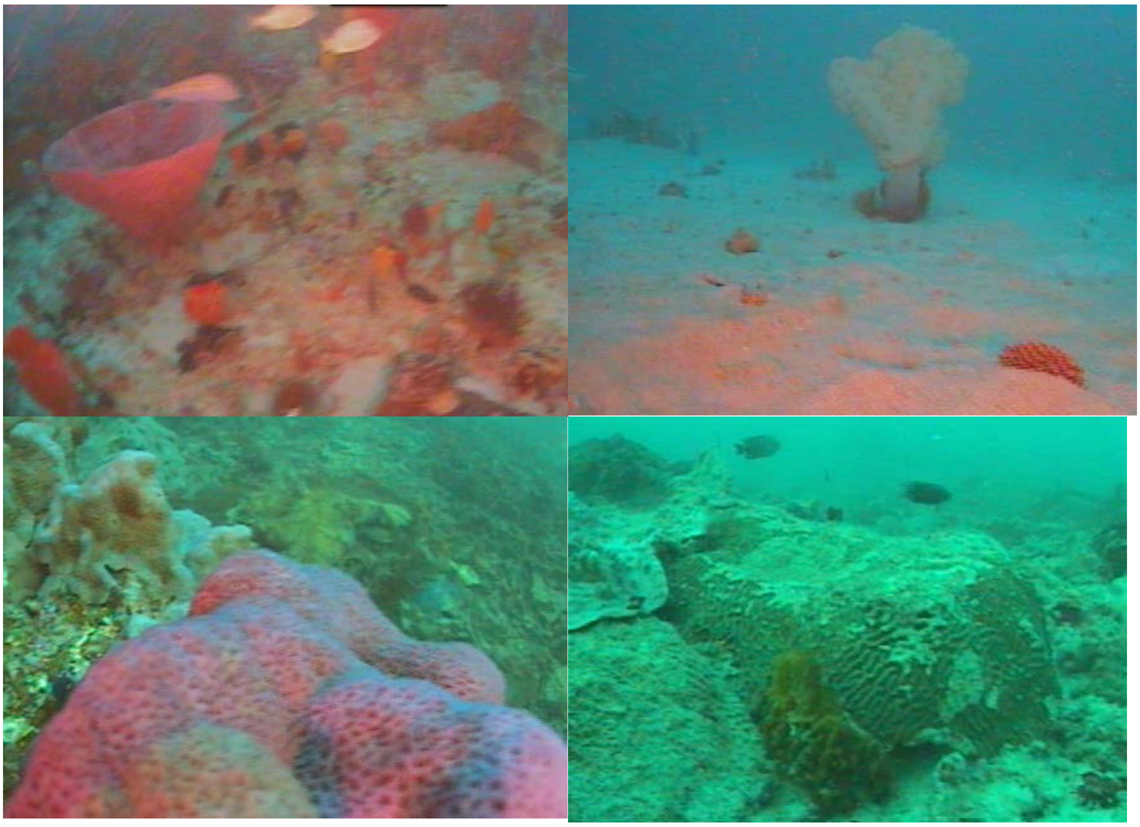


Figure G - Screen grabs of the macro-invertebrate communities (top) and coral (bottom) from the drop camera survey in the Houtman-Abrolhos KEF.

Overall Conclusion

Managers need to choose between delaying monitoring programmes until complete and continuous high resolution habitat maps of marine reserves are acquired, or commencing monitoring programmes earlier using habitat information that is available now or becomes available as the programme is implemented. If upon reflection, the time and cost of acquiring continuous coverage information suggests that effective management decisions may be delayed for too many years, then a complementary strategy based on a spatially balanced sampling design should be considered. This approach can provide a robust baseline, within a year, and can be used to direct and prioritise subsequent continuous mapping programs.

The spatially balanced approach adopted by the United States National Park Service and used here, has been shown to be effective in detecting the presence of valuable, sensitive habitats in areas in which they might be thought to be absent based on existing knowledge. Sequential implementation of spatially balanced designs, complemented by continuous habitat mapping, will eventually provide a complete description of the habitats with commonwealth reserves, and if implemented correctly we anticipate that they will allow status and trend assessments to be completed within ten to fifteen years.

We recommend that Autonomous Underwater Vehicles (AUVs) be used to collect imagery on the continental shelf whenever possible rather than Towed Stereo Camera Systems (TSCS). Image quality from the AUV is far more consistent and provides greater detail on proportions and changes between benthic habitats. It will provide a more reliable baseline and have the ability to detect smaller changes more rapidly than images from the TSCS.

The use of the CATAMI standard for scoring imagery in the three surveys was an effective approach to measuring the benthic community in a nationally consistent approach that enables comparison between different geographic areas and researchers. The standard does not prevent researchers collecting more detailed information to meet their individual research needs, so we recommend that the CATAMI or an equivalent standard be used as a minimum for all surveys in CMRs and KEFs.

The use of shallow water Baited Remote Underwater Video systems (BRUVs) is an effective and proven way to estimate the composition of, and changes in, benthic fish community in shelf waters, and if used in conjunction with forward and rear facing cameras can simultaneously provide habitat information. However we recommend further analysis into the potential advantages of MeanN as a sample statistic (or indicator) as it may be less subject to spatial autocorrelation. Regardless of which sample statistic is used, BRUV data should be assessed for spatial autocorrelation before analysis, or preferably before full deployment so that valuable resources are not wasted. The new deep water BRUV has the potential for assessing mobile fish communities in off-shelf waters using phased releases of liquefied bait over extended deployments. The attractiveness of the liquefied bait, and the effect of video lighting, needs to be explored further before routine deployment could be recommended.

Stable compound-specific isotopes appear to be capable of detecting changes in the trophic status of offshore pelagic communities. More research is required, however, to understand the variability and potential biases of this approach. Our initial assessment, however, is that it this relatively new methodology could provide a cost-effective way to detect trends in mesopelagic ocean productivity. Hence, in a properly designed monitoring program it may be possible to use this technique to monitor changes in the pelagic ecosystem in multiple use CMRs and KEFs.

Additional Information

For additional information on the survey methodologies and outcomes of particular analysis, the reader should refer to the following journal publications:

- Hill et al., (2014); identifies demersal fish assemblages, quantifies assemblage relationships with environmental gradients (primarily depth and habitat type), and describes their spatial distribution across a variety of reef and sediment habitats in the Flinders CMR shelf.

- Lawrence et al., (2015); contrasts quantitative estimates of habitat type on the shelf of the Flinders reserve, using multibeam sonar (MBES) mapping of: (i) a continuous (~30 kms2) area; and, (ii) a set of discrete spatially balanced cells chosen with a GRTS design.

- Ferrari et al., (submitted); investigates the role of reef structural complexity, benthic community composition and depth as potential surrogates of fish abundance across multiple scales in shelf reefs in the Solitary islands KEF.

- Althaus et al., (2015); describes in detail the CATAMI classification scheme (CCS) used to score all marine imagery collected during the field surveys in a standardized fashion.

- Monk et al., (2016) describes the particular importance of outcropping reef ledge features in the continuous mapped region of the Flinders CMR. These reef ledges represent a small fraction of overall reef habitat yet contain much of the benthic faunal diversity.

- Perkins et al., (2016) examines the trade-off between the number of images selected within transects and the number of random points scored within images when quantifying the cover of benthic biota using imagery collected by an Automated Underwater Vehicle. The efficacy of various image selection approaches was also investigated as was the influence of properties of the biota themselves including size, abundance and distributional patterns.

- Durden et al., (accepted) reviews underwater imagery methods including choice and availability of platforms for capturing underwater imagery, logistical considerations, sample design and analysis issues.

Details of all of the papers listed above are provided in the References listed in this report, and all are, or will soon be, available in the scientific literature. Several additional papers are also in the process of submission or preparation, notably:

- Monk et al., (submitted) examines the effect of different sub-sampling strategies of images along AUV transects on the accuracy of species distribution models for a continuously mapped region of the Flinders CMR shelf.

- Hill et al., (in prep) examines the distribution, relative abundance and size structure of key demersal fish species in the Flinders CMR and assess their potential suitability as indicator species for monitoring.

- Monk et al., (in prep) examines the effects of spatial scale on abundance estimates for key benthic morpho-species in the continuously mapped region of the Flinders CMR shelf.

We anticipate that these papers will become available in the scientific literature through the course of 2016.

1. INTRODUCTION

The overall objective of Project 2 of the Marine Biodiversity Hub's national monitoring evaluation and reporting theme (Theme 1) was to contribute to a blue-print for a sustained national environmental monitoring strategy. It was envisaged this strategy would evaluate the status and trends of indicators of environmental health, within Key Ecological Features (KEFs) and the Commonwealth Marine Reserve Network, focusing initially on the Southeast Marine Region (see also Hayes *et al*., 2015).

To help achieve this, Project 2 undertook three field surveys between August 2012 and May 2013:

- A large regional survey in the Flinders Commonwealth Marine Reserve (CMR) located offshore northeast Tasmania.
- Smaller scale surveys, targeted at known shelf reefs features in the Solitary Islands Marine Park (SIMP) and Solitary Islands Marine Reserve (SIMR), hereafter referred to generically as the Solitary Islands surveys.
- An exploratory survey in the KEF east of the Houtman-Abrolhos islands designed to identify coral-kelp features, and other benthic habitat features of interest within commonwealth waters, and to test the possibility of using compound specific isotopes to track changes in this KEF.

In most cases, these surveys used a probabilistic, spatially balanced design known as a Generalized Random Tessellation Stratified (GRTS) design. GRTS is a flexible sampling approach that can accommodate multiple survey objectives and provides unbiased estimates of habitats and biota in surveyed regions (Stevens and Olsen 2004). GRTS designs have been used by the United States National Parks Service for many years (Fancy *et al*., 2009), but to our knowledge, these surveys represent the first time it has been employed in the marine environment.

A sustained national monitoring strategy for environmental health needs to be able to assess the status of, and track changes in, the habitats and biota within the monitored ecosystem. In Commonwealth Marine Reserves an important restriction is that the monitoring methods should be non-destructive.

Non-destructive sampling tools for the marine environment include remote sensing using acoustics (e.g. multibeam) that provide information on seafloor characteristics (bathymetry, hardness and texture), and direct observation using video and camera stills, taken by towed units, autonomous units or baited units.

This report documents the field work – including sample selection, sample acquisition and sample processing - that was conducted as part of the three surveys. The report provides a description of each of these steps, and provides a summary of survey outcomes, but does not document in detail the results of any subsequent analysis applied to the data collected during the surveys. In some instances the analysis of this data is on-going and in many instances this analysis has already been reported in journal articles.

For additional information on the survey methodologies and outcomes of particular analysis, the reader should refer to the following journal publications:

- Hill *et al.,* (2014); identifies demersal fish assemblages, quantifies assemblage relationships with environmental gradients (primarily depth and habitat type), and describes their spatial distribution across a variety of reef and sediment habitats in the Flinders CMR shelf.

- Lawrence *et al.,* (2015); contrasts quantitative estimates of habitat type on the shelf of the Flinders reserve, using multibeam sonar (MBES) mapping of: (i) a continuous (~30 kms^2) area; and, (ii) a set of discrete spatially balanced cells chosen with a GRTS design.

- Ferrari *et al.,* (submitted); investigates the role of reef structural complexity, benthic community composition and depth as potential surrogates of fish abundance across multiple scales in shelf reefs in the Solitary islands KEF.

- Althaus *et al.,* (2015); describes in detail the CATAMI classification scheme (CCS) used to score all marine imagery collected during the field surveys in a standardized fashion.

- Monk *et al.,* (2016) describes the particular importance of outcropping reef ledge features in the continuous mapped region of the Flinders CMR. These reef ledges represent a small fraction of overall reef habitat yet contain much of the benthic faunal diversity.

- Perkins *et al.,* (submitted) examines the trade-off between the number of images selected within transects and the number of random points scored within images when quantifying the cover of benthic biota using imagery collected by an Automated Underwater Vehicle. The efficacy of various image selection approaches was also investigated as was the influence of properties of the biota themselves including size, abundance and distributional patterns.

- Durden *et al.,* (accepted) reviews underwater imagery methods including choice and availability of platforms for capturing underwater imagery, logistical considerations, sample design and analysis issues.

Details of all of the papers listed above are provided in the References listed in this report, and all are, or will soon be, available in the scientific literature. Several additional papers are also in the process of submission or preparation, notably:

- Monk *et al*., (submitted) examines the effect of different sub-sampling strategies of images along AUV transects on the accuracy of species distribution models for a continuously mapped region of the Flinders CMR shelf.

- Hill *et al*., (in prep) examines the distribution, relative abundance and size structure of key demersal fish species in the Flinders CMR and assess their potential suitability as indicator species for monitoring.

- Monk *et al*., (in prep) examines the effects of spatial scale on abundance estimates for key benthic morpho-species in the continuously mapped region of the Flinders CMR shelf.

We anticipate that these papers will become available in the scientific literature through the course of 2016.

2. FLINDERS COMMONWEALTH MARINE RESERVE

2.1 Background and objectives

The Flinders Commonwealth Marine Reserve (CMR) lies offshore from the Furneaux island Group, off the coastline of North Eastern Tasmania. The inshore CMR region covers an area of approximately 1230 km^2. The northern boundary of the CMR extends 35 km, the eastern boundary 49 km, the southern boundary 24 km and the western boundary 42 km. The depth strata range from 30 m to 1500 m across an east west margin of 30 km (Fig 1).

The objectives of the Flinders CMR survey were;

1. Develop an inventory of demersal and epibenthic conservation values in the shelf and slope environments of the reserve, including the first field trial of deep BRUVs to inventory fish communities on the slope.

2. Conduct continuous multibeam sonar mapping of a portion of the shelf edge environment, including a shelf incising canyon head, thought to contain communities with a relatively high biodiversity.

3. Test the accuracy of habitat classification derived from continuous and GRTS-based multibeam sonar data, and the extent to which habitat maps derived from this data can usefully inform subsequent sampling strategies.

2.2 Sample design

Sampling on the Flinders CMR shelf (to ~ 150 m depth) consisted of two phases. The first phase collected coarse information on the distribution of habitats and informed the site selection for the second phase which was targeted towards surveying biota.

2.2.1 Phase I

In the first phase 40, 200 x 200m GRTS sites were surveyed with multibeam sonar and assigned a broad habitat category (sand, mixed, reef) based on the in situ unprocessed multibeam data and imagery from a drop video camera. Reefs in the region are low profile and patchy and therefore sites were classed as either ‘mixed’ reef or ‘sand’ (Fig 2).

2.2.2 Phase II

Shelf

During phase two, eight 'mixed' sites and three 'sand' sites and a judgementally chosen canyon-head site were selected for targeted biological sampling with the CSIRO towed stereo camera system and shallow water Baited Remote Underwater Videos (BRUVs).

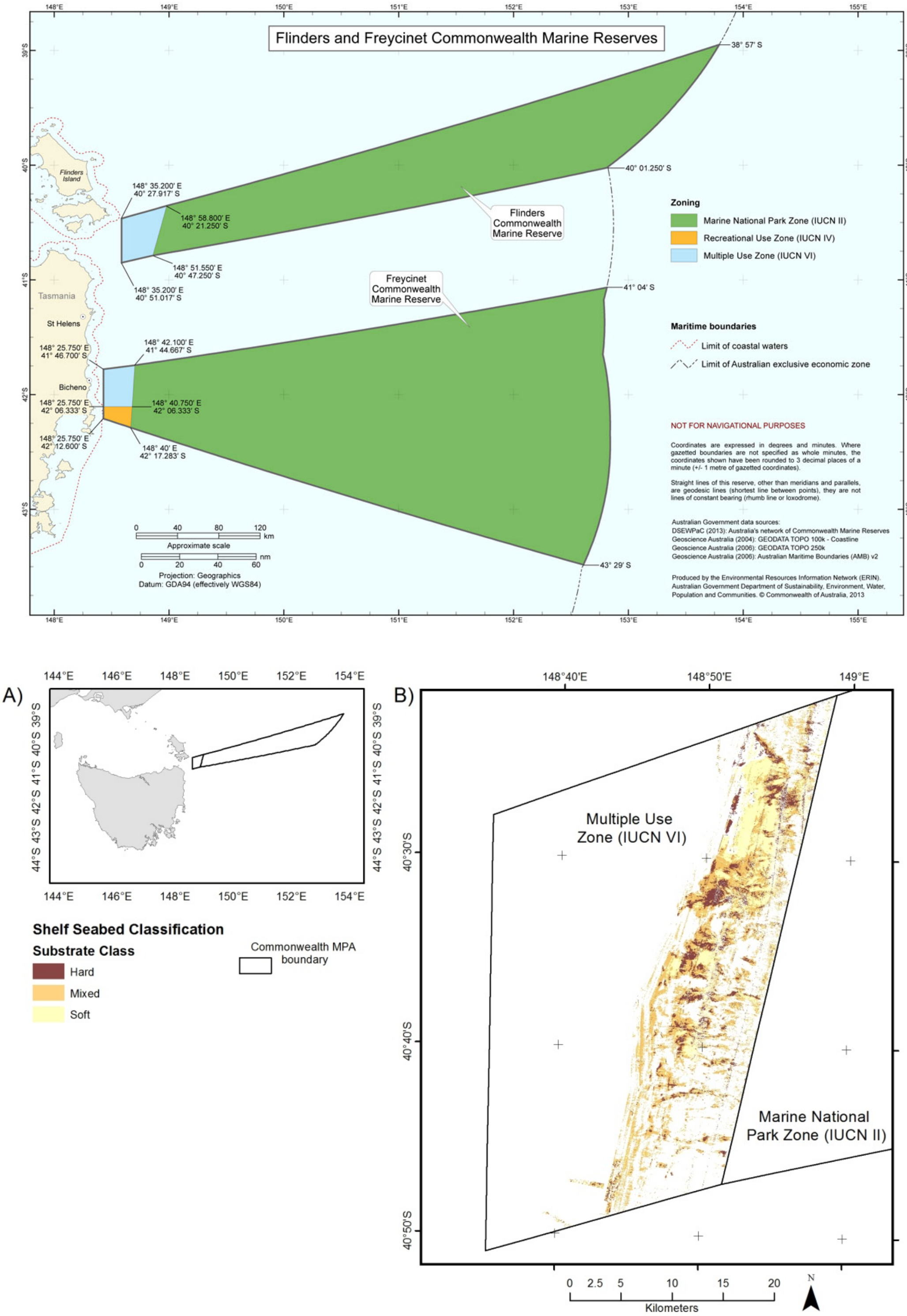
An area of approximately 4 x 7 km on the edge of the continental shelf between approximately 60 and 300 m depth was also continuously mapped with multibeam sonar and then subsequently sampled with an Autonomous Underwater Vehicle (AUV). This region contained linear reef features and shelf-incising canyon heads that are characteristic of the northeast shelf of Tasmania. The region was divided into 1 km square grids. Each 1 km grid was further subdivided into the maximal number of non-overlapping, 1 km long west-east AUV transect lines (Fig 3).

Hard reef features in the continuous mapped patch were identified and mapped using the methods described in Lawrence *et al*., (2015). Transects within grids were then selected for sampling based on the proportion of hard substratum they contained - i.e. their inclusion probabilities in the GRTS methodology were altered so that they were proportional to the amount of hard substratum contained within each transect according to the habitat map for the region. In the field, the AUV could not be deployed greater than 300 m and in canyon heads (because of the risk of entrapment) so therefore all grids thought to contain hard substratum, in less than 300m depth and outside of the canyon, were sampled with the AUV.

Slope

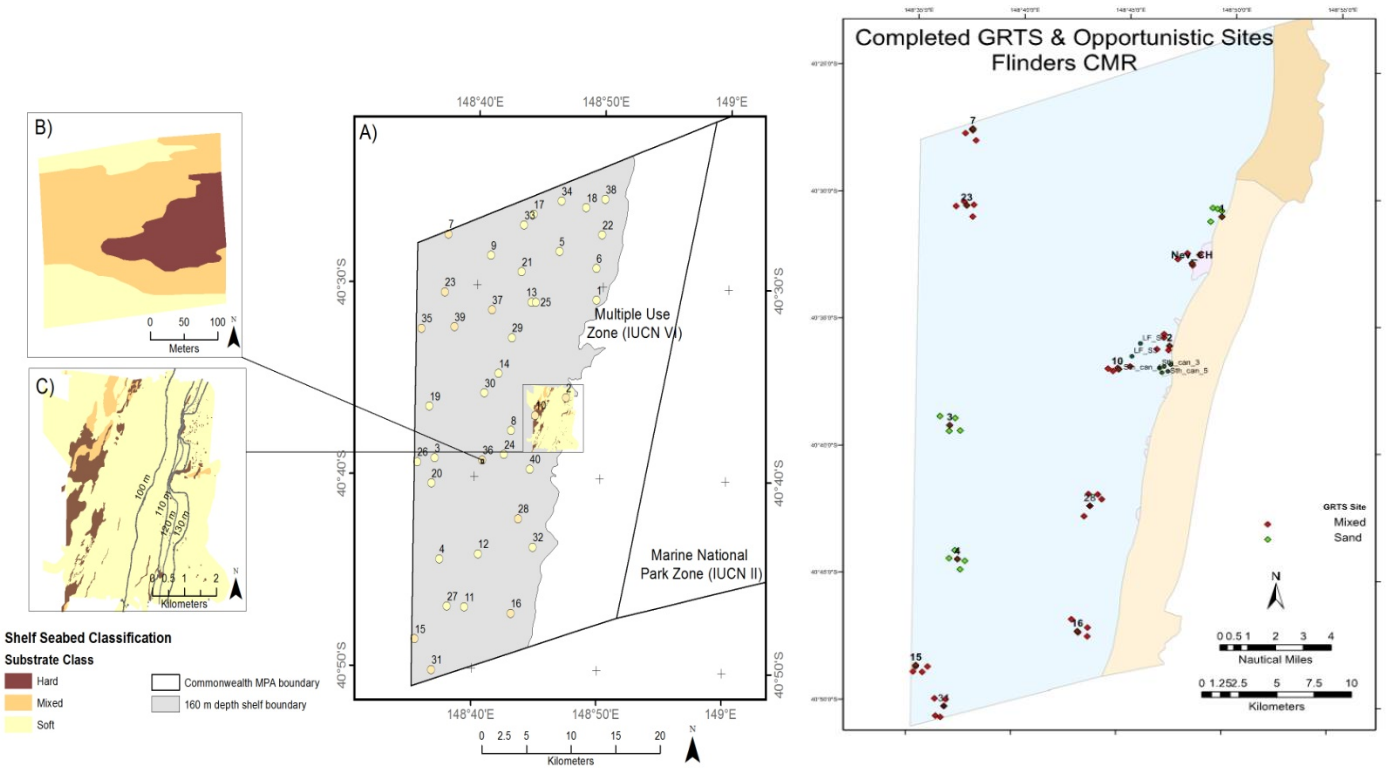
Reef and hard habitats on the continental slope were targeted by using pre-existing multibeam data (Kloser *et al*., 2010; Kloser and Keith, 2013) to identify the proportion of hard substrate in all possible transects. Transects were run down the slope between the 200 and 500 m contour and each transects inclusion probability (in the GRTS methodology) was again made proportional to the amount of 'hard' substratum contained within the transect path according to the habitat mapping developed by Kloser and Keith (2013). Transects were between 1.8 and 4.4 km in length (Fig 4).

Fig 1 - Overview of the Flinders (and Freycinet) Commonwealth Marine Reserves



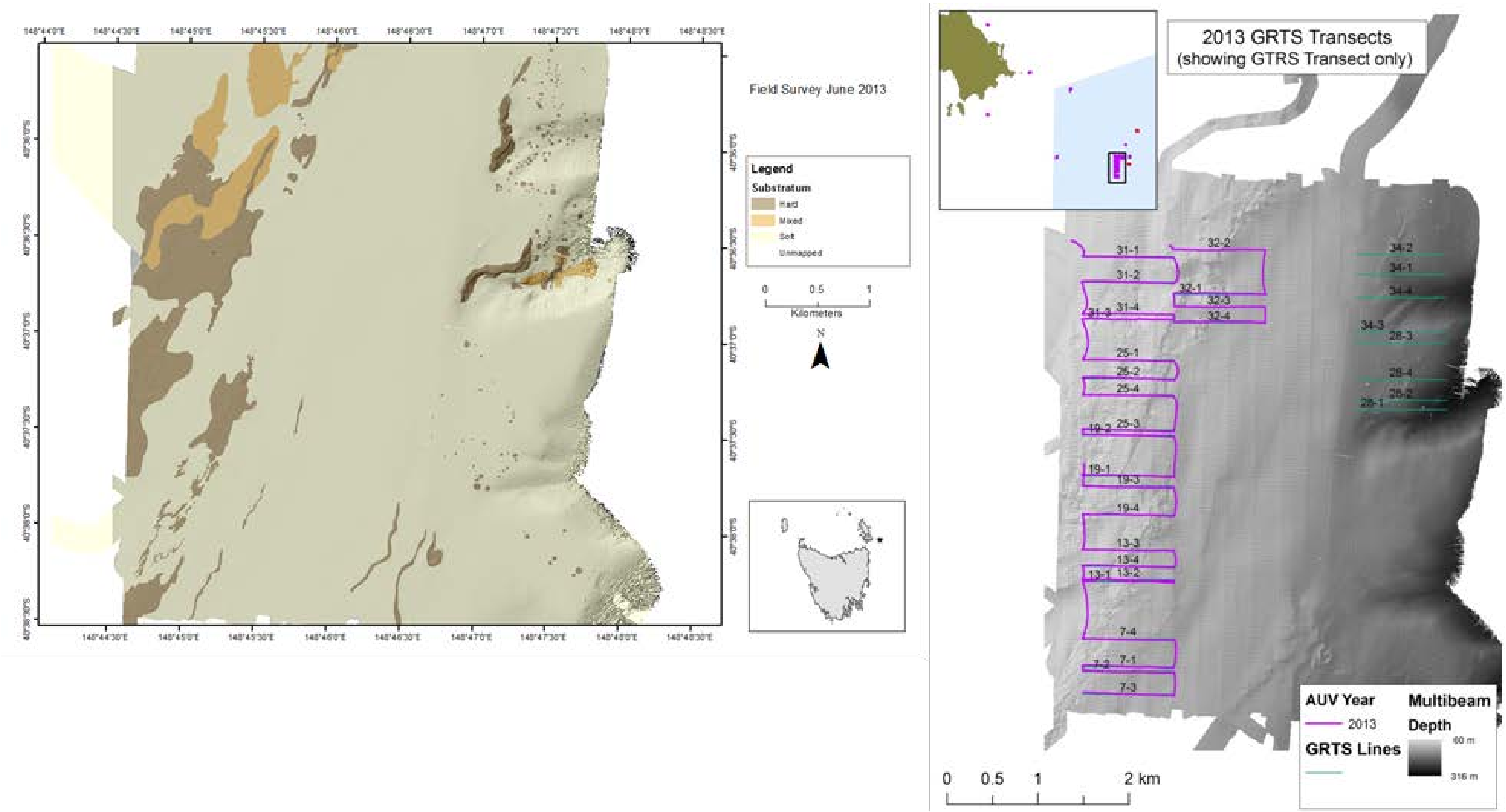
(Top) Outline of the Flinders Commonwealth Marine Reserve. (Bottom) Summary of the available habitat information, for the shelf and slope environments, of the Multiple Use Zone (IUCN VI) prior to the start of the field survey conducted by the NERP Marine Biodiversity Hub.

