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Mapping Shelf Rocky Reef Habitats in the Hunter Commonwealth Marine Reserve

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Theme D3 -
Evaluating and Monitoring the Status of Marine Biodiversity Assets on the Continental Shelf

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EXECUTIVE SUMMARY

This report documents results of a targeted acoustic field survey of areas on the continental shelf of the Hunter Commonwealth Marine Reserve undertaken as part of Hub research to improve our understanding of the nature and distribution of shelf rocky reefs found within the reserve, and, by inference, are likely to be found in adjacent east Australian shelf waters. It was also intended to identify areas of reef habitat suitable for subsequent biological inventory and monitoring. Shelf rocky reefs are identified as Key Ecological Features (KEFS) within the Commonwealth marine bioregional planning framework, and improving the knowledge of the distribution of this KEF within the Hunter CMR, the only Temperate East region CMR with significant shelf representation, was identified as a high priority in a Hub planning workshop (Lucieer et al. 2015).

Initial planning involved collation and processing of pre-existing bathymetric data which consisted of a number of single track transit lines from the RV *Southern Surveyor* as it passed through the region. Areas of interest, such as reef outcrops, identified from this existing information were then targeted for further evaluation by field swath bathymetry survey using the NSW Government Research Vessel, RV *Bombora*. In addition, a series of cross-shelf transits were incorporated in the survey to identify cross-shelf patterns in reef distribution, such as the presence of drowned ancient coastlines, and the nature of their extent along the coast. Such features had previously been found to be common in other regions of NSW.

Overall, reef habitat was not extensive within the shelf region of the CMR, and there was no evidence of continuous coverage of relict coastal reef features. Despite this, some reef features were identified, including one area that was mapped in detail and spanned depths between 75 to 110 m. The mapping showed the reef to be of relatively low relief, reaching only 7 m above the surrounding soft sediments over km scales. Significant scour trenches exist beside mapped reef systems, probably reflecting the strong currents which exist in this location associated with the southward flow of the EAC.

It is not possible to ascertain from this limited survey what the geological provenance of these reefs is likely to be. The depths in which they are found is consistent with the possibility that the reefs could represent low stand coastal features formed during past periods of low sea-level. However, the shape and orientation of the features, oblique to the depth contours, and the general blocky appearance of the reefs may indicate that they represent outcrops of bedrock.

This survey was a preliminary investigation only, and does not provide a comprehensive understanding of the nature and extent of reef systems in this region/CMR. It is certainly likely that many reef systems have yet to be mapped, and it appears likely that the reefs extend to the north and south of the surveyed area. Further work would also ideally be targeted at reef systems that appear to extend into state waters, particularly with a focus on the degree of connectivity that such reefs may form with the adjacent Port Stephens-Great Lakes Marine Park. Further biological surveys would reveal the ecological significance of these reefs and inform future management within the Hunter CMR.

1. INTRODUCTION

Research conducted in Theme D in the NESP Marine Biodiversity Hub aims to improve understanding of the biophysical, economic and social aspects of the marine environment. The primary aim of project D3 is to evaluate and monitor the status of marine biodiversity assets on the continental shelf, with a key initial objective focussed on collating and classifying national seabed mapping data, and identifying key gaps in priority areas.

This is particularly aimed at capturing baseline information on continental shelf habitats within Commonwealth Marine Reserves (CMR) where the information is vital for monitoring the effectiveness of various management arrangements.

Much of this focus has centred around building our understanding of Key Ecological Features (KEFs). These are elements of the Commonwealth marine environment that are considered to be of regional importance for either a region's biodiversity or its ecosystem function and integrity. As shelf rocky reefs have been identified by the Australian Government in their Marine Bioregional plans as KEFs, and are known to be hotspots of biodiversity and productivity, the Marine Biodiversity Hub has focussed a substantial effort on understanding their distribution and improving this knowledge where it is inadequate. Filling this knowledge gap is an important starting point to develop the Australian Government's capacity to monitoring the health of the Commonwealth Marine Area (Towards a blueprint for monitoring Key Ecological Features in the Commonwealth Marine Area; Hayes et al. 2015).

A significant gap in our current knowledge has been the distribution of habitats, and reef in particular, within the Hunter CMR in the Eastern Temperate reserve network. This is the only CMR in the Eastern Temperate region with significant representation of shelf habitats, particularly in a region with high pressures due to its proximity to population centres. To address this gap, and to underpin subsequent biological monitoring programs within this CMR, the Hub initiated an acoustic field survey to map representative examples of reef systems within the region in order to gain an understanding of their extent, spatial distribution and geomorphology.

The total area of the Reserve is 6,357 km², and approximately 1,739 km² of this is located on the continental shelf and mid to upper slope. This region is an important habitat for several protected shark species including grey nurse and great white shark, and straddles the annual migration path for the East Coast humpback whale population. This area is also important habitat for many migratory sea birds. It is also an area that has previously been identified to contain the Key Ecological Feature (KEF) of shelf rocky reef.

The area adjoins the Port Stephens Great Lakes Marine Park (PSGLMP) which extends within New South Wales state coastal waters from the northern end of Stockton Bight to Forster. While the Hunter CMR only extends over approximately half the outer boundary of the PSGLMP, it is immediately adjacent to a large sanctuary zone (IUCN II) immediately offshore of Seal Rocks. Previous mapping in this area, including areas adjacent to Broughton Island and Seal Rocks contain extensive areas of rocky reefs that extend in places from the shoreline to the limit of state waters in depths of around 50 m (Jordan et al. 2010). These rocky reefs are dominated by macroalgal habitats and urchin barrens in depths <30 m, and sessile invertebrates in deeper depths. They are also both known critical habitat sites for the threatened and protected grey nurse shark (Otway et al. 2003). In addition, an important white shark nursery area exists to the west on the beaches of Hawks Nest (Bruce and Bradford 2008). It is possible that the rocky reefs within the Hunter CMR are also important habitats for these species.

A number of existing multibeam datasets provide some coverage of seabed habitats within the Hunter CMR. The continental slope is well covered from previous surveys conducted on the RV *Southern Surveyor*, however, limited mapping exists within the rest of the reserve, particularly over the continental shelf where swath acoustic coverage consists of single lines collected during vessel transits. These data have been compiled as part of the larger NESP D3 hub project.

Previous seafloor mapping along the New South Wales Shelf (Jordan et al. 2010) has revealed linear reef features at depths of around 70 m to 90 m which occur at numerous locations along the coast, such as offshore of the Solitary Islands. It is thought that these features may be paleo-coastline features which have been formed during low stand sea level during the last glacial maximum between 21,000 to 19,000 years BP (Lewis et al. 2012). It was thought that similar linear features, may also be found here.

This report summarises results from collated/reprocessed historical multibeam sonar surveys and new swath acoustic surveys designed to characterise the presence and structure continental shelf rocky reef habitats within targeted areas of the Hunter CMR. The ecological values of the rocky reef KEFS within the Hunter CMR as well as connectivity with the adjacent PSGLMP is assessed in a subsequent report following targeted video surveys of the identified rocky reefs.

2. METHODS

Prior to, and to inform new surveys, all existing bathymetric datasets were identified and reprocessed at finest possible resolution to examine the current knowledge of the distribution of shelf habitats within and adjacent to, the Hunter CMR. In summary, the existing RV *Southern Surveyor* multibeam acoustic data were gridded to 10 x 10 m and derivative products created in ArcGIS were used to identify potential areas of reef through visual analysis of slope and hill-shaded bathymetry layers.

The analysis of the existing multibeam data indicated certain areas of interest where shelf rocky reefs may be present. Existing NSW OEH swath acoustic data gridded at 5 x 5m resolution were also examined and target points identified at the seaward edge of previously identified reefs. A list of the identified targets and features are presented in Table 1. The existing data was also collated and analysed as a sub project by a student intern working under the guidance of CSIRO and UTAS. The compilation of data is attached as an appendix to this report.

The coarseness of the RV *Southern Surveyor* data, and the fact that it consisted of single ships tracks rather than targeted adjacent survey lines makes it difficult to equivocally identify reef areas where relief is low. However, identified targets were investigated in the field using the NSW Government 11.8 m survey vessel, *RV Bombora*.

Acoustic surveys were conducted using a 125 kHz Geoswath interferometric swath system (2003) and POSMV Wavemaster with XYZ 000 as centre of mass at the water line - vertical offset to centre of transducer faces -0.619. Echosounder cross-validation at nadir was provided by Tritech, surface sound velocity via Valeport SVS and SV profiles by SeaBird CTD. Noting that the sea conditions were rough during these surveys, and hence the quality of the acoustic data and resulting imagery was less than optimal.

Position was provided as a Virtual Reference Station (Rinex) with Smartnet RTK corrections provided to POSPac across Telstra Mobile 3G network and Hypack software. Real-time ephemeris data were saved in POSPac log files for post-processing and calculating a 3 min forward-backward smooth for improved SBET in Single Base Station Mode. Mean SBET positional accuracies were improved to be better than 0.1 for X, Y and Z at nadir. SBETs were applied to Geoswath data before rough processing using amplitude, box, across-track and along-track filters in GS+. Data were exported as GSF for further data cleaning and cube modelling of soundings and production of a final digital elevation model. Backscatter data were output from GS+ in XTF data and then mosaicked using Sidescan Solo module within Fledermaus FMGT.

3. RESULTS

As part of the Marine Biodiversity Hub D3 project all existing seafloor data is being collated into a searchable database. All available data for the region were extracted from the database and gridded. The gridded data showed that there were a number of possible rocky reef outcrops across the shelf. A decision was made to first explore the targets in depths of 120 m and 90 m where paleo-coastline features may be likely to occur.

3.1 Existing data from the Hunter CMR

Relatively extensive datasets of seafloor mapping from within state waters (<3 nm) have previously been completed as part of the planning process for the Port Stephens Great Lakes Marine Park (Figure 1). Defined sanctuary zones and habitat protection zones around Broughton Island and Seal Rocks lie in close proximity to the current survey area. The range and distribution of seabed habitat types within these zones are described in detail in Jordan et al. (2010).

In addition to the mapping in state coastal waters, a total of 177 km² of seabed on the shelf (<200 m water depth) from the *RV Southern Surveyor* data was used to identify a number of possible reef locations from hill-shaded grids of this data (Figure 2, 3; Table 1). A more detailed analysis of existing multibeam data within the Hunter CMR is reported by Raphael et al. 2016) (Appendix 1). The area of the seabed lying over the shelf is wholly contained within the Hunter CMRs inshore Special Purpose Zone.

3.2 Detailed acoustic data from this survey

A total of approximately 80 km² was mapped during the current survey (Figure 4). Three areas were surveyed in detail, two in depths of 100 to 120 m (Figure 4; Areas B and C) and one closer to state waters in depths between 60 m and 80 m (Figure 4; Area A). The shelf in the area mapped is almost level (slope = 0.22 degrees), with a fall of only 35 m over 9 km from west to east. The swath mapping revealed some shelf rocky reef features which have not been previously mapped. The surveys indicate the existence of potential areas of shelf rocky reef within the Hunter CMR on the inner shelf at depths between 75 m and 120 m, particularly in an area situated approximately 10 km to the north-east of Broughton Island.

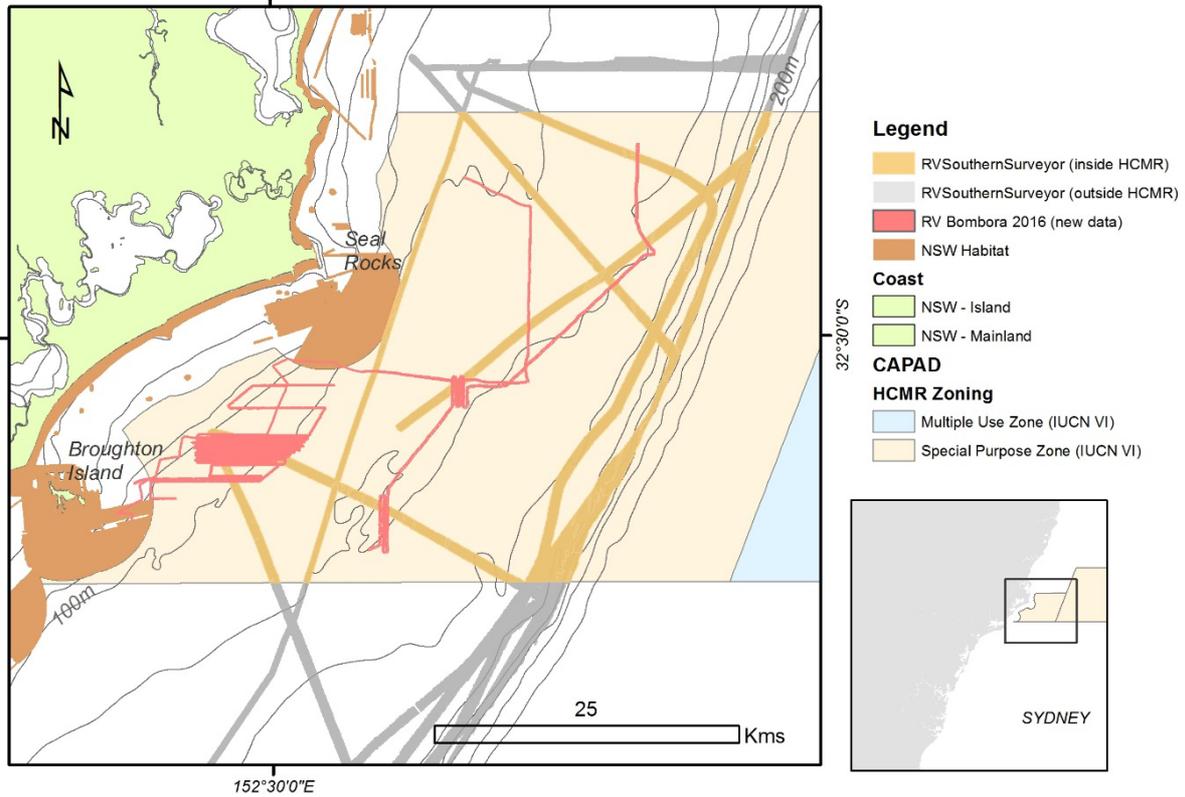


Figure 1 Coverage map of multibeam data in the vicinity of the Hunter CMR (Commonwealth) and Port Stephens Great Lakes Marine Park (NSW). Sources are 1) data obtained during this new NESP survey conducted by NSW OEH in December 2015 (pink), 2) RV Southern Surveyor multibeam data from CSIRO and Marine National Facility archives (light orange) and 3) New South Wales Office of Environment and Heritage multibeam/habitat data (dark orange) over the continental shelf (<200 m).

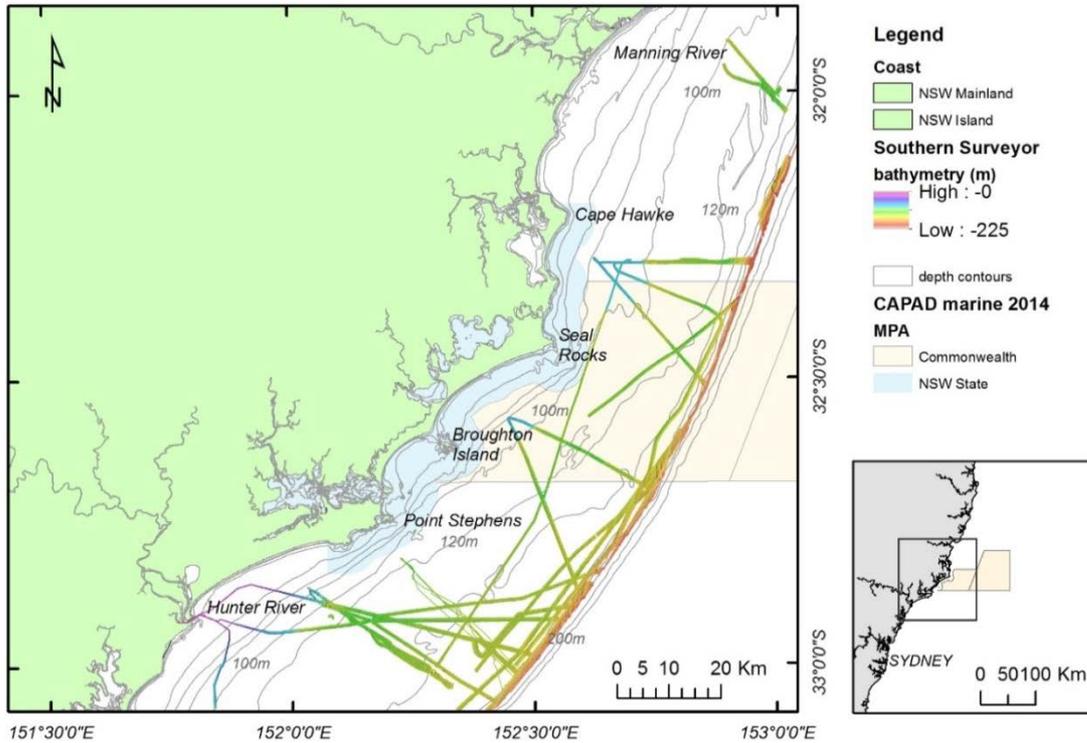


Figure 2 Regridded (10 x 10 m) Southern Surveyor multibeam bathymetry data over the continental shelf (<200 m water depth) between 32° – 33° S

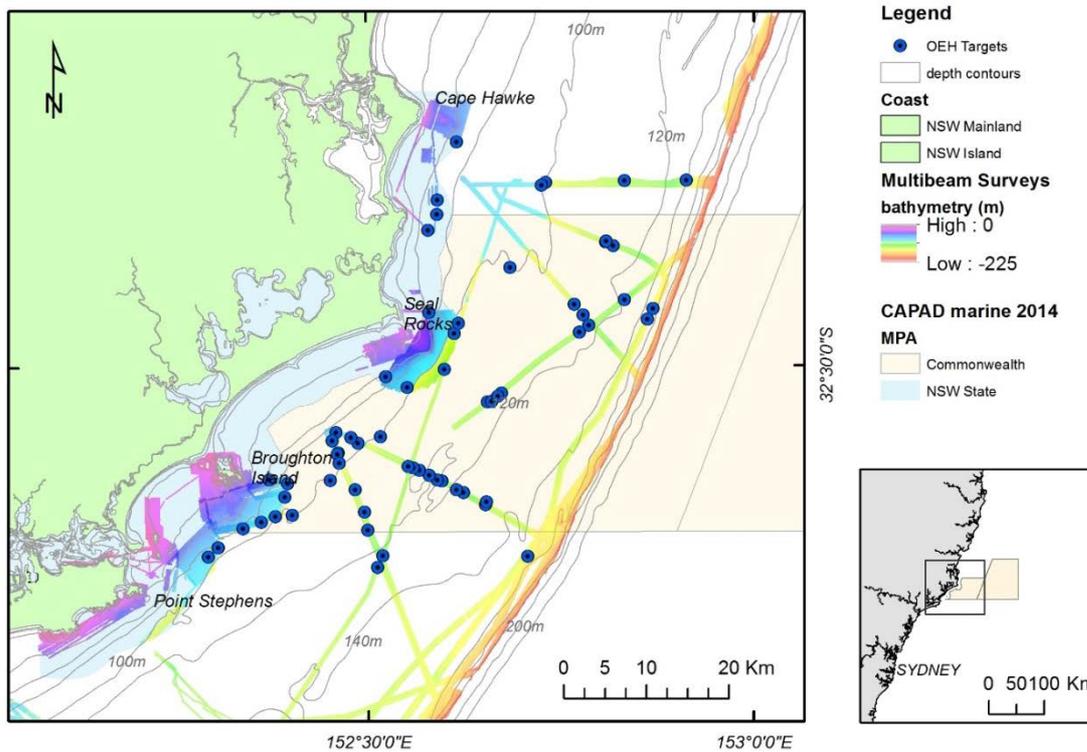


Figure 3 Location of possible reef targets identified from existing multibeam data.

