Marine Biodiversity Hub

National Environmental Science Programme

Collation of existing shelf reef mapping data and gap identification

Phase 1 Final Report - Shelf reef key ecological features

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Project D3 - Evaluating and monitoring the status of marine biodiversity assets on the continental shelf

Milestone 4 – Research Plan v2 (2016)

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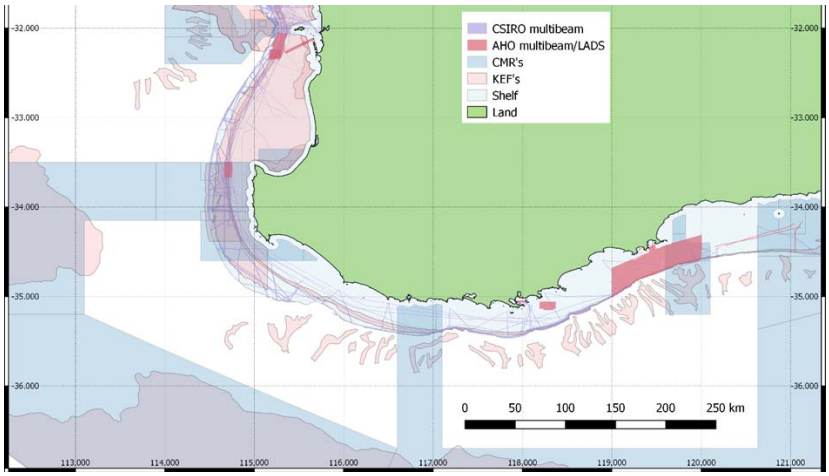

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Important Disclaimer

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EXECUTIVE SUMMARY

This report details the collation of all of the existing Australian continental shelf mapping data, methods used for reef habitat mapping and classification, and documentation of the spatial data products. It presents summary statistics of the distribution and extent of mapping surveys conducted on the continental shelf. The collation of these data has generated a valuable understanding of the distribution and extent of this key habitat around Australia, as well as a quantitative description of the current extent, nature and spatial location of mapping programs in shelf waters. The latter component both informs our understanding of the significant gaps in our current knowledge, and provides ready access to existing mapping data from which more detailed local scale maps can be generated from individual QGIS files will can be downloaded from the Australian Online Data Network (AODN).

The project has made significant inroads towards building collaboration across agencies to share habitat mapping data for the public good, as well as furthering discussions on mechanisms to making data more widely available. We have made a number of recommendations in this report relating to the need for data standards, central data storage, and tools for data visualisation. All of these recommendations are readily achievable, and discussions are progressing on all fronts, including visualisation of much of the data collated through this project by the AODN via its SeaMap Australia project (in development).

Successful adoption of the recommendations will significantly enhance the planning process for future surveys across all jurisdictions and management needs, as well as the uptake of such information into future spatial management. Critically, if the CMR network is to form the backbone of a national integrated monitoring program that includes shelf waters, these processes, and the information generated by appropriately targeted surveys, are going to be essential to underpin planning of biological surveys to ensure they are regionally relevant and representative of important habitat features.

1. INTRODUCTION

1.1 Background and Project Aim

This report is Milestone 4 of the D3 project "Evaluating and monitoring the status of marine biodiversity assets on the continental shelf - Phase 1-Shelf reef key ecological features (Collation of existing shelf reef mapping data and gap identification)". The aim of this milestone was to collate all known bathymetric data within the region of the Australian shelf (0 – 200 m water depth) including derived spatial products that may represent the distribution of reef habitat. In addition to the generation of a new reef distribution map, the documentation of the sources of spatial data, quality, lineage and extent have been collated as a metadata record on the Australian Online Data Network (AODN) portal. Where possible, links have been made to the original mapping data. On collation of the spatial geodatabase synthesised data products were to be delivered to the Department of Environment via the AODN. A second aim, was to identify and collate all additional shelf habitat and bathymetry data, that also would be made readily available to the Australian marine science community through the AODN. The sources of these data were initially identified through national collaborations identified in the National Environmental Science Program D3 workshop report Milestone 3, Lucieer et al. (2016). Data has been contributed from partner agencies (CSIRO and Geoscience Australia), previously funded Marine Biodiversity Hub programs (Commonwealth Environmental Research Funding (CERF) and the National Environmental Research Program (NERP)) and collaborating agencies, including Parks Victoria, the Australian Hydrographic Office, the Royal Australian Navy and Universities.