Fig 2 - Summary of Phase I and Phase II data collection sites in the Flinders CMR shelf



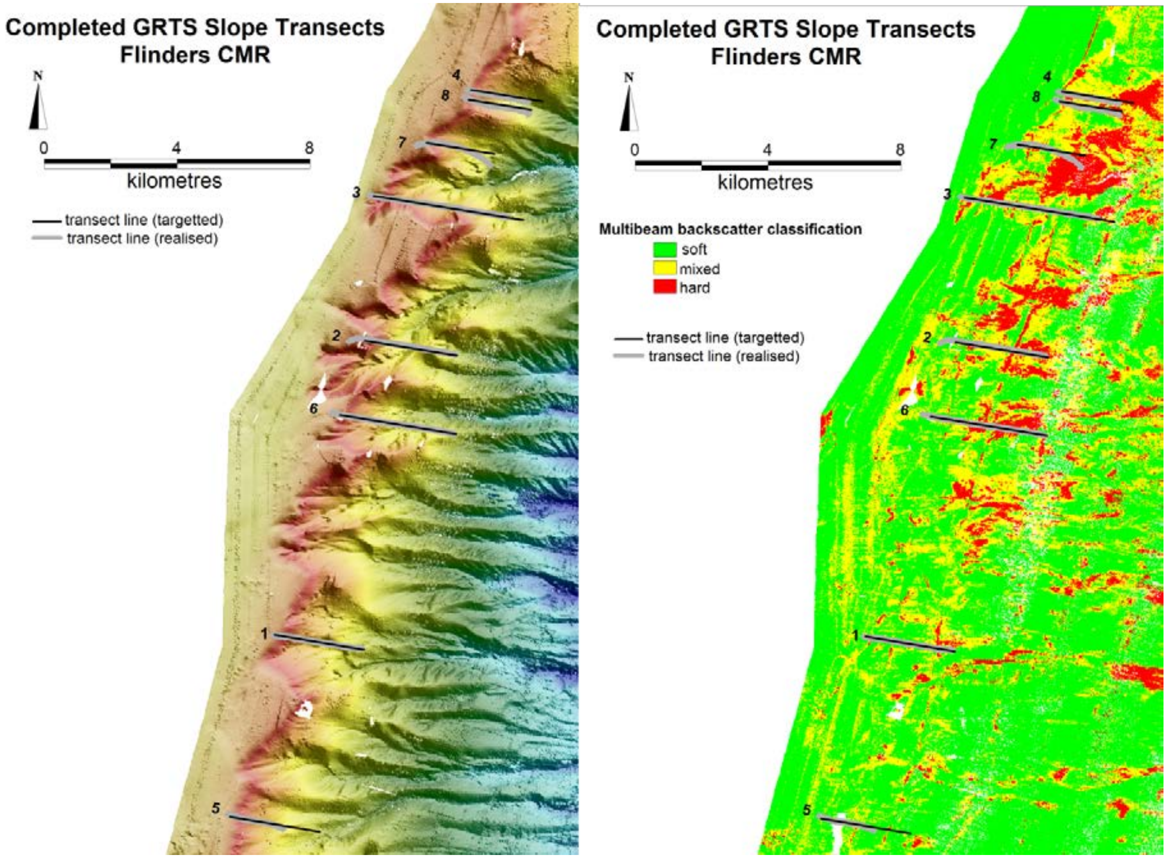
(Left) Summary of the habitat classification of the 40 GRTS sites based on the drop camera survey and the multibeam sonar survey (Phase I), together with the multibeam sonar survey of the continuous patch (Phase II). (Right) Location of the 12 Phase II GRTS sites, together with the additional canyon head site, showing four BRUV drop locations around each of the 13 central sites.

Fig 3 - Details of the Phase 1 and Phase II data collection in the continuously mapped region of the Flinders CMR shelf



(Left) Classified bathymetric map of the seafloor in the continuously mapped region of the Flinders CMR shelf that was used to plan AUV sampling. (Right) Location of the planned (green) and completed (pink) AUV transects in the continuously mapped region of the Flinders CMR shelf edge. Transects are named using the combination of their ordered GRTS grid cell number and transect number (i.e. 7-2 indicates GRTS transect line 2 within GRTS grid cell 7).

Fig 4 - Summary of Phase II stereo towed camera transects in the Flinders CMR slope



(Left) Bathymetric map of the continental slope within the Flinders CMR, showing targeted and realised transects. (Right) Habitat classification map of the continental slope within the Flinders CMR again showing targeted and realised transects. Bathymetry and seabed habitat are derived from previous multi-beam mapping of the Australian continental shelf (Kloser et al., 2010; Kloser and Keith, 2013).

2.3 Data processing, scoring and analysis

2.3.1 Multi-beam sonar

A sustained monitoring strategy of ecosystem health is reliant on information about potential changes in the habitats and biota within the monitored ecosystem. Non-destructive sampling tools available to gain such information include remote sensing using acoustics (e.g. multibeam) that provide information on seafloor characteristics (bathymetry, hardness and texture), and direct observation using imagery.

This section describes the acquisition and processing of the multi-beam sonar data used to generate spatial statistics of habitat type and distribution across the Flinders CMR. Characterising the distribution pattern of marine habitats within the Flinders CMR is a prerequisite to understanding the relationships between inshore (shelf) and offshore (slope) habitats. Habitat characterisation provides the underlying spatial framework for understanding habitat dynamics, trophic interactions and spatial distribution of marine biodiversity across the CMR.

Acquisition and signal processing

A Kongsberg EM 3002 multibeam sonar system was employed for the survey. The system was run in a single-head mode and operated on a frequency of 300 kHz with swath coverage of four times water depth. In single-head mode it forms 160 beams across the swath. Maximum swath width coverage is 130° with a single head. For the continuous patch, sample track spacing was completed at an average of 120 m apart which allowed for 40% overlap between the swaths within the depth range of 60- 260 m. For the GRTS cells data was collected in a single line, hence sample track spacing is not applicable. The data was processed using CARIS Hips and Sips software to generate bathymetric grids and in-house CMST-GA MB Process software to produce backscatter grids. The data was processed by Geoscience Australia (GA) to the finest resolution and the quality that the original raw data would allow.

Processing of multibeam acoustic variables.

Bathymetric and backscatter grids were generated at 3m resolution for the shelf region and at 20m resolution for the slope. These spatial analysis and bathymetric products were derived using ArcGIS 10.1. From the bathymetric grid a number of spatial products can be generated to characterise the seafloor (Table 1).

Table 1- Spatial derivatives that can be developed from multibeam sonar data

Terrain variable type	Terrain variable	Analysis Window (scale n x n raster cells)	Details	Geomorphological relevance	Ecological relevance
Slope	Slope	n=3x3 (9m)shelf n=3x3 (60m)slope	Computes the slope angle in the direction of the steepest slope	Stability of sediments and discrimination of local seabed features (reefs, bed forms). Can infer local variations in currents. .	Stability of sediments (ability to live on sediments). Local acceleration of currents (food supply, exposure etc.).
Aspect (orient-ation)	Eastness	n= 3 and 20	Computes the orientation of the seabed i.e. the deviation from east	Related to both former and modern depositional and erosional processes	Exposure to dominant and/or local currents from a particular direction (food supply, larval dispersion etc.).
	Hillshade	n= 3 and 20	Computes hill shade values for a raster surface by considering the illumination angle and shadows.		
Relative position	Curvature (mean, planar, profile)	n=3x3 (9m)shelf n=3x3 (60m)slope	Indicates if a pixel forms part of a positive or negative topographic feature with respect to the surrounding terrain. Plan and profile curvature measure this effect perpendicular to the slope	Useful in the classification of seabed geomorphic features, including channels and ridges	Index of exposure, shelter on a peak or in a crevice (relates to food supply, predators).
Terrain variation & depth statistics	Rugosity	n=3x3 (9m)shelf n=3x3 (60m)slope	Measures how much the seabed terrain varies, and how rugged it is.	Terrain variability and structures reflect both former and modern geological and geomorphic processes	Index of degree of habitat structure, shelter from exposure/predators (link to life stages). Structural diversity linked to biodiversity.

The Slope tool in ArcGIS 10.1 calculates the maximum rate of change between each cell and its neighbours, for example, the steepest downhill descent for the cell (the maximum change in elevation over the distance between the cell and its eight neighbours). Every cell in the output raster has a slope value. The lower the slope value, the flatter the terrain. The output slope raster can be calculated as percent of slope or degree of slope.

Curvature calculates the slope of the slope (the second derivative of the surface), that is, whether a given part of a surface is convex or concave. Convex parts of surfaces, like ridges, are generally exposed and drain to other areas. Concave parts of surfaces, like channels, are generally more sheltered and accept drainage from other areas (or in seabed analysis may provide shelter from exposure or even accentuate exposure depending on the angle of the channel to the prevailing currents).

The curvature of a surface is calculated on a cell-by-cell basis, to fit to a surface composed of a 3 x 3 cell window (9m x 9m on the shelf). From an applied viewpoint, the output of the Curvature tool can be used to describe the physical characteristics of a drainage basin in an effort to understand erosion and sediment transfer processes. The slope affects the overall rate of movement down slope. The profile curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition. The planiform curvature influences convergence and divergence of flow.

2.3.2 Towed video and AUV

Image acquisition and conversion to jpeg

Towed video imagery was acquired using CSIRO’s towed stereo camera system (TSCS) and an Autonomous underwater video (AUV). The TSCS combines stereo digital stills cameras and a video camera on a towed platform that can be deployed to about 550 m depth. The system collects continuous video footage and stereo still images at regular intervals, and logs data regarding position, depth altitude etc. of the camera system. The geographic position of the TSCS is usually established via an Ultra Short Baseline Acoustic Positioning (USBL) system (see: http://www.seaviewsystems.com/questions/what-are-your-means-of-positioning-the-rov/ for details). Unfortunately the USBL used in the Flinders failed in the field and hence the camera position was approximated by triangulation of the ship’s position and heading, the length of wire out between the ship and the TSCS, and the camera depth.

The TSCS cameras are mounted in a frame at a 45^0 angle, providing an oblique view of the seabed. The camera platform is towed behind the ship on a fibre-optic cable that has live video feed to the winch control room; the camera is towed at approximately 1 knot and flown at about 2-4 m above the seafloor, resulting in an approximate width of the field of view of 1.5 to 2.5 m.

The AUV imagery was collected with the IMOS AUV “Sirius”. This is a modified Seabed class AUV. The AUV is equipped with strobes, multibeam sonar, depth, conductivity, and temperature sensors, a Doppler Velocity Log (including a compass with integrated roll and pitch sensors), an Ultra Short Baseline Acoustic Positioning System (USBL), and a forward-looking obstacle avoidance sonar (for more details see Williams et al. 2012). Seabed images were collected with a synchronized pair of high sensitivity 12 bit, 1.4 megapixel cameras (AVT Prosilica GC1380 and GC1380C; one monochrome and one colour).

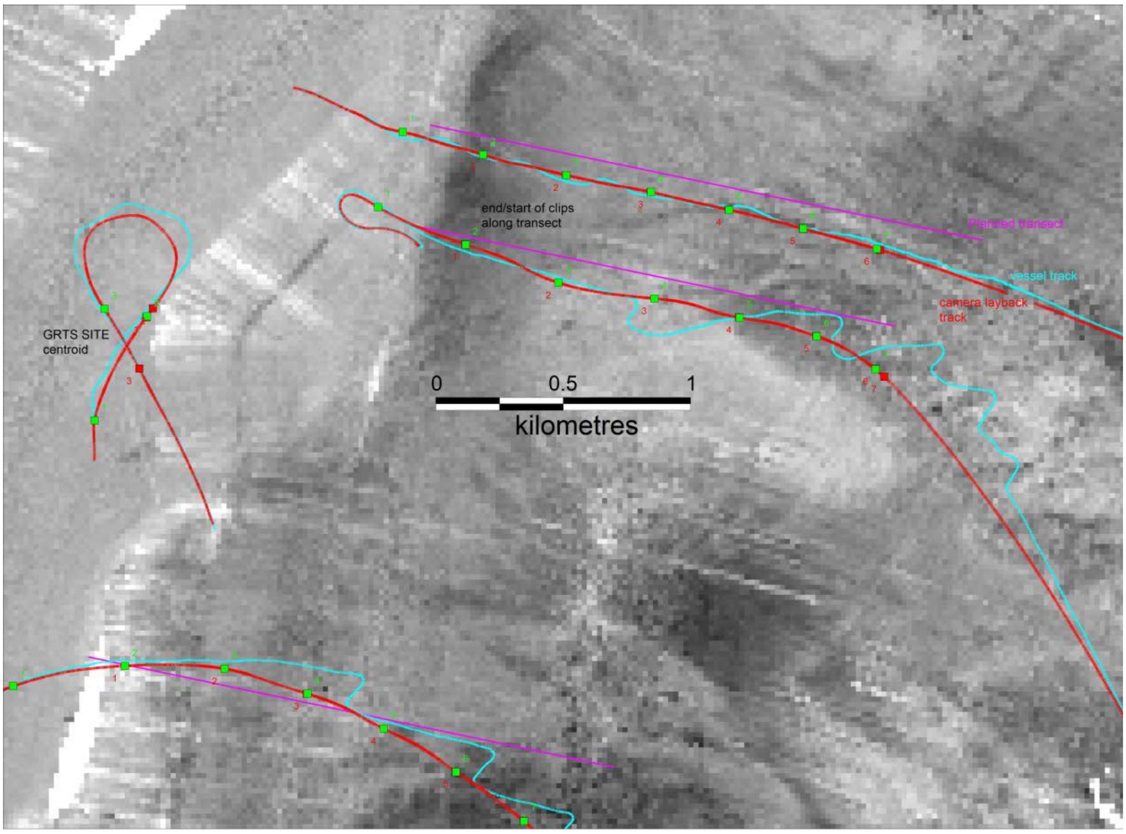
Each AUV transect was pre-programmed so that the AUV tracked the seabed at an altitude of 2 m at a cruising speed of 0.5 - 1m/s, resulting in an approximate width of the field of view of 1.5 - 2.5 m per image. All surveys were conducted during daylight hours over three days in June 2013.

On the shelf, the TSCS unit was towed across eight of the GRTS ‘mixed’ habitat and three ‘sand’ habitat sites identified in Phase I of the survey. In addition one canyon head site was surveyed (Fig 5). At each GRTS site two, short ~250 m transects were run in a cross-over pattern (Appendix D). Digital stills were taken every 3-4 seconds at most sites. Information from samples taken in this way were used to quantify the habitats and biota across the CMR shelf (Lawrence *et al*., 2015).

For the AUV a total of 24 transects (4 GRTS transect within each of the 1 km grid cells) were completed. The aim of this sampling was to describe the seafloor habitats and biota of a characteristic region of the CMR. A total of 720 images (i.e. 30 images per AUV transect) were selected along the AUV transects using a variety of approaches. An additional 695 images were selected to target the linear outcropping reef features. Monk *et* al., (submitted) describes the effect of using different (within transect) image sampling approaches on the results of species distribution models developed using this data.

For the slope the TSCS was towed down-slope, aiming to follow pre-determined transect lines from the shelf-break (~150 m) to ~500 m depth. The depth of the TSCS was monitored using real-time vision and read-outs from the platform sensors and wire paid out with increasing depth down the slope. Digital stills were taken at either 5-6 second intervals or 10 -11 second intervals along the transect path. Fig 5 shows the predetermined transect lines, the vessel track and the triangulated position of the camera. Due to currents and weather conditions the vessel heading needed to be adjusted at various points along transects, in order to maintain the intended direction of the TSCS.

Fig 5 - Details of the targeted and realised camera tracks for a canyon head site and three slope transects.



Example of the vessel and camera tracks, and target transects for a canyon head sites on the shelf and three slope transects, showing the planned transect line (pink), the vessel position track (light blue) and the lay-back camera position track (red). Green/ red squares show positions of video clip start/end

Analysis of raw image files was performed using the dedicated software Transect Measure (http://www.seagis.com.au/transect.html) and Event Measure (http://www.seagis.com.au/event.html). Although Transect Measure and Event Measure will read geotifs images, the original format, compatibility also depends on the operating system. We found on Windows 7 systems that geotifs would load, but not on Windows XP. As several different users were scoring using a range of systems all images were converted to .jpeg to facilitate interoperability.

All video and towed camera imagery collected during the Theme 1 field work was scored at three different levels of biological resolution:

- Broad scale scoring: A coarse assessment of the higher level physical and biological habitat contained within an image.

- Fine scale scoring - CATAMI level: Point scoring of the substratum or biota within an image to coarse morpho-typical or taxonomic groups.
- Fine scale scoring – Morpho-species level: Point scoring of the substratum or biota within an image to the finest level possible or uniquely identifiable morpho-species.

Broad scale scoring

Broad scale scoring was conducted to gain an overview of the habitats and biota in the region. It quantifies the dominant and subdominant physical and biological habitat in an image.

For each platform, images were selected for scoring. For the Flinders CMR (shelf and slope), still images 30-33 seconds apart along the path of each transect were extracted from the raw image files, corresponding to an average distance of 35 m between images. 30 images along each of the two shelf transects (per shelf site) were also selected in spatially balanced manner using GRTS to provide an approach that was consistent with the AUV image selection in the continuous patch. All images were then scored at a broad and fine scale. If an image was unscorable due to limited visibility or poor lighting in a majority of the field of view then the next scorable image or video frame was scored. Scoring and data recording was facilitated by a customised access database. Repository details are provided in Appendix A.

The Collaborative and Automated Tools for Marine Imagery (CATAMI: http://code.google.com/p/catami/downloads/list.) Standardised Classification Scheme (V1.1) was used to classify the physical (substratum types) and biological (biota types) components of images. The CATAMI scheme provides a common framework for the labelling of substratum types and biota in marine imagery (Althaus *et al.*, 2015). The CATAMI scheme is hierarchical and based on a combination of taxonomy and morphology, with researchers choosing the level appropriate to their research question. Each category in the schema is associated with a Code for Australian Aquatic Biota (CAAB) that is maintained in an online database maintained by CSIRO (http://www.marine.csiro.au/caab/). Species-level identification, if scored, sits below the lowest level of the CATAMI hierarchy.

Each image was first scored for the dominant and subdominant substratum type in the field of view (FOV). The cover of dominant and subdominant substrata were estimated in 20 percentile bins (i.e. 1-20; 21-40; 41-60; 61-90; 81-100 %), where the entire FOV was considered to be 100% (acknowledging that the actual observed area of seafloor varies between frames, particularly for towed systems, depending on the height of the unit above the seafloor). When substratum type was obscured by biota (e.g. rocky reef covered with sponges, macro-algae, etc.) then it was inferred.

A ‘Veneer’ Substratum qualifier was used for both consolidated and unconsolidated substrata. When applied to unconsolidated substrata, images generally appear to be sand, but patches of hard substratum can be inferred based on the organisms present. When applied to consolidated substrata, reef edges or outcrops were visible and/or hard substratum organisms were dense whilst sand was clearly visible. The latter was characteristic of low-profile reef in the Flinders CMR region.

An additional 'Byrozoa crust' substratum qualifier was also created for the Flinders CMR images. 'Byrozoa crust' is a thin, potentially hard crust on the surface of sediments that appears to be composed of bryozoans (mixed with small hydroids, worm tubes and other small organisms). It is often found in the same location as small yellow solitary ascidians. This additional qualifier was created because this 'crust' appears to consolidate the substrate enough to allow for attachment points of other potentially larger organisms. This type of habitat may also represent relatively hard substratum that may be distinguished in multibeam data.

Each image was also assigned a Relief score according to the CATAMI categorisation, and if unconsolidated substrata were present bed forms were also scored according to the CATAMI categorisation. Examples of dominant and sub-dominant sub-stratum scores are provided in Appendix C.

Each image was also scored for the dominant and subdominant biota in the field of view (FOV). Dominance of a category within an image was assessed using pixel cover, rather than substratum basal cover, in order to capture biomass of three-dimensional organisms. The cover of dominant and subdominant biota was also estimated in 20 percentile bins up to a maximum of 81-100%.

Biota was scored to a high level within the CATAMI schema (Table 2), but a free text field was available to record more detailed information, for example, the next level down in the CATAMI hierarchy for sponges and macro-algae or particular species of interest, such as *Ecklonia radiata*.

Mobile invertebrates could be scored as dominant or subdominant biota, but this generally only occurred on unconsolidated sediments where screw shells, or individual echinoderms such as heart urchins or sea cucumbers were the only visible biota. Otherwise mobile biota were recorded in the tick-boxes. In cases where it was not possible to distinguish if the dominant/subdominant biota belonged to one of two possible categories, because of uncertainty in the classification, labels consisting of both categories were used.

Table 2 - Summary of the levels in the CATAMI hierarchy (and their associated CAAB code) used in the broad scale scoring of biota in images collected by AUV and TSCS during the Flinders CMR survey.

Label	CAAB Code
UNSCORABLE	00000001
NO VISIBLE BIOTA	00000003
VISIBLE BIOTA | Ascidians	35000000
VISIBLE BIOTA| Bacterial Mats	72000901
VISIBLE BIOTA | Bioturbation	81000000
VISIBLE BIOTA | Bryozoa	20000000
VISIBLE BIOTA | Cnidaria | True anemones	11229000
VISIBLE BIOTA | Cnidaria | Black & Octocorals	11168901
VISIBLE BIOTA | Cnidaria | Stony corals	11290000
VISIBLE BIOTA| Cnidaria | Hydroids	11001000
VISIBLE BIOTA | Crustacea	27000000
VISIBLE BIOTA | Echinoderms | Sea stars	25102000
VISIBLE BIOTA | Echinoderms | Ophiuroids	25160000
VISIBLE BIOTA | Echinoderms | Sea cucumbers	25400000
VISIBLE BIOTA | Echinoderms |Sea urchins	25200000
VISIBLE BIOTA | Echinoderms | Feather stars	25001000
VISIBLE BIOTA| Jellies	80600903
VISIBLE BIOTA | Macroalgae	80300000
VISIBLE BIOTA | Molluscs | Bivalves	23199000
VISIBLE BIOTA | Molluscs | Gastropods	23590000
VISIBLE BIOTA | Molluscs | Cephalopods	24000000
VISIBLE BIOTA | Seagrasses	63600901
VISIBLE BIOTA | Sponges	10000000
VISIBLE BIOTA| Worms	80600901

Creating standardised quadrats for fine scale scoring

In order to calculate design-based estimates of the cover of habitat and biota across the Flinders CMR, the area of images scored needs to be known or standardised. With the TSCS imagery, the area of the seafloor captured within as image can vary substantially due to environmental factors such as sea state. Transect Measure and Event Measure enable standardised scoring by superimposing a quadrat of known size on the image. This requires a standardised file to be generated with at least 3 known points. This was achieved by first setting the picture directory and Information headers, and then turning on a 5m epipolar line to calibrate left and right camera files.

Having loaded both the left (Port) and right (Starboard) images, an accurate quadrat was superimposed by generating at least 3 ‘3D points’ spread out over the image. In most cases at least 4 points where generated. This was achieved by first picking an object that is clearly visible in both images (with a clearly defined edge) and then adding a point on the object in the left side image by left hand clicking on the spot. This automatically generates an epipolar line in the right image.

Another point was added to the right image in the same location as the left, using the epipolar line as a guide and the zoom feature to accurately place points. The accuracy of the point placement was checked using the “RMS intersection” in the “3D point Info” pop up box. A low RMS value indicates that both points have been placed in the same location according to the calibration. Once points had been accurately placed the same text (“TM point”) was added to the ‘Attributes-3D point’ box for all 3D points. Appendix A lists the repository of the saved Event Measure files.

Fine scale scoring

Fine scale scoring was conducted to gain a more detailed description of the physical and biological habitat in the region using a point count method in the program Transect Measure. Physical attributes and biota were scored using the CATAMI standardised classification scheme for marine imagery.

Biota were scored up to level 6 in the CATAMI hierarchy, a reasonably fine level that describes morphotypes for sponges and some other invertebrates and combines taxonomy and morphology for other groups. Code files appropriate for Transect Measure were generated that contained up to Level 6 in the CATAMI classification and the associated CAAB code (Table 2). Ten images per transect (selected using the GRTS algorithm) were scored to this level for the Flinders CMR TSCS data. A total of 30 images per AUV transect were scored to this level for the Flinders CMR. In all images, 25 points were censused.

The 30 images per transect Flinders CMR AUV data were composed of 10 images (GRTS image numbers 1-10) that were scored to the morpho-species resolution as described below, but aggregated up to CATAMI level 6 (using 25 of the scored points), and 20 images (GRTS image numbers 11-30) that were scored at the CATAMI level 6 resolution.

Scoring at morpho-species level

An additional and finer level of scoring was conducted on a subset of AUV images from the Flinders CMR. 10 images (GRTS 1-10) were scored to the lowest level identifiable, morpho-species, based on previous scoring conducted on AUV imagery in eastern Tasmania by UTAS. The purpose of this was to look for potential indicator morphotypes and to enable a comparison with previously scored imagery in Tasmania.

Previous scored UTAS morphotypes and codes were matched to the CATAMI classification scheme (to enable cross-comparisons and the aggregation of this scoring to the CATAMI level described above. For the morpho-species level scoring, 50 points per image were scored to increase the chance of scoring the less frequent, morphotype categories.

Exporting to txt/Excel

Once all the scoring was complete the Transect Measure TMObs files were batch exported to text files and then the text files merged using the software's 'Text report generation setting' and its 'Text file concatenation' operation. The Location of saved files are listed in Appendix A. The text file was then opened in excel where columns without data were removed, filters applied and then saved as an excel (.xlsx) file in the same location.

Quality assurance and quality control

QA/QC was conducted on Flinders CMR AUV images at the CATAMI (level 6) of scoring. A set of random images were generated and 30 of these images that did not contain only sediment were scored by two scorers. A confusion matrix was generated to look for inconsistencies between the scores (Fig 6).

On the basis of examining the confusion matrix and considering the relative number of points assigned to the various classes across all of the scored imagery, the following operations were performed:

- All sponges were checked to make sure scoring was consistent and adjusted where necessary (sponges were prevalent in the data)
- One scorer rarely distinguished between Bryozoan/Hydroid (CAAB Code 20000000|11001000) and Bryozoan/Hydroid matrix (CAAB Code 4), more commonly scoring it as Bryozoan/Hydroid. Therefore all CAAB Code 4 were re-assigned (in the final output) to CAAB code 20000000|11001000 (Bryozoan/Hydroid)

- All non-sand substrate was double-checked to ensure that the scoring was consistent and adjusted where necessary.

The TSCS images on the shelf and on the slope were scored separately by single individuals. An informal QA/QC that compared the scoring between the shelf and slope was subsequently conducted.