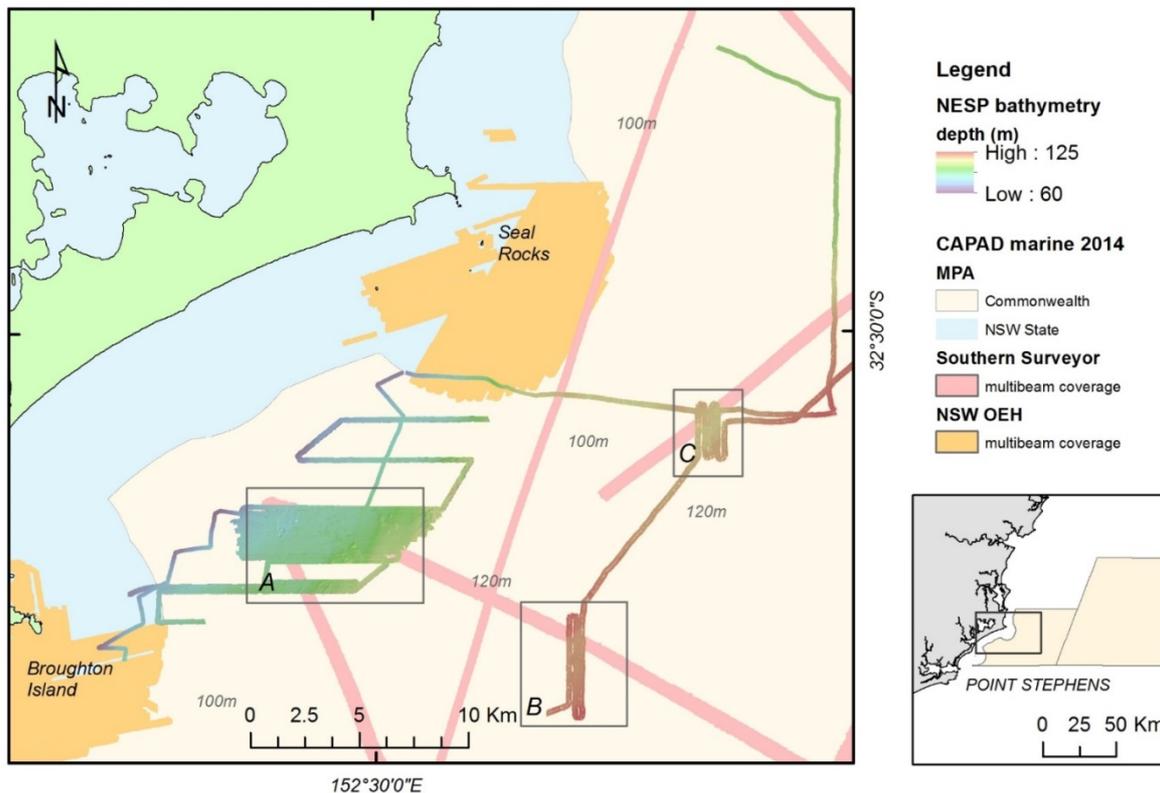


Figure 4 New data collected during this survey. Three areas of interest (Boxes A, B, and C) were surveyed in detail

Area A, located further inshore, not far from the boundary of the PSGLMP was surveyed in detail and revealed numerous sections of discontinuous reefs and reef complexes (Figure 5). The acoustic backscatter image (Figure 6) shows that area consists of soft sediment interspersed with rocky outcrops.

There appear to be two distinct geomorphic forms in this CMR survey area. Shallower reefs in water depths of less than 75 m form the first group and form a mass of reefs around a small rise with an overall relief of 4 m. The second group of reefs appear as a series of deeper reefs across depth of 90 to 100 m. These appear to be more linear in shape than their shallower counterparts, with the greatest height reaching 7 m above the sandy sediment. These reef features are elongated with a strong linear dimension oriented to NW-SE. Profiles of transects across these reefs are shown in Figure 7. The slope and aspect maps (Appendix 1) indicate that the reefs have a dominant aspect of NE and SW. This may indicate the bedding of these reefs is tilted. Some of these reef features are bordered by scour channels some 5 to 6 m deeper than the surrounding seafloor. This may reflect strong currents close to the seabed associated the southward flow of the East Australia Current.

The NSW geological maps indicate that the bedrock of Broughton Island to the south consists of Devonian to Carboniferous sedimentary rocks of the Tamworth Belt. The Tamworth Belt is around 20 to 50 km wide and forms the western and southern margin of the New England Fold belt. It consists of folded and faulted marine sedimentary deposits (Mory, 1980).

The geology of this area is complex and it is difficult to determine the actual geology of the reefs in the survey area without further investigation. Given the depth of these features below sea level, it is possible that these features may form part of a regional scale paleo-coastal barrier systems also identified within other parts of the East Marine Region across similar depths, and may have been formed during previous periods of lower sea level. However, the appearance of the reef structures mapped within the Hunter CMR is quite different from the linear features mapped in state waters to the north and south. The reefs in this study area are quite blocky in appearance and their linearity is oriented obliquely to the depth contours. This may suggest they represent bedrock outcrops rather than low stand coastal barriers formed during previous glaciation periods.

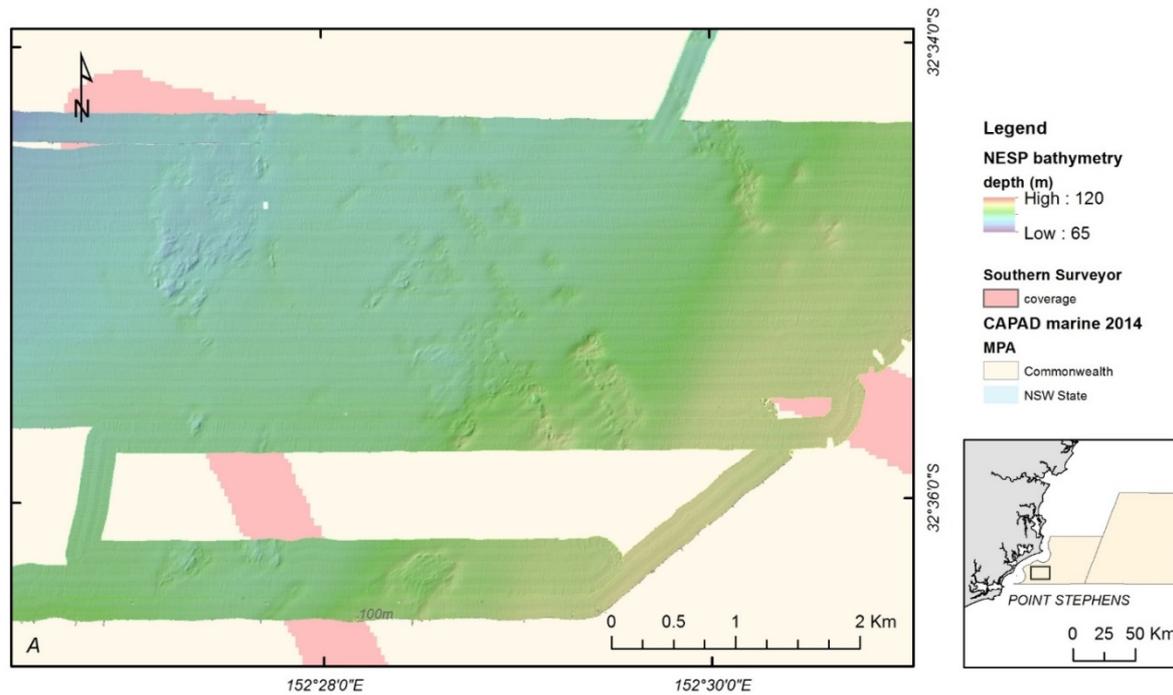


Figure 5 Hill-shaded relief image of survey area A showing illustrating what appear to be two distinct geomorphic reef structures

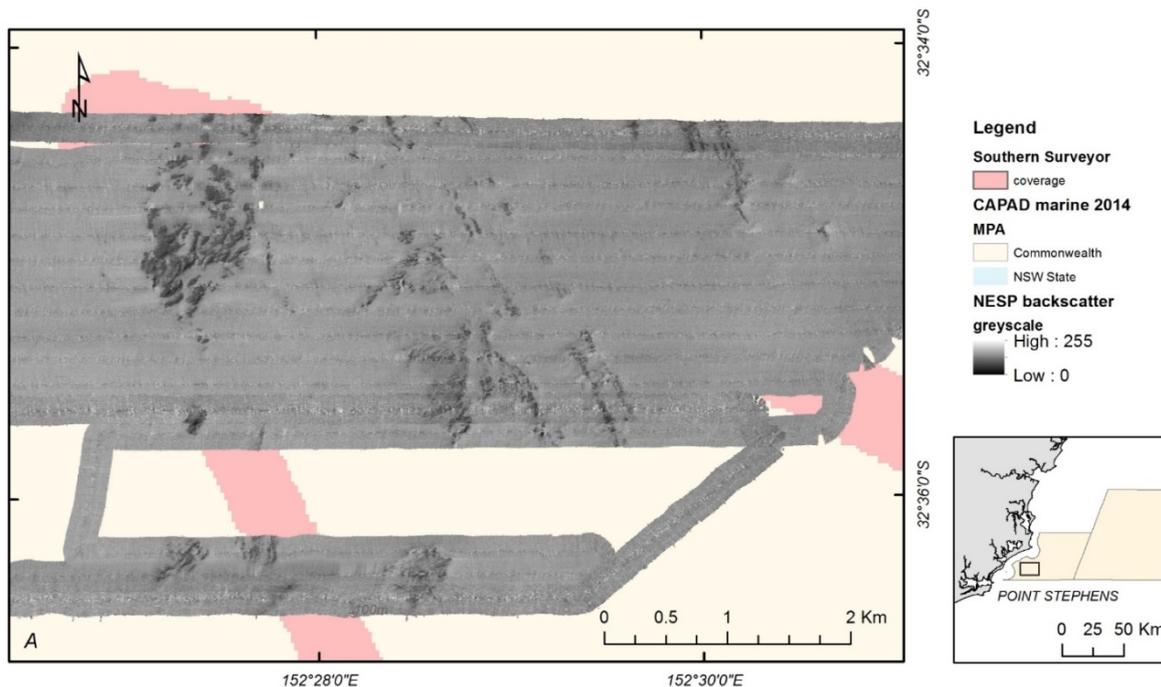
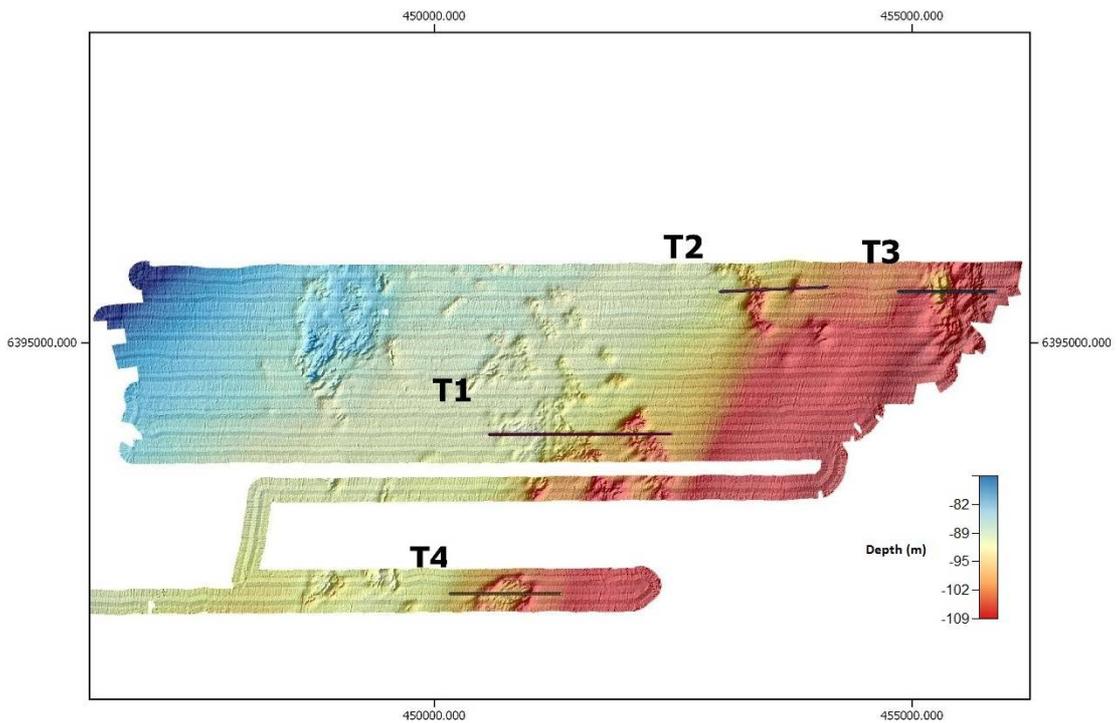
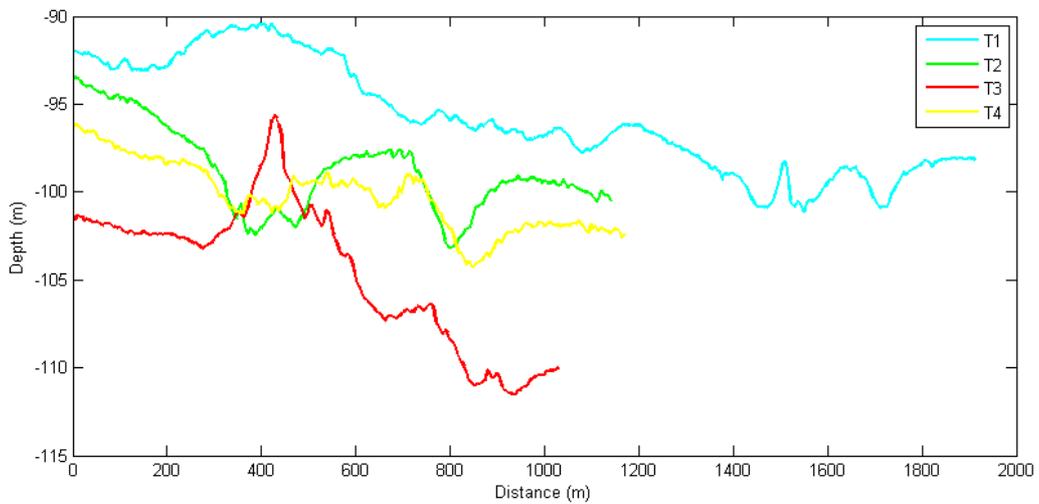


Figure 6 Backscatter image of survey area A. The reef areas are displayed as darker greyscale values

There are some features apparent in the two other areas mapped further offshore which may be reef (Figure 8; Area B and Figure 10; Area C). The data show the features in Area C have an elevation of around 4 m above the surrounding seafloor and the texture appears to be consistent with low lying reef (Figure 12). The data is somewhat ambiguous, however, as the backscatter images do not show the high reflectance which is typical of reefs (Figure 9, 11). This anomaly could be explained by a number of factors. Firstly it is possible that the roughness of the sea state and strong current at the time of the survey reduced the amplitude of the returned acoustic signal. Secondly, the reef may be covered with a layer of soft-sediment which has reduced the return echo. However, despite these uncertainties there are strong indications that there is reef located in these areas and further surveying of the shelf areas of the Hunter CMR is recommended to obtain a better understanding of the extent and distribution of the shelf rocky reefs within the region.



a



b

Figure 7(a) Hill-shaded bathymetry of the shelf rocky reefs in Survey Area A showing location of profiles. (b) profiles across reefs mapped within the Hunter CMR Survey Area A.

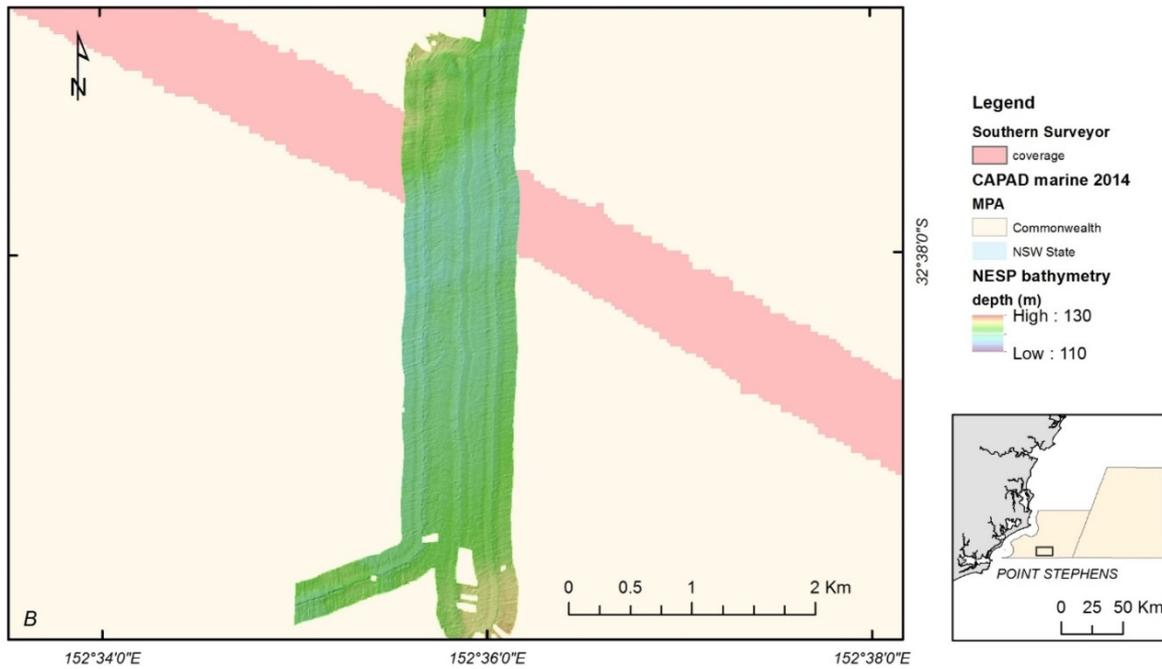


Figure 8 Hill-shaded relief of Survey Area B. There appears to be some feature at the northern end, but it is not clear if it is reef.