This report details the collation of all of the existing continental shelf mapping data, methods used for reef habitat mapping and classification, and documentation of the spatial data products. It also presents summary statistics of the distribution and extent of mapping surveys conducted on the continental shelf. The collation of these data has generated a valuable understanding of the distribution and extent of this key habitat around Australia, as well as a quantitative description of the current extent, nature and spatial location of mapping programs in shelf waters. The latter component both informs our understanding of the significant gaps in our current knowledge, and provides ready access to existing mapping data from which more detailed local scale maps can be generated upon request. The national understanding of how reef systems differ around the nation has underpinned the development of a new reef geomorphology classification system (see Nichol et al., 2016). The development of this reef classification system will provide a framework for a nationally consistent approach to future mapping initiatives. Developing consistency in classification ontologies will move us towards the goal of refining inventory and developing temporal monitoring approaches, including standard methods for State of Environment reporting consistent with measures developed for coastal systems within NESP (i.e. see project C2).

1.2 Rationale

Australia has the third largest ocean territory on the planet, which supports a large network of marine protected areas. Prior to this project, there were significant gaps in our knowledge of the distribution of key biodiversity assets on the continental shelf. This knowledge is required to inform management agencies so that actions are developed to ensure that these assets

are adequately protected. This is the case for the Commonwealth Marine Reserves (CMRs) and off-reserve locations managed under marine bioregional plans. One of the key gaps in our knowledge was the extent and physical characteristics of reefs on the shelf. These reefs consist of both rock outcrops, coral dominated reefs and those formed on relict coastlines (hereafter reefs). These are recognised in marine bioregional plans as a related set of Key Ecological Features (KEFs) that support a range of ecologically and commercially important benthic and pelagic marine assemblages. Despite their nationally significant status, the extent and distribution of reef habitats is poorly understood across the continental shelf, and particularly within Australia's CMR network.

2. DATA SOURCES AND QUALITY ASSESSMENT

This report details the collation of many existing and available spatial data records that have been produced by each state and territory identified in the D3 Workshop report (Lucieer et al. 2016). This project did not fund any further data collection except for one survey in NSW- within the Hunter CMR (Appendix A). The Australian continental shelf in this project is defined as the spatial extent of the seabed area between the coastline and 200 m isobath (Figure 1). The coastline is defined by the Lowest Astronomical Tide Datum by the Australian Hydrographic office (AHO). The 200 m isobath was derived from Geoscience Australia's national bathymetric model (GeoscienceAustralia 2009).