Final outputs for analysis

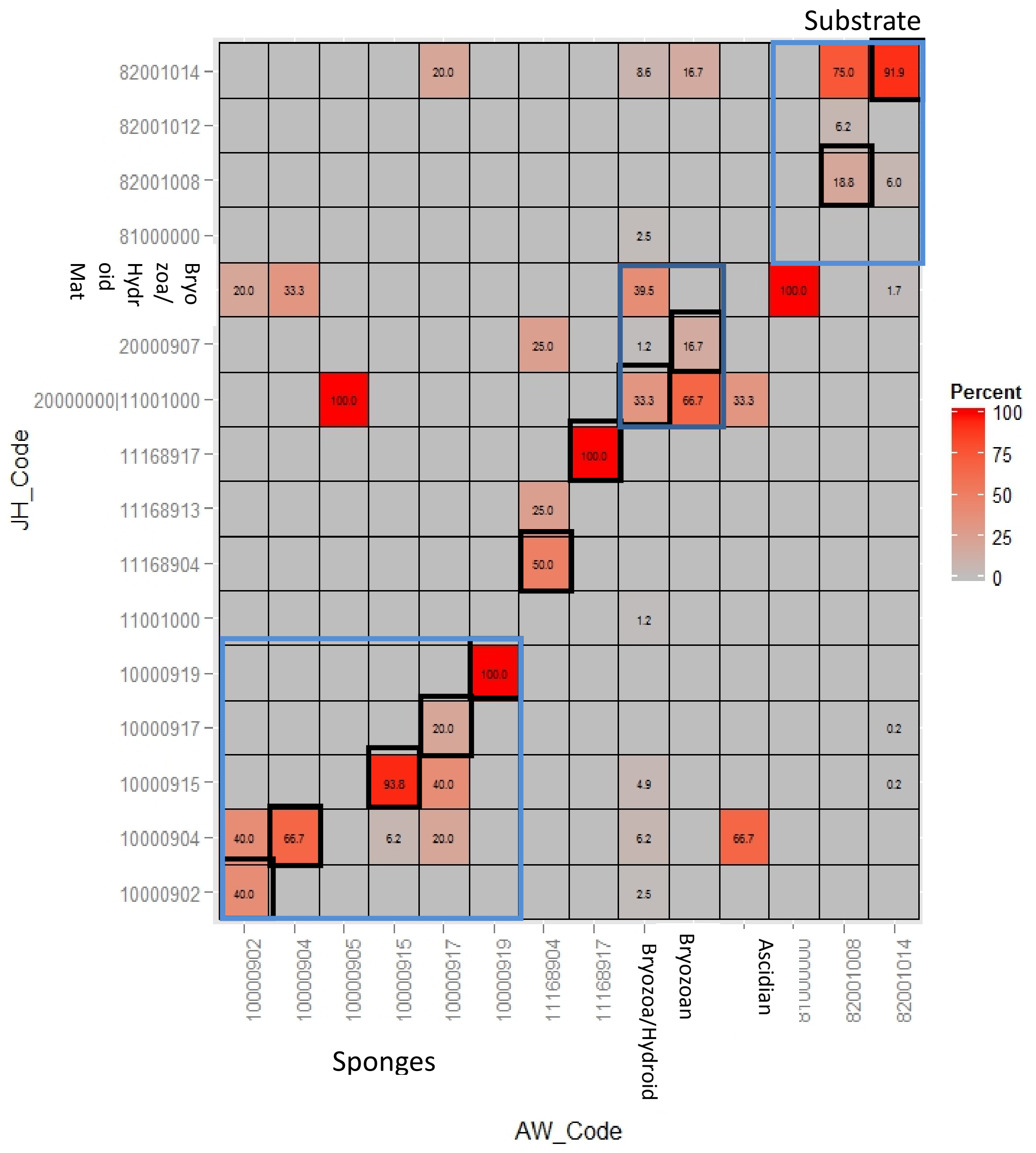
Quality assured outputs were matched to image-level metadata including the latitude, longitude and depth of images. For the AUV data two files were produced - a morpho-species level output for which 10 images were scored with 50 random points, and a CATAMI level 6 output which 30 images were scored with 25 random points.

The morpho-species level output contained labels that match to previous AUV scoring contained within an in-house database of AUV scoring. The repositories of the final data products are listed in Appendix A. Table 3 summarises the number of images scored, for each platform and each level of biological resolution.

Table 3 - Summary of AUV and TSCS scoring in the Flinders shelf and slope

			Type of scoring		
Location	**Platform**	**# of transects**	**Broad-scale**	**Fine-scale**	**Morpho-species**
Flinders CMR shelf	TSCS	13	30	30	
Flinders continuous patch	AUV	24	30	30	10
Flinders slope	TSCS	8	1145	80	33

Fig 6 - Quality assurance confusion matrix



Confusion matrix showing the CATAMI classes scored by Aidan (AW) and Justin (JH) for 30 co-scored images. Black outlined boxes indicate consistent classification between scorers, the percent of all points scored as any particular class are is shown in each box and colour coded. Blue outlined boxes indicate sponge, bryozoan/hydroid and substratum respectively moving from left to right across the image.

2.3.3 Baited Remote Underwater Video

Video acquisition

Due to time and logistical constrains, shallow BRUVS were deployed in clusters. Each cluster consisted of a central GRTS site that was sampled in Phase I and 4 GRTS chosen sites within 1 km of the central site. Phase I reef sites were preferentially targeted as they are recognised as an important biodiversity feature and were expected to support greater diversity than sediment habitat. The same phase 1 sites sampled with the TSCS were sampled with BRUVS; i.e. the first eight “mixed” habitat GRTS sites from Phase I were sampled as well as three ‘sand’ habitat GRTS sites and one site located on a canyon head. A total of 65 BRUV deployments were completed across the Flinders CMR shelf.

Stereo-BRUVs used for sampling consisted of two Canon Legria HFM-300 digital camcorders fitted with Raynox 50 mm wide angle lenses. Cameras were mounted in PVC housings on a weighted galvanized steel frame 700 mm apart angled inwards at 8 ° and approximately 500 mm off the ground. This configuration maximizes the field of view for observation of epibenthic fishes. A synchronizing diode arm with mesh bait bag attached extended 1200 mm in front of the cameras. The bait attractant used was ~1 kg of crushed pilchards (*Sardinops neopilchardus*) and each unit was deployed for 1 hour (soak time).

Adjacent concurrent drops were separated by at least 250 m to avoid overlap of bait plumes and to reduce the likelihood of fish moving between sites within the 60 min sampling period. Due to the reduced light conditions on the Flinders shelf the stereo BRUVs field of view were illuminated by seven Royal Blue CREE XLamps XP-E LEDs (delivering a radiant flux of 350-425 mW at wavelength ranging from 450 to 465 nm). This wavelength was chosen to be consistent with previous work done around Australia using BRUVs in deeper waters. It is thought that the blue LEDs are a compromise between reducing fish repulsion and footage quality. We estimate that with the blue LEDs the field of view was up to 5 m from the camera.

Three units of the Deep BRUVs developed by CSIRO and described by Marouchos *et al*., (2011) were deployed at 500 m depth on the Flinders CMR slope. In short the Deep BRUV units are designed for long-term deployment with programmable recording periods linked to the release of a plume of liquid bait. The units are connected to a sacrificial weight by an acoustic release. For the Flinders CMR deployment, the units were programmed to take samples of 1 hour of video footage at 6 hourly intervals to give a total of four samples per 24 hours. The sequence of events for each sample was (1) the cameras turned on, (2) the lights turned on, (3) the bait-plume was released. The bait used was a mixture of fish oil and fish meals. The units were deployed on August 10 and retrieved on August 13; each unit recorded a total of 12 samples.

Camera calibration

In-water calibration of the Shallow and Deep BRUV stereo camera set-up before and after survey was completed at the local swimming pool, using the software CAL and methods described by SeaGIS (http://www.seagis.com.au/index.html).

Video conversion

To allow analysis of BRUV imagery the video was converted from its native camera format to a format that the Event Measure software can read (namely Xvid–Video .avi). The Canon cameras used in the Flinders CMR record in .mts format and the JVC cameras in .mod format. These formats were converted to Event Measure compatible files using the Xilisoft Video Converter Ultimate software (http://www.xilisoft.com/video-converter.html).

The BRUV cameras are also memory limited and only able to record files up to a set size. As a consequence one BRUV drop is recorded on several different files, usually named in numerical order. Either Event Measure or Xilisoft can be used to organize individual file into one. In this case the Xilisoft software was used to perform this tasking via its “join” function, and the joined files saved in the UTAS repository along with associated meta-data (Appendix B).

Each one-hour Deep BRUV sample consisted of three .MTS files. These were converted to .avi format using Xilisoft software and saved on the CSIRO computer network (Appendix B).

Scoring and measuring

Imagery collected using stereo-BRUVs was scored using standard metrics including scoring the maximum number of fish occurring in any one frame for each species (MaxN). For common species and species of commercial or recreational interest, the length of fish at MaxN was also measured. Scoring was completed using imagery from the left camera only, and only for individual fish within 5 m of the cameras. Scoring proceeds by placing a point on a species the first time that it is seen in the video frame, and then recording it. The same species is not subsequently counted again until there are two or more individuals present in a single frame. The process of only counting a species when more individuals are seen than previously counted in a frame continues for each species until the end of the soak time. If there were a very large number of individuals in a single frame (for example a school of Jack Mackerel) or it was otherwise difficult to identify individuals, an estimate of the total number of individuals was made and this was noted as in estimate in a comments field. During the MaxN counting process, other morphological and behavioural parameters were also recorded, including the sex and maturity of the individual if possible, the size of the individual and their behaviour at the time of recording.
Species length is measured (in Event Measure’s stereo view) in several different ways depending on the morphology of the species concerned, and best practice recommendations drawn for the literature:

- Fork Length (FL): For fish with forked tails, i.e. from the tip of the mouth/nose to the base of the fork in tail.
- Total Length (TL): For fish species with rounded tails (nose to tail tip). Sharks were measured form the tip of the nose to the upper tip of the tail. Rays are measured from the tip of the nose to the tip of the tail.
- Disk Width (DW): Used very occasionally for rays, always recorded as a total length (wherever possible) across the widest part of the body, wing tip to wing tip.
- Mantle Length: Used for squid, defined as the body length excluding the head and tentacles.

Deep BRUVS scoring

Each one-hour sampling period was treated as a distinct replicate. The three video clips representing a sampling period were annotated as one sample. The video was viewed using the Event Measure software at 3x speed. Unlike shallow BRUV deployments, the fish showed no interest in the bait release and only few fish were observed at any one time. In general it appeared to be fish passing in front of the cameras by chance. Due to the low abundance we adapted the scoring system for the deep BRUVS to record both MaxN and a measure of total abundance for each species observed in a one-hour sampling period. We are confident that we could avoid counting the same individual multiple times within each recording period, as the fish appeared not to be attracted to the bait or camera *system.*

Exporting to txt/Excel

The length and MaxN by stage data were exported using ‘Batch text file output’ from Event Measure. Files were exported as a text format.

2.4 Summary of initial results

2.4.1 Multi-beam sonar survey

The results of the multi-beam sonar survey and subsequent habitat interpretation for the CMR shelf are reported in Lawrence *et al*., (2015). Fig 7 provides an overall summary of all current information on the shelf and slope habitats based on information collected previously and in the NERP marine biodiversity hub survey.

2.4.2 Towed video and AUV

Results of the TSCS and AUV surveys conducted on the Flinders shelf (GRTS cells and continuous patch) are reported in Lawrence *et al*., (2015) and Monk *et al*., (2016).

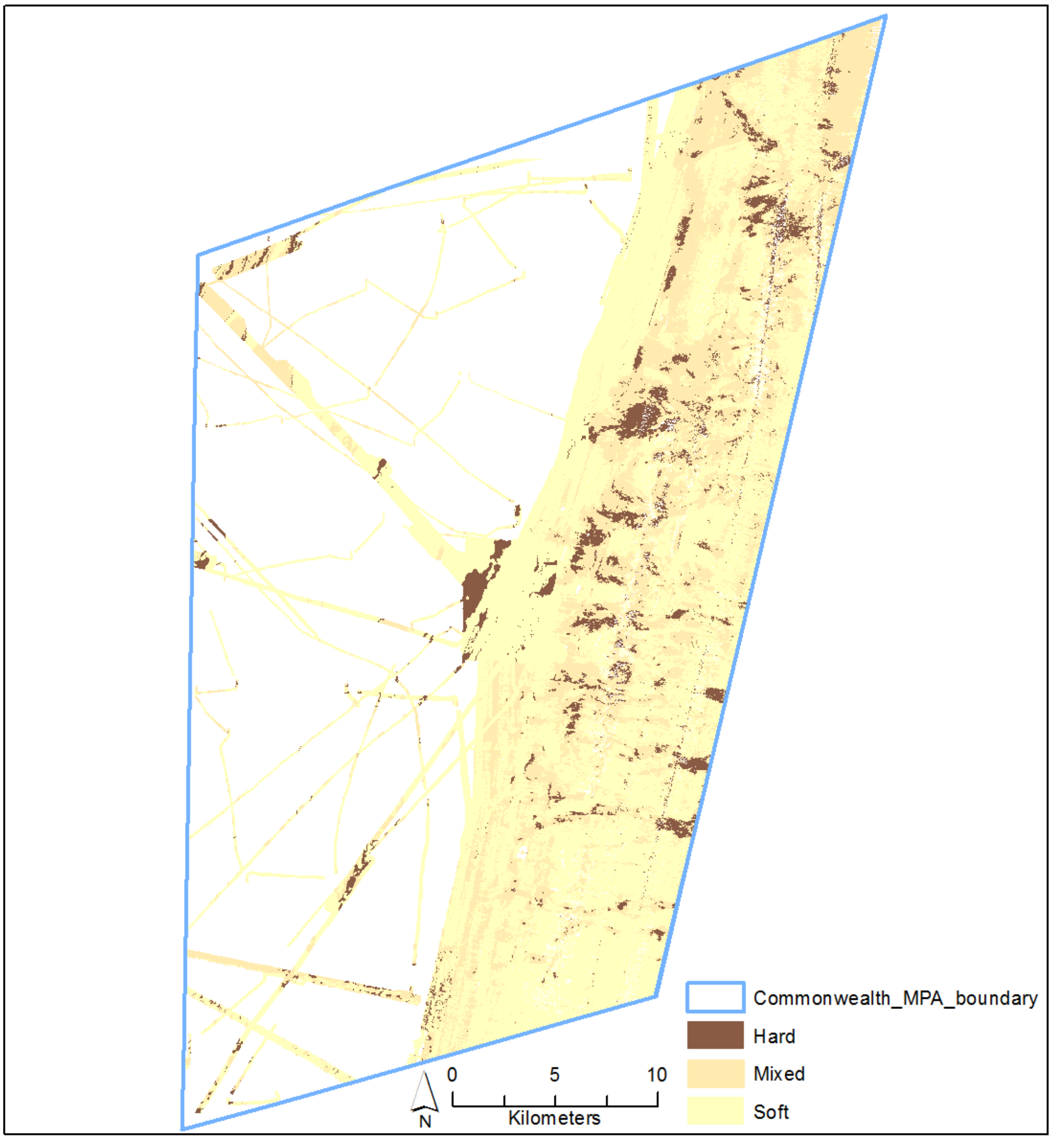
Results from the broad scale scoring of the images from the TSCS surveys of the continental slope are summarised in Figs 7, 8, 9 and 10.

Despite using the existing CSIRO habitat maps to target transects with a relatively higher proportion of hard substrate (according to the habitat classification), the substrate along the TSCS slope transects was dominated by sand/mud (72% of images) with some rocky outcrops where transects intersect some steeper topography (Fig 8). The sand/mud substrate in nearly half of all scored images, however, was found to be consolidated by a matrix of bryozoans (dead and alive) that apparently provide enough stability for settling of fixed fauna and may also confound the interpretation of multibeam backscatter data.

Biota was observed in most images selected from the transect (Fig 9). Faunal cover, however, was predominantly sparse (<20%), and dominated by a mixed category composed of bryozoan and hydroids (24% of images) followed by small ascidians (26%) and sponges (19%) (Fig 10).

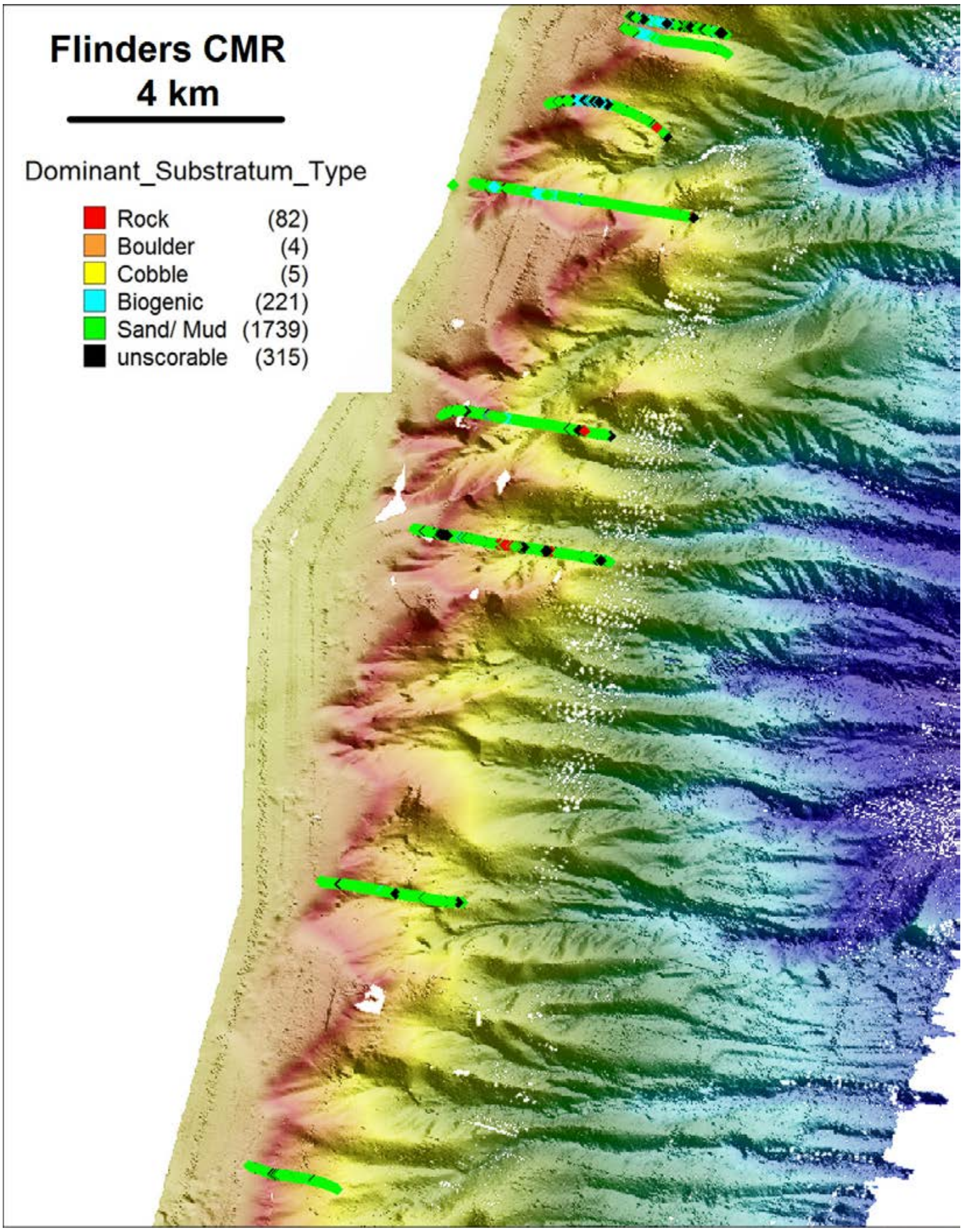
Most individual organisms were found to be small with a low profile (<20 cm height or diameter). On rocky outcrops larger fauna was observed, including some bamboo and other octocorals (0.5% of images). One image showed four giant crabs (*Pseudocarcinus gigas*) under a rocky ledge.

Fig 7 - Summary of shelf and slope habitats classifications for the multiple use zone of the Flinders CMR



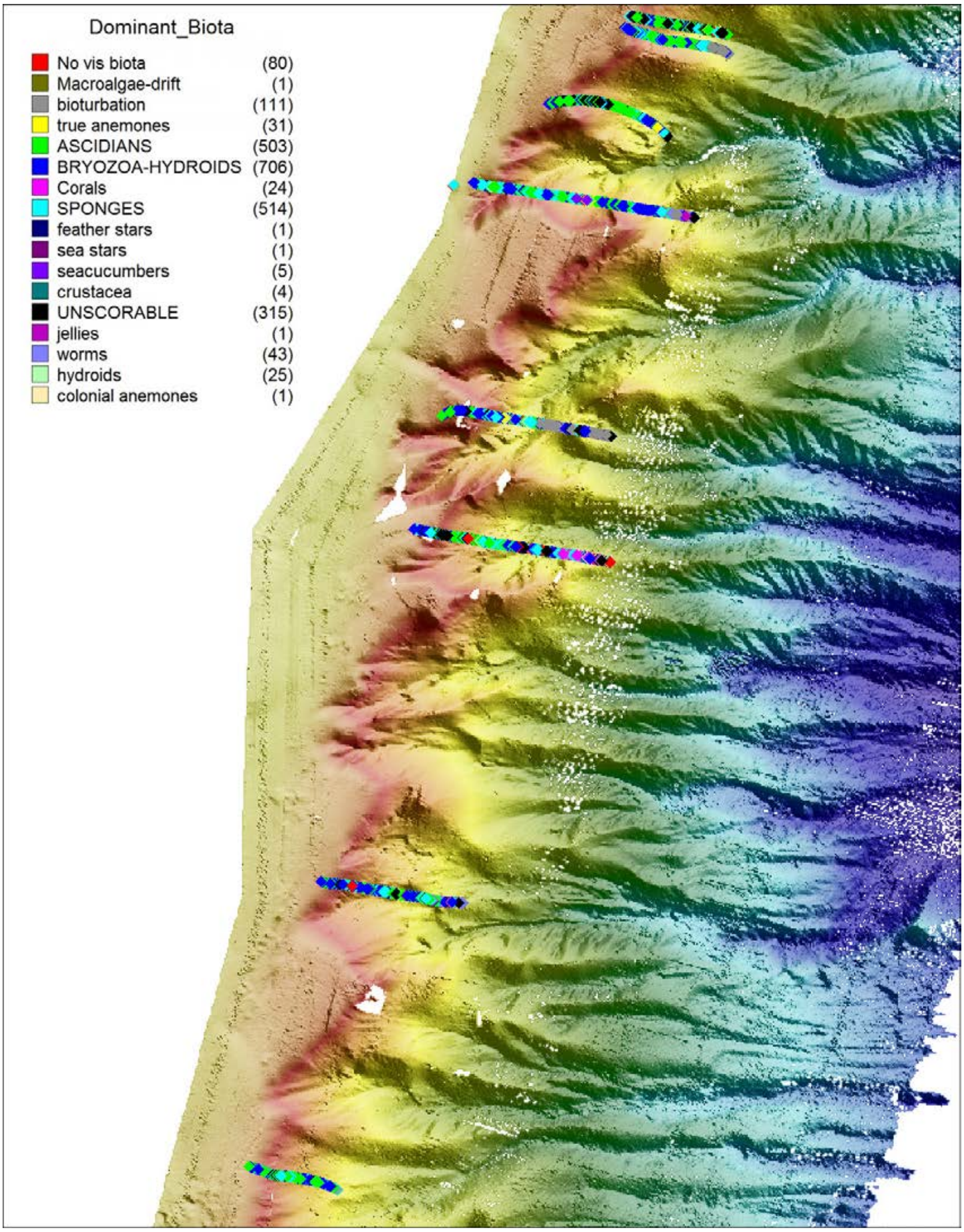
Habitat classifications of the Flinders CMR multiple use zone based on the high resolution multibeam survey at the GRTS sampling sites, the continuous patch and voyage transits (shelf), conducted by the NERP marine biodiversity hub, and the previous multibeam sonar surveys conducted by CSIRO and UTAS (mainly slope).

Fig 8 - Dominant substratum recorded in the Flinders slope TSCS transects.



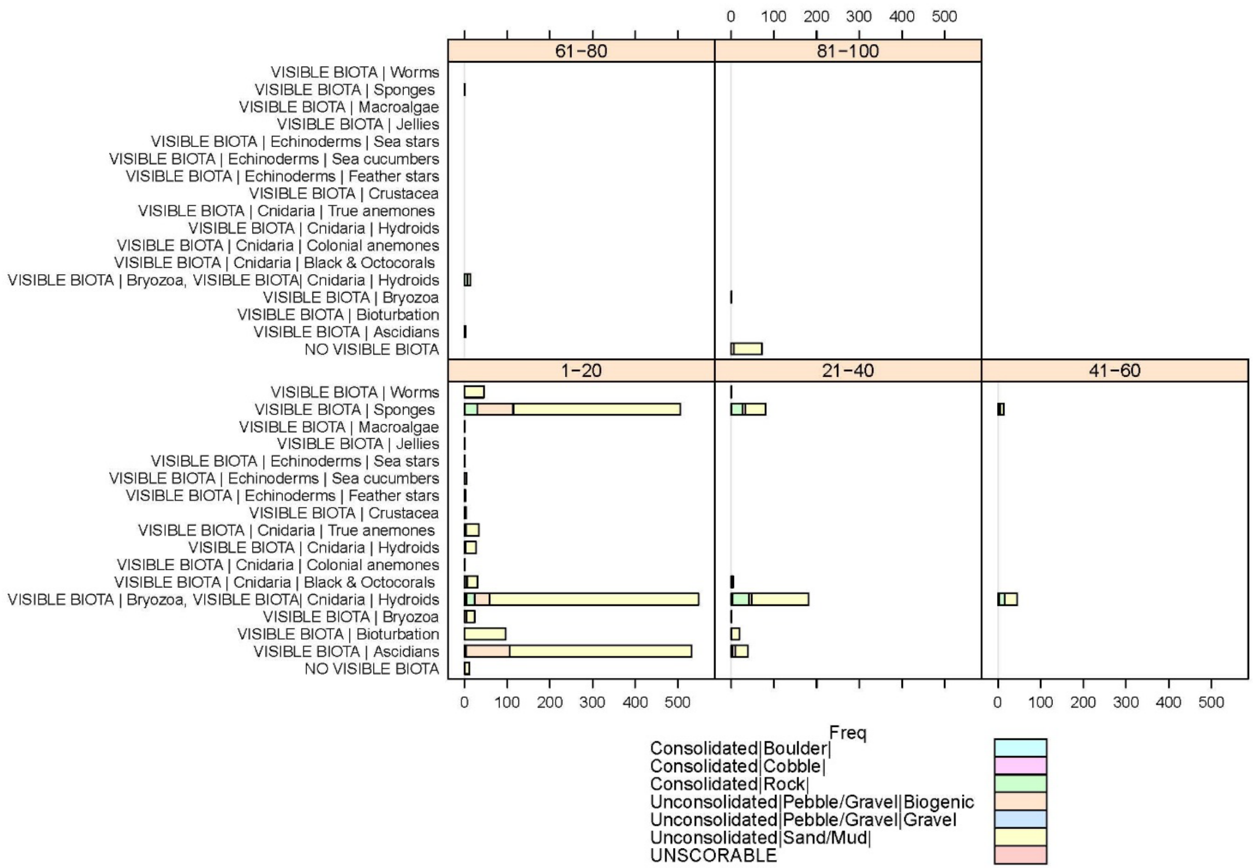
Summary of the broad scale scoring of the dominant sub-stratum from still images 30-33 seconds apart extracted from the path of the down-slope TSCS transects.

Fig 9 - Dominant biota recorded in the Flinders slope TSCS transects.



Summary of the broad scale scoring of the dominant biota from still images 30-33 seconds apart extracted from the path of the down slope TSCS transects

Fig 10 - Summary of broad-scale scoring of the TSCS slope transects in the Flinders CMR.



Summary of the frequency of occurrence of dominant biota categories in 5 percent cover categories, together with dominant substrate category (shown by colour of bars)

2.4.3 Baited remote video

Results of the baited remote video survey of the Flinders shelf are reported in Hill *et al*., (2014). The deep baited remote video recorded a total of 13 taxa of bony fish and 6 sharks and jellies (Table 4 and Fig 11), despite there being no clear evidence that fishes were attracted to the liquefied bait. The bait type and release mechanism will need to be reviewed and tested further.

Numbers of fishes observed were generally low, as they were not reacting to the bait. Thus we recorded Max N using Event Measure, but also counted the total number of individuals observed in each one hour sample. Table 4 summarises the total number of individuals observed for each taxon over 36 samples. Fig 11 shows a box-plots of the samples with whiskers indicating the minimum/maximum counts and Max N per one hour sample.