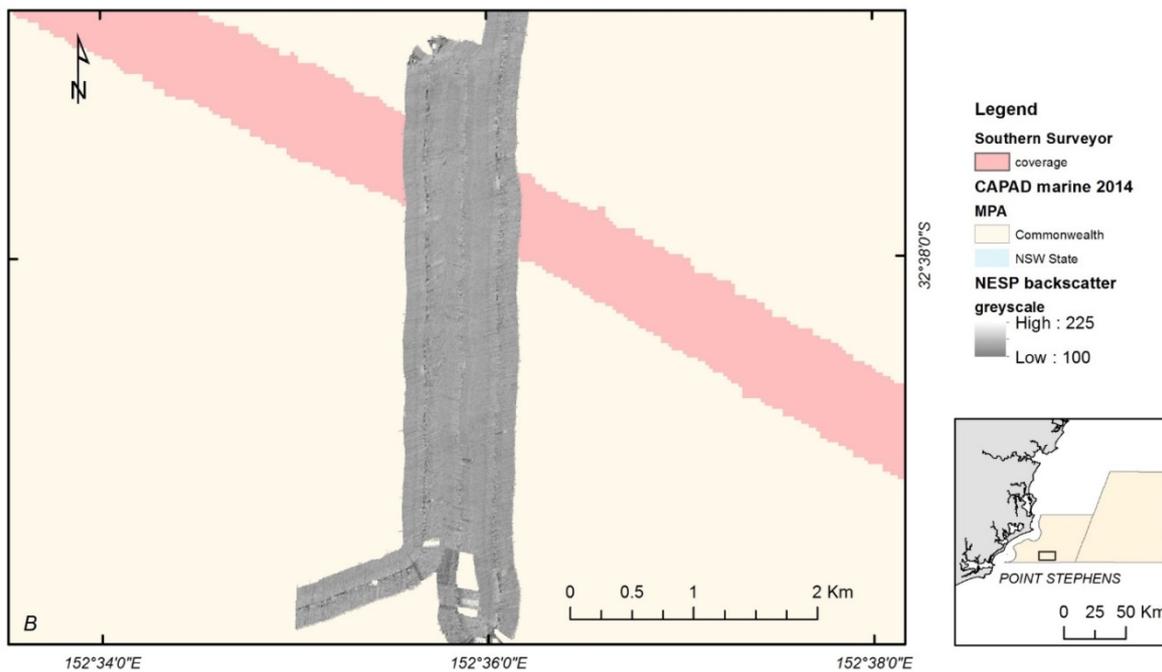


Figure 9 Backscatter image for area B. The feature which can be seen in the hill-shaded relief image (Figure 8) is not obvious in the backscatter.

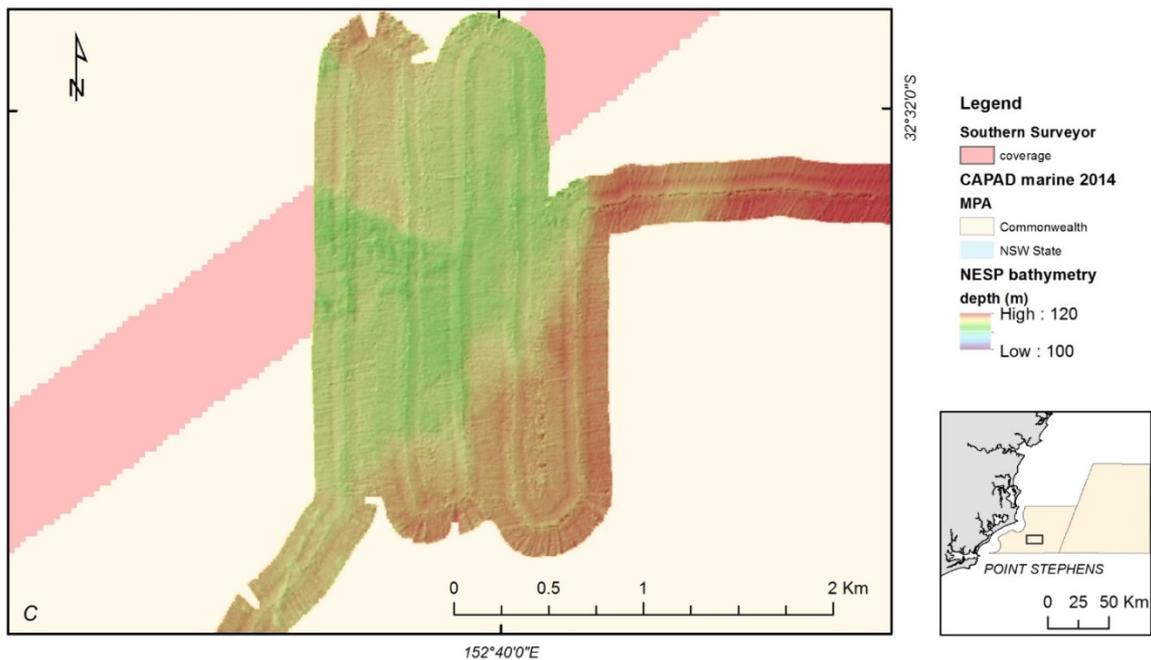


Figure 10 Hill-shaded relief image for Survey Area C. The area has some features which rise some 4 m above the surrounding seafloor.

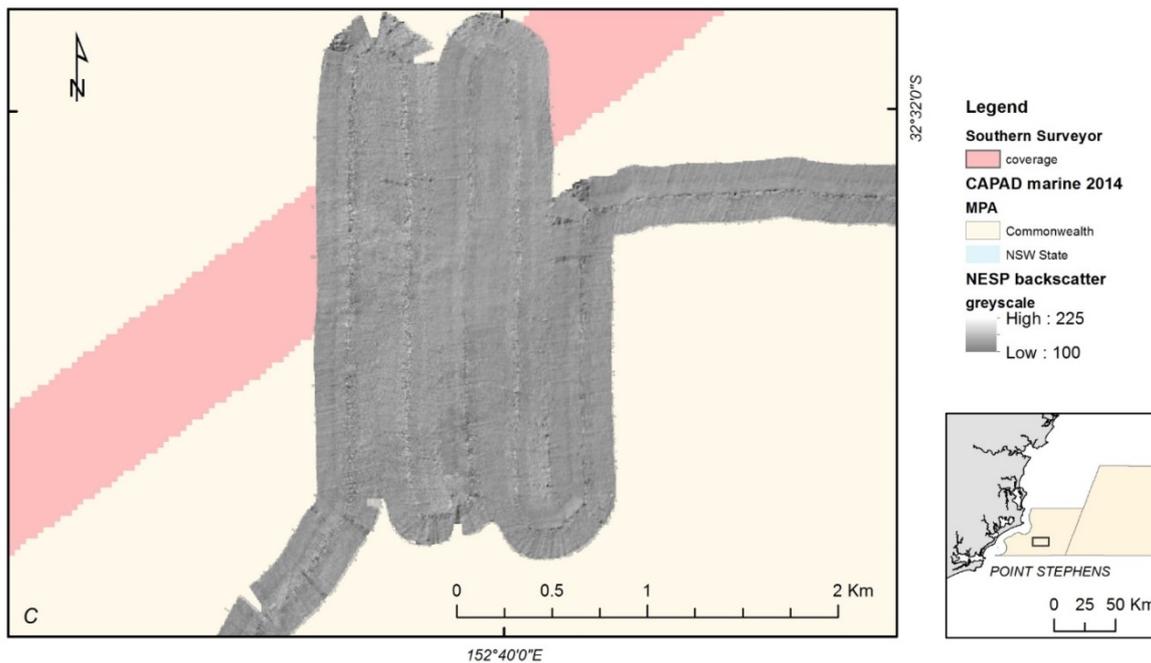


Figure 11 Backscatter image for Survey Area C. The area of low relief which can be seen in the bathymetry data is not obvious in the backscatter

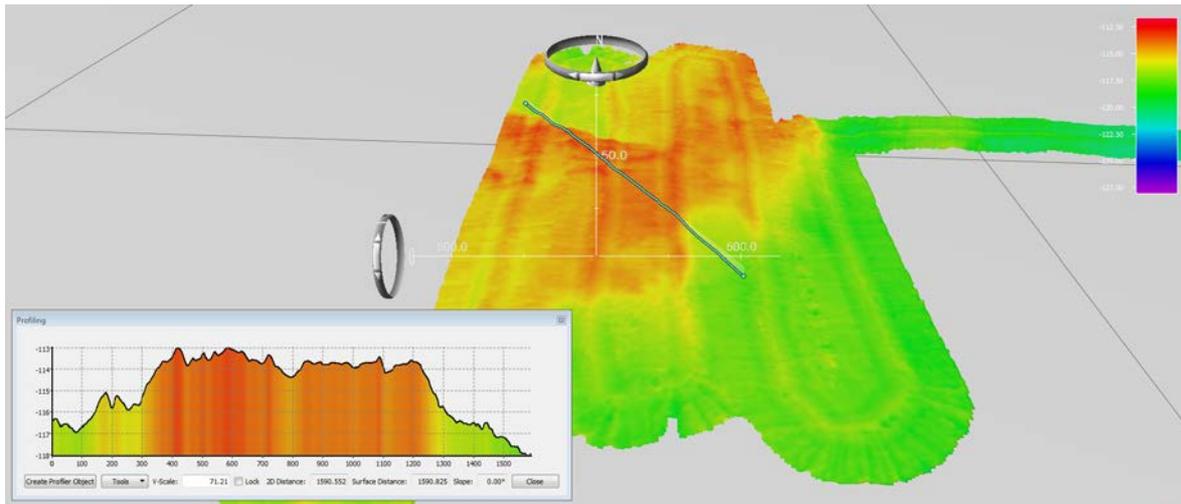


Figure 12 North oriented 3D view (8 x vertical exaggeration, 45 degree inclination) of Survey Area C. The cross section across the possible reef area clearly shows that the relief is only a few meters over a 1500 m horizontal section.

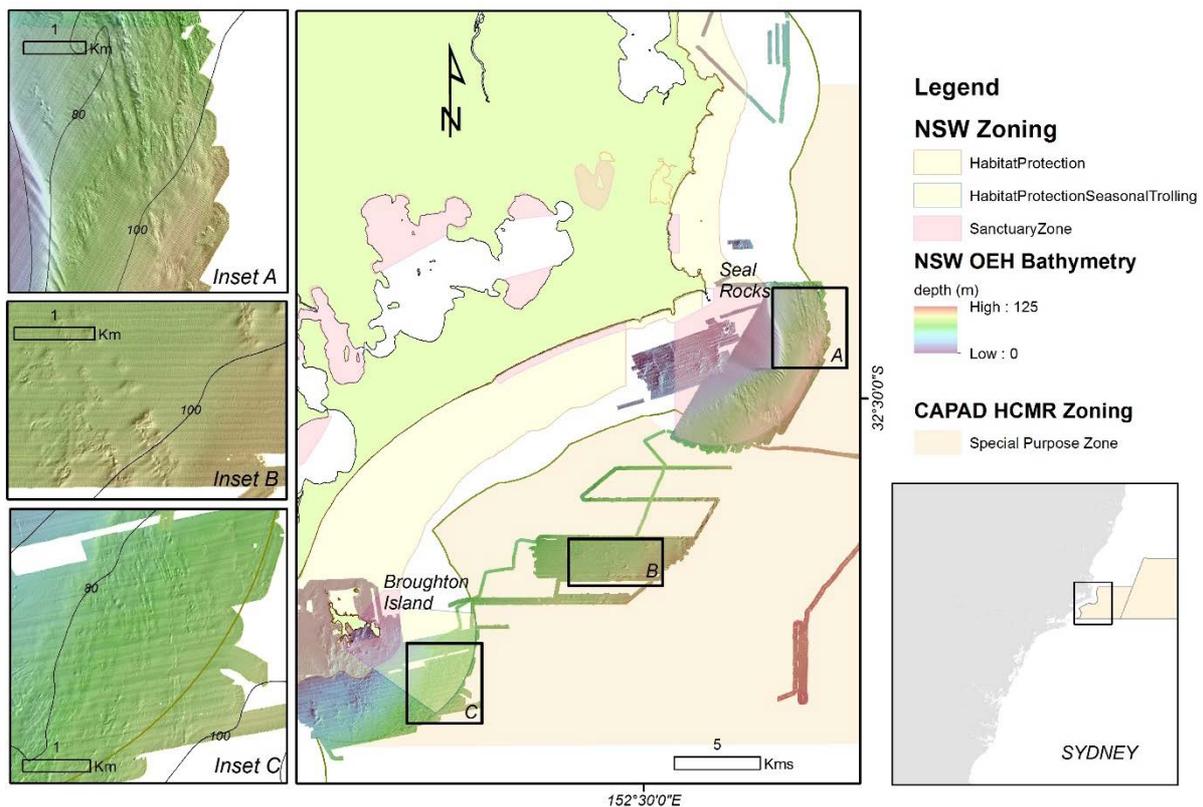


Figure 13 Shaded relief false-colour bathymetry of the survey area within the Hunter CMR and adjacent mapped areas within the NSW Port Stephens Great Lakes Marine Park. The maps highlight the variation in distribution and morphology of reef complexes and typology within the area. Of note are the shore parallel linear reef features off Broughton Island that may represent relict coastline features

Table 1 Target sites of possible shelf rocky reef identified from existing data

<i>Number</i>	<i>Feature description/location</i>	<i>Latitude S</i>	<i>Longitude E</i>	<i>Depth</i>	<i>Comments</i>
1	relic coast Pinnacles	32 15.17	152 36.98	67	southern edge of Pinnacles OEH coverage
2	relic coast Booti Booti	32 19.02	152 35.48	67	eastern most line of OEH 2006 coverage
3	isolated patches Booti	32 19.97	152 35.43	71	eastern most line of OEH 2006 coverage
4	isolated relic coast Booti	32 21.02	152 34.75	67	eastern end of EW transect at Booti OEH coverage
5	contour 67m	32 26.48	152 34.81	67	northern most edge of Seal Rocks coverage
6	reef patches Seal Rocks	32 27.86	152 36.74	102	eastern edge OEH and SS transect
7	reef patches Seal Rocks	33 27.19	152 37.10	103	SS transect
8	isolated reef Seal Rocks	32 30.24	152 35.97	111	SS transect
9	relic	32 17.88	152 43.87	104	SS EW transect of Pacific Palms
10	relic	32 18.05	152 43.54	100	SS EW transect of Pacific Palms
11	relic	32 17.74	152 49.97	113	SS EW transect of Pacific Palms
12	relic	32 21.82	152 48.52	111	SS EW transect of Pacific Palms
13	relic	32 17.73	152 54.77	139	SS EW transect of Pacific Palms
14	relic	32 26.22	152 52.18	148	SS NS transect of Pacific Palms
15	relic	32 26.93	152 51.72	147	SS NS transect of Pacific Palms
16	relic	32 25.63	152 49.96	121	SS NS transect of Pacific Palms
17	relic	32 22.06	152 49.07	112	SS NS transect of Pacific Palms
18	relic	32 21.75	152 48.53	112	SS NS transect of Pacific Palms
19	relic	32 25.94	152 46.08	103	SS NS transect of Pacific Palms
20	relic	32 26.66	152 46.77	113	SS NS transect of Pacific Palms
21	relic	32 27.32	152 47.17	119	SS NS transect of Pacific Palms
22	relic	32 27.78	152 46.47	114	SS NS transect of Pacific Palms
23	relic	32 31.81	152 40.41	113	SS NS transect of Pacific Palms
24	relic	32 32.41	152 39.33	114	SS NS transect of Pacific Palms
25	relic	32 32.37	152 39.66	113	SS NS transect of Pacific Palms
26	relic	32 32.03	152 40.12	113	SS NS transect of Pacific Palms
27	relic	32 42.63	152 42.43	157	SS NS transect of Pacific Palms
28	relic	32 39.21	152 39.16	134	SS NS transect of Pacific Palms
29	reef area	32 38.40	152 37.44	122	SS NS transect of Pacific Palms
30	reef area	32 38.22	152 36.91	122	SS NS transect of Pacific Palms
31	reef area	32 37.63	152 35.77	118	SS NS transect of Pacific Palms
32	reef area	32 37.56	152 35.41	122	SS NS transect of Pacific Palms
33	reef area	32 37.25	152 34.77	121	SS NS transect of Pacific Palms
34	reef area	32 36.92	152 34.03	119	SS NS transect of Pacific Palms
35	reef area	32 36.74	152 33.56	114	SS NS transect of Pacific Palms
36	reef area	32 36.66	152 33.15	115	SS NS transect of Pacific Palms
37	inshore reef area	32 35.09	152 29.28	96	SS NS transect of Pacific Palms
38	inshore reef area	32 34.74	152 28.71	91	SS NS transect of Pacific Palms
39	inshore reef area	32 34.38	152 27.57	86	SS NS transect of Pacific Palms
40	inshore reef area	32 34.94	152 27.25	86	SS NS transect of Pacific Palms
41	inshore reef area	32 35.74	152 27.72	94	SS NS transect of Pacific Palms
42	inshore reef area	32 35.84	152 27.66	94	SS NS transect of Pacific Palms
43	inshore reef area	32 36.42	152 27.81	97	SS NS transect of Pacific Palms

Table 1 Target sites of possible shelf rocky reef identified from existing data (cont.)

<i>Number</i>	<i>Feature description/location</i>	<i>Latitude S</i>	<i>Longitude E</i>	<i>Depth</i>	<i>Comments</i>
44	relic	32 38.19	152 29.04	112	SS NS transect of Pacific Palms
45	relic	32 39.02	152 39.21	111	SS NS transect of Pacific Palms
46	relic	32 39.68	152 29.75	113	SS NS transect of Pacific Palms
47	relic	32 40.86	152 29.98	114	SS NS transect of Pacific Palms
48	relic	32 42.58	152 31.16	126	SS NS transect of Pacific Palms
49	relic	32 43.33	152 30.76	128	SS NS transect of Pacific Palms
50	deep relic	32 55.39	152 30.39	140	SS NS transect of Pacific Palms
51	deep relic	32 57.04	152 29.75	146	SS NS transect of Pacific Palms
52	deep relic	32 58.54	152 29.30	150	SS NS transect of Pacific Palms
53	deep relic	32 56.77	152 30.97	148	SS NS transect of Pacific Palms
54	reef patch	32 55.03	152 7.24	124	SS NS transect of Pacific Palms
55	south relic	32 56.54	151 58.42	90	SS NS transect of Pacific Palms
56	reef	32 42.61	152 17.61	92	OEH Offshore2011
57	reef	32 41.98	152 18.38	87	OEH Offshore 2011 East extent of reef
58	reef	32 41.99	152 18.38	86	OEH Offshore 2011 East extent of reef
59	reef	32 40.73	152 20.32	89	OEH Broughton 2011 S extent of reef
60	reef	32 40.30	152 21.74	92	OEH Broughton 2011 S extent of reef
61	reef	32 37.77	152 23.78	86	OEH Broughton 2011 E extent of reef
62	reef	32 39.94	152 22.81	99	OEH Broughton 2011 SE extent of reef
63	reef	32 38.64	152 23.55	94	OEH Broughton 2011 E extent of reef
64	reef	32 31.42	152 33.10	94	S extent of Seal Rocks 2011 coverage
65	depth	32 30.70	152 31.42	67	67 m water depth on SW area of SR coverage
66	depth	32 37.51	152 22.36	67	67 m water depth on NE area of Broughton coverage
67	contour	32 39.86	152 24.15	100	contour feature
68	contour	32 37.55	152 27.09	100	contour feature
69	contour	32 34.67	152 31.00	100	contour feature
70	contour	32 23.49	152 41.09	100	contour feature

4. DISCUSSION

A targeted acoustic survey has identified a region of patchy outcropping reefs within the Hunter CMR in water depths of 75 to 120 m. While the outcrops are not extensive, the mapping indicates that reef systems are present within the CMR, and that they are likely to be patchily distributed and therefore more difficult to identify and quantify without a more comprehensive mapping program. The acoustic imagery suggests that the reefs within the Hunter CMR may have geomorphological similarities to the deep reefs within the adjacent state waters of the Port Stephens-Great Lakes Marine Park (PSGLMP) (Figure 13). The linear elongation of the reefs running in a north-west to south-east direction suggests that they may extend further to the north and south of the survey area. Further surveys are required to determine the extent that the reef patches have continuity throughout the CMR, and link with reef features identified regionally, particularly in adjacent sanctuary zones within the PSGLMP, and which may provide connectivity between shallow and deep reefs.