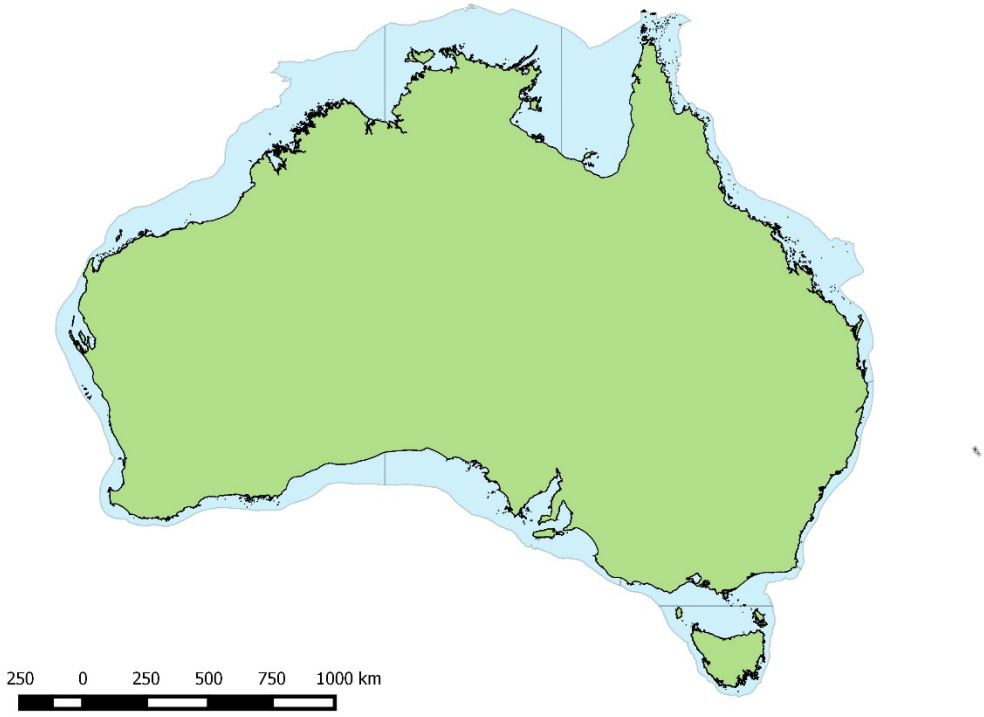


Figure 1. Map showing the extent of the continental shelf as defined by the 200 m isobath.

2.1 Documentation of spatial data products

The reef spatial database has been created by collating mapping data products from a number of data sources (Figure 2). This data collation exercise has produced a comprehensive document listing all of the databases that contain Australian seafloor spatial data. In addition to those datasets that were identified and used to build the reef product, we have also identified sectors/organisations whose data we have not yet been able to access. This document will be provided with the metadata record on the Australian Online Data Network and can be found at [https://portal.aodn.org.au].

Outcome of this data scoping project in a comprehensive database of all Australian seafloor spatial data collected- identified as available or not available for this project.

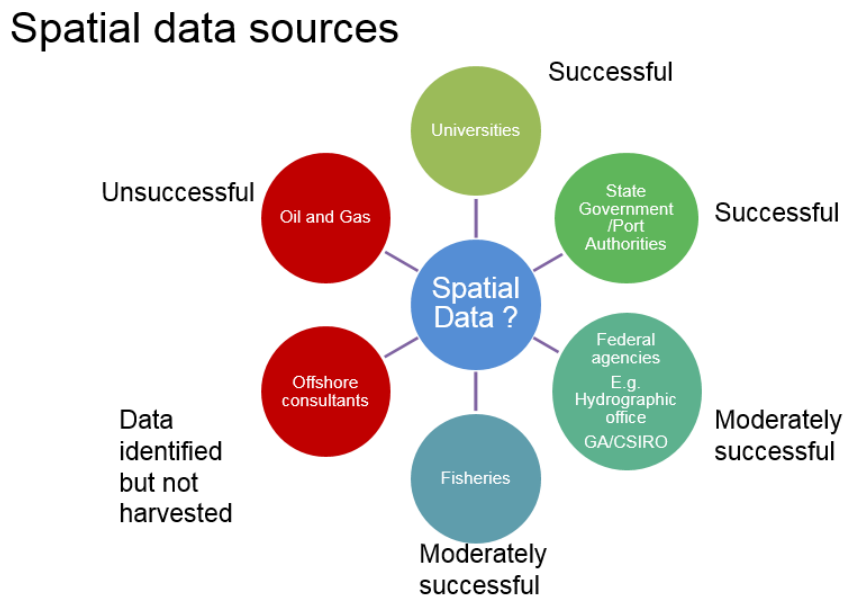


Figure 2. Spatial data sources identified for the reef spatial layer.

Over 70 spatial datasets were collated to map the extent of Australian reef habitats on the continental shelf. Figure 3 shows that the majority of these datasets were extracted from Government databases with the remaining from the university sector. Gaining access to data controlled by Oil and Gas as well as private consultant sectors remains an ongoing challenge.