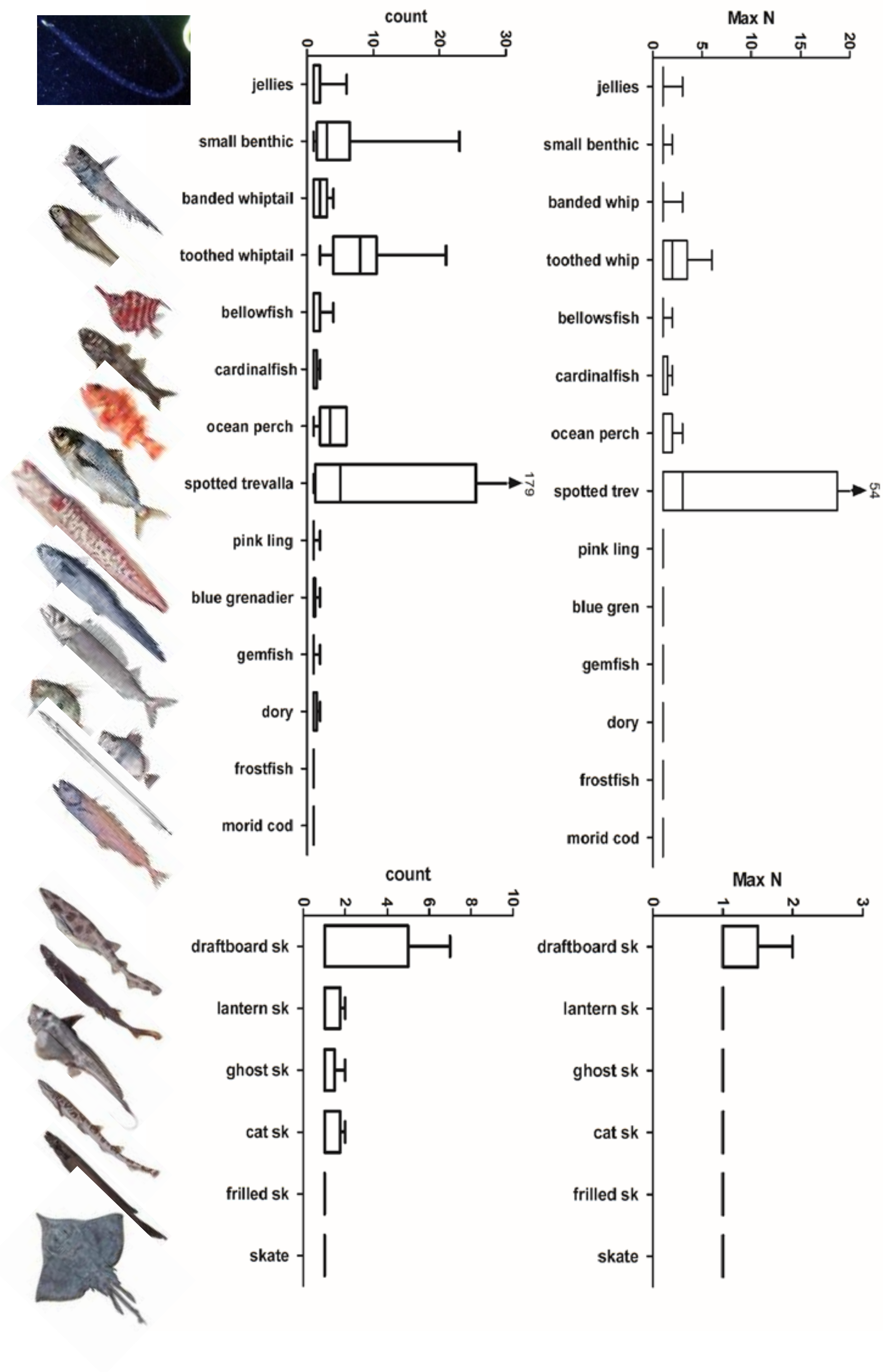
The largest number of individuals observed during each sample was 179 spotted trevalla. This species was observed in large schools swimming through the field of view. Max N for this species peaked at 54, however school sizes ranged from 5 to 79 individuals.

Toothed and banded whiptails were the most commonly observed species, being seen in 92% and 75% of samples, respectively. Observations in more than 40% of samples include bellow fish, ocean perch, small benthic fishes, spotted trevalla and jellies, however the maximum counts per sample were low for all these taxa, except for small benthic species (Table 4). With the exception of the draughtboard shark, sharks and skates were less abundant with total observations ≤6 and no more than 2 individuals per sample; for these taxa Max N only recorded their presence.

Table 4 - Fishes (and jellies) observed during 36 hours of observation over 3 days: 36 samples made up of 12 recording periods of three deep BRUVS units deployed at 500 m depth in the Flinders CMR.

Species	**Total count**	**Max. count per recording period**	**% of recording periods observed**
Jellies	27	6	42
small benthic	93	23	47
banded whiptail	58	4	75
toothed whiptail	264	21	92
bellowfish	32	4	56
cardinalfish	6	2	14
ocean perch	68	6	50
spotted trevalla	404	179	44
pink ling	9	2	22
blue grenadier	7	2	17
gemfish	4	2	8
dory	6	2	14
frostfish	2	1	6
morid cod	2	1	6
draftboard shark	24	7	25
lantern shark	5	2	11
ghost shark	6	2	14
cat shark	5	2	11
frilled shark	1	1	3
skate	2	1	6

Fig 11 - Summary of fish taxa observed by deep BRUVs in the Flinders CMR



Box plots showing the total counts and Max N of fishes (and jellies) observed in 36 samples (i.e. 12 recording periods of three deep BRUVs units) at 500 m depth in the Flinders CMR.

3. SOLITARY ISLANDS KEF

3.1 Background and objectives

The Solitary islands Key Ecological Feature (KEF) is defined as the benthic communities on shelf reefs along the continental shelf of the East Marine Region south of the Great Barrier Reef. At approximately 40m depth these communities shift from being dominated by macro-algae to being dominated by sessile invertebrates. These invertebrates create a complex habitat-forming community composed of large sponges, ascidians, bryozoans and soft corals, and support large numbers of commensal micro-organisms, molluscs, crustacean, annelids, echinoderms and juvenile fish (Dambacher *et al*., 2012).

The objectives of the Solitary Islands field work were:

4. Conduct multibeam sonar mapping of shelf reef features in the KEF to augment and add to the existing mapping and inventory of shelf habitats conducted the NSW Office of Environment and Heritage (Jordan *et al.,* 2009).

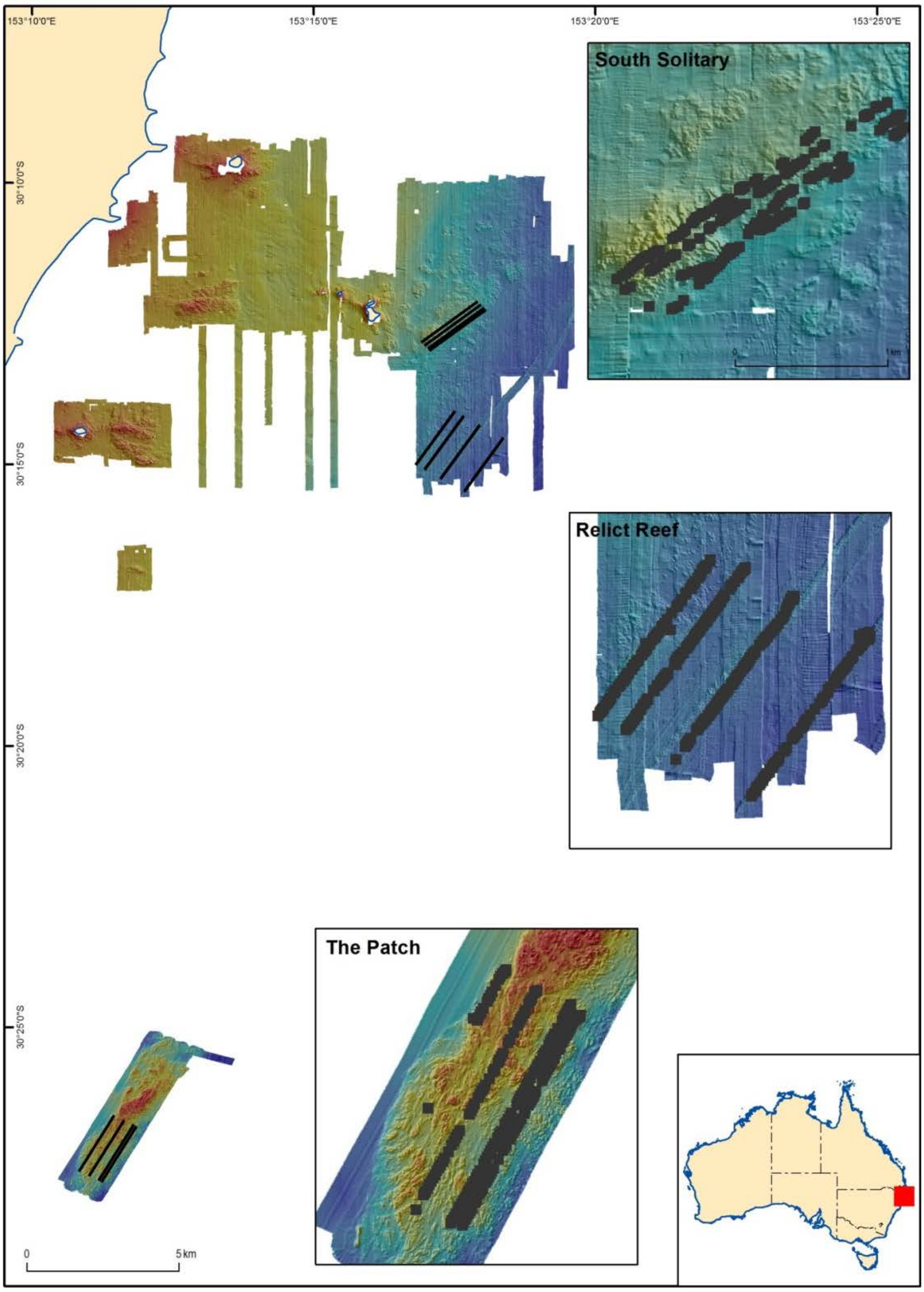
5. Trial the use of selecting AUV and TSCS transects using GRTS to achieve spatially balanced transects whose inclusion probability reflect the proportion of hard substrate that they intersect, as determined by high resolution multibeam sonar, and compare the outcomes of sampling with these two alternative approaches.

6. Use the opportunity afforded by the NSW existing BRUV monitoring programme to conduct an autocorrelation and power analysis for a specific BRUV objective.

3.2 Sample design

Four sites (1 x 2 km) known as The Patch, South Solitaries, 40 Acres and Split Bommie were selected in the Solitary Islands Marine Park (SIMP) and Solitary Islands Marine Reserve (SIMR) using expert knowledge on the benthic habitats in the region. Within these four sites GRTS was used to select 3-5 transects of 2 km long each. However, only three sites were sampled with the towed video due to inclement weather and gear complications during data acquisition (e.g. South Solitary, Relict Reef and the Patch) (Fig 12) and only two sites (South Solitary and Relict Reef) were surveyed with the Autonomous Underwater Vehicle. Again sampling was targeted towards reef areas by using existing NSW OEH habitat maps derived from multibeam survey data, and selecting transects proportional to the amount of 'hard' substratum contained within each transect as per the TSCS survey of the Flinders slope.

Fig 12 - Location of the TSCS transects on three distinct reef features within the Solitary Islands KEF: South Solitary, Relict Reef and The Patch.



3.3 Data processing, scoring and analysis

3.3.1 Multibeam sonar

Areas of long, narrow, low relief reef features offshore of North Solitary and South Solitary islands were first mapped in 2005 by multibeam surveys. Lying in 70-75m water these features were observed as multiple, linear reef systems, largely parallel to the existing shoreline, and were therefore interpreted as relic coastline features, hence the name Relict Reefs (Jordan *et al*., 2009). Currently the boundary demarking the state and commonwealth marine park and reserve cuts through these features at the 3NM line, however, it was expected that these features would likely extend beyond the existing mapping coverage and into Commonwealth waters.

To examine these reefs further, swath data (bathymetry and backscatter) were collected across an area of ~40 km^2 of seafloor within the southern section of the Solitary Islands Commonwealth Marine Reserve in September 2012. Multibeam sonar data was acquired with a 125 KHZ Geoswath deployed from the NSW Office of Environment's vessel RV Bombora. Over the course of 5 days the vessel mapped additional relic reef systems, as well as other complex reef habitat across the southern extent of the reserve.

To process the bathymetry, logged motion system data were combined with final ephemeris and then processed using Precise Point Positioning (PPP) modules in POSPac (Applanix, U.S.A.) to provide a vessel Smoothed Best Estimate of Trajectory (SBET). The SBET was applied to Geoswath raw data files in GS+ (GeoAcoustics U.K.) that were then coarse filtered while applying sound velocity corrections (horizontal and vertical profiles). Data were export as GSF sounding clouds and then gridded in Fledermaus to create a Cube surface based on International Hydrographic Office 1 Standard for point editing. Cleaned soundings were then exported and gridded to 2m and 5m bin scale in WGS84 Zone 56S and Australian Hydrographic Datum. Data were then exported as a raster layer to ArcMap.

For backscatter, GS+ swamp files were mosaicked in Geotexture using extracted beam and scatter functions to normalise the output and return signal (dB). The final mosaic image was then exported to ArcMap.

Hill shaded bathymetry and slope layers were calculated in Arc Map and then combined with bathymetry and backscatter data to hand digitise a 3-tiered classification system. Using a minimum mapping unit of 20m^2, spatial layers were used to identify: (i) Reef (with Profile), (ii) Unconsolidated sediments; and (iii) mixed Intermediate seabed types. Using data from previous surveys the same 3-tiered classification system was used to digitise 2 x 2km areas at each of South Solitary, Forty-Acres Reef, Patch Reef, Split Solitary Island and Relic Reef sites. Digitised shape files were then used to define target towed-video transects to sample across all 3 seabed types using a GRTS based sampling design, with inclusion probability amended to preferentially select transects with a high proportion of reef (as per Flinders AUV transects in the continuous patch).

3.3.2 Towed video and AUV

Image acquisition

Two platforms were used for surveying benthic habitats and biota in the Solitary Islands; the Australian Centre for Field Robotics, Autonomous Underwater Vehicle (AUV) *Sirius* that housed a downward facing stereo camera system, and Geoscience Australia's (GA) towed video unit that housed an oblique facing stereo video system. The AUV system captured digital stereo-pairs at short intervals along the transect path. The AUV completed five transects at the Patch and three at South Solitary (one of which was inadvertently repeated). The AUV also captured images at a number of "dense grids" at the Split Bommie, the Patch and Forty Acres. These results are not report here.

The GA towed video unit captured video continuously. Eleven and a half towed video transects were completed during the Solitary islands fieldwork - four at South Solitary, four at Relict Reef and three and a half at the Patch. Additional planned sites could not be completed due to inclement weather, an engine breakdown and period failure of the Tracklink software that was recording the position of the towed body via the USBL.

The towed stereo camera system (TSCS) was deployed using a winch system affixed to the R/V Bombora. The TSCS was equipped with a total of four cameras: i) a forward-facing Black Magic Cinema Camera; ii) two GoPro Hero 2 cameras in Patima housings with 30 cm spacing; and iii) a downward-facing Nikon D700, Easydive Leo II housing with dome port for capturing still images of the bottom. The camera system was also equipped with evenly spaced forward facing lasers for gauging distance, as well as a USBL (Ultra Short BaseLine) locator which was occasionally inconsistent. The winch system was equipped with 270 m of cable, controlled by an operator monitoring live camera feed transmitted via the winch cable to a computer monitor.

Image selection

For the Solitary Islands, every 100th image, equivalent to one stereo-pair every 25-30 m, was selected from the AUV dataset. For the TSCS data set the video images were selected by pausing the footage at every 30 (±2) second interval. In cases where it was not possible to reconcile image quality (e.g. blurry, turbid, water column etc.), the image was labelled as unscorable and the next image was used for scoring.

The total number of TSCS images selected (unscorable) for broad scale scoring in each of the three survey locations were: (i) Relict Reef – 415 (101); (ii) South Solitary – 262 (56); and, (iii) The Patch – 209 (21). For fine scale scoring 40 images from South Solitary and The Patch were extracted, and 39 from the Relict Reef (Table 5). The total number of AUV images selected for broad scale scoring was 127 and 207 in the South Solitaries and the Patch, with 30 images from each site scored to a fine scale (Table 5).

Table 5 - Summary of the AUV and TSCS scoring in the Solitary Islands KEF

			Type of scoring		
Location	**Platform**	**complete transects**	**Broad-scale**	**Fine-scale**	**Morpho-species**
South Solitaries	TSCS	4	262	40	0
Relict Reef	TSCS	4	415	39	0
The Patch	TSCS	3	209	40	0
South Solitaries	AUV	3	127	30	0
The Patch	AUV	5	207	30	0

Image conversion and creation of standardised quadrats

Image conversion and creation of standardised quadrats followed the same methodology as described for the Flinders CMR survey.

Broad scale scoring

At the Solitary Island sites consolidated rocky substrata were generally covered in mats of turfing algae. This was also added as a substratum qualifier because the algae mat may facilitate settlement of other, larger organisms. In cases where it was not possible to distinguish if the dominant/subdominant biota belonged to one of two possible categories, because of uncertainty in the classification, labels consisting of both categories were used. For example in the Solitary Islands it was often difficult to distinguish if organisms were sponges or cnidarians, and so were assigned “VISIBLE BIOTA | Sponges; VISIBLE BIOTA | Cnidaria”.

Quality assurance and quality control

Solitary Island AUV imagery was scored solely by Nick Perkins. No official QA/QC was performed although Nick received training from, and was in contact with, Renata Ferrari, who also regularly scores AUV imagery in the Solitary Islands.

Solitary Island TSCS imagery was scored solely by Maggie Tran. No official QA/QC was performed although Maggie was in contact with CSIRO and UTAS colleagues who regularly score benthic underwater imagery.

3.3.3 Baited remote underwater video

Deployment and sample collection

A total of 65 BRUV deployments were completed across the Solitary Islands KEF in August-September 2012, comprising 40 deployments around proposed AUV-sites (40 Acres reef, Split Solitary, Southern Solitaries reef, The Patch, Relic reef) and 25 deployments (40 Acres reef) as part of an autocorrelation experiment. Sampling design for the autocorrelation experiment used GRTS with all sampling undertaken during a two-day period.

Stereo-BRUVs used for sampling consisted of two Canon digital camcorders fitted with Raynox 50 mm wide angle lenses. Cameras were mounted in PVC housings on a steel frame. A bait pole with mesh bait bag attached extended ~1.2 m in front of the cameras. The bait attractant used was ~1 kg of crushed pilchards (*Sardinops neopilchardus*). Adjacent concurrent drops were separated by at least 200 m to reduce the likelihood of fish moving between sites within the 60 min sampling period.

Video analyses for each 60 minute deployment were conducted using Event Measure (SeaGIS Pty. Ltd.). Length measurements were undertaken for commercially and recreationally important species as previously described for the Flinders CMR survey.

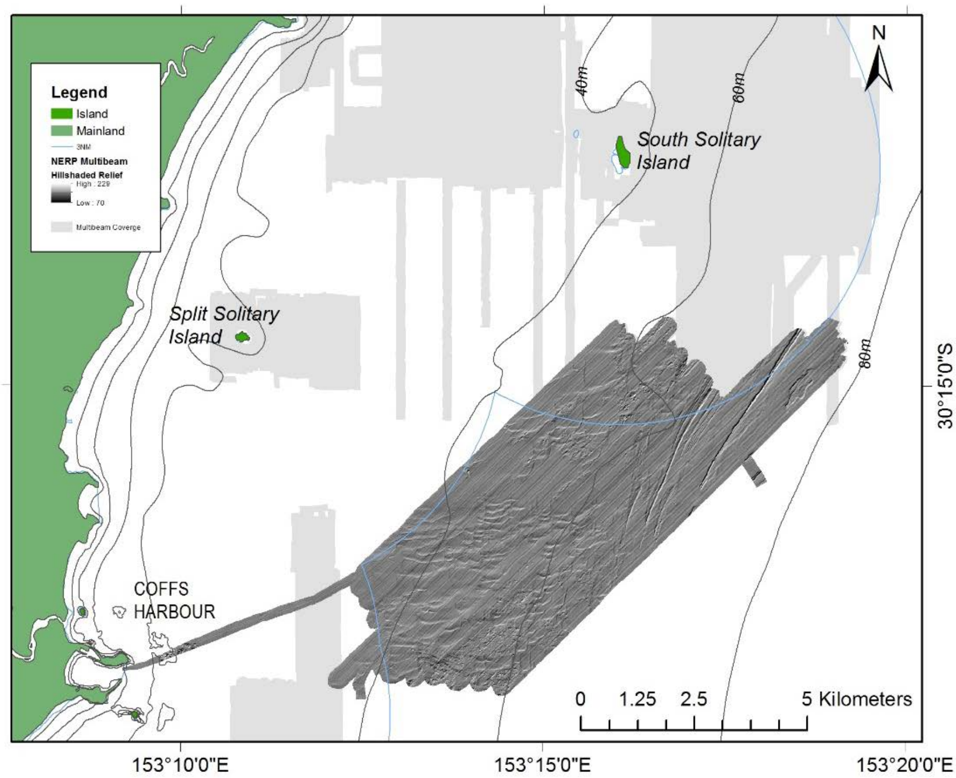
3.4 Summary of initial results

3.4.1 Multi-beam sonar survey

Fig 13 illustrates the additional multi-beam sonar data collected during the Solitary Islands survey, showing hill shaded relief and backscatter mosaic. The backscatter mosaic and bathymetry data were then used to develop a 3-class habitat map that clearly shows the extension of the relict reef previously mapped in state waters(insert Panel Fig 15), extending into Commonwealth waters (linear reef features in Fig 14).

The equivalent habitat maps for the other target areas in the Solitary islands, mapped previously by the NSW Office of Environment and Heritage, are shown in Fig 15 for comparison (note the change of scale between Fig 14). The sites marked as South Solitary, The Patch and Relict Reef were targeted for AUV and TSCS survey (Section 3.4.2). The site marked as 40 Acres was targeted as a suitable site to conduct a BRUV autocorrelation study (Section 3.4.3).

Fig 13 - (Top) Hill shaded relief and (Bottom) backscatter mosaic of Solitary Islands Marine Reserve multibeam survey data.



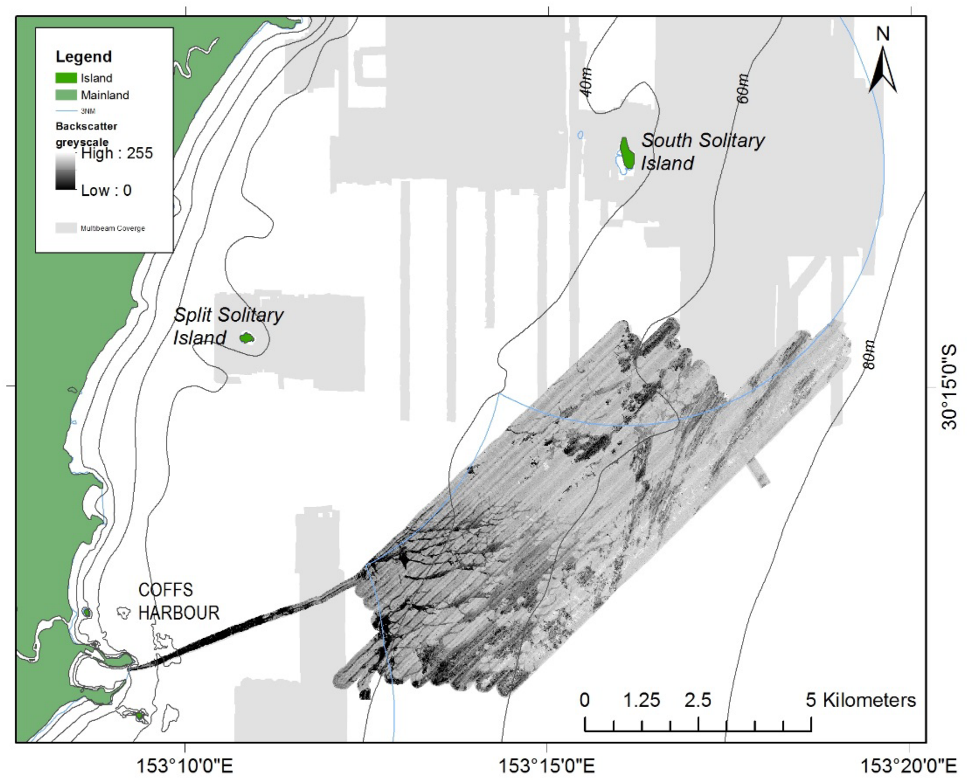


Fig 14 - Interpreted 3-class habitat layer based on swath bathymetry and backscatter data.

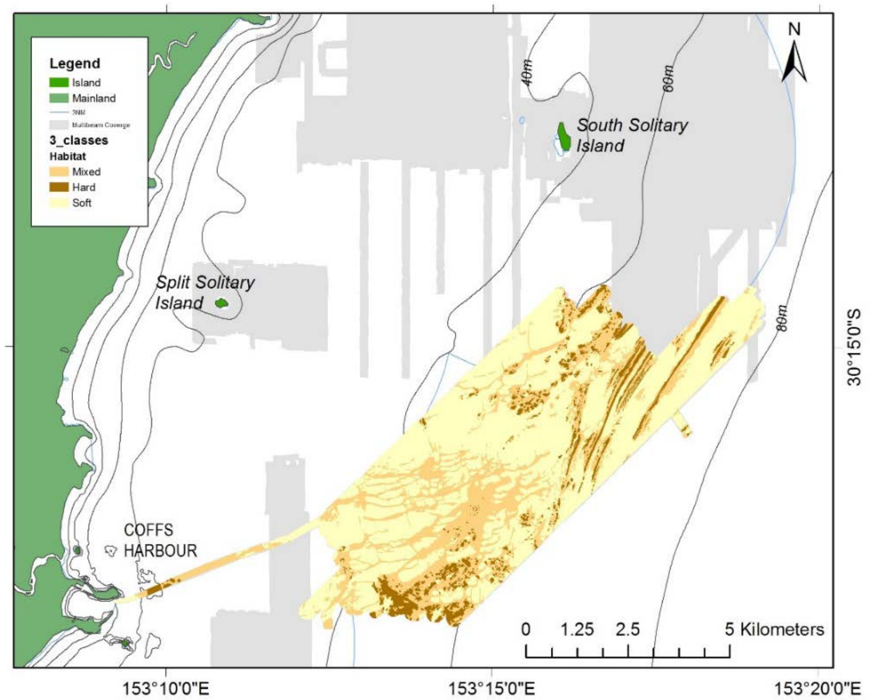
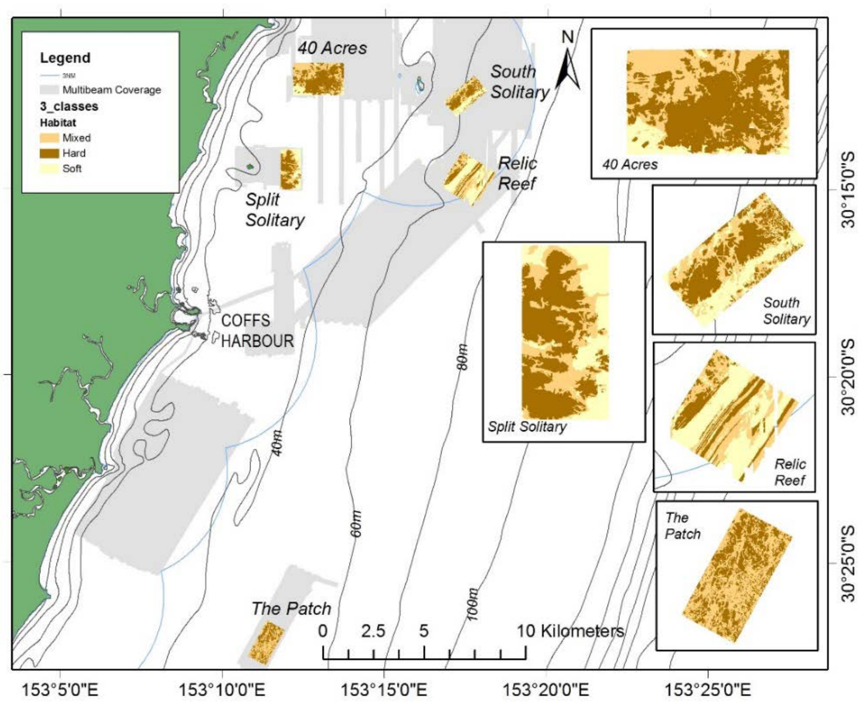


Fig 15 - 3-class habitat classification for five sites targeted for GRTS designed Towed Video and AUV surveys.