In particular, the Broughton Island area contains extensive areas of rocky reefs that extend from the shoreline to at least the limit of state waters in depths of around 50 m (Jordan et al. 2010). Further surveys are required to determine the full extent and connectivity of deep reefs in this area of the PSGLMP and those in the Hunter CMR. The shallow areas of these rocky reefs are dominated by macroalgal habitats and urchin barrens in depths <30 m, whereas the reefs in deeper depths are dominated by sessile invertebrates (Jordan et al. 2010).

In addition, both Broughton and Seal Rocks are identified grey nurse shark aggregation sites (Otway et al. 2003, 2009). In addition, a nearby beach at Hawks Nest has been identified as an important nursery area for juvenile white sharks (Bruce and Bradford 2008). Satellite tagging of white sharks has found that they frequently visit areas up to 120 m depth in this region of the coast (Bruce et al. 2013).

The reefs located in this survey within the Hunter CMR could therefore represent important habitats for these threatened and protected species, as well as a migration pathway. Management within the Hunter CMR and, possibly a co-management strategy with the adjoining PSGLMP could provide for enhanced protection of these species. The recent review of Commonwealth Marine Reserves (Buxton and Cochrane, 2016) suggested that the feasibility of providing additional protection for continental shelf waters could warrant further investigation in this region where suitable habitat exists. The results of this survey suggest that suitable habitat does exist, and that surveys of adjacent reefs indicate that they are likely to contain a high diversity of associated biota.

Further research is therefore recommended to more fully understand the significance of the shelf rocky reefs in the Hunter CMR. Such work should fully explore whether management arrangements (including co-management with NSW MPAs) could be developed which will maximise protection of key species within the Hunter CMR shelf area. Further seafloor mapping could establish the extent of these reefs and the degree of connectivity with sanctuary zones in the PSGLMP. Biological surveys using video and baited underwater video as well as placement of acoustic listening stations on these reef systems could be used to reveal more information on the ecological significance of these features for threatened and protected species, and for other mobile and sessile flora and fauna.

The existence of similar habitats within the sanctuary zones in state waters may also provide opportunities for monitoring the effectiveness of different management interventions within protected areas. Rocky reef fish assemblages within these areas are regularly surveyed

using Baited Remote Underwater Video, and underwater imagery of benthic assemblages is collected using both towed video and the Integrated Marine Observing System (IMOS) AUV system. Both of these datasets could be expanded offshore to improve our understanding of the KEF features in the Hunter CMR, and evaluate regional changes associated with marine reserve management arrangements.

5. CONCLUSIONS

Outcrops of Shelf Rocky Reef Key Ecological Features were discovered within the Hunter CMR, and may represent components of a relict coastal feature. As this survey mapped a small area of these reef patches, and no rock samples were taken, it is not possible to determine the geological provenance of these outcrops without further investigations. From examination of historical and new mapping, the data suggests that similar reef patches may extent throughout the Hunter CMR shelf, and that they may be connected to relict coastal reef features mapped in adjacent NSW state coastal waters at similar depths (70-120 m). Further work is needed to assess the extent of these reefs and also to assess the ecological significance of these systems, but it is possible that these reefs are important habitats for grey nurse sharks and possibly white sharks which are known to aggregate at locations nearby.

The existence of similar habitats types in adjacent PSGLMP sanctuary zones may provide opportunities for monitoring the effectiveness of different management interventions within protected areas.

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APPENDIX A – Report by Claire Raphael et al. (2016)

Appendix A-

Mapping Rocky Reefs Using Multibeam Bathymetry

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19 February 2015

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Raphael CE (2015) Mapping Rocky Reefs using multibeam bathymetry

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Executive summary

This study detailed the extent and distribution of rocky reef on the continental shelf in the Hunter Commonwealth Marine Reserve. This involved collating multibeam, geoswath and S-57 data in CARIS HIPS and SIPS 9.0, where processing and bathymetric cleaning was undertaken. Bathymetric highs were indicative of potential reef features, which was determined visually and manually in CARIS. Backscatter mosaics were generated in FMGeocoder Toolbox to increase the confidence when identifying features and for further analysis in ArcMap. Using the broadscale bathymetry of the region (10m resolution), eight bathymetric derivatives were computed in ArcMap for further classification of the seafloor: slope, ruggedness (VRM), Northness, Eastness, standard deviation, curvature, planar curvature and profile curvature. This study reveals the diverse range of physical characteristics that rocky reef encompass within the Hunter Commonwealth Marine Reserve. Reefs vary in terms of size, shape, extent of patchiness, depth, elevation, orientation, slope, terrain complexity, backscatter intensity and distance from shore.

The mapping achieved in this project has improved current knowledge about the distribution, extent and structure of rocky reef habitats on the continental shelf in the Hunter Commonwealth Marine Reserve. This study has identified gaps in data coverage that need filling before the map could be used as a reliable management tool but is the first step towards improving the knowledge required for sustainable resource management. In the context of marine parks it is particularly useful step towards ensuring that the zones contain a comprehensive and representative selection of biodiversity.

Part 1 Introduction

Introduction

Rocky reefs are important ecosystems that support both sessile and mobile marine flora and fauna (Witman and Dayton, 2001). These systems house a range of sessile reef biota including filter feeders, primary producers and ecosystem engineers which perform a number of essential ecosystem functions including maintaining water quality and providing food, habitat and structure. Rocky reefs are of greater recreational and commercial importance relative to soft sediment communities, often containing high densities of large-bodied fishes and mobile invertebrates (Cowles, HeWitt and Taylor, 2009). Despite their ecological and commercial importance, our knowledge of their extent, geographical range and ecological functioning is limited. This, coupled with the fishing, pollution and climate change pressures acting on them, significantly hinders the application of effective management approaches (Evans et al, 2002). This lack of knowledge of marine biodiversity has been globally recognized and has driven a shift from the conservation of species to the conservation of spaces (Roff & Evans 2002). It is estimated that only 5-10% of the seafloor is mapped with a resolution of similar studies on land (Wright and Heyman, 2008). Reliable benthic habitat maps at local to regional scales and an understanding of the biological and physical processes structuring these systems are required to manage these resources effectively (Huang, Brooke and Harris, 2011)

A common approach to mapping benthic habitats is to employ acoustic data (Lucieer et al., 2013; Iampietro et al., 2008; Kostylev et al., 2001). Only recently, advancements in acoustic surveying techniques have enabled wide-scale surveying and production of accurate, aerial-like imagery of the seafloor. These improvements, coupled with equally large improvements in Geographic Information Systems and computing power have allowed the production of comprehensive habitat maps. Multibeam Echo Sounders (MBES) are particularly useful, due to their ability to simultaneously generate high-resolution bathymetry and backscatter imagery over a swath of the seafloor (Michaels, 2007). MBES operate by emitting sound waves in a fan shape from underneath the ship's hull. The depth to the seafloor (bathymetry) is calculated from the time a sound wave takes to travel to the seafloor and back up to the receiver (two-way time). Benthic species tend to exhibit preferences for topographic conditions and certain depths, and therefore bathymetry can be employed to divide the seafloor into areas that reflect particular biological characteristics (Kostylev et al., 2001).

A number of secondary-derived bathymetric layers such as slope, orientation, curvature and terrain variability are often used to help further segment the seafloor into distinct habitats. This method combats the lack of biological data coverage, which is expensive and labour intensive to collect. These variables are commonly employed to represent variation on the seabed and to infer the resulting biological distributions (Calvert et al. 2015; Hill et al., 2014; Iampietro, 2008).

Backscatter imagery has recently been recognised as an important tool for classifying marine habitats. MBES measure backscatter as the amount of acoustic energy received by the sonar system after a complex interaction with the seafloor (NOAA, 2011). Backscatter return reveals important information about the seafloor substrate (Lucieer et al., 2013). Harder bottom types such as rock tend to return a much higher backscatter return than softer bottom types. This is useful for mapping rocky reef, which, in most cases, will have a higher backscatter return than the soft sandy sediment that typically surrounds them. In this way, backscatter increases confidence when classifying seafloor features as rocky reef. However, in situ sampling is needed to verify interpretations based on backscatter intensities alone.

This study aims to detail the distribution and extent of rocky reef on the continental shelf of the Hunter Commonwealth Marine Reserve. Bathymetric data was collated and manually processed to identify potential rocky reef. Bathymetric derivatives and backscatter mosaics were generated to further characterise rocky reef habitat with the aim of producing a comprehensive map of the distribution of rocky reefs within the area.

Part 2 Data acquisition and methods

1 Available Australian reef data sets

Introduction

Data was obtained from a number of sources for this study. The dominant data source was multi-beam bathymetry and backscatter imagery acquired through ten years-worth of voyages on board CSIRO's RV Southern Surveyor. Additional Geoswath interferometric data was acquired from the NSW Department of Environment and Heritage specific to the Hunter Commonwealth Marine Reserve. Vector reef data sets, courtesy of the Australian Hydrographic Office were also employed in this study.

1.1 CSIRO data holdings

This project incorporates bathymetric and backscatter data acquired from the EM 300 multibeam system on board the RV Southern Surveyor. The RV Southern Surveyor was Australia's previous Marine National Facility research vessel, operated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). In 2003, the vessel was fitted with a gondola-mounted Kongsberg EM 300 multibeam echosounder. Positioning and motion correction was achieved with a Seapath 320 and Kongsberg MRU. Table 1 provides the specifications of this sonar system. Data was sourced from multiple voyages spanning a ten-year period between 2003 and 2013. Data acquired for this project was in both raw (.all) and processed formats. Raw data was processed prior to interpretation. A list of all the voyages collated and employed in this study is presented in Appendix A.

Table 1 EM 300 Multibeam echosounder sonar specifications

SONAR SYSTEM	DEPTH RANGE	FREQUENCY (KHZ)	PULSE LENGTH (MS)	SOUNDING MODE	BEAM WIDTH (TX,RX,°)
EM 300	10m - 5000m	30-34	0.7 – 15	0-2 (very shallow-medium)	1x1, 1x2, 2x2, 2x4

1.2 State-based data holdings

Additional data was sourced for the Hunter Commonwealth Marine Reserve courtesy of the NSW Department of Environment and Heritage (DEH). Sonar data was acquired using a pole mounted Geoswath 125kHz interferometric swath system (2003) on board the RV Bombora. The interferometric swath-mapping system collects georeferenced depth and sidescan backscatter data from swath widths up to eight times the water depth from which high-resolution bathymetric and backscatter data is generated. The data was pre-processed by the DEH as follows. Motion correction was achieved using a POS MV Wavemaster system. Real time position was provided as DGPS using a Trimble dual antenna. To improve motion solution for the sounding data, 9-day

ephemeris data was employed and processed using Precise Point Positioning in POSPac. Improvements to the X, Y and Z component accuracies were obtained and used to provide an alternate Smoother Best Estimate of Trajectory (SBET). The SBETs were applied to the Geoswath data followed by rough processing using amplitude, box, across-track and along-track filters before being exported to GSF format.

1.3 Australian Hydrographic Office (AHO) S-57 Data

S-57 data obtained from the Australian Hydrographic Organisation (AHO) was also employed in this study. The Australian Hydrographic Service (AHS) is Australia's Commonwealth Government agency responsible for the creation and publication of nautical charts and other information required for safe maritime navigation in Australian waters. Through the UN Safety of Life at Sea (SOLAS) navigation act, the AHS is obliged to enable safe navigation, support national infrastructure and maritime trade and support the protection of the marine environment. Surveying and consequent mapping is achieved using specialised ships and boats operating echo sounders and sounders, satellite observations and LIDAR operating survey aircrafts. Nautical charts are available in electronic chart format. The International Hydrographic Office (IHO) developed a standard format to be used for national electronic navigational charts (ENC). The chart must conform to IHO's Publication S-57 before it can be certified as an ENC. S-57 vector data has multiple layers and each layer contains several layers of information. The reefs identified in the Hunter Commonwealth Marine Reserve study site by the AHS were extracted and used in this study.

2 Study sites

2.1 Selection of the study site

The study site was selected due to economic interest and the likelihood of rocky reef presence with potential pollution, fishing or climate pressures. The sites also required sufficient data coverage for effective characterisation of the seafloor. Reef was mapped at depths less than 200m with deeper reefs ignored for the purpose of this study.

2.1.1 Hunter Commonwealth Marine Reserve

The Hunter Commonwealth Marine Reserve (CMR) is located between 5 -10 kilometres off the coast of New South Wales. The CMR covers an area of 6257km² and has depths ranging from 15 – 6000 meters. The reserve is managed for the primary purpose of conserving the biodiversity within it. Specifically, the Hunter CMR provides an important habitat for a population of critically endangered grey nurse sharks, migratory humpback whales and great white sharks. It also includes a key ecological feature of particular interest to this study, rocky reef. As seen below in figure 1, large amounts of seafloor were surveyed outside of the reserve boundary. Reef outside the CMR was also included in this study.

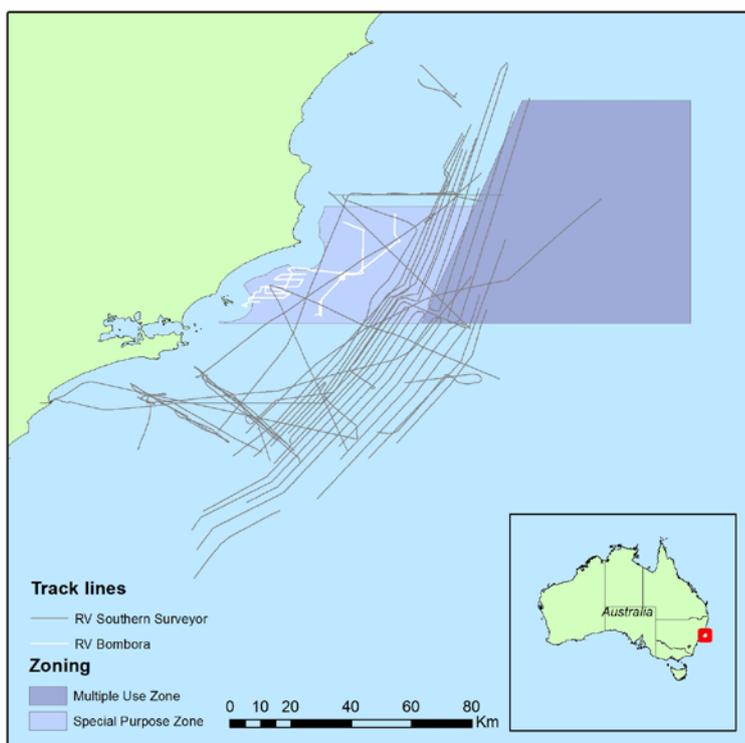


Figure 1 Overview of the Hunter Commonwealth Marine Reserve. The dark and light purple boxes represent the multiple use and special purpose zones within the Hunter Commonwealth Marine Reserve. The grey lines represent RV Southern Surveyor track lines and the white lines represent the RV Bombard track lines

3 Data processing

Introduction

Data was processed using CARIS HIPS and SIPS 9.0 software. The HIPS and SIPS product is a hydrographic data processing system capable of integrating bathymetry, seafloor imagery and water column data. For this study, the software was primarily used for bathymetric cleaning, backscatter generation and 3D visualisation. The workflow for processing data in CARIS is presented below in Figure 2. Backscatter was processed in FMGeocoder Toolbox, part of the Fledermaus suite of software, independent of CARIS.

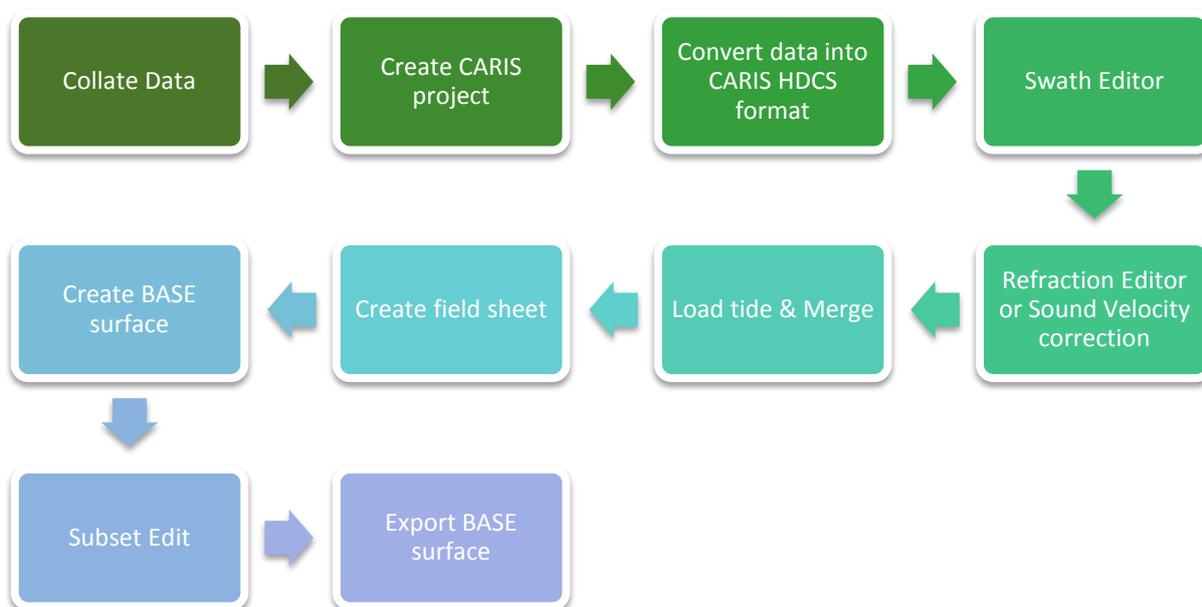


Figure 2 Workflow for processing data in CARIS HIPS and SIPS

3.1 Creation of CARIS project

A project was created in CARIS HIPS and SIPS named “Hunter CMR” for the Hunter Commonwealth Marine Reserve.

3.2 Processing and visualising bathymetry in CARIS HIPS and SIPS

3.2.1 Data conversion

Fully processed CARIS formatted HDCS data was added to the CARIS directory when available. When processed data was not available for certain voyages, raw data (Simrad. all) and processed GSF data were converted into the CARIS HDCS format using the CARIS conversion wizard.