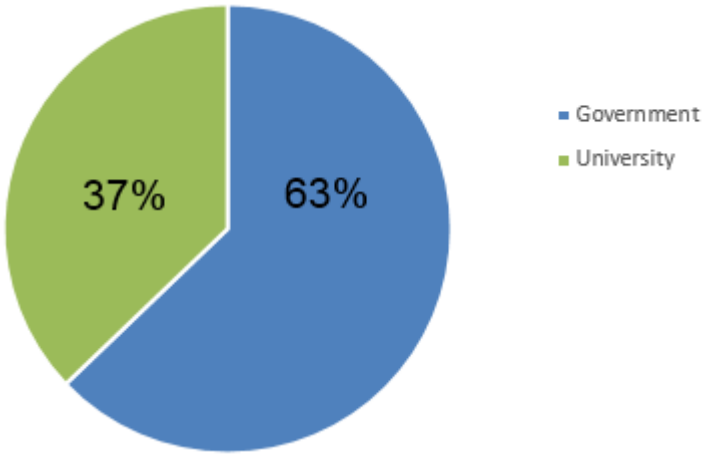


Figure 3. Percentage contribution of data sets from University or Government sector.

To provide a qualitative assessment on the accuracy and suitability of the input data layers to the final reef spatial product it was decided that the data would be categorised into four data tiers. These four tiers were organised according to the methods of data processing, reef extraction and level of synthesis required to develop the reef spatial product. The four tiers represent the following data inputs:

> **Tier 1-** Spatial data that has been compiled from targeted seafloor mapping projects where reef areas have been mapped using a published classification procedure and have been validated with an external data source (such as video data or diver surveys). This tier represents the highest quality mapping data.
>
> **Tier 2-** Bathymetric data that has been compiled from the CSIRO data holdings. These data have primarily been collected from a multibeam acoustic system. These data have been supplied to the D3 project at various resolutions (i.e. bathymetric grid sizes). Reef area has been extracted using bathymetric modelling techniques as outlined in section 3.2. (Methods as per Appendix B).
>
> **Tier 3**- Bathymetric data that has been compiled from the Royal Australian Navy (RAN) data holdings. The data incorporated into the reef spatial product were those polygon areas that have been labelled by the RAN with particular reef associated labels such as shoal, reef, rock, etc.
>
> **Tier 4**- Bathymetric data that has been compiled from the Royal Australian Navy (RAN) data holdings that have been processed using the bathymetric modelling technique as applied to Tier 2. This data product produces a probability product of the likelihood of the seafloor being hard substratum based on a number of spatial parameters as outlined in section 3.4.

In summary, Tier 1 data has been validated and identified accurately as reef. Data from Tiers 1 -3 are 'seabed features' that may or may not be reef, but have characteristics in their bathymetric form that suggest that they may be a reef feature.

Data incorporated from each of the Tiers have been reprojected from their native projection into GDA94 [EPSG4283] which is the Geocentric Datum of Australia (1994) using the GRS 19080 ellipsoid. The coordinate system is ellipsoidal 2D CS with axes of latitude and longitude (in degrees). It has a bounding system to capture the whole of Australia including Lord Howe Island, Macquarie Islands, Ashmore and Cartier Islands, Christmas Island and Norfolk Island.

Area calculations of mapped reef were completed in the Lambert-Conformal projection. This is a conic map projection was used as it minimised distortions near the standard parallels and maintains accuracy in small shapes.

The reef classification product is a spatial layer that contains the attributes outlined in Table 1.

Table 1. Description of attribute fields for the spatial reef layer product.

Attribute Field	Description of attribute field
NATIVE CLASSIFICATION	Source classification. Extracted on (e.g. GBRMPA's 'FEAT_NAME; GA's 'Geomorph'; AHO's 'NATSUR')
D3 Classification	IMAS/D3 classification e.g. 'Reef/Other'
CUSTODIAN	Custodian of the source data
META_LINK	HTML link to metadata or website of source dataset
DATASET	Source dataset
REGION	Location
SOURCE_ID	Source reef id (e.g. GBRMPA's UNIQUE-ID)
Object name	Source object name (e.g. GBRMPA's 'GBR_NAME'; IHO's 'Objnam')
DEPTH	Water depth in meters from LAT.
WATLEV	Vertical description of reef (e.g. IHO watlev), see www.s-57.com for definitions
AREA KM	Area of reef polygon in square kilometres (km^2)
PERIMeter KM	Perimeter length of reef in kilometres (km)
CENTROID-X	Longitudinal coordinate for centre of reef polygon
CENTROID-Y	Latitudinal coordinate for centre of reef polygon
CMR MPA Name	Name of Commonwealth Marine Reserve
STATE MPA name	Name of State Marine Protected Area
KEF	Name of Key Ecological Feature