3.4.2 Towed video and AUV

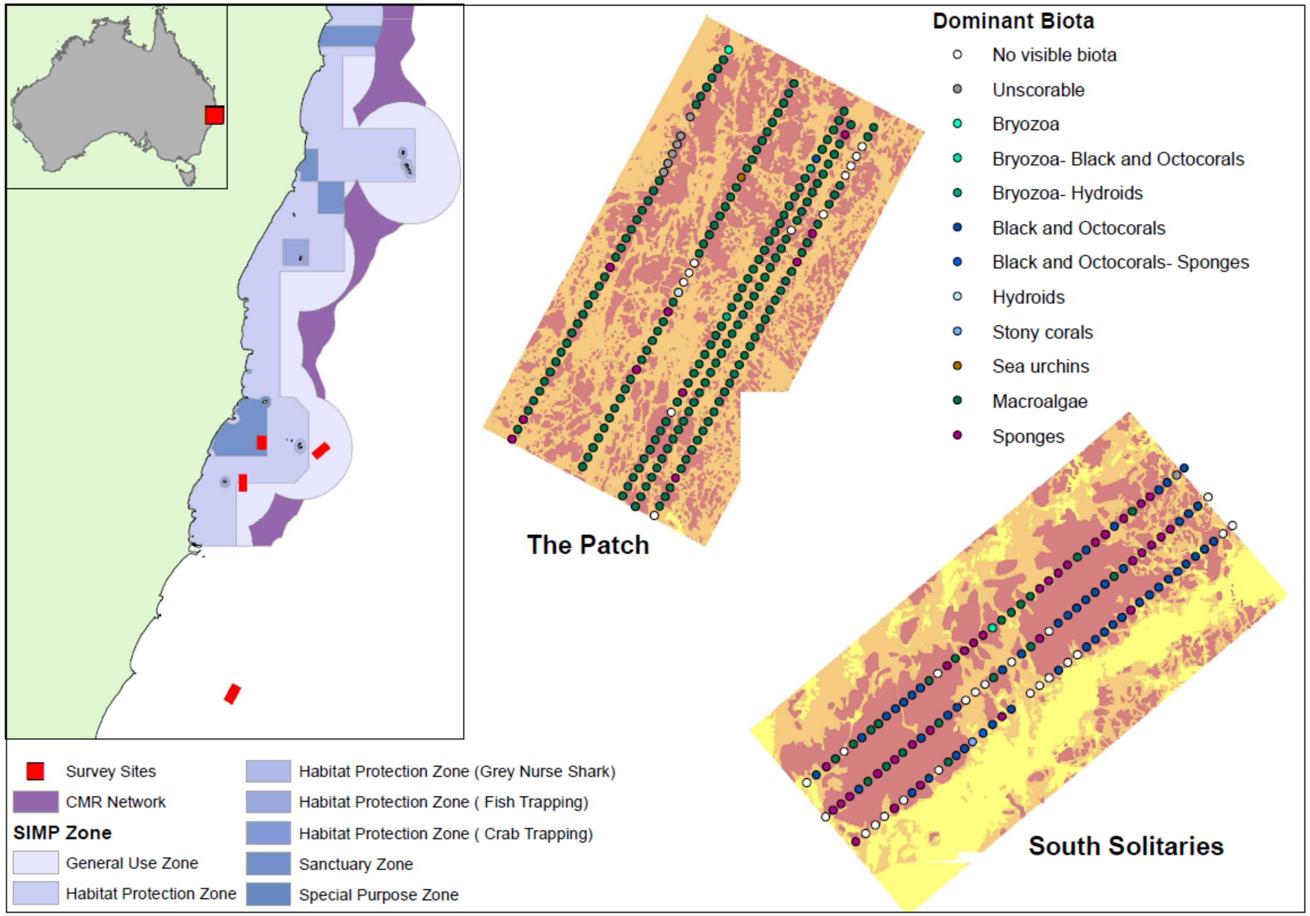
Fig 16 summarises the dominant biota classes identified during the broad scale scoring for the AUV transects on The Patch and South Solitaries, together with the habitat classification (derived from multibeam sonar data) that was used to identify the proportion of hard substrate that transects would intersect during the GRTS survey design.

The effect of selecting transects using the GRTS approach with an inclusion probability that reflects the proportion of hard substrate intersected by each transect is most clearly seen in the South Solitaries. All of the transects in the Solitary Islands survey were selected probabilistically to ensure that the probability of transects intersecting predominately soft or hard habitat reflects the proportion of soft and hard habitat in the survey frame. In the case of South Solitary the three transects selected are clearly clumped into the nearly-linear reef feature in the centre of the survey frame. This effect of targeting hard substrate is not so evident in the Patch because the hard and soft substrates are more interspersed.

Figs 17 and 18 summarise the broad scale scoring results of the AUV and TSCS images (respectively) from the (combined) Patch and South Solitary transects. It is important to emphasise that the AUV and TSCS surveys were planned to collect images along the same transects. The surveys did not, however, achieve a complete overlap but did manage to overlap three out of four transects in the South Solitaries and three out of five in the Patch. Comparing the broad scale scoring results between the two platforms in this instance suggests that the AUV is a much better platform: very few of the images (< 20) selected were deemed unscorable, the images record a rich diversity of macroinvertebrates and macroalgae, and the number of images with no visible biota was relatively low (~40) and this only occurred in images taken from locations were the dominant substrate was unconsolidated mud and sand (Fig 17).

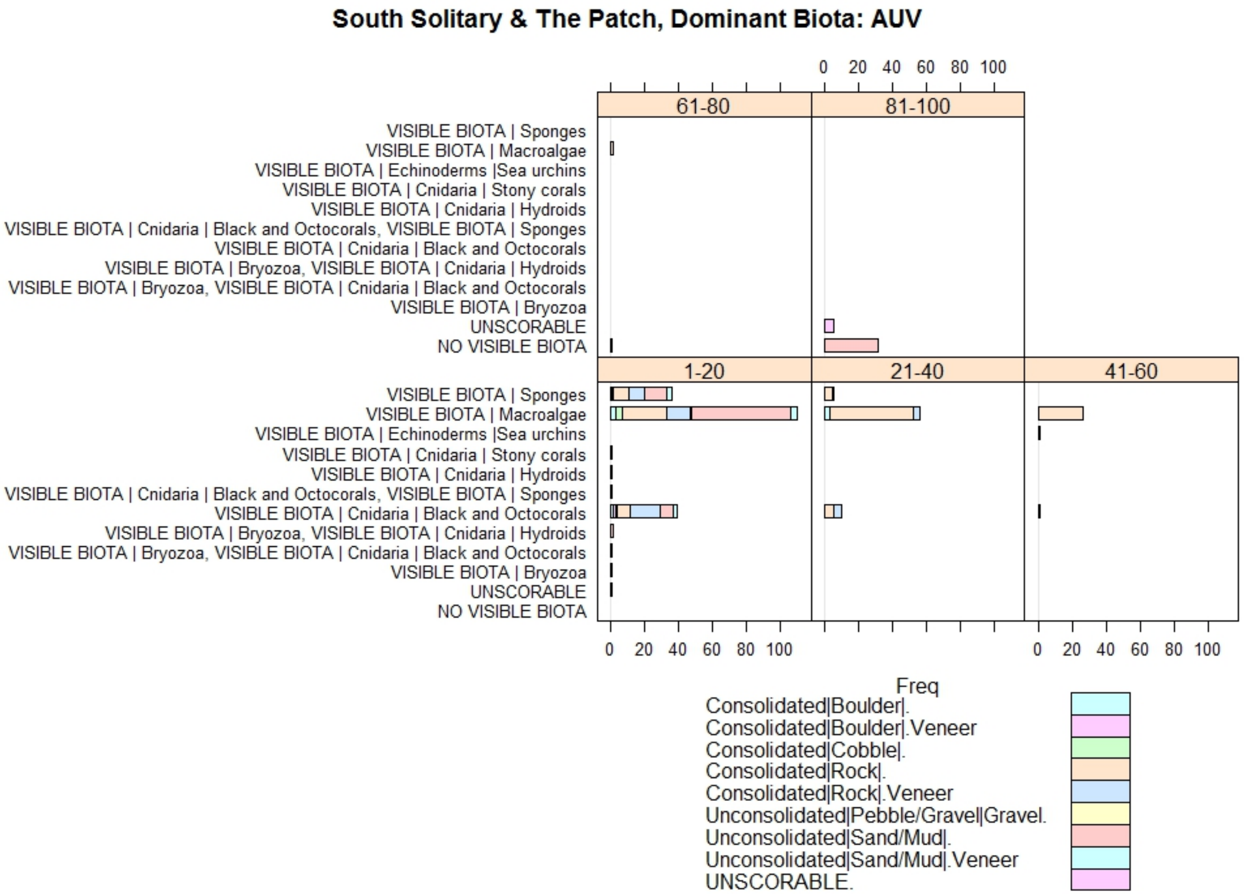
By contrast the number of images collected by the TSCS that were deemed unscorable was much higher (>60) and the number of images with no visible biota, again predominately (but not exclusively) from images taken over unconsolidated sand and mud, was much higher (almost 150). The overall image quality was clearly much lower, and this causes a far smaller number of biota categories to be recorded (Fig 18). The Bryozoa and Echinoderms groups, for example, are completely absent from the TSCS data set whereas they are recorded in the AUV data set.

Fig 16 - Dominant biota classes from the broad scale scoring of AUV transects taken at the Patch and South Solitaries



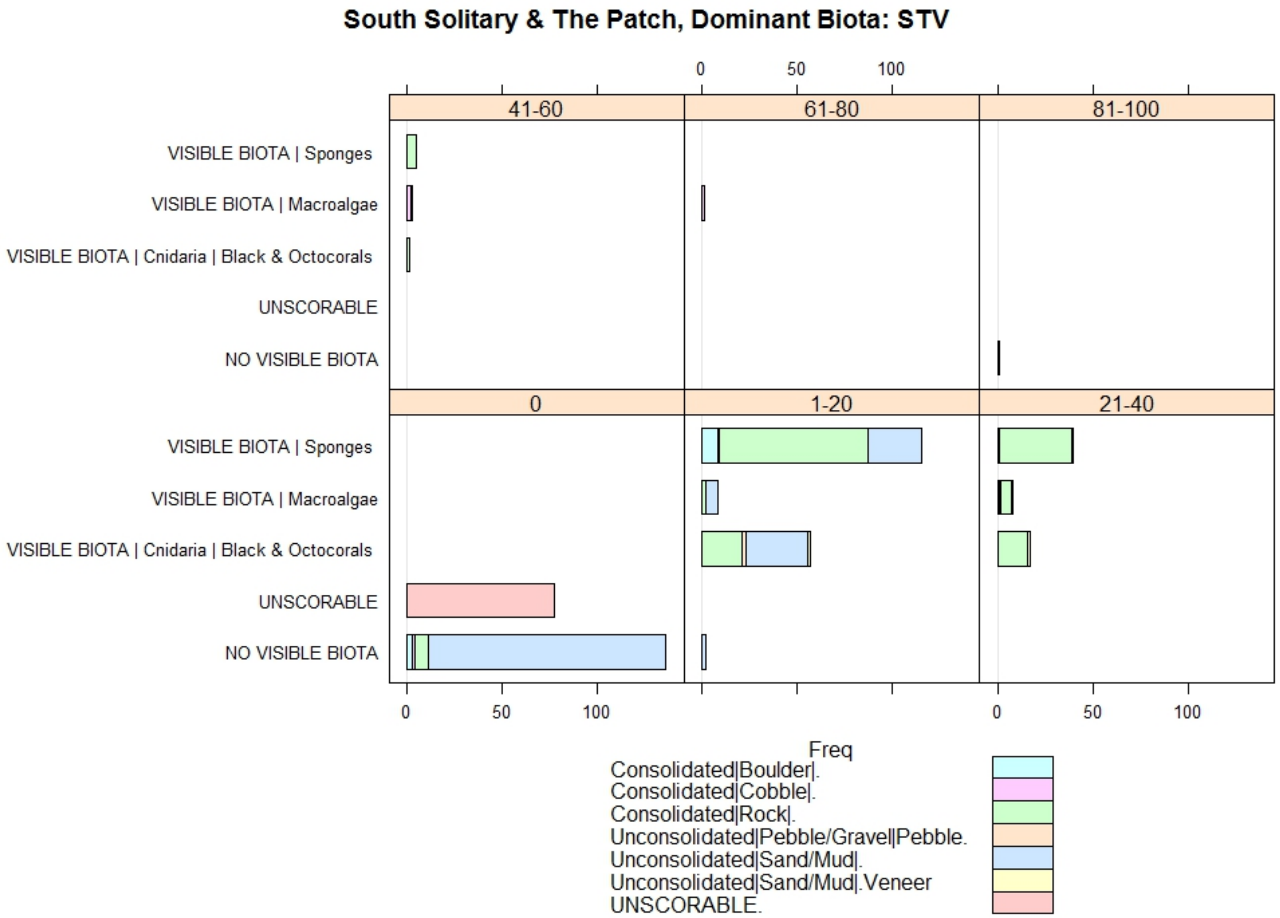
Dominant biota along the AUV transects taken from the Patch and South Solitaries overlaying the three class – hard (pink), mixed (orange), soft (yellow) habitat classifications derived from multibeam sonar data.

Fig 17 - Broad scale scoring results for AUV transects taken at the Patch and South Solitaries



Frequency of occurrence of dominant biota categories in 5 percent cover categories, together with dominant substrate category (shown by colour of bars)

Fig 18 - Broad scale scoring results for TSCS transects taken at the Patch and South Solitaries



Frequency of occurrence of dominant biota categories in 6 percent cover categories, together with dominant substrate category (shown by colour of bars)

3.4.3 Baited remote video

Spatial dependence or autocorrelation among BRUV deployments can arise from at least two sources. One source is any shared but unmeasured covariate that may introduce similarity among sites. The second source can arise if one individual fish visits different deployments. Both of these sources of spatial dependence would mean that sites that are closer to each other tend to be more similar than those that are farther away. All things being equal, non-negligible spatial dependence means that greater sampling effort may be necessary to, for example, accurately estimate the abundance of a fish species in a given time and area.

Estimating abundance from BRUV data is difficult. Much effort has been devoted to developing ambitious models of fish behaviour coupled with plume dynamics, but estimates of abundance are dependent on the many assumptions within these models (e.g., Farnsworth *et al.* 2007, Trenkel and Lorance 2011), which can often obscure and lessen the usefulness of the resulting abundance estimates (Sainte-Marie and Hargrave 1987).

Currently, MaxN (the maximum number of fish observed in a frame over the course of a BRUV drop) is the most widely used index of abundance for BRUV drops, but as an order statistic it omits a lot of useful information. In some cases, MaxN appears not to be a useful proxy for abundance compared to other proxy indices such as time of first arrival (Priede *et al*., 1996). One alternative is to use BRUV data to estimate presence-absence instead of abundance (Terres *et al*., 2015), which is an approach that might be especially useful for rare species with few appearances per drop. Alternatively, a recent study suggested that the mean count ("meanN") observed over the course of a BRUV drop is a better metric than MaxN (Schobernd *et al*., 2014).

For the NERP autocorrelation study, the MaxN and MeanN responses were compared using two separate models that assessed the magnitude of spatial dependence. The case study was trialled on snapper (*Chrysophrys auratus*). Fig 19 shows the spatial distribution of the BRUV drops in the NERP autocorrelation study. The minimum distance between sites was 92 m and the maximum distance was 1998 m; with a median inter-site distance of 920 m.

Fig 20 shows the period of overlap for some BRUV drops. Since there were four BRUVs available, up to four drops may overlap at any one time. Due to some misdrops and logistical issues some drops occur alone. The drops occurred over two days, hence the two distinct clusters. For each of the 23 drops in the NERP autocorrelation study, the 60 minute video was systematically scored every 30 seconds. The count data were log(x + 1) transformed and MeanN and MaxN were calculated from these transformed observations.

Fig 19 - The locations of BRUV sites in the NERP autocorrelation study. The coordinates are in units of metres (UTM). The site labels in red were sampled on the first day and those in black on the second day.

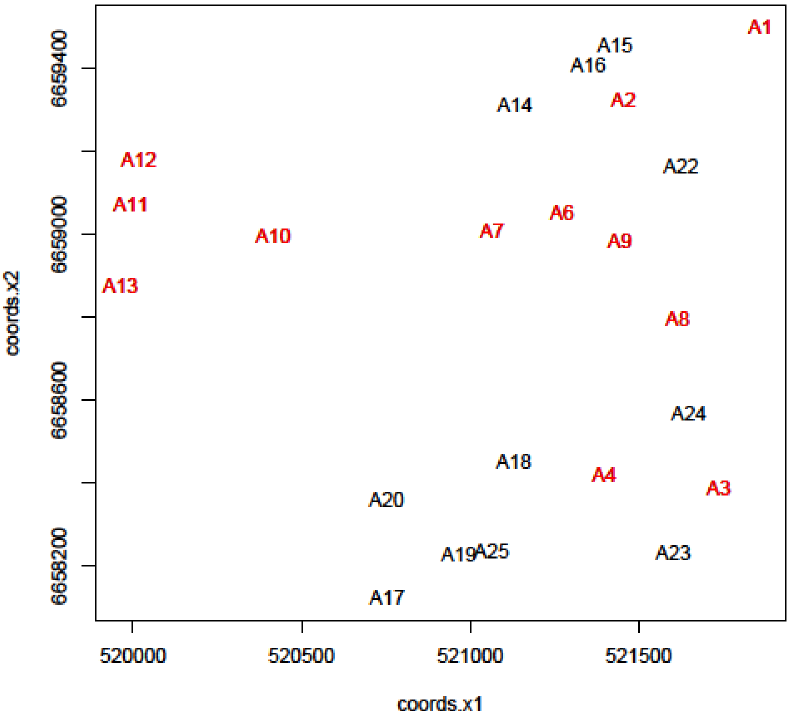
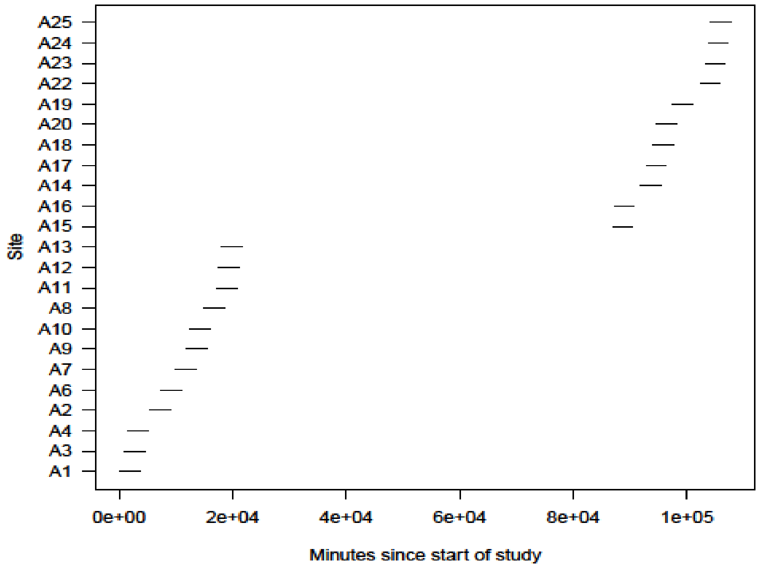


Fig 20 - The duration of BRUV deployments over the course of the NERP autocorrelation study.



For each choice of response, the data were fit to a relatively simple geo-statistical model,

$$y_i = \alpha + \beta x_i + w(s_i) + e_i \,,$$

where *α* is an intercept, x_i is the day of the survey (scored 1 if the drop occurred on day 2 and 0 otherwise), the spatial random effects *w* have an exponential spatial covariance function with spatial correlation given by, exp($-d_{ij}/\varphi$), with distance between sites s_i and s_j (in metres) given by d_{ij}, and spatial correlation parameter *φ*. The residuals, *e*, are assumed independently and identically distributed normal with common variance. This model was estimated by Restricted Expected Maximum Likelihood.

The results of fitting this model to the autocorrelation experiment data are shown in Table 6. The choice of response does influence the parameter estimates. Significantly higher values of MaxN were found on day 2, but this relationship was not significant for MeanN. The spatial correlation parameter for MaxN was roughly double that of MeanN. This means that the spatial dependence was stronger for MaxN than for MeanN responses.

Defining the effective range (approximately 3* *φ* in this model) as the distance at which the spatial correlation drops to 0.05 allows a comparison with respect to Fig 19. The estimated effective range for the MeanN response was 242m (95% CI: 45m to 1312m). The estimated effective range for the MaxN response was 593m (95% CI: 144m to 2443m). Thus, the effective range was roughly doubled for the MaxN response relative to MeanN.

Given that the maximum distance between sites was 2km, it is possible that spatial dependence for MaxN in particular can have an effect on estimates, whereas MeanN may be relatively more robust to spatial dependence. Comparison of these two metrics with actual abundance will benefit from field or laboratory assessments that include alternative sampling methods to BRUVs (e.g., Priede *et al.,* 1996; Trenkel and Lorance, 2011; Schobernd *et al*., 2014).

Table 6 - Results of two geostatistical models testing for mean day effect and exponential spatial autocorrelation. Model 1 was fit to MeanN, Model 2 was fit to MaxN. The first row of each parameter is the REML point estimate with 95% confidence interval below.

	Model 1 (MeanN)	**Model 2 (MaxN)**
Intercept	0.33 [0.00, 0.67]	1.17 [0.68. 1.66]
day2	0.27 [-0.19, 0.74]	0.67 [0.13, 1.20]
Phi	81.10 [15.0, 438.4]	197.79 [47.8, 815.5]

4. HOUTMAN-ABROLHOS ISLANDS KEF

4.1 Background and objectives

The Houtman-Abrolhos islands lie within a transitional zone between major marine biogeographic provinces caused by the juxtaposition of the warm Leeuwin Current and colder water more typical of their latitude (28^0 15' to 29^0 S). The shelf reefs in this area are identified as a KEF because of the diverse and highly complex mixture of tropical and temperate species that occur in this region, particularly associated with the coral-kelp communities that occur in waters greater than 20m (Hayes *et al*., 2012).

The Abrolhos islands are also the largest seabird breeding station in the eastern Indian Ocean, and are an important location for monitoring populations of Sooty and Crested Terns, and Shearwaters. Initial modelling of the coral-kelp communities in the waters to the East of the islands suggested that the Crested Tern communities might provide an indirect indicator of the status of these shelf reef communities.

Three objectives were identified for the Houtman-Abrolhos KEF:

4. Identify the location of coral-kelp communities and other shelf reef communities in commonwealth waters east of the Houtman-Abrolhos islands.

5. Conduct multibeam sonar mapping of shelf reef features in the KEF to augment and add to the existing mapping and inventory of shelf habitats conducted in state waters by WA fisheries.

6. Trial the application of an analysis of compound specific isotopes in samples of feathers collected from crested and sooty terns for their application as an indicator of the status of shelf reef communities in the KEF.

4.2 Data collection, processing and scoring

4.2.1 Drop camera

A drop camera survey was completed according to a GRTS design as discussed in Section 2. An additional feature of the design, however, was to divide the sample frame into two strata – shallow (<20m) and deep (>20m). Separate GRTS designs were developed for both strata and an equal number of samples were collected in a spatially balanced from both.

The survey area was approximately defined as the commonwealth waters to the east of the Houtman-Abrolhos islands. The biota and habitat at 140 GRTS points (70 deep and 70 shallow) in the survey area (together with 3 additional sites) were classified by dropping a video camera to the sea floor and recording the dominant habitat type (soft or hard), and the dominant and sub-dominant biota at a coarse biological resolution.

4.2.2 Multibeam sonar

Multibeam sonar mapping of shelf reef features was undertaken from RV Linneaus using a hull-mounted Kongsberg EM3002 sonar system. Motion compensation for the data was undertaken at acquisition. Data were acquired at nine priority sites over four days and processed into high-resolution grids using Caris HIPS. Tide compensation was applied at the time of processing. Data quality is high despite significant swell at the time of acquisition. Depths in the area range from 45 m to just below active wave height. Reefs were found to be located in less than 25 m of water and can stand up to 20 m from the seafloor.

4.2.3 AUV

The AUV survey was conducted with the ‘Sirius’ Autonomous Underwater Vehicle. Sirius is equipped with a full suite of oceanographic instruments, including a high resolution stereo camera pair and strobes, multibeam sonar, depth, conductivity and temperature sensors, Doppler Velocity Log (DVL) including a compass with integrated roll and pitch sensors, Ultra Short Baseline Acoustic Positioning System (USBL) and forward looking obstacle avoidance sonar.

Six priority areas for the AUV survey were identified from the drop camera and multibeam surveys. The objective was to target key ecological features in the region (coral and kelp) (Fig 21). Surveys in commonwealth waters were conducted as part of an extension to the planned surveys of coral-kelp communities in state waters that have been repeated annually since 2010. The discovery of similar coral-kelp features in Commonwealth waters provided an opportunity to collect additional data on these reefs.

The AUV was consistently flown approximately 2 m above the seafloor along transects that followed an elongated grid design (Hill et al 2014) (Fig 21 inset B). These grids were between 2 and 5 km in length. Overall eleven AUV dives were conducted over 4 days on reefs that varied in depth from approximately 10 – 20 m (Table 7).

Fig 21 - Houtman-Abrolhos Islands AUV survey locations and example of the sampling grid design (inset B).