3.2.2 Sound velocity correction

Inaccurate sound velocity profiles for the water column will produce significant vertical errors in the outer beams of the resulting bathymetry. Sound velocity profiles are usually applied to the data during data acquisition to reduce this effect. However, some older RV Southern Surveyor data was acquired without sound velocity control and consequently lines displayed significant sound velocity errors. Two methods were employed to correct these errors: the creation of sound velocity profiles or by employing the CARIS HIPS and SIPS Refraction Editor. A sound velocity profile was created for three voyages listed below in Table 2. The means of creating each profile is presented in Appendix B. The sound velocity profiles were applied to the lines in that voyage using the Sound Velocity Correction tool in CARIS HIPS and SIPS.

Table 2 Sound velocity corrections

VOYAGE	LINE NUMBERS	SOUND VELOCITY PROFILE
SS2009_v05	294-299	ss2009_v05_CTD24_profile.svp
SS200812	310	svp_clim_ss2008_v12.svp
SS2010_v08	0135	ss2010_v08_CTD33_profile.svp

Sound velocity errors were also corrected line-by-line using the Refraction editor. Through trial and error, depth and velocity values were chosen that best flattened the outer beams of the bathymetry without distorting the central bathymetry. Figure 3 displays an example of bathymetry with a sound velocity error and the same bathymetry after a sound velocity correction using CARIS Refraction Editor. The exact corrections applied using this method are also presented in Appendix B

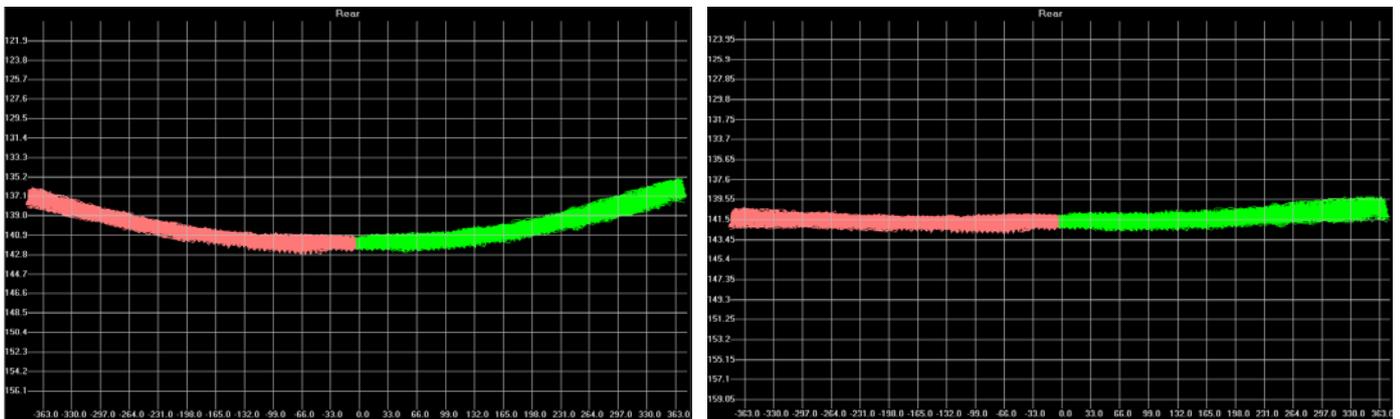


Figure 3 a) Cross section of bathymetry with a sound velocity error b) Bathymetry after a sound velocity profile had been created using CARIS Refraction Editor. Red represents port pings and green displays starboard pings.

3.2.3 Tide correction

Tide corrections were not applied to the data.

3.2.4 Data cleaning

All raw data was cleaned to remove any outliers, artefacts or noise. Firstly, using the CARIS HIPS and SIPS Swath editor, each line was examined individually as a time series and spikes removed as necessary. Secondly, multiple lines were edited simultaneously using the CARIS HIPS and SIPS Subset editor. The data was cleaned and corrected to produce bathymetry that most realistically represented the seafloor.

3.2.5 Field sheet creation

Small field sheets were created to cover the bathymetry of the Hunter CMR to optimise processing time. The study site had even smaller, higher resolution field sheets created over potential reef structures for later exportation. Field sheets were numbered sequentially. Figure 4 displays a map of the field sheets created within the Hunter CMR study site. One large field sheet covering the entire Hunter CMR study site was also generated to display the broad scale bathymetry of the region.

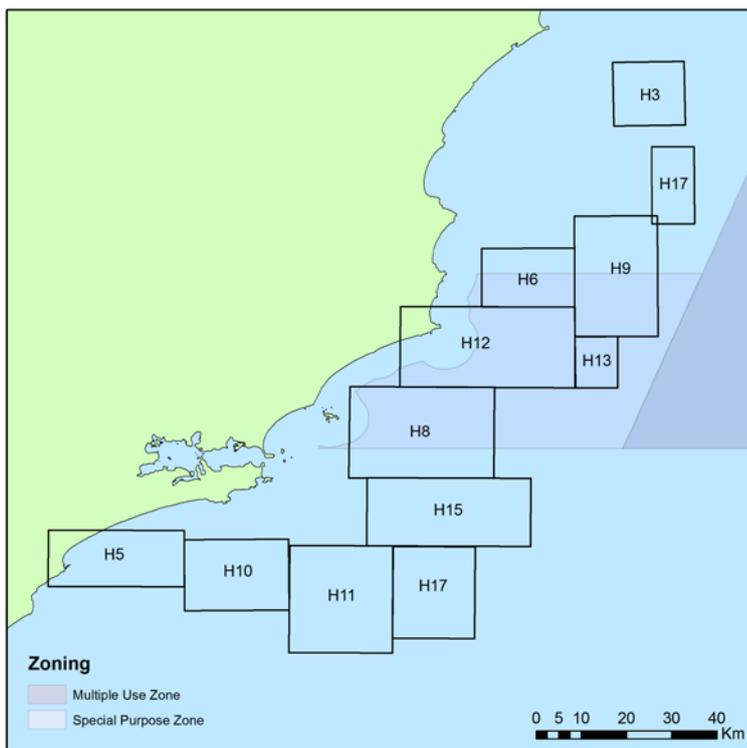


Figure 4 Map displaying the location and names of the field sheets created for the Hunter CMR region.

3.2.6 Base surface creation

A swath-angle weighted grid BASE surface was created for each field sheet. In the Hunter CMR study site, the large BASE surfaces were all gridded at a 10m resolution. Smaller base surfaces covering potential reef structures were gridded at resolutions dependent on the size of the structure. The field sheet encompassing the whole study site displaying the broad scale bathymetry of the region was gridded at a 30m resolution. Each base surface name included the

algorithm used to generate it and its resolution. For example “SA_20m” indicates the BASE surface was gridded using the swath angle algorithm at a resolution of 20 metres. Swath angle BASE surface is a rasterization method specifically designed for multibeam data. It is used in representing multibeam data as it considers the geometry of the sonar system. The swath angle BASE surface takes into account the variable radius of influence, range weighting and grazing angle weighting. This BASE surface can produce numerous layers, but for this study, depth was the only layer generated.

3.2.7 Data rejection

Some lines were removed from the CARIS HIPS and SIPS project. These lines were poor quality and hindered the bathymetry of other intersecting lines. See Appendix B for the list of lines rejected in this study.

3.3 Processing and visualising backscatter

Both CARIS HIPS and SIPS 9.0 and Fledermaus were trialed in generating backscatter imagery. Both processing systems produced good backscatter images but Fledermaus FMGeocoder Toolbox was used as it optimised processing time. The methods for processing the backscatter for each programme are presented below.

3.3.1 GeoBaR creation in CARIS HIPS and SIPS

CARIS HIPS and SIPS Mosaic editor was employed to generate GeoBaRs (Georeferenced Backscatter Rasters) for all the lines in each study site. The Geocoder engine was used to create a backscatter time series of each line. Specific corrections were applied to correct for the strong effect of nadir and artefacts and to ultimately produce a smooth and continuous surface with distinguishable features. By applying a trial and error approach; the following corrections were applied: Auto Gain, Auto TVG correction, Anti-Aliasing, no beam pattern correction, AVG Trend, AVG window size of 100, and no despeckle. Details of these corrections are presented in Appendix C Optimal backscatter corrections in CARIS HIPS and SIPS. The GeoBaRs were gridded to produce a backscatter mosaic using the CARIS HIPS and SIPS Mosaic editor with the Geocoder processing engine. Through applying a trial and error approach, the optimal setting for gridding the surfaces was achieved through applying the full blend setting at a resolution of 1m.

3.3.2 Mosaic creation in FMGeocoder Toolbox

FMGeocoder Toolbox is a component of Fledermaus, a suite of software that provides a powerful set of 3D visualisation tools for bathymetric data. FMGeocoder Toolbox, like CARIS, uses the Geocoder engine to generate corrected backscatter mosaics. Unlike CARIS, this software automatically merges lines into backscatter mosaics. A project for each field sheet in CARIS HIPS and SIPS was created in FMGeocoder Toolbox and the corresponding lines added to the projects. A mosaic was generated for each field sheet, all of which were gridded at 10 meters resolution. The default settings which were applied to the data which were as follows: a flat AVG algorithm with a window size of 300, the Tx/Rx Power gain correction, beam pattern correction, blend mosaicking

style and a dB mean filter. Each mosaic computed was adjusted manually using the Histogram tool to produce backscatter that showed a contrast between hard and soft sediments. The FMGeocoder Toolbox was not compatible with the GSF data from the Hunter CMR region so this data was not used in generating backscatter mosaics.

3.4 Data Exportation

All the bathymetry BASE surfaces were exported from CARIS using the “Export into ESRI grid” function and named according to their field sheet name. The BASE surfaces were all exported with a decimal precision for elevation value of three and the attribute exported was always depth. The backscatter mosaics generated in FMGeocoder Toolbox were exported as “Floating Point GeoTIFF Grids”.

4 Data Visualisation

Introduction

Data visualisation was performed using ArcGIS software. ArcGIS is a Geographic Information System capable of storing, managing, manipulating, analysing and presenting geospatial data. For this study ArcMap 10.0 and ArcCatalog 10.0 were employed. ArcMap was employed to draw reef polygons, generate bathymetric derivatives and to present and format maps. ArcCatalog was used to create new shapefiles needed for mapping purposes.

4.1 Rocky reef distribution map

Potential reef features were determined visually based on their bathymetry. Any feature of any size that showed relief above the seafloor was treated as a potential feature. When editing in CARIS HIPS and SIPS Swath and Subset Editor, the lines were analysed to ensure that potential reef features were not artefacts or noise. GeoBaRs were also generated in CARIS to validate to the presence of reef. An example of the type of features considered potential rocky reef are presented in Figure 5. The reef field sheets from CARIS were then added to ArcMap. A shapefile was created in ArcCatalog and using the ArcMap Editor, polygons were manually drawn on top of all potential reef features.

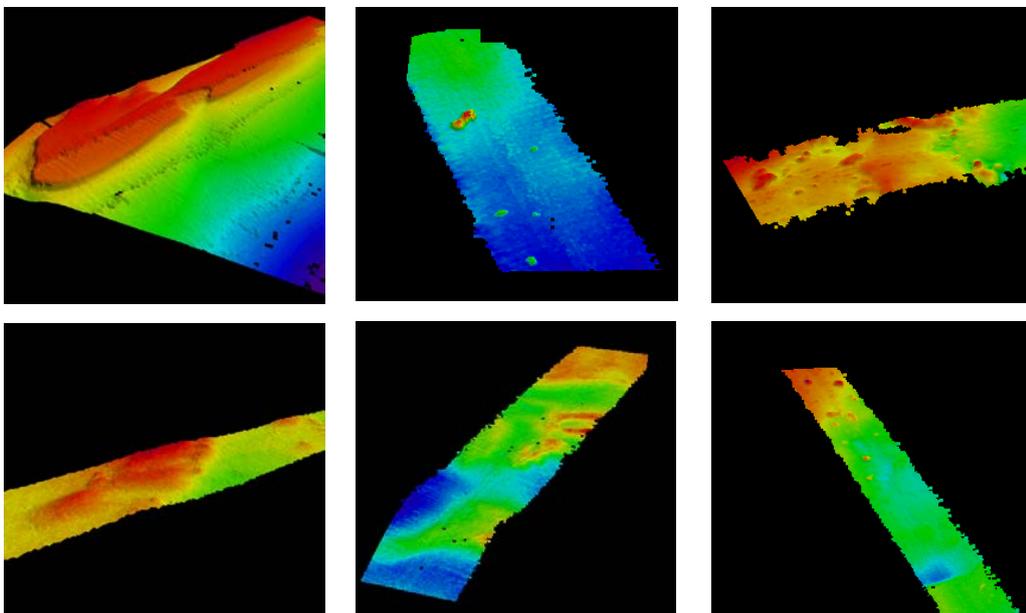


Figure 5 Examples of bathymetry with potential reef features. Scale is relative in each image, with red representing low depths and dark blue representing high depths.

4.2 Bathymetric derivatives

For this study, eight bathymetric derivatives were generated using tools readily available in ArcGIS v10.0 (ESRI 2012) to characterise seafloor topography: slope, Northness, Eastness, vector rugosity measure (VRM), standard deviation, curvature, plan curvature and profile curvature. Each of the bathymetric derivatives is listed in Table 3 with a description of the variable, what the variable represents and the software employed to generate it. To overcome issues in analysing radial data to represent aspect (e.g. $360^\circ = 0^\circ$), the aspect layer was split into “Northness” and “Eastness” where 1 represents perfect North and -1 represents South, or East and West, respectively. A map including each bathymetric derivative was produced and formatted in ArcMap.

Table 3 Bathymetric derivative descriptions

DERIVATIVE	VARIABLE DESCRIPTION	REPRESENTS	SOFTWARE/TOOLS
Bathymetry	Depth (negative elevation) of the grid cell. Bathymetric product converted to ESRI ASCII grid with 10m resolution	Light availability, temperature, exposure	CARIS HIPS and SIPS
Slope	Slope denotes the maximum change in depth between each cell and the cells in an analysis neighbourhood. Calculated in degrees from the horizontal	Likelihood of sediment accretion, Water flow	Spatial Analyst ArcGIS 10.0
Northness (aspect)	Deviation of aspect from 0 degrees	The impact of wave action and local/regional currents	Spatial Analyst ArcGIS 10.0
Eastness (aspect)	Deviation of aspect from 90 degrees	The impact of wave action and local/regional currents	Spatial Analyst ArcGIS 10.0
Rugosity (VRM)	Ratio of the surface area to the planar area across the neighbourhood of the central pixel	Habitat complexity	Benthic Terrain Modeller Tool for ArcGIS
Standard Deviation	The variation of cell values from the mean value	Variability	ArcGIS 10.0
Curvature	Maximum rate of change in the seabed slope Secondary variable derived from aspect	Water flow	Spatial Analyst ArcGIS 10.0
Plan Curvature	Rate of change perpendicular to the slope direction	Defining ridges, valleys and slopes, Water flow	Spatial Analyst ArcGIS 10.0
Profile Curvature	Rate of change in the direction of the slope of the seabed	Highlights convex/concave shapes, Water flow	Spatial Analyst ArcGIS 10.0

4.3 Backscatter map

The backscatter mosaics were added to ArcMap and were manually adjusted to ensure all mosaics represented the same range of backscatter intensities (10 – (-) 70dB). The backscatter mosaics were mapped with the reef polygons identified to enable comparison between the bathymetry and backscatter imagery. A map was also generated to display the backscatter associated with the reef polygons alone using the “Extract by mask” tool in the Spatial Analyst toolbox.

4.4 Zonal statistics

Two sets of statistics for the reef polygons were generated for each bathymetric derivative. One set computed statistics on the reef in each field sheet (e.g. the median value associated with reef polygons in the H3 field sheet), the other produced statistics for every reef polygon. The first approach was achieved by converting the derivative rasters to points using the ArcGIS conversion toolbox. These points were then clipped to the reef polygons and using the “Extract multivalued to point” tool, a value was computed for each point. This was done for each derivative. The resulting tables were exported as .csv files and were collated in Microsoft Excel where a variety of statistics were performed. The median values of each derivative are presented in Appendix E. The median statistic was chosen to best represent the data, as the mean value may contain outliers due to the noisy nature of acoustic data.

To compute statistics for each individual polygon, the “Zonal Statistics to Table” tool was employed. The statistics were automatically generated and included mean, minimum, maximum, count, range and area. These were calculated for each bathymetric derivative. The tables were exported as .csv text files and each derivative was collated in a Microsoft Excel spreadsheet. The Zonal statistics toolbox was unable to compute median values as the data was in a floating-point data format. Instead, the mean value was chosen to best represent the statistics. The resulting table is presented in appendix E.

These statistics were used to determine if there were any significant spatial relationships between variables. The slope and ruggedness statistics were plotted against latitude, longitude and depth but none yielded any significant relationships. The graphs are presented in appendix E to enable further analysis.

Part 3 Results

1 Results

1.1 Broad-scale bathymetry

The broad-scale bathymetry of the region is presented in Figure 6. In the map, the continental shelf (focus of this study) and the shelf break are very distinguishable. The width of the continental shelf, which is defined as the distance to the shelf break (this being characterised by a rapid change in the slope of the seabed) is subject to variation within the site, as is the depth at which the shelf breaks (Bates and Jackson, 1987). Due to the large contrast between the very deep (+4000m) seafloor and the relatively shallow continental shelf, bathymetry on the shelf is displayed very homogenously.