3. METHODS

Each of the tiers of data were subject to different processing and analysis techniques depending on their source. The following section details the methods for extraction of the reef spatial layer by Tier.

3.1 TIER 1 reef data extraction

TIER 1 data has been sourced from seafloor mapping programs completed around the nation by, predominantly, State-based/funded agencies. This mapped reef data represents the highest quality mapping data, with reef extents being field validated. Typically the data products supplied included processed map products, with reef areas identified as polygons. In many cases the underlying raw data was not supplied or processed by this project, but it is increasingly being made available by these agencies, with the source data being linked to the AODN metadata records provided in this report. All datasets were spatially merged with the original reef attribute class maintained, along with the addition of a new attribute- D3 reef-, which was added to the spatial database for consistency in mapping terminology for the web based mapping server (as shown in Table 2).

The extent of TIER 1 data represents a total of 22.5 % (21,835.09 km^2) of all data collated within the reef mapping project.

Table 2. Custodians of TIER 1 data holdings supplied to the reef mapping project.

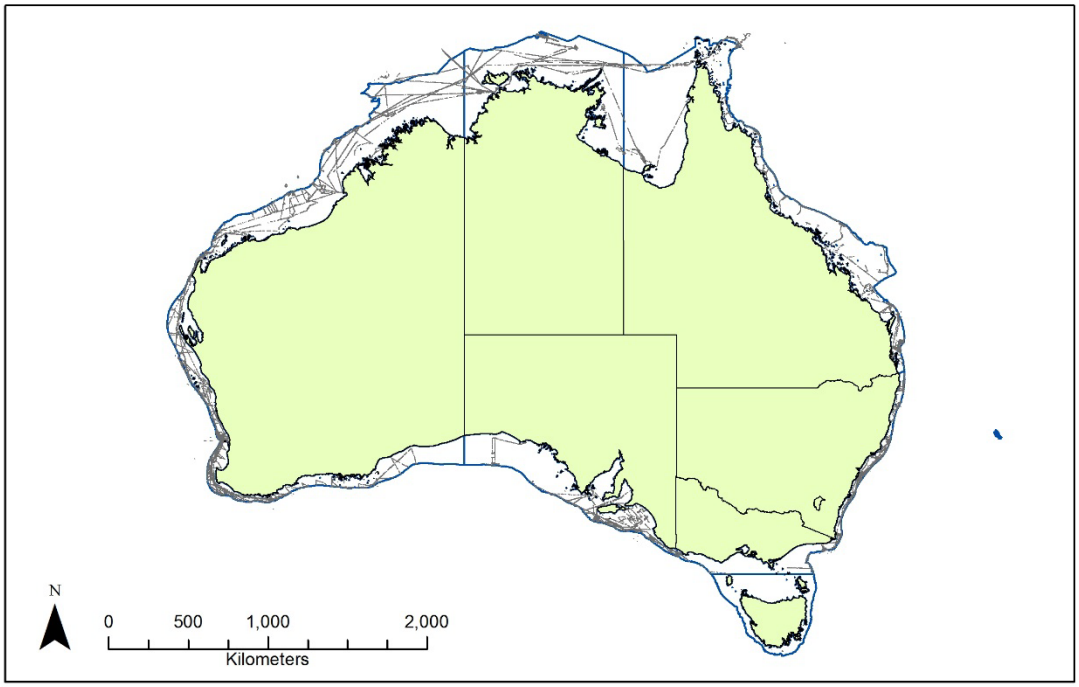
Custodian	Number of data products supplied
Centre for Marine Futures (UWA)	11
Department of Environment, Water and Natural Resources (DEWNR), South Australia	1
Geoscience Australia (GA)	17
Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	14
Northern Territory Government (NTG)	1
Office of Environment and Heritage (OEH), New South Wales	6
School of Life and Environmental Sciences (LES), Deakin University	1
Total data products compiled	**51**