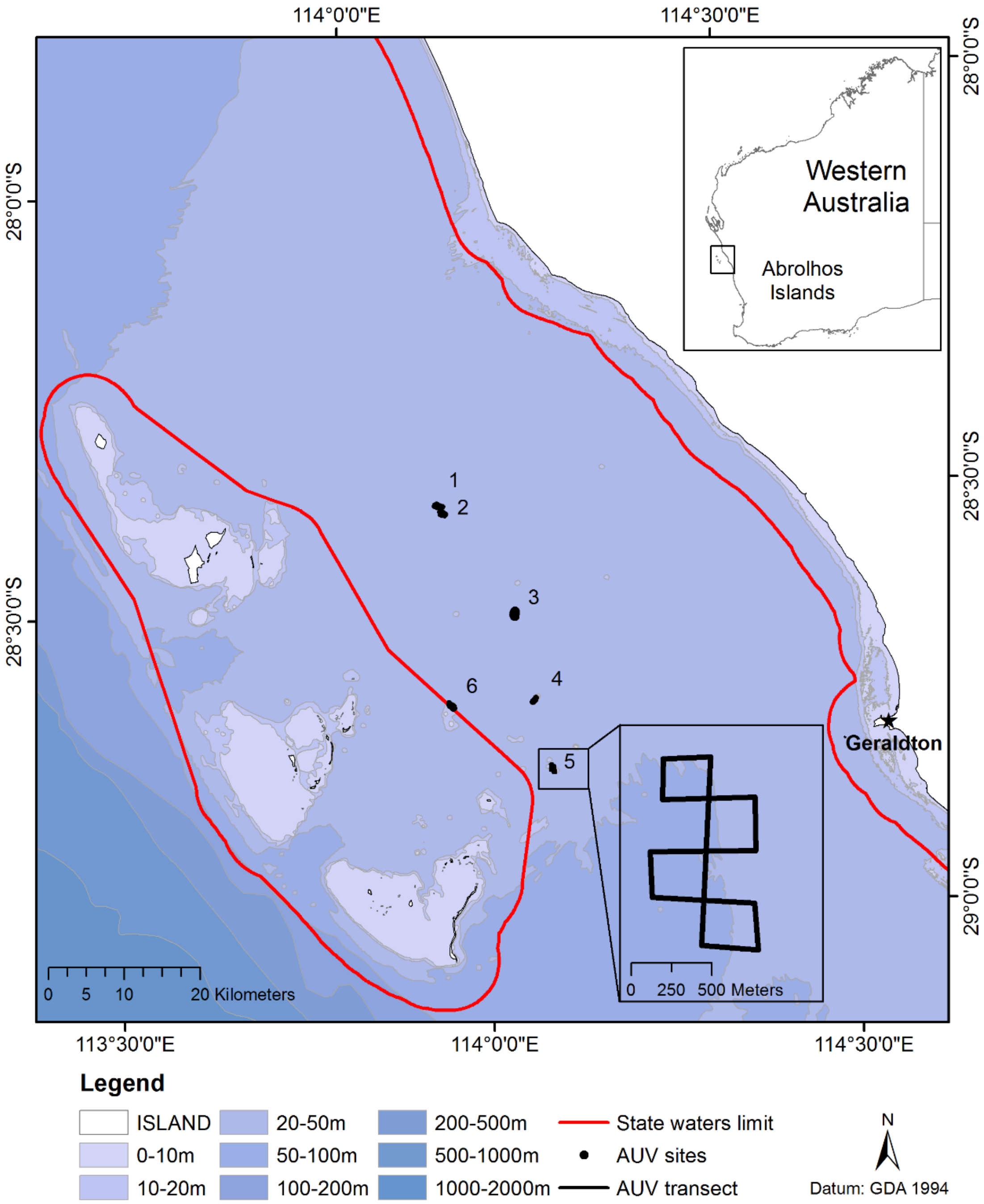


Table 7 - Summary of the 2104 AUV survey of coral-kelp communities in state and commonwealth waters east of the Houtman-Abrolhos islands

Site name	Day	Grid type
Coral patches 15 m	1 (Thursday)	3 x Dense
Geebank 15 m	1 (Thursday)	3 x Dense
Geebank 30 m	1 (Thursday)	3 x Dense
Snapper bank	2 (Friday)	3 x Dense
Snapper bank1	2 (Friday)	Broad (~ 3.3 km)
Mid Mid	2 (Friday)	Broad (~ 2 km)
Coral patches 40 m	2 (Friday)	3 x Dense
Mid North	3 (Saturday)	Broad (~ 2.3 km)
NE Horse shoe1	3 (Saturday)	Broad (~ 3 km)
NE Horse shoe2	3 (Saturday)	Broad (~ 2.5 km)
Mid South	4 (Sunday)	Broad (~ 4.5 km)

Broad scale scoring of AUV imagery was conducted to gain an overview of the habitats and biota in the region. The dominant and subdominant physical and biological habitats in an image were recorded along with any presence of coral and kelp. For fine scale analysis, images were selected along the transect line using the Generalised Random-Tessellation Stratified (GRTS) approach. This ensures image samples are well spread out along the transect line.

Image analysis was completed using Coral Point Count with Excel extension (CPCe) (Kohler and Gill, 2006). The Collaborative and Automated Tools for Marine Imagery (CATAMI: http://code.google.com/p/catami/downloads/list.) Standardised Classification Scheme (V1.1) was used to classify the physical (substratum types) and biological (biota types) components of images. This was achieved by placing 50 random points onto each image, then labelling these points usually to level 6 in the CATAMI hierarchy.

Fine scale analysis at site 5 was not completed due to a problem with the left hand colour camera on the AUV. The absence of colour images made it difficult to confidently classify the biota in particular, to the same level as the other sites in the CATAMI scheme.

4.2.4 Compound specific isotopes

A single tail feather (adults) and approximately 5-10 pin feathers (chicks) from two species of terns nesting on the Houtman-Abrolhos islands were collected in a non-lethal and minimally-invasive fashion. 15N individual amino acids from seabird feathers were extracted and measured in a procedure called compound specific isotope analysis (CSIA). This analysis enables an estimate of the base of the food web and the trophic enrichment of the bird's diet from the same sample.

Estimates of trophic enrichment are founded on observations that 15N values increase in a consistent fashion with trophic level increases; i.e. from primary production through various consumers to the top level predators. These two variables can provide significant insight into medium to large scale water movements and nutrient dynamics within the ecosystems that seabirds feed.

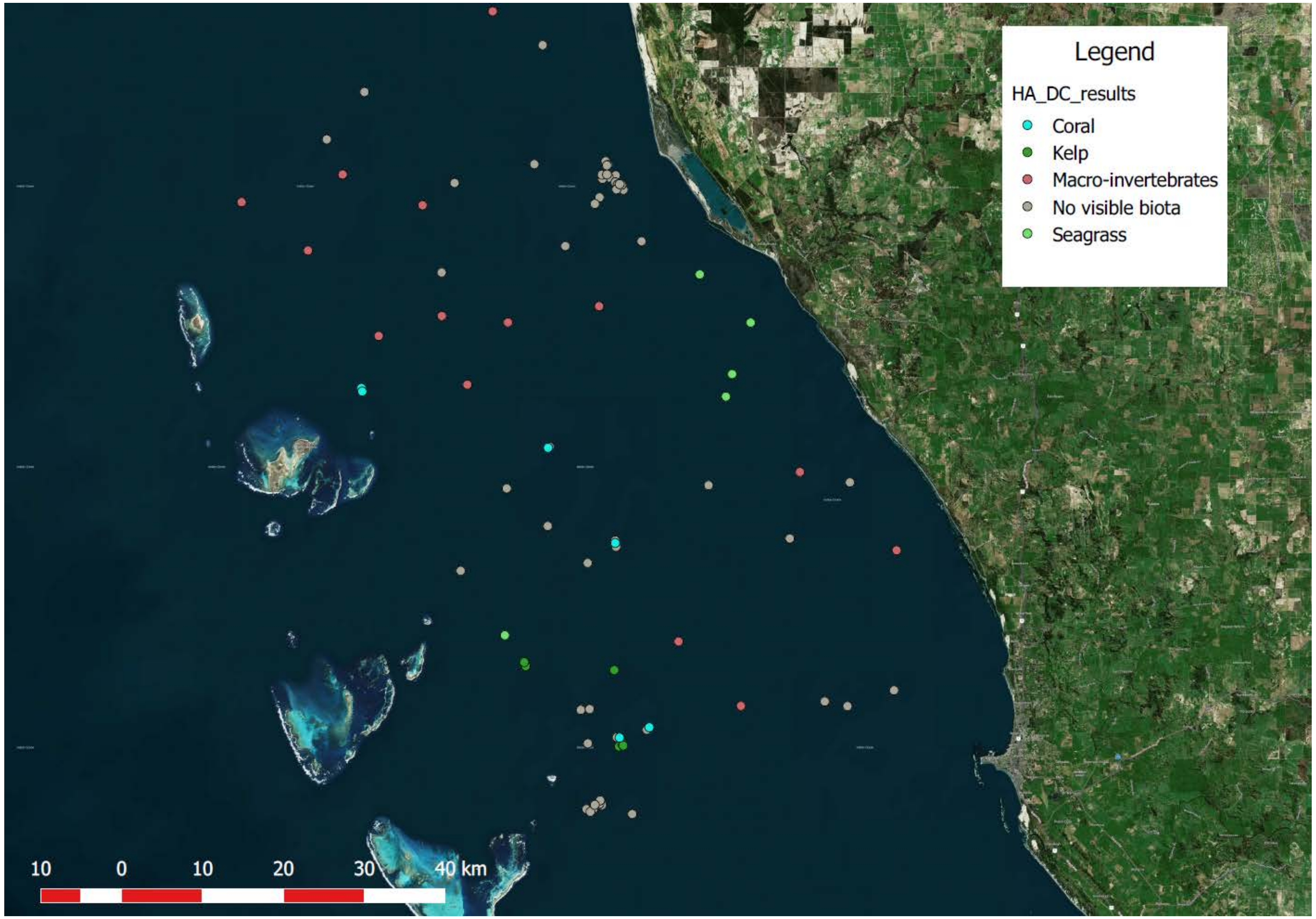
4.3 Summary of initial results

4.3.1 Drop camera

The results of the Houtman-Abrolhos drop camera survey are summarised in Fig 22. The survey made a number of new discoveries, most notably:

- An extensive area of sea-grass habit exists along the eastern margin of the KEF. Sea grass communities as also found, but in apparently more isolated patches elsewhere in the KEF.
- Coral-kelp communities were confirmed to be present within the KEF but are apparently restricted to its western margin, and in one instance are simply an extension of a known feature ((Snapper Bank) within state jurisdictional waters around the islands (section 4.3.3)
- Rich macro-invertebrate communities comprised of dense sponge gardens are scattered throughout the KEF, but particularly to the North, and are likely to contribute significantly to the KEFs biodiversity values. These appear to have been previously undescribed and represent a separate component of the KEF biodiversity in deeper waters.

Fig 22 - Summary of the drop camera survey results from Houtman-Abrolhos KEF highlighting the dominant habitat and biota types at 82 GRTS selected survey locations



4.3.2 Multi-beam sonar survey

Fig 23 shows an overview of the multibeam sonar data acquired near the Abrolhos Islands. The data show isolated rocky reefs surrounded by softer sediment, located between the Geelvink Channel and Abrolhos Islands. The shape of the reefs appears to be controlled partly by current or prevailing weather, and shallower and larger reefs show wave platforms. Two types of reefs are evident: narrow reefs with a NW – SE grain and larger, more rounded reef forms with wave platforms. The reefs are surrounded by softer sediment which may suggest sand inundation or infill. Further details on shape and location of these features are provided in Figs 24 and 25.

4.3.3 AUV

Bare substrate (mostly rocky reef) and coral were the dominant benthic habitats at Sites 1, 2 and 3, which were in the northern most area of the study region (Figs 26, 27 and 28). Conversely, the sites to the south were dominated by bare, rocky substrates and macroalgae, with more sandy substrates prevailing at Site 6.

Mean coral cover was highest at Site 2 (29.1% ± 4.8 s.e.), followed by Site 1 (23.1% ± 5.7 s.e.) then Site 3 (9.3% ± 3.4 s.e.). Mean macroalgae cover was highest at Site 4 (56.2% ± 5.4 s.e.), followed by Site 5 (48.9% ± 7.3 s.e.) then Site 6 (33.2% ± 5.7 s.e.). Seagrass was found at all sites, though it was more prominent at Sites 5 (9.1% ± 7.6 s.e.) and 6 (4.3% ± 3.2 s.e.), in the south-west area of the study region.

Macroalgae and coral habitats comprised of a number of colour and growth morphologies, resulting in assemblage compositions that differed between sites (Fig 29). Kelp (Ecklonia radiata), was found in low cover (mean of < 10%) at Site 6 only. Sargassum sp, another large canopy forming brown seaweed, was also recorded at Site 6. Erect fine branching red algae (fine red) comprised nearly 50 % of the biota cover at Site 4. Encrusting red, erect fine branching red and turfing algae were the only macroalgae categories found across all sites.

Encrusting corals were the dominant biota at Sites 1, 2 and 3, but occasionally present in low cover at Sites 4 and 6 (Fig 29). Other stony coral morphotypes (massive, sub massive, plate and tabulate) were present at Sites 1, 2 and 3 with mean percent covers between 1 and 5%. Coral rubble and dead coral, which still maintains its morphology, made up less than 3% of the habitat at these coral dominated sites.

Fig 23 - Overview of the swath mapping of potential coral-kelp communities in commonwealth waters in the Houtman-Abrolhos KEF

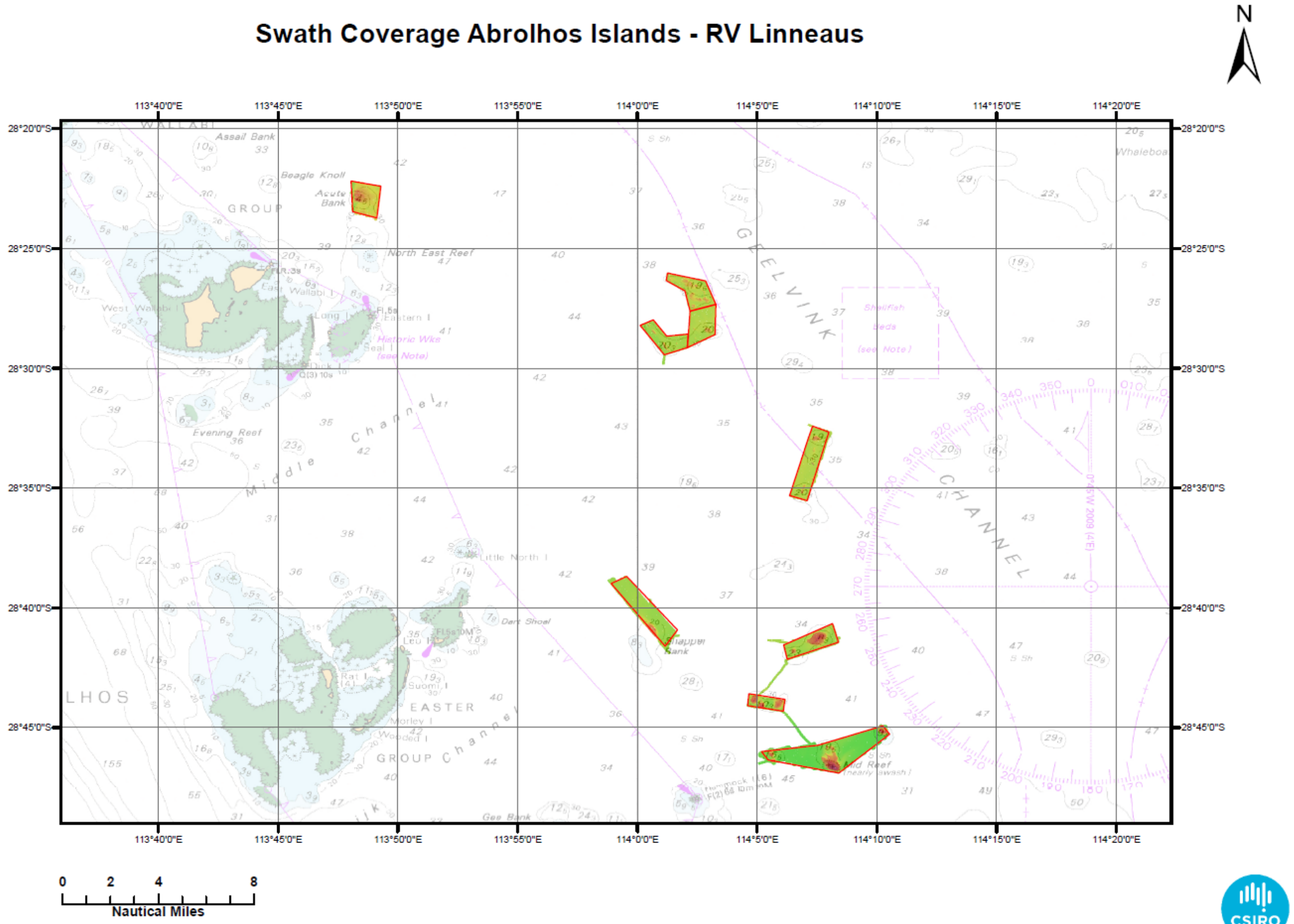


Fig 24 - Location of potential kelp-coral communities discovered by drop camera survey and multibeam sonar mapping in the northern half of the Houtman-Abrolhos KEF, together with tracks of AUV survey.

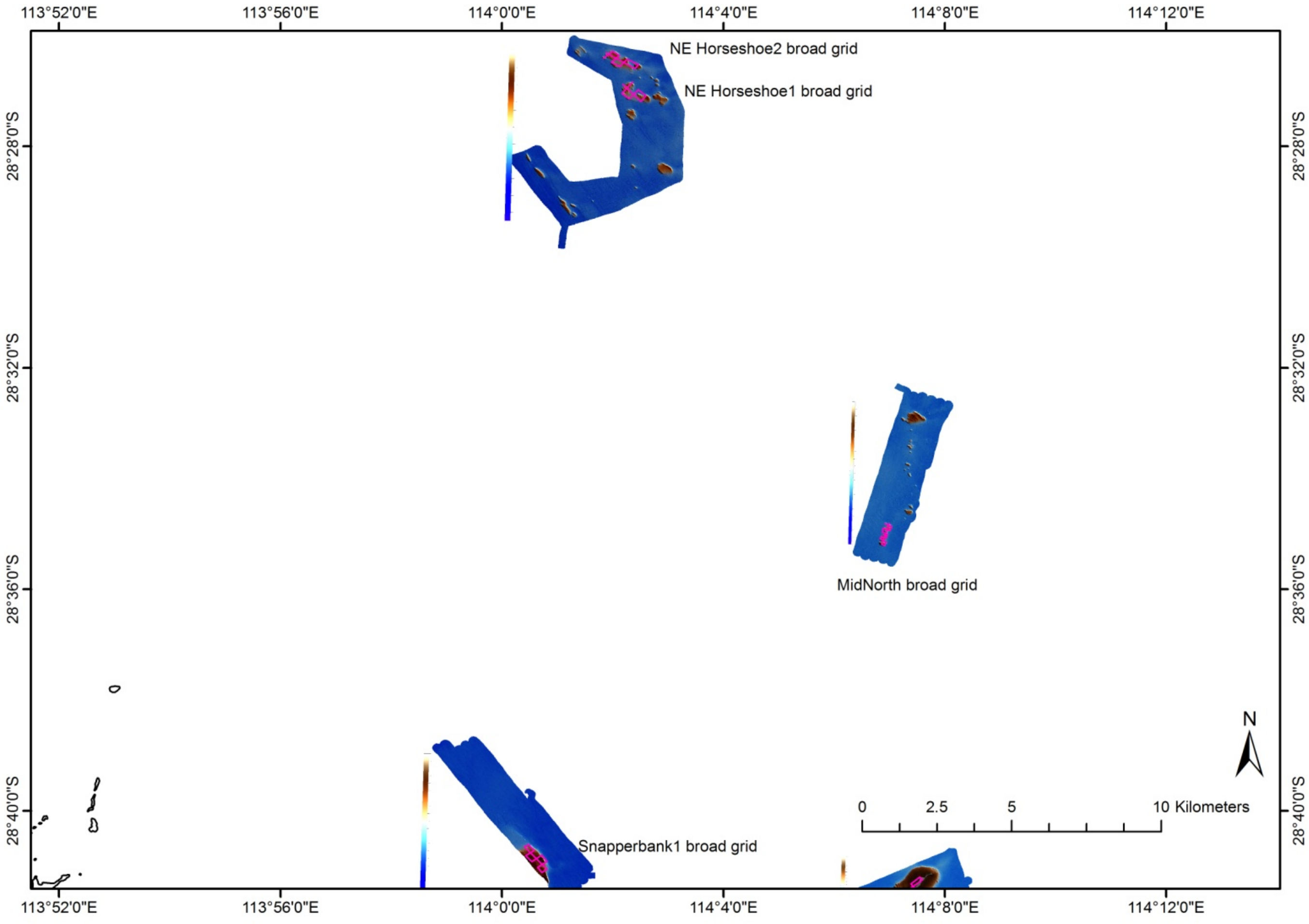


Fig 25 - Location of potential kelp-coral communities discovered by drop camera survey and multibeam sonar mapping in the southern half of the Houtman-Abrolhos KEF, together with tracks of AUV survey

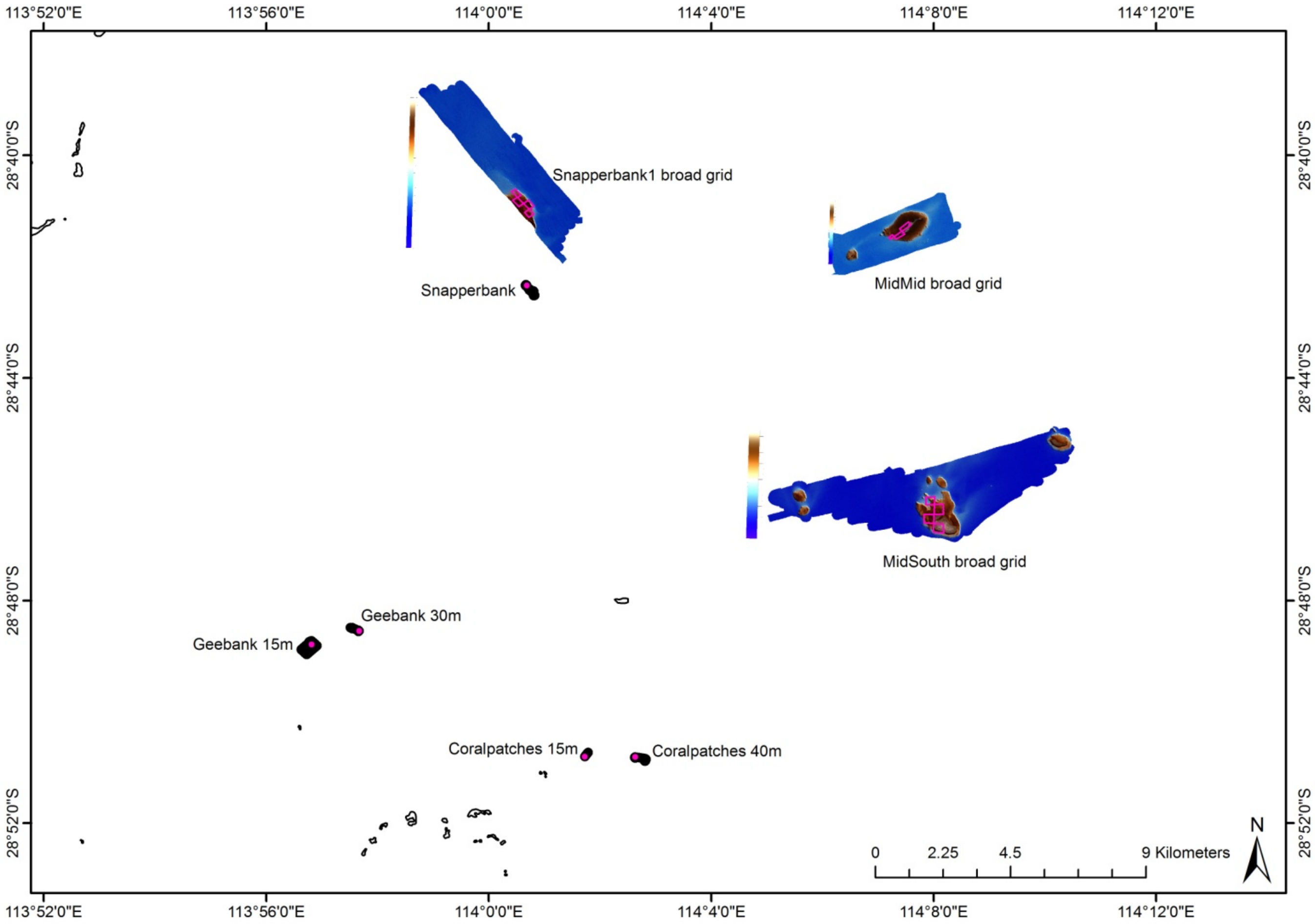


Fig 26 - Mean percent cover of broad habitat categories at each of the AUV survey sites.

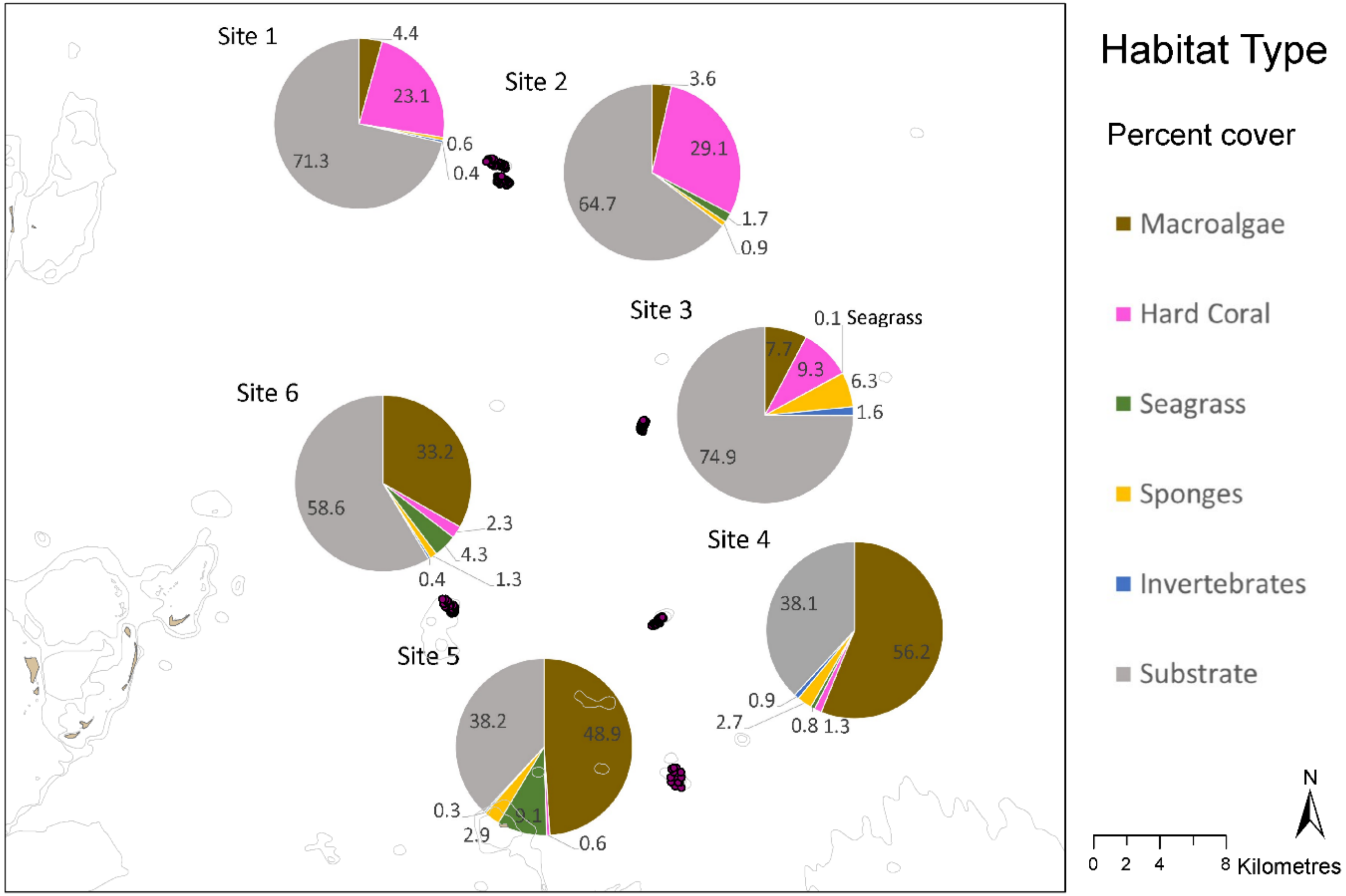


Fig 27 - Spatially explicit representation of dominant substrates at the AUV survey sites, with the bathymetry from hydro-acoustic surveys of the sites in the background.