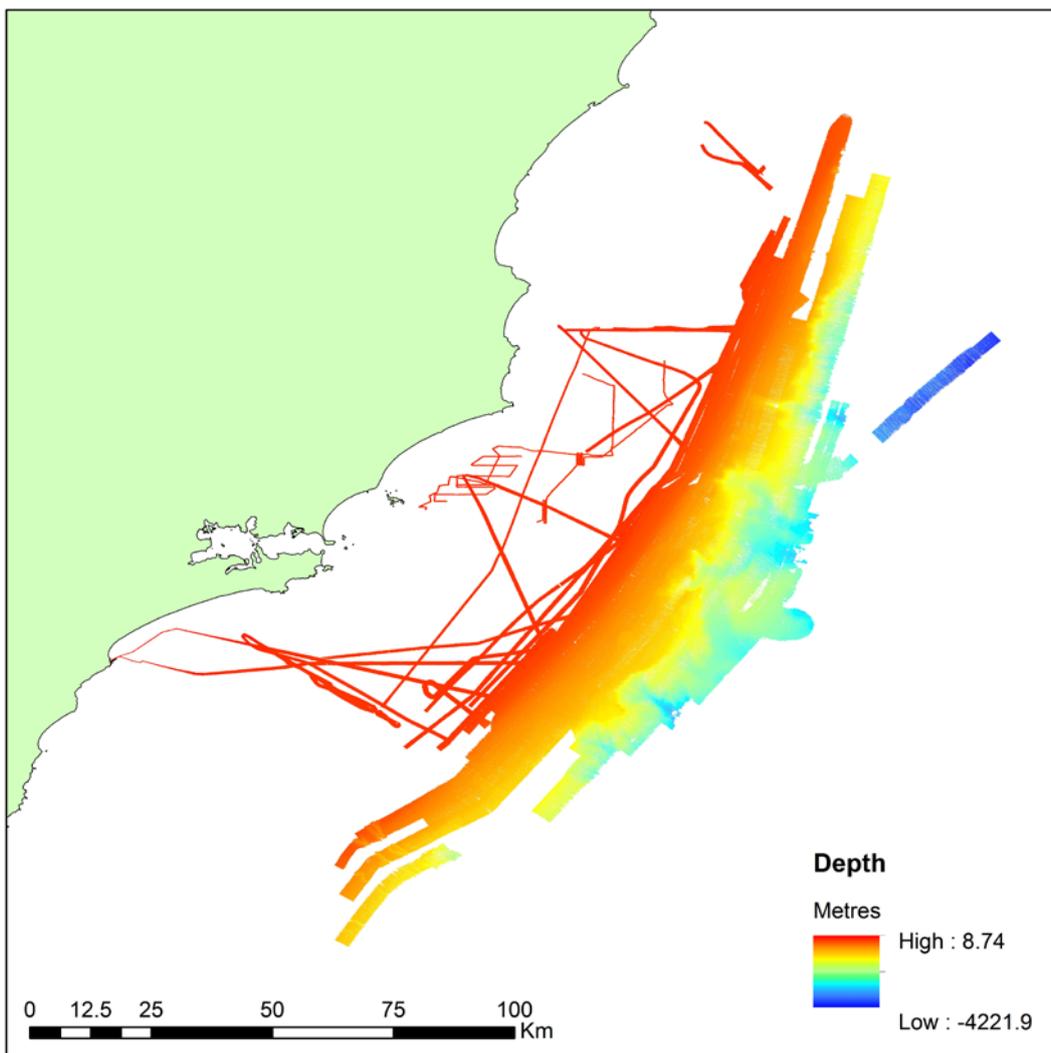


Figure 6 Broad-scale bathymetry of the Hunter Commonwealth Marine Reserve study site. The distance to and depth of the shelf break is subject to regional variation.

1.2 Rocky Reef distribution

95 new reef features were identified from the multibeam and geoswath imagery, which covered a total area of 44.1 km² within the Hunter Commonwealth Marine Reserve study site. A map of all the potential rocky reef features is presented in Figure 7. The map displays reef previously identified and mapped by the AHO (pink polygons) and reef identified in this study using sonar imagery (yellow polygons). Unfortunately there was no overlap between the S-57 reef and the reef identified in this study to enable a comparison of what constitutes reef in each study. A majority of the reef identified is located closer to the coast, with little reef found in the Multiple Use Zone of the marine reserve. This is because a majority of the Multiple Use zone is located off the continental shelf and covers areas deeper than reef tend to occur. The map and bathymetry associated with the features reveals that the reefs showed considerable variety in terms of geoform (platforms, mounds, pinnacles etc.), size, depth and patchiness. The smallest reef identified was 0.0001 km² and was approximately 11 meters in length. The largest feature found was 7.3 km² in size with a length of 6km. Close to the coast, there are a lot of smaller, interconnected reefs while further from the coast; isolated large reefs are more common. It is important to note, that a lot of the reef size and geometry imaged in the map is limited by the width and size of the survey lines, resulting in inaccurate representations of what some reef features may actually look like.

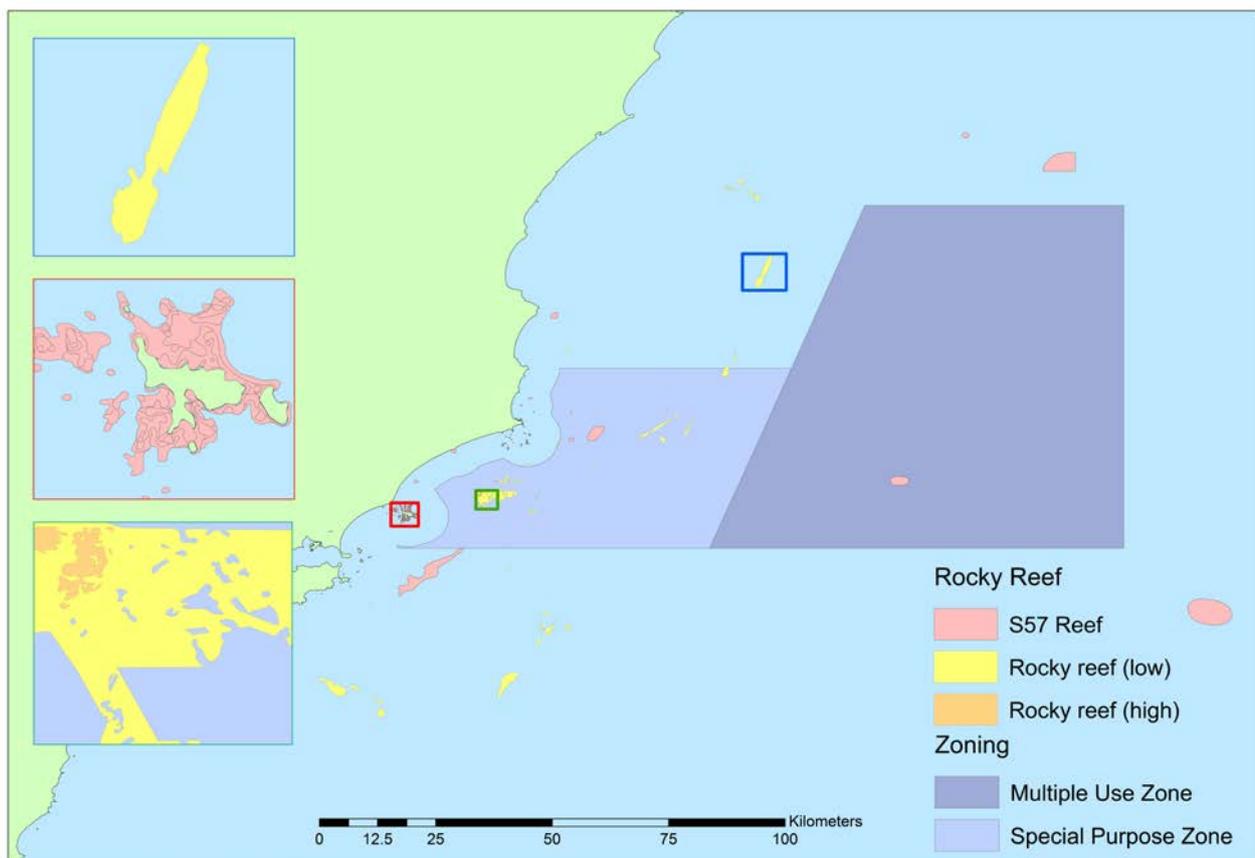


Figure 7 Map displaying the rocky reefs identified in the Hunter Commonwealth Marine Reserve. The yellow polygons represent potential rocky reef features found in this study. The pink polygons represent the rocky reef already mapped by the Australian Hydrographic Office. Shape and geometry of the reefs is varied throughout the

study site. Note that reef geometry is limited by the width and size of the survey lines resulting in inaccurate representations of reef features.

1.3 Backscatter

The backscatter mosaic for the Hunter CMR is presented in Figure 8. The contrast between hard and soft sediments (light and dark grey) is subtle due to the large range of backscatter intensities within the region. In most cases, the reef polygons drawn from the bathymetry match up with lower backscatter intensities, indicating they do correspond with a harder substrate. There are a lot of areas with low backscatter intensities that did not correspond with bathymetric highs from the bathymetry data. Some of these areas are located off the continental shelf (figure 8b and figure 8e) and therefore were not mapped. Due to the difficulty in producing backscatter mosaics from GSF data in FMGeocoder Toolbox, backscatter data is missing from figure 8d.

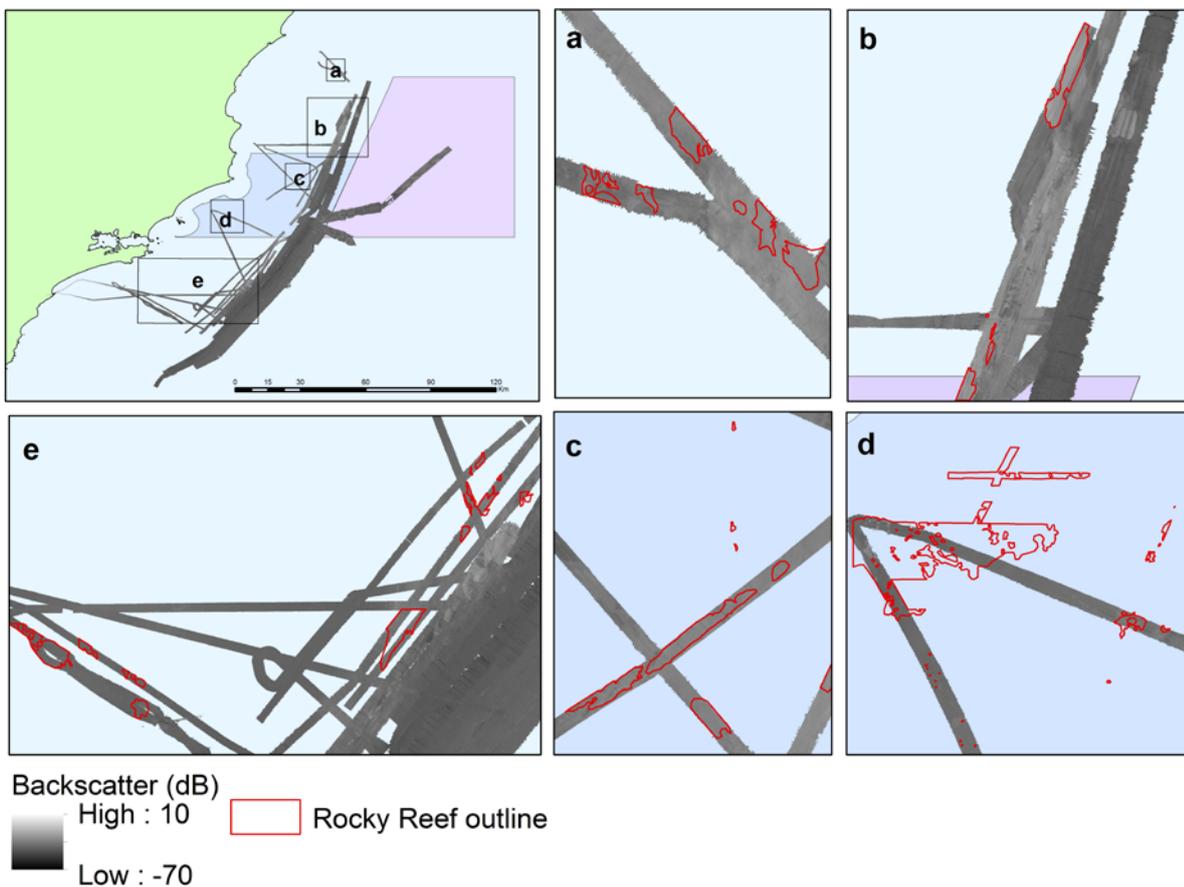


Figure 8 Backscatter intensity of the Hunter CMR. White colours indicate high backscatter intensity. Black represents low backscatter intensity. The red polygons represent the reef identified in this study. Reef polygons roughly match with higher backscatter returns however a lot of high backscatter intensity areas were not recognised as reef in the bathymetry data.

Figure 9 displays the backscatter associated with the reef identified in this study. The backscatter intensity ranges from -12dB to -54dB. A majority of the reef displayed has relatively high backscatter intensities, between -25dB and -12dB. The backscatter intensity is quite consistent within individual reef features, an exception being the reef imaged in figure 7d, where backscatter intensities vary within the reef polygon.

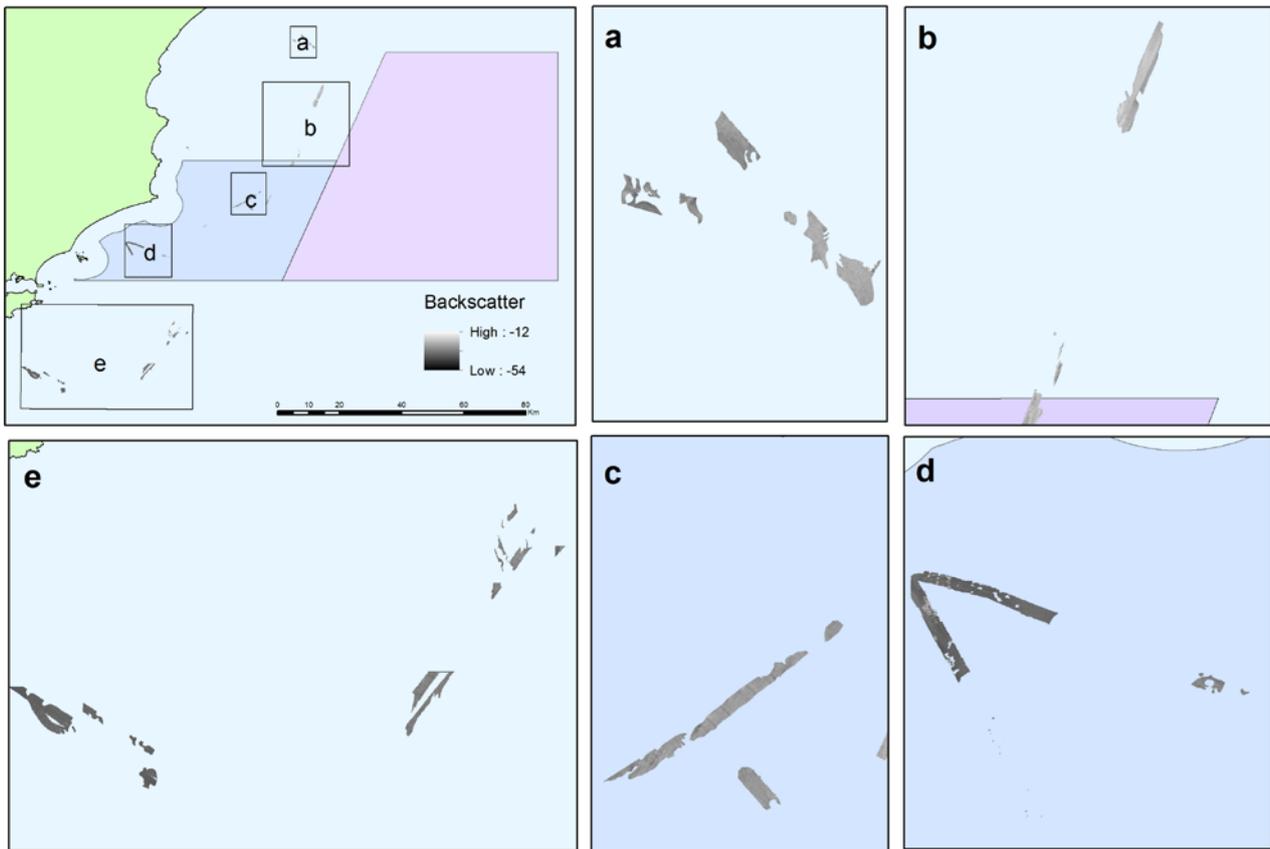


Figure 9 Backscatter intensity associated with the reef polygons. Back intensity within the reef polygons is usually quite consistent with the exception of the reef imaged in figure d.

1.4 Bathymetric derivatives

Figure 10 illustrates the slope of the shelf. As seen in Figure 10, a majority of the seafloor on the continental shelf is quite flat (light yellow colour). The shelf break is recognisable through the rapid change in the seabed slope (blue-dark purple colours). The distinct linear features running northeast off the continental shelf are bathymetric artefacts, not real geological features. On the shelf, reef features are distinguishable and are typically characterised by high slope values with even steeper sloping sides surrounded by relatively flat substrate. Figure 11 shows the slope (degrees) associated purely with the reef polygons found in this study. As seen in the map, there is a lot of variation of the slope of the reef polygons. Most reef is bound by very steeply sloping sides as shown in figure 11a, while other reef, as seen in figure 9e, has relatively low slope values. Other reef systems, such as the reef displayed in figure 11d, show both steep and flat slopes.

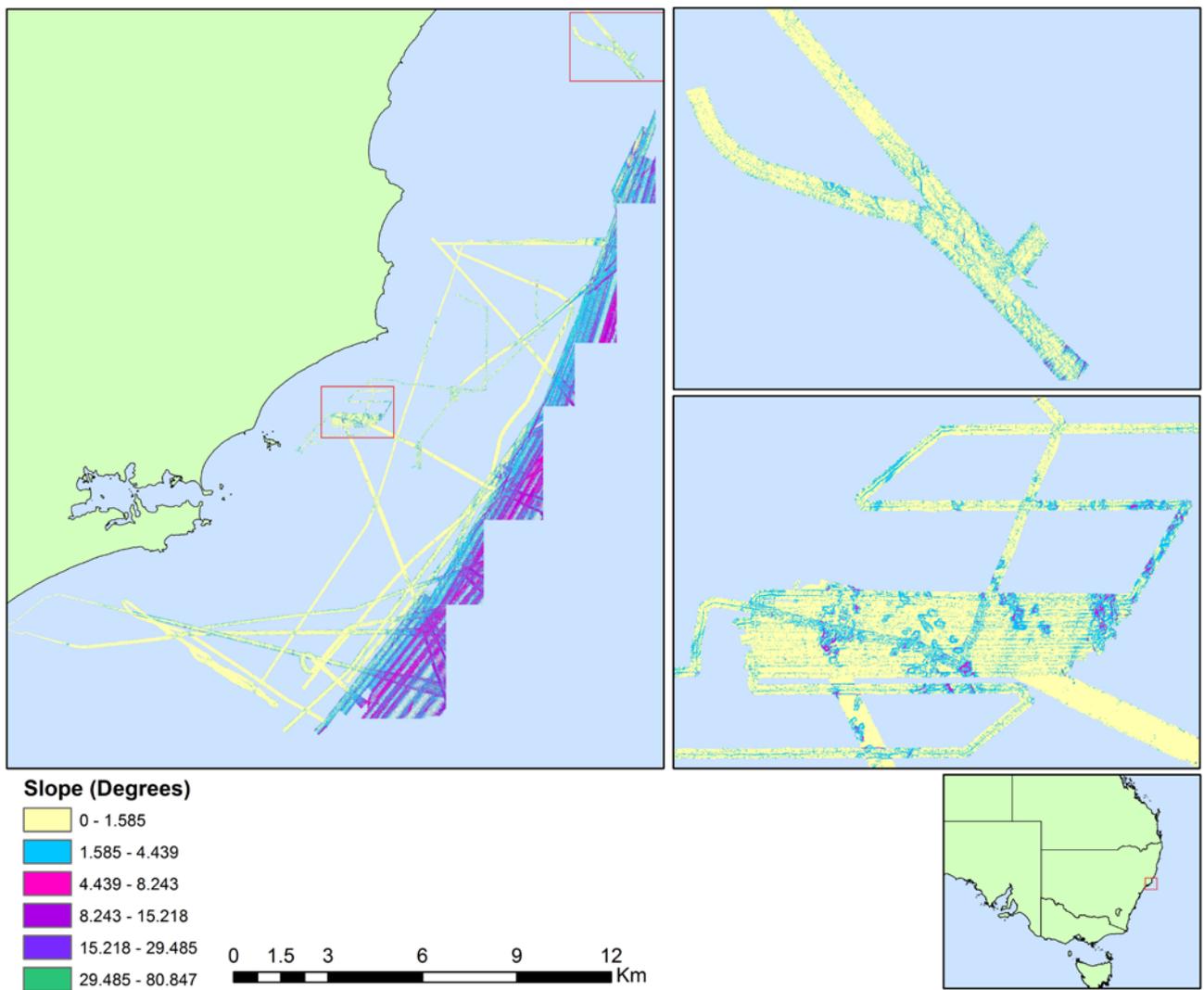


Figure 10 Slope map of the Hunter CMR. The continental shelf is relatively flat with reef outcrops that are associated with higher slope values. The slope increases significantly off the continental shelf.