An example of the classes that have been compiled into the reef spatial data product from Geoscience Australia include: geomorphic sponge habitat, geomorphic features with sponge, Jervis Bay Reefs and Lord Howe Shelf reefs. Although not always directly classified as “reef” if the mapping data alluded to reef being present (e.g. sponge communities, which require hard substratum to present for attachment) then it was assigned a reef attributes in the Tier 1 data product.

3.2 TIER 2 data extraction

TIER 2 data was generated from the collation and reprocessing of CSIRO's acoustic bathymetric data holdings on the continental shelf (Figure 4).

Figure 4. CSRIO acoustic survey data within the continental shelf region (0- 200 m water depth).



The CSIRO multibeam echosounding (MBES) acoustic bathymetric data holdings have not previously been extracted or processed at a national scale for seafloor habitat mapping purposes. Therefore, for the D3 project the bathymetric data required a mix of extraction of raw multibeam sonar data from shelf waters, processing to 5 m resolution and subsequent post-processing to extract seafloor features that would infer the presence of reef-like structures. It is important to note that these reef-like structures have not been validated with appropriate ground truthing to identify conclusively that they are hard substratum.

The CSIRO multibeam swath on the continental shelf data were exported from MB-Systems software as 702 half-degree asci grid tiles. Each 0.5-degree tile was converted to a grid at 5 m resolution – and sliced vertically (again at 5 m). The resultant sliced grid was then converted to a shapefile. An algorithm written in Python was applied to each shapefile to isolate higher polygons (potential reefs) (Appendix B).

Each sliced depth band from 0 m (coastline to 200 m (shelf edge) was iterated through in 5 m increments. On every depth band all polygons (representing a feature) were selected. Polygons that were deeper (in the depth band) were deleted. On completion of this iterative process higher features were isolated.

This algorithm was originally used to isolated high features in the AHO S57 data format where it performed well given the nature of the format and file structure. A major drawback

with this approach and treatment of data is that it was largely collected by a system (EM300) that was ill-equipped for data acquisition at depths on the continental shelf. Therefore, there is a high-likelihood that noise from areas with poor-quality data will have led to artefacts in the algorithm, resulting in the presence of "reef" being over estimated. Typically, for more accurate estimations of reef coverage, backscatter data would have been used in addition to bathymetry data to improve predictions, however, a national backscatter output was not able to be generated within the timeframe of this project. Producing such a product remains a priority action for improved knowledge from currently held MBS datasets.

3.3 TIER 3 data extraction

The creation of Tier 3 data involved the extraction of AHO S57 data to a shapefile format. AHO S57 data is the official vector electronic chart produced to the standards of the International Hydrographic Organisation (IHO). It is a digital databased of all the objects (points, lines and polygons) represented on a chart. A variety of different AHO S57 attributes were extracted based on their relevance where the attribute defined a reef system. The Australian Hydrographic Offices' definition of a reef pertains to whether the feature is a danger to navigation and shipping, and therefore by habitat definition differs to the D3 classification of reef. It should be noted that any raised features in the AHO data could possibly be a reef even though not labelled as such.

The AHO has various data holdings of several resolutions including, 30°, 10° and 1°. The most suitable resolution providing both accuracy and national coverage (with exception of a section of the Great Australian Bight) was the 1° data structure. From this, the following data attributes were extracted (Table 3).

Table 3. Extracted datasets for S57 files. It should be noted that the suffixes of '_a', '_l' and '_p' indicate that the data are polygon, line and point features respectively.