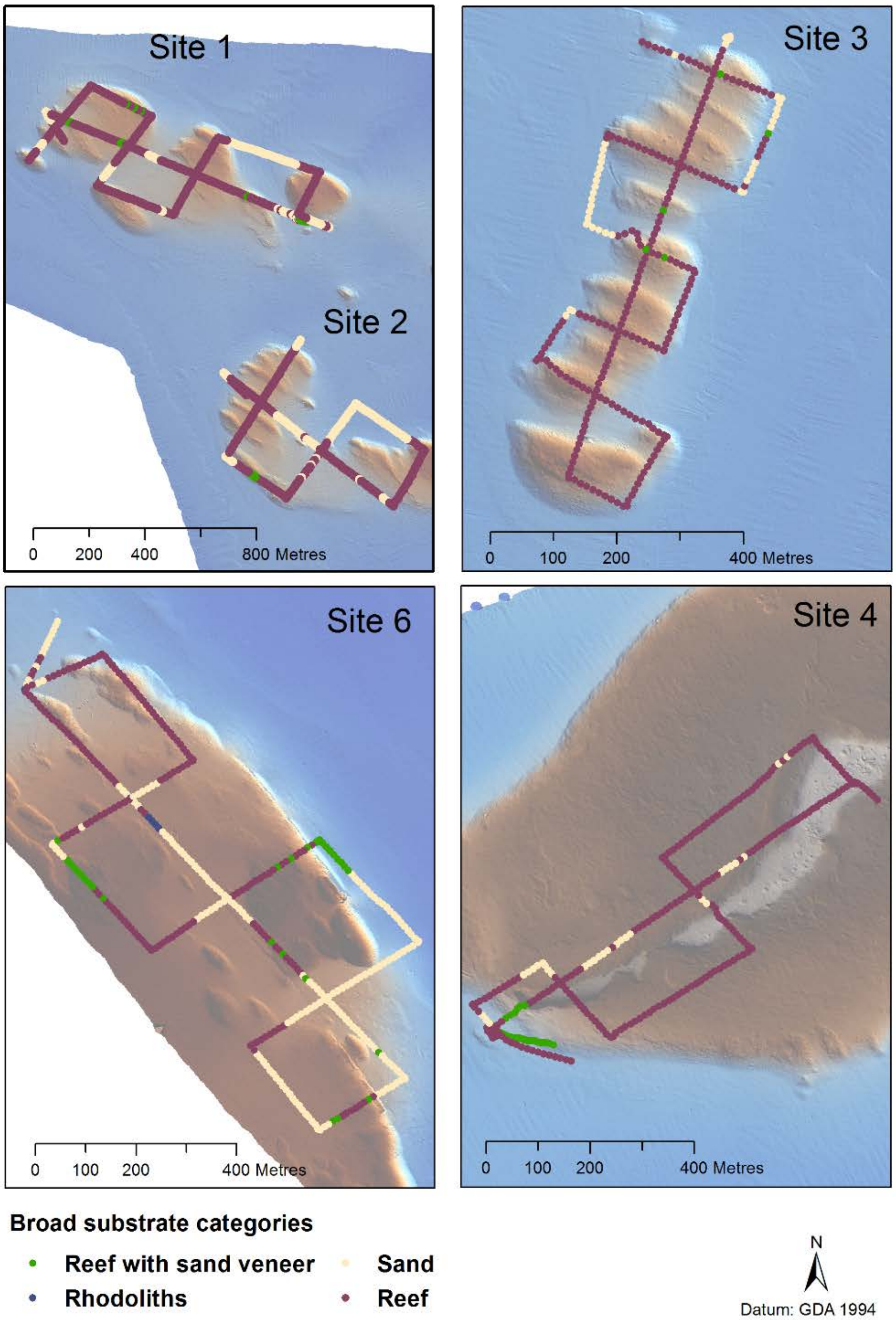


Fig 28 - Spatially explicit representation of dominant biota at the AUV survey sites, with the bathymetry from hydro-acoustic surveys of the sites in the background.

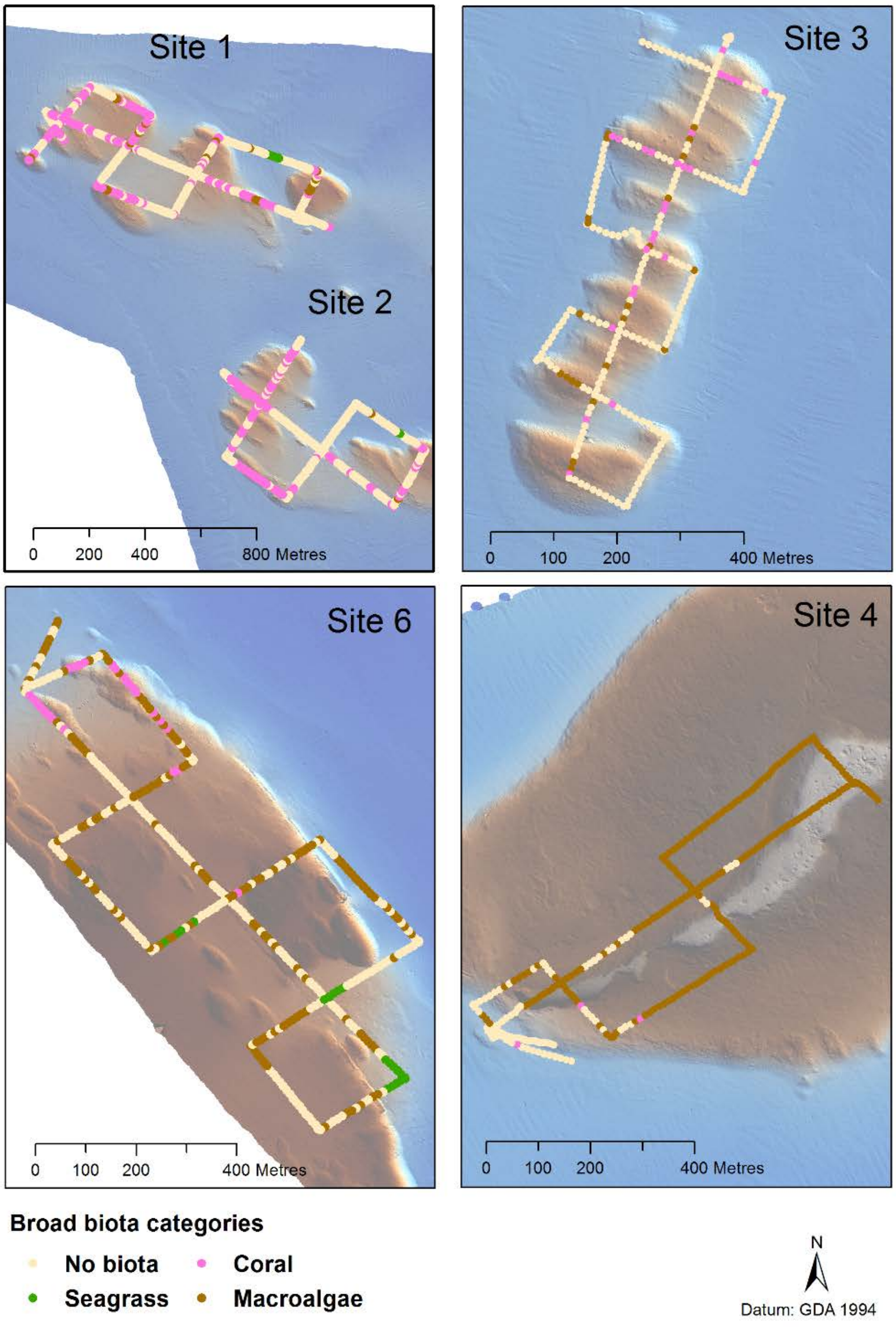
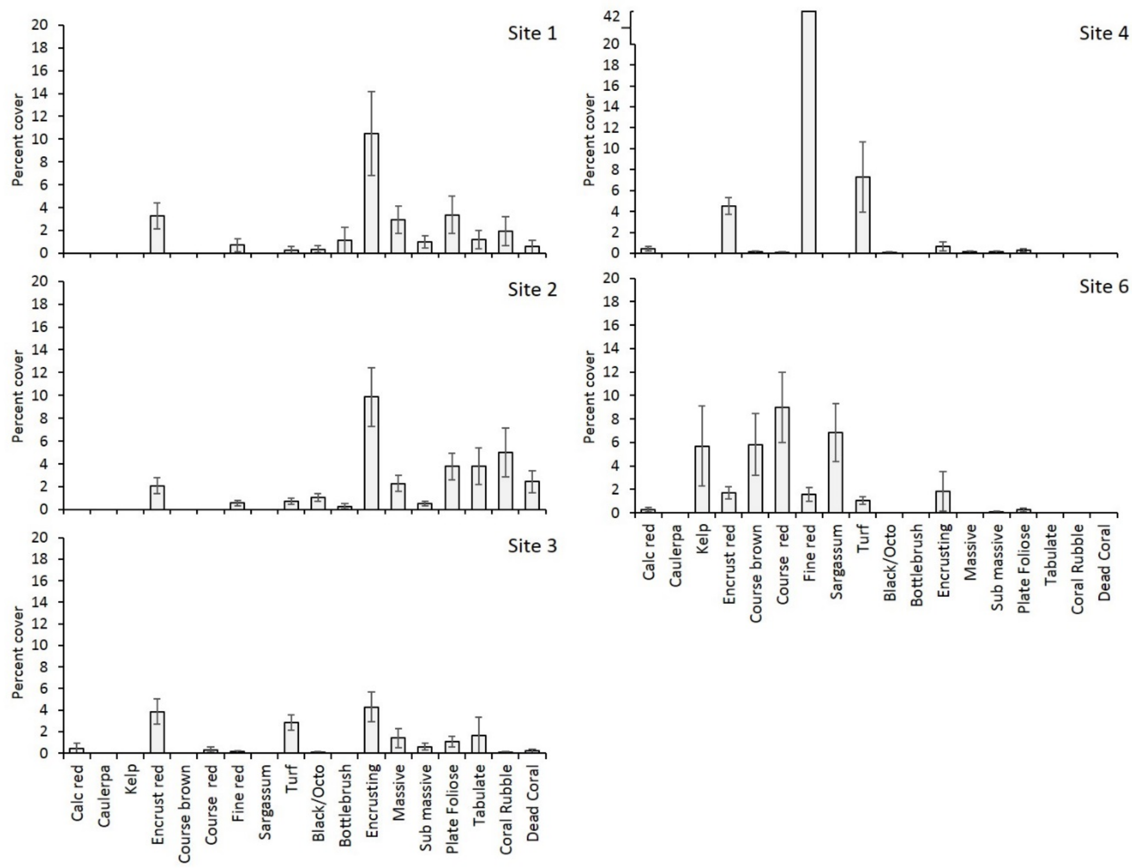


Fig 29 - Mean percent cover (± s.e.) of macroalgae and coral categories from the fine scale image analysis using CPCe.



4.3.4 Compound specific isotopes

Terns regrow individual feathers over a relatively short period after the previous feather moults (about 6 weeks in mid-year for terns). The isotope measurements taken reflect their diet only during this period because the bird cannot store nitrogen. Similarly pin feathers from chicks reflect the food brought by their parents during a narrow window of time during nesting. These two discreet windows of time are separated by 4-6 months and so provide separate measurements of the base of the food web and their trophic level wherever they were feeding at that time of year. These time windows can be increased by analysis of egg shell fragments (earlier time period), nuptial breeding plumage (earlier still) and also targeting autumn breeding cohorts for some species (later time period). This can be accomplished in a single sample collection exercise.

The preliminary data gathered during this analysis was able to distinguish the feeding niches between Sooty Terns, Bridled Terns and Crested Terns where this was previously not possible. The data suggest it would be possible to measure the trophic level for a number of important seabird species and monitor both the bird's trophic level and the base of the food web for fluctuations or trends. The data also show that resident adult Crested Terns and their chick's share a year long tightly coupled association with their food supply. In contrast, migratory Sooty Terns occupy a different feeding niche at different times of the year depending on whether they are nesting or roaming.

The CSIA analysis enables us to see that the base of the food chain that Sooty Terns feed from whilst roaming, is very different to when they feed their chicks. This set of information has significant implications for understanding the nutrient dynamics of the Leeuwin current which support the breeding success of Sooty Terns and many other seabirds of the Abrolhos. For example, in the 2013-14 breeding season, many Sooty Terns abandoned their initial attempt to nest. We hypothesise that this was because there was simply not enough food available in the Leeuwin current eddies west of the Abrolhos to support raising chicks. By comparing the 15N food web baseline data and the observed breeding success with sea surface temperature, chlorophyll measurements and other ocean current data, we can begin to correlate the food supply with the transfer of nutrients from the north-west shelf via the Leeuwin current to waters east and west of the Abrolhos.

REFERENCES

Althaus, F., N. Hill, R. Ferrari, L. Edwards, R. Przeslawski, C. H. L. Schönberg, R. Stuart-Smith, N. Barrett, G. Edgar, J. Colquhoun, M. Tran, A. Jordan, T. Rees, and K. Gowlett-Holmes. 2015. A Standardised Vocabulary for Identifying Benthic Biota and Substrata from Underwater Imagery: The CATAMI Classification Scheme. PLoS ONE 10:e0141039.

Dambacher, J. M., Hosack, G. R. and Rochester, W. A. (2012) Ecological Indicators for the Exclusive Economic Zone of Australia's East Marine Region. A report prepared for the Australian Government Department of Sustainability, Environment, Water, Population and Communities. CSIRO Wealth from Oceans Flagship, Hobart, Australia, 120 pp.

Durden, J.M., Schoening, T., Althaus, F. Friedman, A., Garcia, R., Glover, A., Greinert, J., Jacobson Stout, N., Jones, D.O.B., Jordt, A., Kaeli, J.W., Köser, K., Kuhnz, L.A., Lindsay, D., Morris, K.J., Nattkemper, T.W., Osterloff, J., Ruhl, H.A., Singh, H., Tran, M. and Bett, B.J. (accepted). Perspectives in visual imaging for marine biology and ecology: from acquisition to understanding. *Oceanography and Marine Biology: Annual Review*

Fancy S., Gross J. and Carter S. (2009) Monitoring the condition of natural resources in US national parks. *Environmental Monitoring and Assessment*, **151**: 161–174.

Farnsworth, Keith D., Uffe Høgsbro Thygesen, Susanne Ditlevsen, and Nicole J. King (2007) How to estimate scavenger fish abundance using baited camera data. *Marine Ecology Progress Series,* **350**: 223.

Ferrari, R., Malcolm, H. A., Byrne, M. Jordan, A., Williams, S., Fiedman, A., Schultz, A. and Figueira, W. (submitted) Habitat structural complexity is an important surrogate of fish abundance. Journal?

Hayes, K. R., Dambacher, J. M., Lyne, V., Sharples, R., Rochester, W. A., Dutra, L. X. C. and Smith, R. (2012) Ecological Indicators for Australia's Exclusive Economic Zone. Rationale and Approach with Application to the South West Marine Region. A report prepared for the Australian Government Department of Sustainability, Environment, Water, Population and Communities. CSIRO Wealth from Oceans Flagship, Hobart, Australia, 204pp.

Hayes, K. R., Dambacher, J. M., Hedge, P. T., Watts, D., Foster, S. D., Thompson. P. A., Hosack, G. R., Dunstan, P. K. and Bax, N. J. (2015) Towards a blueprint for monitoring Key Ecological Features in the Commonwealth Marine Area. Theme 1, NERP Marine Biodiversity Hub, Hobart, Australia, 117 pp.

Hill, N. A., Barrett, N., Lawrence, E., Hulls, J., Dambacher, J. M., Nichol, S., Williams, A. and Hayes, K. R., (2014) What's in a reserve? Quantifying fish assemblages in a large offshore marine reserve using spatially-balanced and non-extractive sampling. PLoS One. 9(10): e110831. doi:10.1371/journal.pone.0110831.

Jordan, A., P. Davies, T. Ingleton, E. Mesley, J. Neilson, T. Pritchard (2009). Seabed habitat mapping of the continental shelf waters of NSW. NSW Department of Environment, Climate Change and Water Occasional Paper Series.

Kloser R. J., Penrose J. D. and Butler A. J. (2010), Multi-beam backscatter measurements used to infer seabed habitats. *Continental Shelf Research*, **30**: 1772-1782.

Kloser R. J. and Keith G. (2013) Seabed multi-beam backscatter mapping of the Australian continental margin. *Acoustics Australia*, **41**: 65-72.

Lawrence, E., Hayes, K. R., Nichol, S. L., Lucieer, V., Dambacher, J. M., Hill, N., Barrett, N., Williams, A., Kool, J. and Siwabessy, J. (2015), Developing long-term monitoring programs in offshore waters with little prior knowledge. PLoS ONE 10(10): e0141051. doi:10.1371/journal.pone.0141051.

Marouchos, A., Sherlock, M., Barker, B., and A. Williams (2011). Development of a Stereo Deepwater Baited Remote Underwater Video System (DeepBRUVS). Proceedings of the Oceans 11 Conference, Santander, June 2011.

Monk J., Barrett N., Hill, N., Lucieer V., Nichol S., Siwabessy J. and Williams S. (2016), The importance of physical structure: outcropping 1 reef ledges drive patterns of epibenthic assemblage diversity on cross-shelf habitats in the Flinders Commonwealth Marine Reserve. *Biodiversity and Conservation,* **25**: 485-502.

Perkins, N., Foster, S., Hill, N. and Barrett, N. (2016), Image subsampling and point scoring approaches for large-scale marine benthic monitoring programs. *Estuarine, Coastal and Shelf Science*, **176**: 36-46.

Priede I. G. and N. R. Merrett (1996) Estimation of abundance of abyssal demersal fishes; a comparison of data from trawls and baited cameras. *Journal of Fish Biology*, **49**: 207-216.

Stevens, D. L. and Olsen, A. R. (2004). "Spatially Balanced Sampling of Natural Resources." Journal of the American Statistical Association 99(465): 262-278.

Sainte-Marie, B., and B. T. Hargrave. "Estimation of scavenger abundance and distance of attraction to bait." *Marine Biology* 94, no. 3 (1987): 431-443.

Schobernd, Zeb H., Nathan M. Bacheler, and Paul B. Conn. "Examining the utility of alternative video monitoring metrics for indexing reef fish abundance." *Canadian Journal of Fisheries and Aquatic Sciences* 71, no. 3 (2013): 464-471.

Terres, Maria A., Emma Lawrence, Geoffrey R. Hosack, Michael DE Haywood, and Russell C. Babcock. "Assessing Habitat Use by Snapper (*Chrysophrys auratus*) from

Baited Underwater Video Data in a Coastal Marine Park." *PloS one* 10, no. 8 (2015): e0136799.

Trenkel, Verena M., and Pascal Lorance. "Estimating *Synaphobranchus kaupii* densities: contribution of fish behaviour to differences between bait experiments and visual strip transects." *Deep Sea Research Part I: Oceanographic Research Papers* 58, no. 1 (2011): 63-71.

Williams, S. B., Pizarro, O. R., Jakuba, M. V., Johnson, C. R., Barrett, N. S., Babcock, R. C., Kendrick, G. A., Steinberg, P. D., Heyward, A. J., Doherty, P. J., Mahon, I., Johnson-Roberson, M., Steinberg, D, and Friedman, A. (2012) *Monitoring of benthic reference sites*. IEEE Robotics and Automation Magazine 19:73-84 doi:10.1109/MRA.2011.2181772.

APPENDIX A - AUV AND TSCS FILE REPOSITORIES

Flinders CMR TSCS and AUV

FIle	Repository
AUV images	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\GRTS_Image_Selection
TSCS images	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\MASTER_Shallow Video System Aug 2012 Digital Stills\GRTS_Scoring\GRTS_Image_SelectionShelf and slope BRUVs
Converted AUV images	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Images\All jpegs
Converted TSCS images	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\MASTER_Shallow Video System Aug 2012 Digital Stills\GRTS_Scoring\Image_extract_EMfiles\GRTS images\enhanced
Event Measure files	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\MASTER_Shallow Video System Aug 2012 Digital Stills\GRTS_Scoring\Image_extract_EMfiles\EM output
Transect Measure code file	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\CodeFiles \NERP Fine Scale 040314.txt
Broad scale scored AUV	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Broadscale_scoring
Broad scale scored TSCS	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\MASTER_Shallow Video System Aug 2012 Digital Stills\GRTS_Scoring\Broadscale_scoring
AUV and TSCS code files	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\CodeFiles CatamiCodes_NERP_finescale_030314_v2sponges.txt
Morpho-species catalogues	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Species Catalogues: Sponge ID Catalogue_231213 FlindersAUV.docx: Non-sponges Catalogue 231213 FlindersAUV.docx
OneNote note book	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Documentation
AUV Morpho-species level scoring excel outputs	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Data\TM txt outputs 1-10
AUV CATAMI level scoring excel outputs	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Data\TM txt outputs 11-30
TSCS CATAMI level scoring excel outputs	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\MASTER_Shallow Video System Aug 2012 Digital Stills\GRTS_Scoring\Fine scale_Scoring\TM Cleaned OutPut\Cleaned JH TM outputs
AUV QA/QC files	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Finescale_scoring\Data\QAQC_results
AUV final output	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\AUV_GRTS\Finescale_scoring\Data\Finescale_final_outputs
TSCS final output	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\MASTER_Shallow Video System Aug 2012 Digital Stills\GRTS_Scoring\Finescale_Scoring\Final_outputs

Solitary islands KEF TSCS and AUV

FIle	Repository
Converted AUV images	R:\TAFI\Data\CERF\AUV\SolitaryIs201208\GRTS_Image_subsampling\Images
Broad scale scored AUV	R:\TAFI\Data\CERF\AUV\SolitaryIs201208\Broadscale_Scoring\GRTS_Images
AUV code files	R:\TAFI\Data\CERF\AUV\SolitaryIs201208\Finescale_Scoring\Code file CatamiCodes_NERP_finescale_Solitaries_270414.txt
AUV final output	R:\TAFI\Data\CERF\AUV\SolitaryIs201208\Finescale_Scoring\Final_outputs
Converted TSCS images	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_c7d0be77-7733-27d5-e044-00144fdd4fa6/Videos,+images,+and+positional+information+from+NERP+Marine+Biodiversity+Hub+survey+of+the+Solitary+Islands+KEF+(GA0338)
Broad scale scored TSCS	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_c7d0be77-7733-27d5-e044-00144fdd4fa6/Videos,+images,+and+positional+information+from+NERP+Marine+Biodiversity+Hub+survey+of+the+Solitary+Islands+KEF+(GA0338)
Fine scale scored TSCS output	

Abrolhos islands KEF AUV

FIle	Repository
Converted AUV images	
Broad scale scored AUV	
AUV code files	
AUV final output	

APPENDIX B - BRUV FILE REPOSITORIES

Flinders CMR

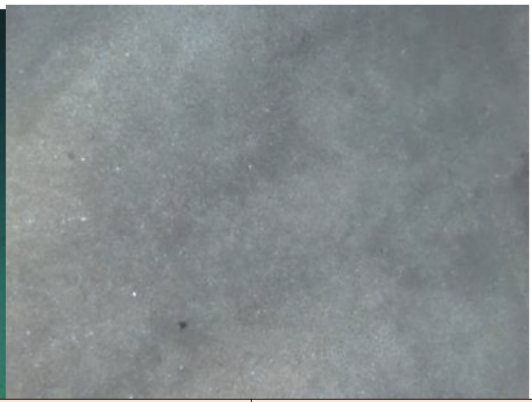
FIle	Repository
Converted Video	*R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\Shelf_BUV\All avi*
Species files	EventMeasure Sp list CAAB 050213.txt: *R:\TAFI\Data\CERF\EventMeasure Files*
Camera Calibration files	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\BRUV_Calibration
Master Station Data	CH201201_Station Data_20121106.xlsx: R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\MASTER_StationData
BRUV Depth Information	Operations_log.xlsx: *R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\GIS_and_Data_Files*
Measured species	FI_BRUVS_Species_to Measure. xlsx : R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\GIS_and_Data_Files
Event Measure files	*R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\Shelf_BUV\EM_Outputs*
Event Measure Output Summaries	*R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\EM Summaries*
Merged Event Measure MaxN outputs	Nmax Merged Cleaned 160813.xlsx: R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\EM Summaries
Merged Event Measure Length outputs	Length Merged Cleaned 160813.xlsx: R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\EM Summaries
Joined and converted video (shelf)	*R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\Shelf_BUV\All avi*
Calibration files	R:\TAFI\Data\CERF\Flinders_Survey_Aug2012_Data\BRUV_Calibration
Deep BRUVs files collected on the CSIRO network • PORT & STARBOARD • Deployment_dBRUV_AVI	\\strait-hba\NERP\DeepBRUVS Each separate deployment of a BRUV unit has its own sub-folder containing • Original video files for port & starboard camera • Converted video files from port camera and Event Measure files
Calibration files	\\strait-hba\NERP\DeepBRUVS\Camera CAL files - deep BRUVS One sub-folder per BRUV unit
Scoring data summary	\\strait-hba\NERP\DeepBRUVS\DeepBRUVS data summary_Oct23_v1.xlsx
Notes on scoring	\\strait-hba\NERP\DeepBRUVS\DeepBRUVS video scoring_notesv2.docx

Solitary Islands KEF

FIle	Repository
Video files	Provided to CSIRO but also help in DPI office, SIMP, Coffs Harbour
EMOB files	Provided to CSIRO but also help in DPI office, SIMP, Coffs Harbour
Calibration files	Provided to CSIRO but also help in DPI office, SIMP, Coffs Harbour
Sampling data	Provided to CSIRO but also help in DPI office, SIMP, Coffs Harbour

APPENDIX C - IMAGE SCORING EXAMPLES

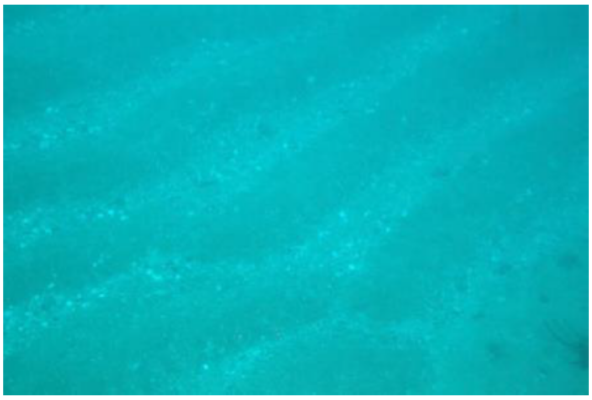
Unconsolidated substrata: Sand/Mud

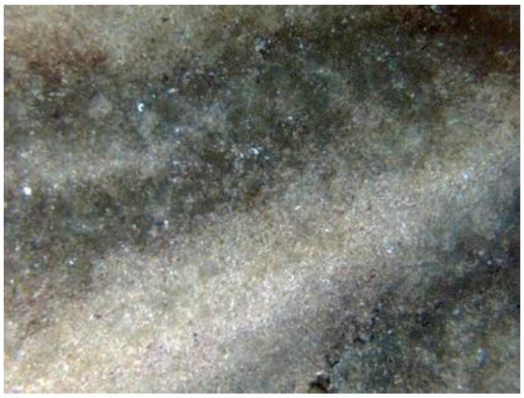


Platform	CSIRO TSCS (Stills)	**Platform**	AUV
Region	Flinders CMR Shelf	**Region**	Solitary Islands
Image Name	CH201201_062_060138_P_1378.JPG	**Image Name**	PR_20120827_041846_925_LC16
Dominant Substratum Type	Unconsolidated | Sand/Mud |	**Dominant Substratum Type**	Unconsolidated | Sand/Mud |
Dominant Substratum Modifier		**Dominant Substratum Modifier**	
Dominant Substrate Cover	81-100	**Dominant Substrate Cover**	81-100
Subdominant Substratum Type	Unconsolidated | Pebble/Gravel | Pebble	**Subdominant Substratum Type**	
Subdominant Substratum Modifier		**Subominant Substratum Modifier**	
Subdominant Substratum Cover	1-20		