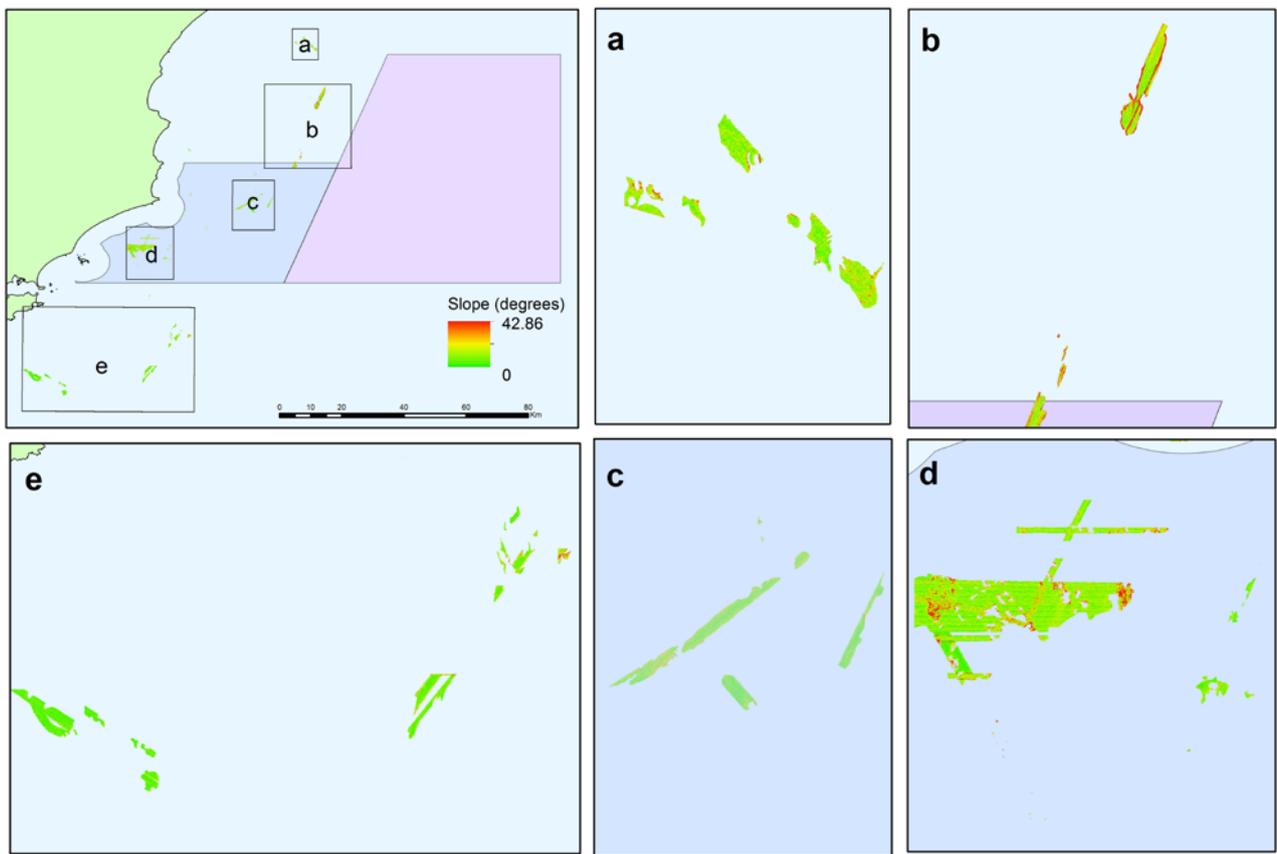


Figure 11 Slope map of reef polygons. Green represents low slope and red represents high slope values. Slope of the polygons varies from flat to steeply sloping.

Figure 12 displays a broad overview and close-up map of the six of the eight bathymetric derivatives generated in this study: curvature, slope, standard deviation, Northness, Eastness and ruggedness. Each close-up map highlights the reef features with different levels of success. The curvature (figure 8a) is not particularly useful in distinguishing or characterising potential rocky reef for this example. This is predominantly due to the large range of values that it displays. Unlike the curvature map, reef is very distinguishable on the slope, standard deviation, ruggedness, Northness and Eastness maps. The contrast between reef features and the relatively flat seafloor surrounding is best displayed in the slope map. The slope map shows that most of the reef features are associated with high slope values and bound by even steeper sloping sides. The standard deviation map also presents reef features relatively well, due to the effect of slope. The standard deviation map shows that these reef features correlate with high standard deviation values, indicating that their elevation varies significantly compared to the flat seafloor (low standard deviation values). The reef features are also distinguishable on the ruggedness map. The Vector Ruggedness Measure (VRM) used to generate the ruggedness map usually outputs values between 0 and 0.4 for natural terrains, with 1 representing complete terrain variability (Sappington et al. 2007). The reef features correspond with a high VRM (up to 0.72), indicating they are very structurally complex. The Northness and Eastness maps highlight different reef features depending on their orientation. The East or West and North or South facing reefs are recognisable and could be used to confidently predict the impact of different wave or current systems.

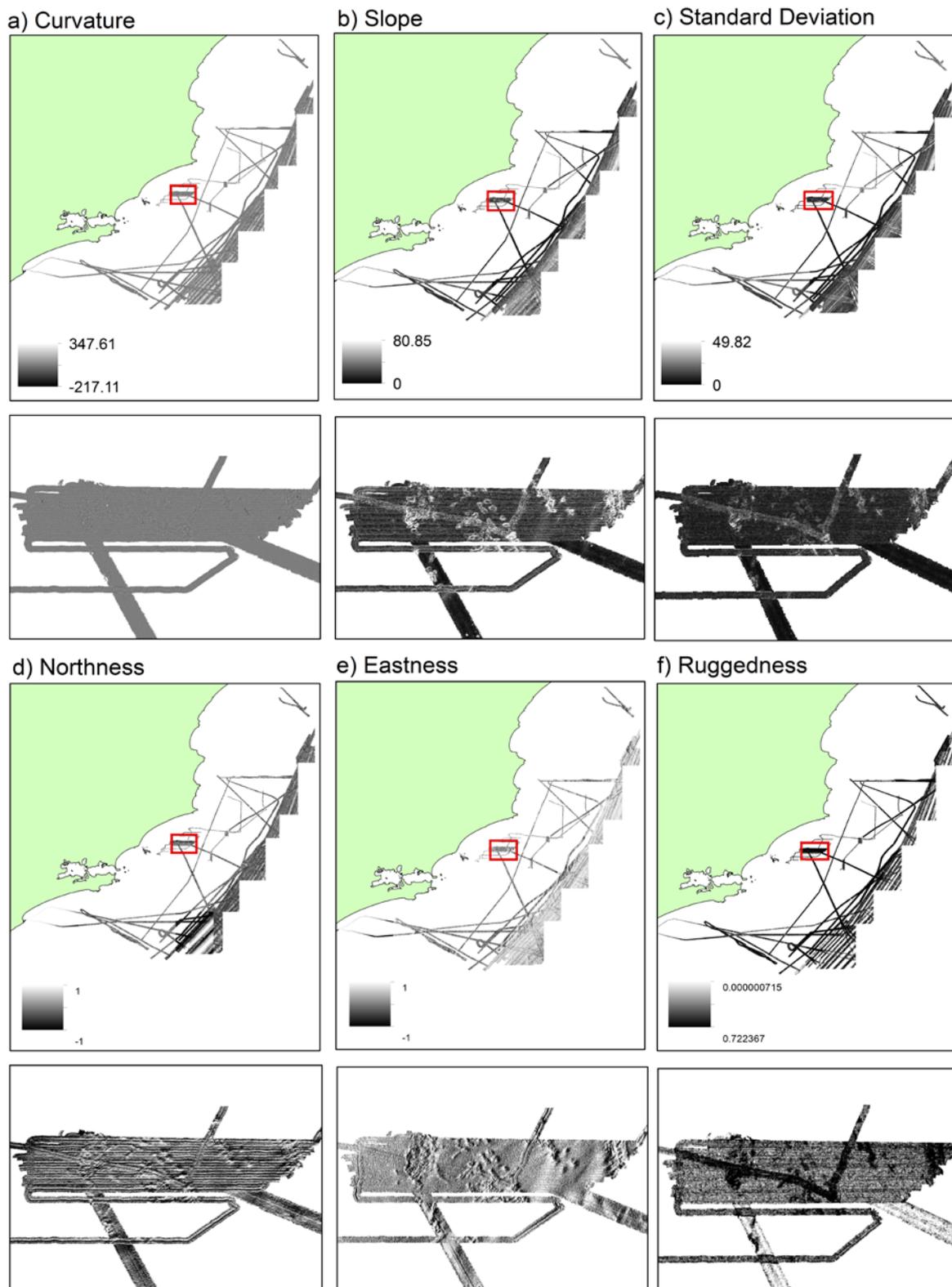


Figure 12 Map displaying a overview map and close-up example of each of the bathymetric derivatives calculated including a) curvature b) slope c) standard deviation d) Northness e) Eastness and f) ruggedness. Each derivative highlights reef features differently. The curvature (9a) and ruggedness (9f) derivative are not very effective at highlighting reef in this example.

Part 4 Discussion

Discussion

This study has successfully established a baseline map for the rocky reef distribution in the Hunter Commonwealth Marine Reserve. 95 potential rocky reef features have been identified by manually analysing bathymetry and backscatter data. The results of this study demonstrate that reef features have a very diverse range of physical characteristics. The reefs span a wide range of sizes, geometries, depths, elevations and are located both near shore and offshore. Eight bathymetric derivatives were computed for further classification of the seafloor. The variables have varying usefulness in highlighting reef features, and can each be utilised for different purposes.

The slope derivative was very efficient at highlighting potential reef features. Slope is commonly used in mapping studies to characterise reef (Hill et al., 2014; Lucieer et al., 2013; Calvert et al., 2015). The high slope values associated with reef indicate the presence of complex reef-forming ridges and gutters (Jordan et al., 2010). Many studies have concluded that structurally complex habitats provide greater niche availability and therefore support greater biodiversity (Tews et al., 2004). Applying this hypothesis, one could assume that reefs with high slope values have the potential to support biological distributions. However, some reefs have high slope values associated with steep reef walls, which drop down into sandy substrate, and in this way, are not good surrogates of biological distributions. Similar to this, the ruggedness derivative (measure of habitat complexity) could be applied to assess the potential space for niches. The Northness and Eastness maps were very effective at identifying North and East facing reefs respectively. This result shows that these derivatives could be confidently employed to assess the impact of wave action and local and regional current systems on a particular reef feature or set of features. This is particularly important in the context of rocky reef biota, as a lot of filter feeders rely on currents to supply their food (Gage and Tyler, 1991). The curvature map was not effective at highlighting any reef features.

Backscatter was also used to characterise the rocky reef identified in this study. A majority of the reef displayed backscatter intensities between -12 dB and -25 dB, but some reef returned values up to -54 dB, which is lower than expected for a rocky substrate. A study by Lucieer et al. (2013) showed that backscatter intensities associated with rock (contiguous reef), boulders and patchy reef were indistinguishable and roughly ranged between -13 dB and -18 dB, which is lower than the backscatter intensities associated with the reef found in this study. It is possible that some reef polygons encompassed sandy substrates resulting in lower backscatter intensities than expected. It is also important to note that backscatter intensity relates to grain size, volume heterogeneity and seafloor roughness which varies site to site, which may also explain the lower than expected backscatter returns (Ferrini and Flood, 2006).

It is recognised that marine species show preferences for certain types of terrain which provide the structure best suited to their mode of living (Wilson et al., 2007). In this way, the bathymetric

derivatives, backscatter and other abiotic variables such as depth provide a valuable tool to characterise distinct habitats (Bekkby et al., 2002). This study details the extent and distribution of rocky reef as one distinct habitat but it is important to note that the benthic composition of the reefs vary significantly depending on the terrain complexity and depth (and indirectly temperature and light availability). As an example, a study by Iampietro et al., (2008) used slope, aspect, rugosity, topographic position index and depth to predict the distribution of rockfish in Del Monte, California. Using models, the variables generated in this study could be applied to predict the distribution of different benthic assemblages such as coral, macroalgae and sponges. However a majority of these models rely on biological data to validate the models, which this study lacks.

Habitat mapping based purely on abiotic variables, often termed “abiotic habitat mapping”, is subject to error and may be inaccurate and misleading. Morphological and geological characteristics do drive biological patterns but only explain a small proportion of the pattern (Kostylev et al., 2001). A 2004 study by Stevens and Connolly found that, at best, abiotic variables explained less than 30% of the pattern of biological distributions. When abiotic habitat mapping is employed two types of error are possible: false homogeneity, where sites with similar abiotic conditions support different biological distributions, or false heterogeneity, where sites with different abiotic conditions support very similar biological distributions (Stevens and Connolly, 2004). Reef distribution is controlled by other important abiotic variables. Overlying water column conditions such as temperature, salinity and currents strongly influence reef distribution through controlling the supply of food, nutrients, gametes and new recruits. Ground truthing or in situ sampling is required to ameliorate errors that evolve from abiotic habitat mapping. To produce a reliable habitat map, it is necessary to measure the biological characteristics of the seafloor, which can be linked in some way to the abiotic data layers. This can be achieved through various methods including underwater towed video (Cavert et al., 2015), AUV imagery (Lucieer et al., 2013; Hill et al., 2014) or in situ snorkel or scuba sampling (Holmes et al. 2007).

Potential reef features may not be represented in the distribution map generated in this study. The resolution of the data impacts the scale of the features that were able to be identified. MBES are advantageous due to their ability to survey very large areas of the seafloor but due to this, their ability to pick up smaller features is hindered. The smallest feature identified in this study was a mound-like reef approximately 11 meters in radius. Because of this, any reef smaller than 11 meters may have been missed due to the resolution of the bathymetry and thus is not represented in the distribution map. Potential reef features are also missing in the large spaces between the survey lines on the continental shelf. The RV Southern Surveyor has conducted most of its investigations on or just outside the shelf break (see figure 1). There is limited data on the continental shelf, which hinders this study significantly. To produce an accurate map of the rocky reef distribution of the Hunter CMR, continuous bathymetric coverage of the area is needed.

This study has extended current knowledge of the extent, distribution and structure of rocky reefs on the continental shelf of the Hunter Commonwealth Marine Reserve. In order to use these results for effective management purposes, full bathymetric coverage of the continental shelf and ground truthing is required. This baseline information is the first step towards sustainable

resource management and ensuring that marine parks contain both a comprehensive and representative selection of biodiversity.

Appendix A Reef data sets

A.1 Hunter Commonwealth Marine Reserve

A.1.1 CSIRO Data holdings

Table A.1.1 CSIRO RV Southern Surveyor voyage and line numbers employed in this study

VOYAGE	LINES
SS200405	0006-0008
SS200406	0307-0309
SS200610	0006, 0007, 0038, 0039, 0048, 0049, 0055-0061, 0070-0080
SS200812	0001-0016, 0315
SS2009_V05	0127-0134, 0152-0155, 0162-170, 0174-0186, 0198-0207, 0238-0240
SS2010_V08	0016-0020, 0135-0140
SS2010_V09	0010-0014, 0016-0021, 0237-0251
SS2011_t01	0100-0103
SS2012_t01	0082-0084
SS2013_t04	0038-0046
ST200706	0194-0206
ST200803	0078-0090

A.1.2 NSW Department of Environment and Heritage

Table A.1.2 NSW (DEH) RV Bombora voyage and line numbers employed in this study

VOYAGE	LINES
1 (25 TH – 30 TH November 2015)	001, 001 (cont.001-002), 002, 002 (Cont. 001), 003, 003 (Cont. 001-003), 004, 004 (Cont. 001-002), 005, 005 (Cont. 001-007), 008, 008 (Cont.001-005)
2 (17 TH January 2016)	003-008, 008 (Cont. 001), 009-010
3 (17 TH January 2016)	001, 001 (Cont.001-002), 002, 002 (Cont. 001), 003, 003 (Cont. 001-003), 004, 004 (Cont. 001, 002)

Appendix B Detailed data processing and visualisation methods in CARIS HIPS and SIPS

B.1 Sound Velocity Corrections

B.1.1 Creation of sound velocity profiles

Each sound velocity profile generated for the three voyages with sound velocity errors were obtained through different methods. For the ss2009_v05 voyage, CTD data was downloaded from CSIRO’s Ocean and Atmosphere Data Trawler and a sound velocity profile created from CTD cast 24 using GSM MATLAB code. CTD data was similarly downloaded from the data trawler for voyage ss200812 and a sound velocity profile was generated from cast 33 using SVPBuilder. For the ss2010_v08 voyage, no CTD data was available so a sound velocity profile was created using climatology in in-house software SVPBuilder for the locations and times of the survey. These sound velocity profiles were applied to the lines in that voyage with errors using the Sound Velocity Correction tool in CARIS HIPS and SIPS.

B.1.2 Refraction Editor

The CARIS HIPS and SIPS Refraction Editor was employed to correct the lines presented in table 6 using a trial and error approach. Through trial and error, depth and velocity values were selected that most effectively flattened the outer beams of the bathymetry without distorting the central bathymetry.

Table B.1 The sound velocity profiles (depth and velocity values) applied to voyage lines

VOYAGE	LINE NUMBER	DEPTH (M)	VELOCITY (MS ⁻¹)
2007-294	0199	20	9
	0200	20	9
	0203	20	7
	0204	20	7
	0308	20	5
2013-277	0043	20	4
	0044	20	4
	0045	20	3
	0046	20	6

2006-295	0079	20	9
	0080	20	7
	0081	20	7

B.2 Rejected data

Table B.2 List of the data rejected in this study

VOYAGE	LINE NUMBER
SS2010_V08	0078-0085, 0100-0107, 0126-0134
SS2010_V09	0010-0014

Appendix C Optimal backscatter corrections in CARIS HIPS and SIPS

C.1 Optimal GeoBaR corrections

Geo-referenced Backscatter Rasters (GeoBaRs) were created for all available processed lines using the CARIS HIPS & SIPS Mosaic Editor. GeoBaRs were created for the purpose of visually comparing data and for applying geometric and radiometric corrections. All GeoBaRs were named with the variables “%l_%i_%r”, where “%l” is the line identifier, “%i” is the imagery source data type and “%r” is the resolution. All GeoBaRs were generated at a resolution of 1m.