Attribute	Definition
admare_a.shp	Administrative area
coalne_l.shp	Coastline
conzne_a.shp	Contiguous zone
depare_a.shp	Depth area
depcnt_l.shp	Depth contour
lndare_a.shp	Land area
m_qual_a.shp	Quality of data
pilbop_p.shp	Pilot boarding place
resare_a.shp	Restricted area
sbdare_a.shp	Seabed area
seaare_a.shp	Sea area
soundg_p.shp	Sounding
tesare_a.shp	Territorial sea area
unsare_a.shp	Unsurveyed area
uwtroc_p.shp	Underwater/awash rock

The extraction of points, lines or polygons from each of the AHO S57 files required a high degree of automation given the number of themes that each AHO S57 file contained. Each of these attributes was not consistent across the AHO S57 database, and therefore may or may not have represented any data holdings. The existence of data was dependant on the geographical location and the data collection method. To expedite processing the AHO S57 tiles on the continental shelf an automated procedure was employed, to extract, convert, construct and manipulate tiles. This was done using spatial tools within the open source GIS QGIS (http://www.qgis.org/en/site/) and GDAL (http://www.gdal.org/) software suites (Appendix B). From the AHO S57 layer SBDARA_a.shp (see http://www.s-57.com for full description) the records defined as rock (code #9) and coral (code #14) were extracted.

Three hundred and forty-three AHO S57 files were extracted, converted to shapefile format in order to achieve a national coverage on the Australian shelf. These individual shapefiles were then aggregated and common feature boundaries between adjacent tiles dissolved to make a seamless national shapefile that extends across the continental shelf. These data represented hydrographic surveys of the Great Barrier Reef- also provided by GRRMPA. The GBRMPA corals shapefile and reefs were merged together using the script in Appendix B to ensure that there was no 'double counting' of reef systems- mapped through this technique as opposed to the reefs already mapped from the sbdare_a shapefile.

3.4 TIER 4 data extraction.

TIER 4 was created utilising the bathymetric data in the AHO S57 database. This TIER indicates the probability of a reef being present based on a bathymetric analysis of the AHO S57 data layers on the continental shelf. The following attributes were utilised in this analysis (Table 4) using the algorithm in Appendix B. The use of depth by the AHO is not represented by proportional increments. Therefore, as reefs are identified at various depths, they may not be two-dimensionally proportional. The algorithm for extraction increments through the depth bands from the deepest to shallowest, and for each polygon that intersects or is contained within the selected depth band the polygon is retained, if it was deeper than it was deleted. The difference between the processed AHO data and the CSIRO data is the choice of selected depth bands. The AHO depths were processed in bands of AHO bathymetric depths: 1, 2, 5, 10, 20, 30, 50, 100, 200m. This created a reef layer of probability. Where the results overlapped (duplicates) with Tier 3 the results were not included in Tier 4.

Table 4. Tier 4 data labels extracted from the Australian Hydrographic Organisation (AHO) S57 charts.

Attribute	AHO labelled attribute	Definition
Depth area	depare_layer	This is a polygon layer that has drval1 (depth range value 1) and drval2 (depth range value 2) associated with each polygon. These give the shallowest and deepest depth associated with each polygon respectively.
Intertidal area	aho_intertidal	Intertidal areas were defined from the depth features that were between the coastline (LAT) and the zero isobath of the depth features area. Foreshore/littoral zone between high and low water. Positive depare_a interpreted as intertidal
Raised features	sbdare_a	Does not ensure that it is a 'reef' however, on comparison of results (between the raised features and seabed areas allocated as reefs (sbdare_a), there was a 100% capture of AHO allocated reefs. From raised areas are able to be extracted along with the intertidal area (vertical datum LAT). Depth area derived from this dataset was raised features and the intertidal zone. Extraction of raised features was done by isolating raised features and potential reefs.
Land area	Land area (lndare_a)	The land areas shapefiles were aggregated together and dissolved Land area complements the reef extraction by providing a coastline at lowest astronomical tide (LAT) datum. These were aggregated to one shapefile – LAT national coverage (Great Australian Bight from 1: 100k – grafted into AHO shapefile).
Seabed area	sbdare_a -> sbdare_reefs-only	Seabed area was although complementary to depth area some areas were actually defined as reefs AHO named reefs SBDARE

4. RESULTS

4.1 Mapping coverage

The total area of the Australian continental shelf between 0 m and 200 m is 2,148,140km^2. Not surprisingly, on a state-by-state basis, Western Australia has the highest area of shelf waters based on both coastal length and width of the continental shelf, while NSW, with a narrow shelf had the smallest (Table 5).