Platform	GA TSCS (Video)	**Platform**	CSIRO TSCS (Stills)
Region	Solitary Islands	**Region**	Flinders Shelf
Image Name	Txt 2 ID:6178	**Image Name**	CH201201_011_235049_P_0279.JPG
Dominant Substratum Type	Unconsolidated | Sand/Mud |	**Dominant Substratum Type**	Unconsolidated | Sand/Mud |
Dominant Substratum Modifier		**Dominant Substratum Modifier**	
Dominant Substrate Cover	81-100	**Dominant Substrate Cover**	61-80
Subdominant Substratum Type		**Subdominant Substratum Type**	Unconsolidated | Pebble/Gravel | Biogenic
Subdominant Substratum Modifier		**Subominant Substratum Modifier**	
Subdominant Substratum Cover		**Subdominant Substratum Cover**	21-40

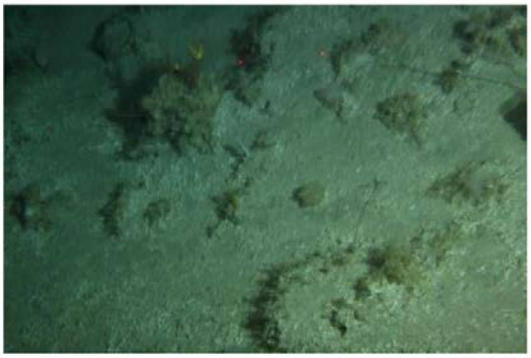
Platform	AUV	**Platform**	GA TSCS (Video)
Region	Solitary Islands	**Region**	Solitary Islands
Image Name	PR_20120827_033943_625_LC16	**Image Name**	Txt 8 ID: 2617
Dominant Substratum Type	Unconsolidated | Sand/Mud |	**Dominant Substratum Type**	Unconsolidated | Sand/Mud |
Dominant Substratum Modifier		**Dominant Substratum Modifier**	
Dominant Substrate Cover	61-80	**Dominant Substrate Cover**	61-80
Subdominant Substratum Type	Unconsolidated | Pebble/Gravel | Gravel	**Subdominant Substratum Type**	Unconsolidated | Pebble/Gravel | Biogenic
Subdominant Substratum Modifier		**Subominant Substratum Modifier**	
Subdominant Substratum Cover	21-40	**Subdominant Substratum Cover**	21-40

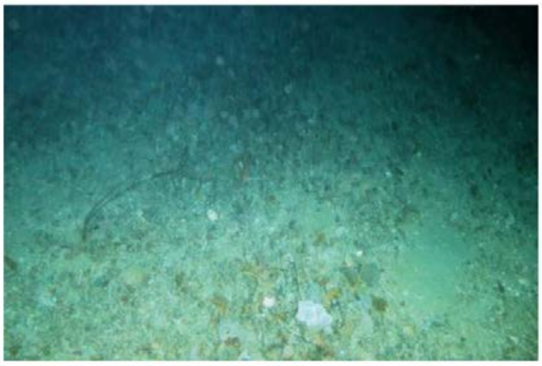




	CSIRO TSCS (Stills)	**Platform**	AUV
Region	Flinders CMR Shelf	**Region**	Solitary Islands
Image Name	CH201201_011_235118_P_0288	**Image Name**	PR_20120827_040654_225_LC16
Dominant Substratum Type	Unconsolidated | Sand/Mud |	**Dominant Substratum Type**	Unconsolidated | Pebble/Gravel | Biogenic
Dominant Substratum Modifier		**Dominant Substratum Modifier**	
Dominant Substrate Cover	61-80	**Dominant Substrate Cover**	41-60
Subdominant Substratum Type	Unconsolidated | Pebble/Gravel | Biogenic	**Subdominant Substratum Type**	Unconsolidated | Sand/Mud |
Subdominant Substratum Modifier		**Subominant Substratum Modifier**	
Subdominant Substratum Cover	21-40	**Subdominant Substratum Cover**	21-40

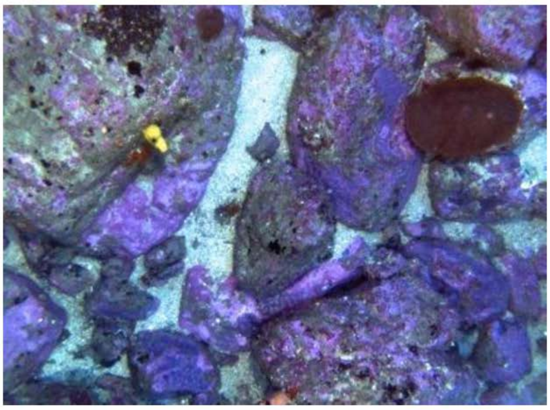
Unconsolidated substrata: |Pebble/Gravel|Biogenic

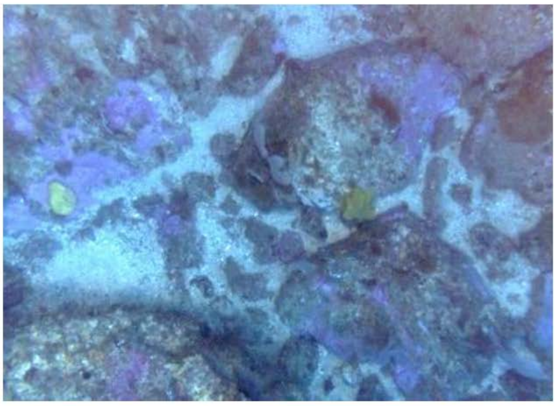




Platform	CSIRO TSCS (Stills)	Platform	CSIRO TSCS (Stills)
Region	Coal Canyon Slope	Region	Flinders CMR Shelf
Image Name	CH201201_094_053251_P_0797	Image Name	CH201201_063_223112_P_0050
Dominant Substratum Type	U nconsolidated | Pebble/Gravel | Biogenic	Dominant Substratum Type	Unconsolidated | Pebble/Gravel | Biogenic
Dominant Substratum Modifier	Veneer	Dominant Substratum Modifier	
Dominant Substrate Cover	61-80	Dominant Substrate Cover	61-80
Subdominant Substratum Type	Consolidated | Cobble |	Subdominant Substratum Type	Unconsolidated | Sand/Mud |
Subdominant Substratum Modifier		Subominant Substratum Modifier	
Subdominant Substratum Cover	21-40	Subdominant Substratum Cover	1-20

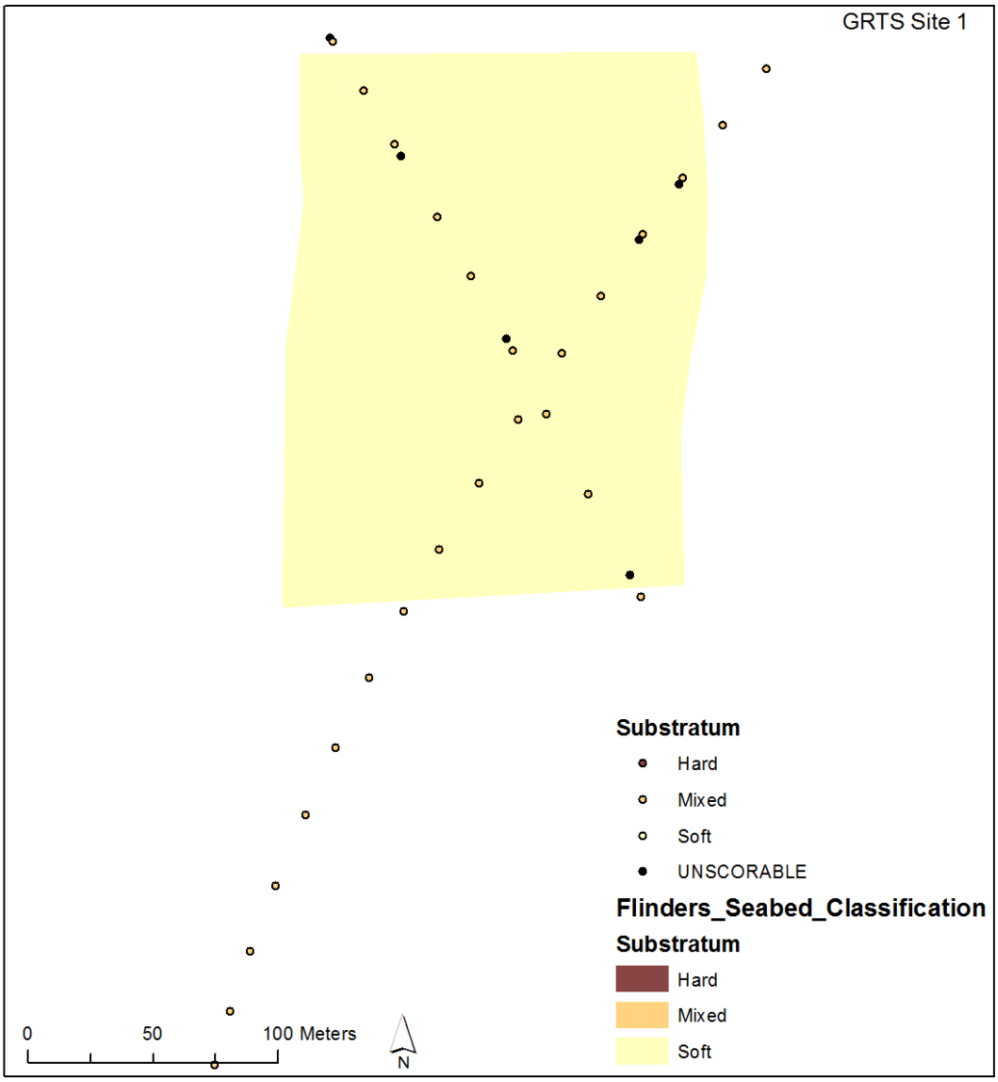
Consolidated| Boulder Substratum



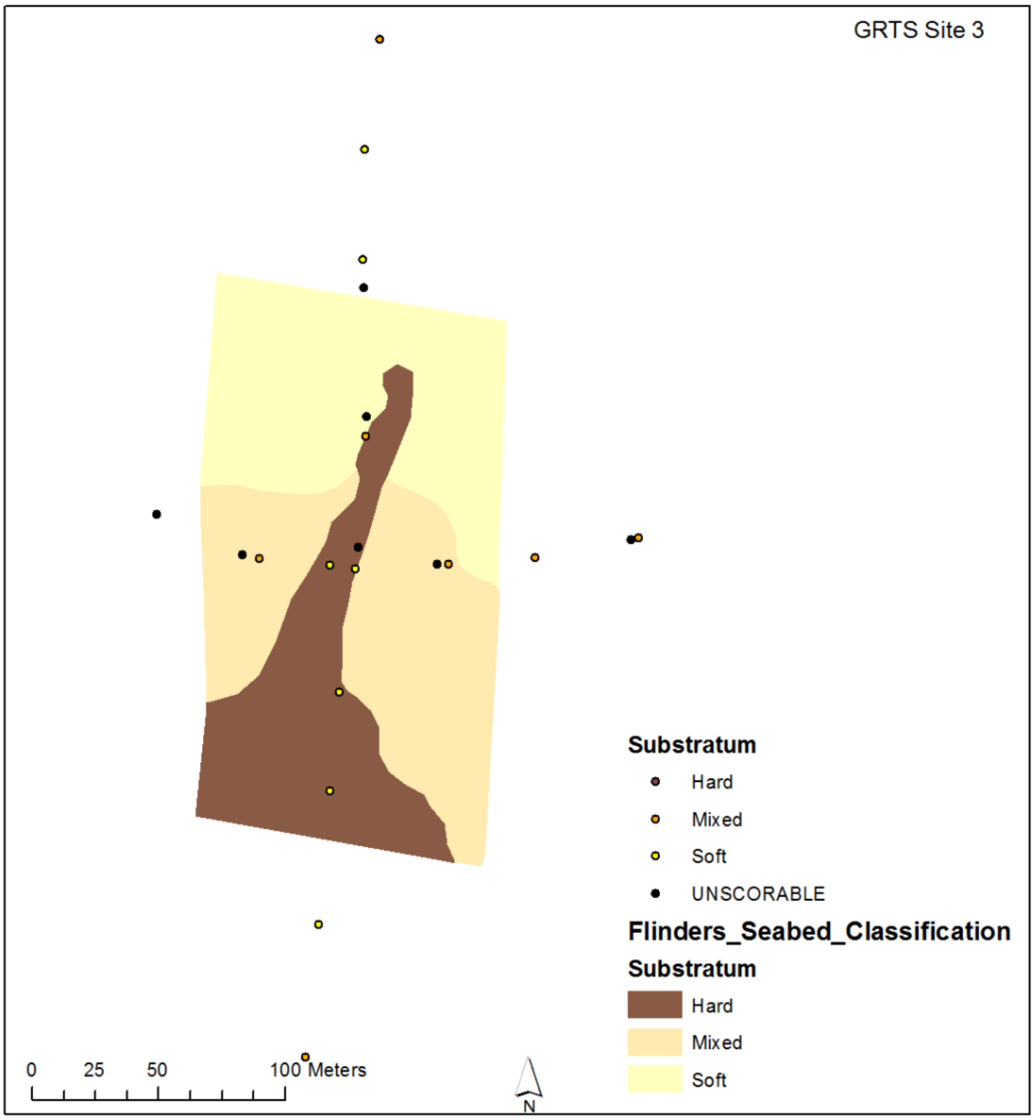


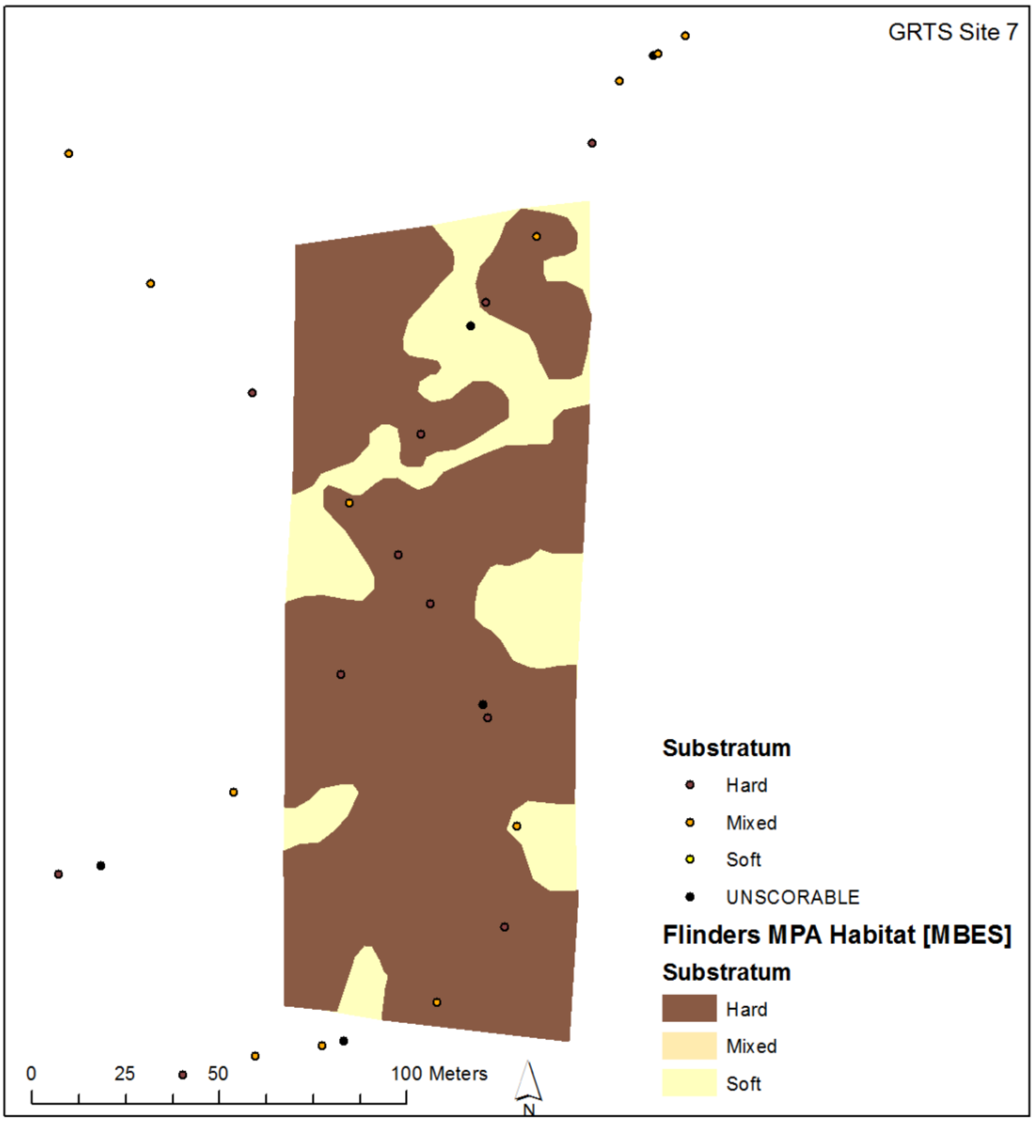
Platform	AUV	Platform	AUV
Region	Solitary Islands	Region	Solitary Islands
Image Name	PR_20120828_233822_502_LC16	Image Name	PR_20120828_233858_529_LC16
Dominant Substratum Type	Consolidated | Rock | Boulder	Dominant Substratum Type	Consolidated | Rock | Boulder
Dominant Substratum Modifier		Dominant Substratum Modifier	
Dominant Substrate Cover	81 – 100	Dominant Substrate Cover	81 – 100
Subdominant Substratum Type	Unconsolidated | Sand/Mud |	Subdominant Substratum Type	Unconsolidated | Sand/Mud |
Subdominant Substratum Modifier		Subominant Substratum Modifier	
Subdominant Substratum Cover	1-20	Subdominant Substratum Cover	1-20

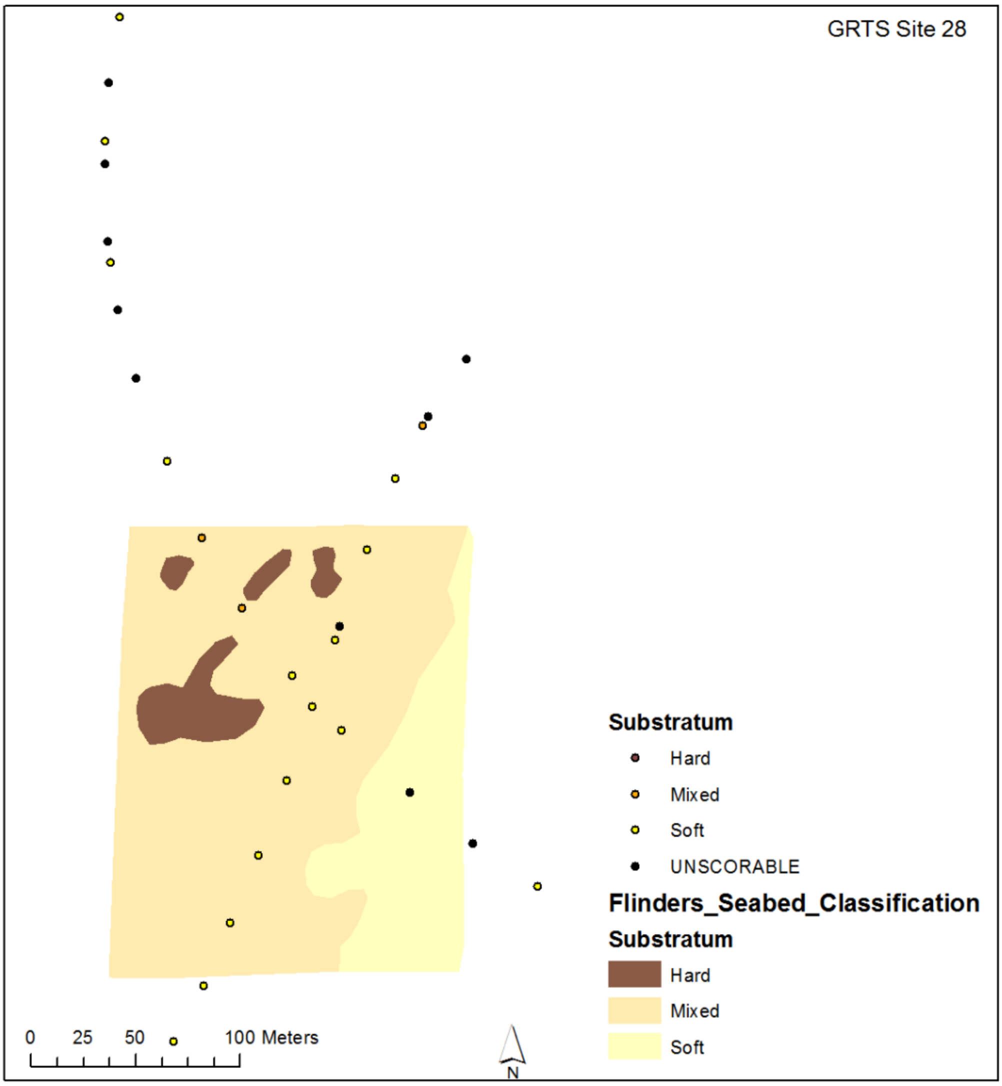
APPENDIX D - GRTS CELLS MULTIBEAM VALIDATION

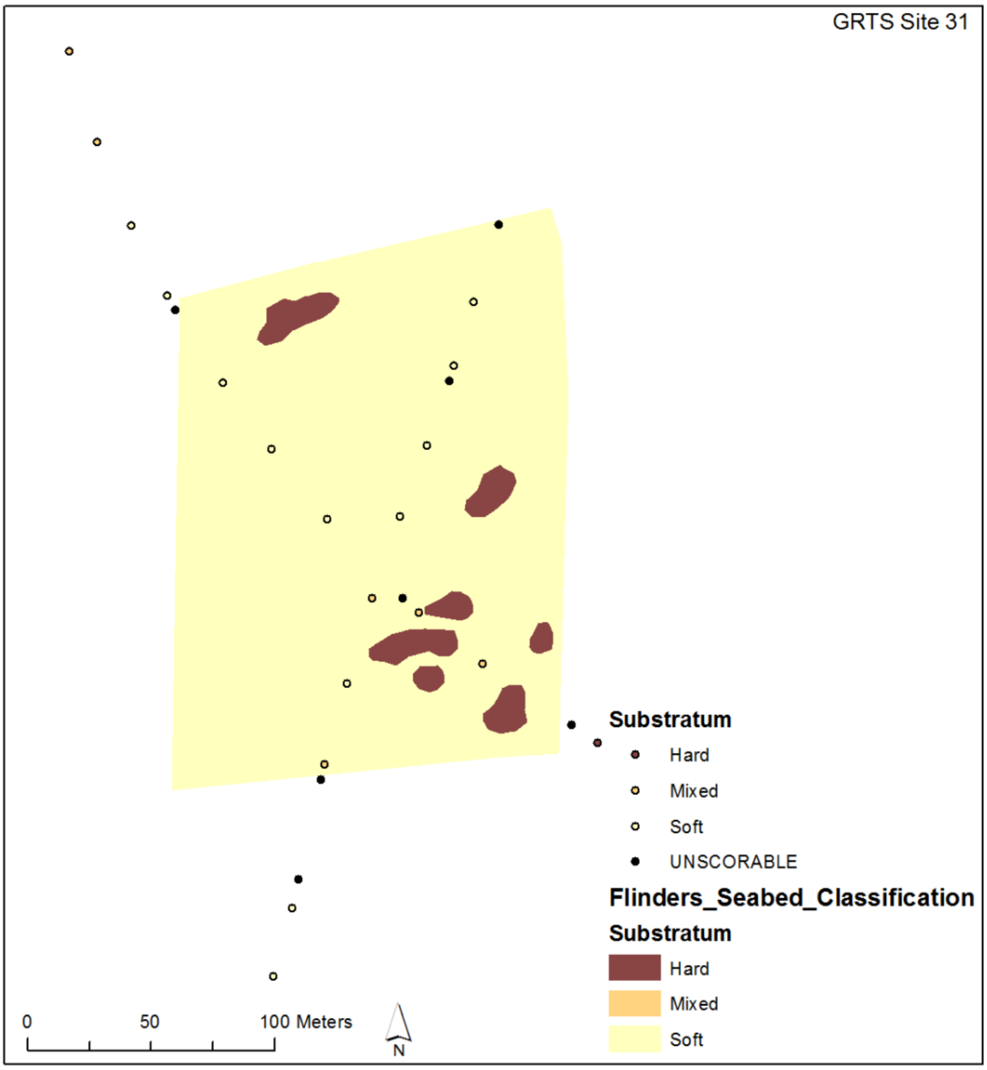



GRTS Site 2
Substratum
Hard
Mixed
Soft
UNSCORABLE
Flinders MPA Habitat [MBES]
Substratum
Hard
Mixed
Soft
0
25
50
100 Meters
N


GRTS Site 3
Substratum
Hard
Mixed
Soft
UNSCORABLE
Flinders_Seabed_Classification
Substratum
Hard
Mixed
Soft
0 25 50 100 Meters
N

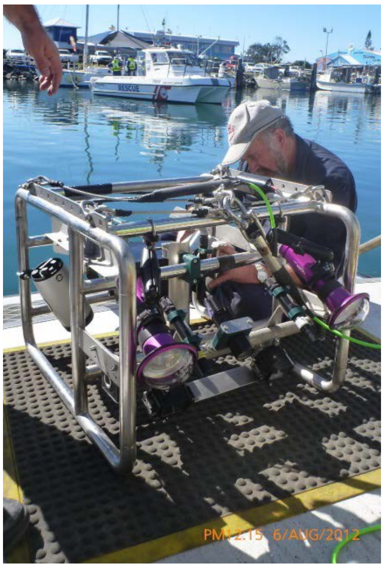

GRTS Site 7
Substratum
Hard
Mixed
Soft
UNSCORABLE
Flinders MPA Habitat [MBES]
Substratum
Hard
Mixed
Soft
0
25
50
100 Meters
N

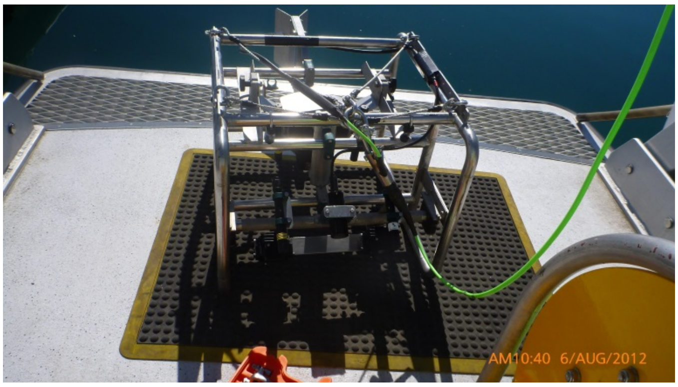

GRTS Site 28
Substratum
Hard
Mixed
Soft
UNSCORABLE
Flinders_Seabed_Classification
Substratum
Hard
Mixed
Soft
0 25 50 100 Meters
N


GRTS Site 31
Substratum
Hard
Mixed
Soft
UNSCORABLE
Flinders_Seabed_Classification
Substratum
Hard
Mixed
Soft
0
50
100 Meters
N

APPENDIX E - TSCS DEPLOYED AT THE SOLITARY ISLANDS


AM10:40 6/AUG/2012


PM2:15 6/AUG/2012


AM10:40 6/AUG/2012

www.nerpmarine.edu.au