The ideal radiometric and geometric corrections were determined through a trial and error process. The optimal corrections sought to adjust the intensity of backscatter at nadir, through time, and the angular response of sediment, remove distortion artefacts and generate imagery with a range of backscatter intensities large enough to contrast soft and hard sediment. The particular settings are outlined below.

C.1.1 Processing engine

Geocoder is a software programme that reads multibeam or sidescan data in a range of formats and applies a series of radiometric and geometric corrections to the data. It is a mosaicking tool capable of gridding multiple lines. Geocoder was used in this study as it is best suited to reading multibeam backscatter in either a beam average or time series return.

C.1.2 Source data type

Geocoder can provide backscatter returns either as beam average or time series values. Beam averaged back scatter generates a single backscatter return value (intensity) for each beam, taken as an average intensity centred on the bottom of the entire time series to produce an image of the seafloor. Reducing a full time series to a single value results in a loss of spatial resolution. Time series backscatter allows for much high spatial resolution of seafloor features by generating a series of intensity values. These are logged for each beam and added based on their time and range. For identifying potential reef structures, high spatial resolution is crucial so the time series backscatter was selected as the source data type.

C.1.3 General mosaic editor options

All of the default corrections including the Auto Gain Correction, the Auto TVG Correction and the Anti-Aliasing correction were applied to generate the GeoBaRs.

Auto Gain Correction

The Auto Gain correction adjusts signal intensities using independent port and starboard gain factor settings. When applied, the correction resulted in much better contrast between dark and light intensity values. The correction was applied uniformly to both the port and starboard sides.

Auto TVG Correction

Auto TVG (Time Varying Gain) correction adjusts signal intensity by applying a non-uniform, time-dependent gain that corrects for attenuation of sound waves by absorption and geometric spreading. This correction, like the Auto Gain correction increased the contrast in the backscatter imagery.

Anti-Aliasing Correction

The application of the anti-aliasing correction significantly increased the detail of the backscatter imagery and increased the contrast.

C.1.4 Beam pattern correction

Beam pattern corrections resolve radiometric distortions of the backscatter inherent to the sonar beam unique to the particular transducer. The correction attempts to equalise the difference in pixel intensity from nadir to the outer beams. The correction relies on a user generated beam pattern to remove this effect. Multiple beam patterns were taken from featureless sandy areas and applied to the GeoBaRs but consistently increased the effect of nadir, significantly increased the contrast and produced significant ripple artefacts particularly evident at nadir. Due to this, a beam pattern correction was not applied to the final back scatter GeoBaRs.

C.1.5 AVG correction

The AVG (Angle Varying Gain) correction removes the angular response of sediment from the imagery. The correction can be customised to be flat, trend, or adaptive with a flexible window size. Trend and adaptive corrections resulted in better contrast between soft and hard sediment than the flat correction. Trend and adaptive were indistinguishable in the backscatter imagery so trend was selected. Determining the window size was a compromise between contrast and the effect of nadir. A window size of 300 provided a very good contrast but had a stronger intensity backscatter at nadir. A window size of 10 resulted in a very poor contrast, making sea floor features very difficult to distinguish, but had a much less pronounced nadir. Through trial and error, a window size of 100 was found to be the optimum value to balance contrast and the effect of nadir.

C.1.6 Despeckle

The De-speckle correction reduces the noise associated with the backscatter by passing the data through a mean or median filter. Given the noisy nature of acoustic signals, the de-speckle tool is often desirable for generating GeoBaRs. The correction was applied in varying degrees (weak, moderate, strong and very strong) and increasingly smoothed the data. However, because this study aims to identify reef structures which are often associated with increased 'speckliness', the

correction was not applied as to preserve the speckliness associated with potential reef structures. The application of the de-speckle correction also resulted in a decrease in contrast that increased with increasing strength of the de-speckle correction.

Appendix D Zonal statistics results

D.1 Zonal statistics by reef polygon

Apx Table D.1 Table displaying the mean value for area, depth, slope, ruggedness, Northness, Eastness, curvature and standard deviation for each reef polygon. Table also lists the latitude and longitude associated with each polygon

FID	LATITUDE	LONGITUDE	AREA (KM ²)	DEPTH (M)	SLOPE	RUGGEDNESS	NORTHNESS	EASTNESS	CURVATURE	STANDARD DEVIATION
0	-32.574	152.571	0.1002	-145.6363	0.1226	0.00005	0.12261	-0.28429	0.01554	0.14933
1	-32.585	152.565	0.0846	-111.3668	-0.0817	0.00005	-0.08166	0.07965	0.01817	0.15286
2	-32.587	152.564	0.0037	-111.7633	-0.1694	0.00007	-0.16937	-0.09987	0.08805	0.17238
3	-32.368	152.819	0.0699	-112.3552	1.3948	0.00025	0.01516	0.03799	0.04716	0.30427
4	-32.364	152.816	0.0172	-111.5192	1.1295	0.00006	-0.03149	-0.00137	0.04618	0.18623
5	-32.445	152.805	1.7746	-117.4317	0.9733	0.00007	-0.03414	0.02565	0.01399	74.83969
6	-32.426	152.836	0.2379	-121.7290	1.1480	0.00008	-0.09495	0.30696	0.02392	0.23991
7	-32.450	152.859	0.9912	-144.6133	0.8072	0.00005	-0.21489	0.45416	0.00654	0.16764
8	-32.426	152.630	0.1423	-98.4201	1.9703	0.00021	-0.09988	0.31521	0.04285	47.42277
9	-32.419	152.632	0.0109	-99.2322	1.8566	0.00014	-0.10969	0.36332	0.13610	46.45793
10	-32.421	152.633	0.0056	-100.3465	1.5244	0.00026	-0.15507	0.08936	0.25389	62.75898
11	-32.418	152.633	0.0047	-100.2364	2.1277	0.00053	0.14927	0.22718	0.60519	81.36237
12	-32.419	152.633	0.0019	-100.5171	1.6287	0.00027	0.09483	0.10601	0.53079	75.64321
13	-32.420	152.634	0.0027	-100.5371	1.3568	0.00035	0.13169	-0.06203	0.57079	50.07602
14	-32.474	152.611	0.0969	-106.8683	1.2246	0.00010	-0.09426	0.07830	0.08491	52.19544
15	-32.490	152.603	0.0223	-108.3434	1.2629	0.00007	-0.12031	0.52527	0.04730	40.31114
16	-32.478	152.609	0.0228	-107.7098	1.4713	0.00014	-0.21053	0.42794	0.12438	38.97638
17	-32.480	152.607	0.0434	-107.7648	0.9651	0.00005	-0.34153	0.46954	0.04812	44.91161
18	-32.479	152.610	0.0075	-108.0992	1.7248	0.00022	0.29883	-0.11323	0.12923	74.73319
19	-32.481	152.608	0.0103	-108.3441	0.7572	0.00005	-0.04847	-0.05067	0.04100	64.17216
20	-32.488	152.606	0.0417	-109.1216	0.9438	0.00009	-0.08576	-0.24888	0.00243	67.56672
21	-32.484	152.607	0.0245	-109.4158	1.3721	0.00015	0.02838	0.08834	0.10454	56.22695
22	-32.486	152.604	0.0082	-109.3286	1.7997	0.00034	0.14557	-0.08706	0.18586	58.73772
23	-32.147	153.005	6.3243	-167.2431	2.4503	0.00056	-0.15413	0.38152	0.02110	-
24	-32.939	152.154	0.3039	-126.8221	0.4945	0.00004	-0.03232	-0.00433	0.00346	0.12348
25	-32.945	152.164	0.1723	-127.0945	0.5272	0.00004	0.01782	0.02121	0.00009	0.13543

26	-32.955	152.216	0.9784	-131.1520	0.495	0.00003	-0.04843	0.09193	0.00271	0.12149
27	-32.565	152.575	0.0001	-111.2800	-0.8742	0.00029	-0.87416	0.48564	1.90800	0.25076
28	-32.566	152.575	0.0001	-111.2780	-0.0153	0.00032	-0.01526	0.99988	2.53700	0.28907
29	-32.891	151.851	0.0311	-24.1193	1.1262	0.00009	0.91267	-0.40862	0.07155	0.19588
30	-32.464	152.774	1.0308	-115.1541	1.1373	0.00010	-0.13799	0.13315	0.01437	64.51417
31	-32.295	152.626	0.2040	-83.1513	0.5355	0.00002	-0.18017	0.55861	0.00475	0.11170
32	-32.299	152.630	0.0267	-84.7052	0.4485	0.00001	-0.00827	0.15146	0.01591	0.09674
33	-31.986	152.949	0.1629	-115.6947	1.3046	0.00035	-0.22722	-0.02086	0.00963	0.26344
34	-31.982	152.939	0.0711	-114.3657	1.1267	0.00015	0.09583	0.08456	0.08720	0.37303
35	-31.971	152.960	0.6465	-113.1900	1.2023	0.00014	-0.22672	-0.07929	0.01256	0.23927
36	-31.993	152.981	0.4412	-117.2380	2.0314	0.00028	0.00957	0.14715	0.01642	0.23754
37	-31.986	152.938	0.1114	-115.2713	1.0752	0.00012	0.04203	0.02967	0.01783	0.24958
38	-31.982	152.934	0.1892	-114.3800	1.0223	0.00013	-0.19341	-0.14923	0.03667	0.29494
39	-32.943	152.509	7.2848	-145.6363	1.1673	0.00016	-0.13051	0.14065	-0.00080	0.18871
40	-32.765	152.489	0.0008	-136.4875	1.466	0.00019	0.19943	-0.00036	0.61867	0.46070
41	-32.766	152.489	0.0010	-136.2631	0.823	0.00009	0.02421	0.46204	0.98800	0.55801
42	-32.765	152.486	0.0015	-136.2977	2.7062	0.00070	-0.28639	-0.12218	0.60741	0.34162
43	-32.295	152.946	0.0311	-189.3000	4.1647	0.00055	-0.00692	0.29530	0.17026	0.69149
44	-32.340	152.931	1.7362	-194.2264	3.293	0.00033	-0.19067	0.49291	0.01202	0.36201
45	-32.318	152.948	0.3760	-205.6143	1.814	0.00067	-0.17791	0.49454	0.06780	0.57059
46	-32.305	152.950	0.1186	-198.3107	2.8454	0.00061	-0.15547	0.52854	0.09249	0.56825
47	-32.381	152.819	0.0190	-112.7713	3.3008	0.00024	-0.03772	0.24432	0.07931	0.32485
48	-32.412	152.818	0.0293	-120.3306	1.5782	0.00016	-0.07728	0.23487	0.05418	0.25536
49	-32.419	152.820	0.0111	-119.9985	1.181	0.00018	0.23383	0.49269	0.01539	0.28933
50	-32.614	152.571	0.0473	-116.4260	1.4426	0.00006	-0.24850	-0.17325	0.04057	0.19240
51	-32.612	152.557	0.4762	-114.8245	-0.2485	0.00006	-0.06283	0.02611	0.02086	0.18081
52	-32.608	152.555	0.0204	-115.8014	-0.0628	0.00005	0.15054	-0.04939	0.04145	0.15812
53	-32.635	152.549	0.0097	-116.7000	0.1505	0.00010	0.01921	0.26644	0.19328	0.21906
54	-32.865	152.570	0.6551	-144.8200	0.0192	0.00005	-0.05562	-0.04767	0.00046	0.20233
55	-32.809	152.585	0.4908	-143.8777	0.9072	0.00010	0.14961	-0.19335	0.00767	0.14050
56	-32.817	152.576	0.0627	-144.4197	1.2867	0.00010	0.06732	-0.18774	0.03810	0.17043
57	-32.833	152.575	0.3521	-143.5870	0.8630	0.00004	-0.06793	-0.22742	0.02920	0.19969
58	-32.822	152.603	0.1075	-144.1872	0.5912	0.00006	-0.15935	0.18748	0.02382	0.31901
59	-32.842	152.590	1.5823	-142.7908	0.8672	0.00010	-0.05167	-0.00427	0.00524	0.23666
60	-32.843	152.573	0.2609	-144.4013	1.0641	0.00027	-0.02821	0.05411	0.02977	0.23953
61	-32.842	152.580	0.0254	-144.4090	1.3912	0.00014	0.11004	-0.48262	0.11759	0.43533
62	-32.844	152.580	0.0075	-145.1881	1.0296	0.00015	-0.11340	0.21408	0.17906	0.42492
63	-32.837	152.626	0.7464	-173.4716	1.2833	0.00045	-0.38792	0.34995	0.00956	0.40842
64	-32.924	151.780	0.0229	-14.9960	2.8451	0.00040	0.96590	-0.25874	0.09666	0.28540

65	-32.921	151.788	0.0426	-16.7325	2.4108	0.00041	0.95764	-0.28790	0.13583	0.23109
66	-32.581	152.569	0.0055	-110.5671	2.2298	0.00024	-0.09720	0.22803	0.10606	0.18286
67	-32.001	152.992	0.7289	-118.5929	1.6298	0.00016	-0.00838	0.02070	0.00483	0.29128
68	-32.472	152.810	0.8450	-120.8183	1.2532	0.00006	-0.14869	0.20644	-0.00056	0.25800
69	-33.003	152.266	1.6658	-136.8657	0.69	0.00022	0.02779	0.01331	0.00120	0.14693
70	-32.982	152.264	0.5891	-136.7720	1.3279	0.00004	-0.11156	-0.08967	0.00285	0.13583
71	-32.975	152.252	0.2467	-137.1893	0.6693	0.00005	0.07798	0.03726	0.00440	0.12591
72	-32.952	152.172	0.1257	-128.0283	0.6082	0.00004	0.06061	-0.00232	0.00897	0.12198
73	-32.954	152.167	0.1896	-126.5774	0.5811	0.00003	0.16004	0.37259	0.00500	0.12197
74	-32.967	152.200	0.0723	-130.4108	0.4931	0.00003	-0.04079	-0.04929	0.01046	0.16063
75	-32.955	152.176	7.0597	-129.3532	0.4948	0.00003	0.02684	0.10117	0.00045	0.13129
76	-32.524	152.676	0.1336	-112.6445	0.5091	0.00008	-0.48542	0.47275	0.02415	40.33442
77	-32.624	152.478	0.0049	-105.4099	1.1378	0.00004	0.00602	0.22520	0.31780	0.59022
78	-32.629	152.476	0.0034	-106.8002	0.5350	0.00034	-0.17674	0.06080	0.24025	0.42724
79	-32.630	152.477	0.0009	-107.1540	-0.1767	0.00049	0.71903	0.23536	0.40940	0.46195
80	-32.661	152.496	0.0024	-110.8035	0.7190	0.00038	-0.11984	0.11867	0.21248	0.37662
81	-32.661	152.490	0.0011	-110.1247	-0.1198	0.00056	0.06943	0.11601	0.36869	0.36442
82	-32.659	152.490	0.0025	-110.2895	0.0694	0.00008	-0.18877	0.29830	0.11752	0.13584
83	-32.638	152.480	0.0011	-108.7820	-0.1888	0.00135	0.40692	0.05362	1.26809	0.54050
84	-32.635	152.480	0.0010	-107.6295	0.4069	0.00414	0.20341	0.18540	1.68808	1.04099
85	-32.632	152.482	0.0004	-108.5250	0.2034	0.00105	-0.01997	-0.20187	1.66650	0.47424
86	-32.633	152.478	0.0013	-108.3970	-0.012	0.00040	-0.04592	0.48804	0.47608	0.36070
87	-32.681	152.500	0.0086	-112.7994	-0.0459	0.00169	-0.04593	0.07357	0.70607	0.86922
88	-32.651	152.491	0.0019	-108.0908	-0.0459	0.00059	0.00884	0.11902	0.39837	0.44865
89	-32.731	152.507	0.0108	-132.1721	0.0088	0.00020	-0.36845	0.43953	0.10244	0.36861
90	-32.721	152.512	0.1295	-128.8302	-0.3685	0.00018	-0.08866	0.10212	0.04346	0.26369
91	-31.988	152.975	0.0774	-117.4481	-0.0887	0.00020	-0.04326	0.05768	0.02446	0.26173
92	-32.552	152.510	1.6072	-88.7086	1.2472	0.00014	-0.12999	0.08552	0.00406	66.47791
93	-32.583	152.480	1.4913	-92.9489	-0.1154	0.00018	-0.11538	0.12276	0.00654	0.25559
94	-32.519	152.546	0.1516	-88.2698	1.4642	0.00021	-0.12669	0.19890	0.02606	66.61910

D.2 Zonal statistics by field sheet

Apx Table D.2 Table displaying the median value for Planar Curvature, Profile Curvature, Curvature, Rugosity, Eastness, Northness, Standard Deviation and Slope for each field sheet

FIELD SHEET	DEPTH (M)	PLANAR CURVATURE	PROFILE CURVATURE	CURVATURE	RUGOSITY	EASTNESS	NORTHNESS	STANDARD DEVIATION	SLOPE
H3	-	0.010755	-0.005763	0.018993	0.00012	0.016033	-0.176853	0.243919	1.04962

H5	-	0.022837	-0.046365	0.097997	0.00008	-0.289633	0.957138	0.188398	1.100839
H6	-83.347	-0.002194	-0.001821	0.004005	0.000012	0.814771	-0.21936	0.099985	0.482108
H7	-	0.007549	0.035197	-0.021001	0.000043	0.3173515	-0.243941	0.155085	0.653339
H8	-91.934	0.001574	-0.008395	0.010994	0.000087	0.189687	-0.26589	0.215057	1.02512
H9	-145.847	0.007204	-0.010902	0.017013	0.0001	0.670327	-0.259507	0.252081	1.167629
H10	-	0	-0.001980	0.003997	0.000027	0.210368	0.030719	0.120126	0.461726
H11	-	0.001909	-0.006949	0.009994	0.00003	-0.028014	0.010742	0.128101	0.514231
H12	-113.3575	0.0055275	-0.013079	0.021995	0.000077	0.2251475	-0.262303	0.216598	1.0099345
H13	-	0.000061	0.012528	-0.004989	0.000026	0.545592	-0.280351	0.235386	0.591035
H15	-	0.003716	-0.010424	0.014022	0.000063	-0.007213	-0.150434	0.188456	0.861179
H16	-	0	-0.007124	0.009017	0.000043	0.3173515	-0.825989	0.154998	0.653339
H17	-	0.0060815	-0.020253	0.031982	0.000144	0.720995	-0.241371	0.294665	1.47571

Shortened forms

AHO	Australian Hydrographic Organisation
AVG	Angle Varying Gain
BASE	Bathymetry Associated with Statistical Error
CMR	Commonwealth Marine Reserve
DGPS	Differential GPS
GeoBaR	Georeferenced Backscatter Raster
GIS	Geographic Information System
HIPS	Hydrographic Information Processing System
HVF	HIPS Vessel File
IHO	International Hydrographic Organisation
KEF	Key Ecological Feature
LIDAR	Light Detection And Ranging
MBES	Multibeam Echo Sounders
MPA	Marine Protected Area
MRU	Motion Reference Unit
SBET	Smoother Best Estimate of Trajectory
SIPS	Side-scan Information Processing System
TVG	Time Varying Gain
VRM	Vector Ruggedness Measure

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