Table 5. Area of continental shelf waters by state boundary.

State	Area (Km^2)
NSW	37372
VIC	77500
TAS	104867
SA	223780
NT	404612
QLD	601734
WA	698275

Based on the higher quality data (i.e. Tiers 1-3), approximately 15 % (326,917 km^2) of Australian continental shelf waters have been mapped (Table 6). The AHO dataset represents that largest single holding of mapping data, as a percentage of total area mapped by survey type, which accounts for nearly 12 % of all mapping, followed by CSIRO 2 % and state mapping projects 1 % (Table 6).

Table 6. All reef-like mapping data collected on the shelf by Tier data source.

STATE	Total area of shelf (Km^2)	Tier 1 (Km^2)	Tier 2 (Km^2)	Tier 3 (Km^2)	Total area mapped	Mapped area as % of total area
VIC	77500.00	4935.07	1218.36	3091.58	9245.01	11.93%
WA	698275.00	4757.78	20295.21	35924.40	60977.39	8.73%
TAS	104867.00	4856.44	8904.37	3328.08	17088.89	16.30%
SA	223780.00	1546.48	4975.91	16204.75	22727.14	10.16%
NT	404612.00	2134.20	6177.88	63314.18	71626.26	17.70%
QLD	601734.00	6.47	6445.09	128671.49	135123.05	22.46%
NSW	37372.00	3598.65	4371.39	2158.72	10128.76	27.10%
Total area (Km^2)	2148140.00	21835.09	52388.21	252693.20	326916.50	
Total area as % of survey type		1.02%	2.44%	11.76%	**15.22%**	

New South Wales has mapped more of its state waters than any of the states (27 %), but also has the smallest area of all state waters (Figure 5). This is followed by Queensland where 22 % of its state waters have been mapped. The AHO have surveyed a greater proportion in Queensland waters (51 % of effort) followed by Northern Territory (25 % of effort) and Western Australia (14 % of effort) (Figure 6).

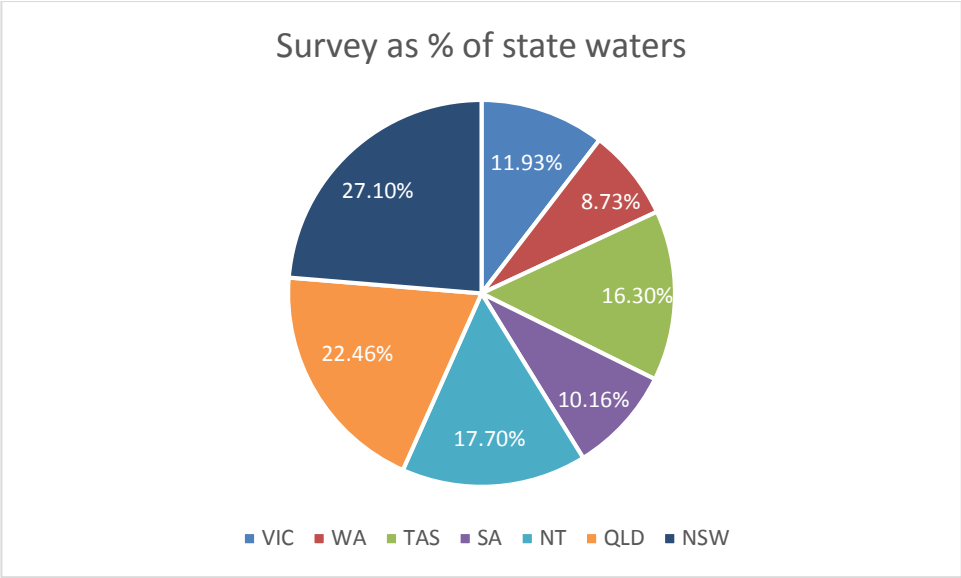


Figure 5 Survey as a percentage of state waters area.

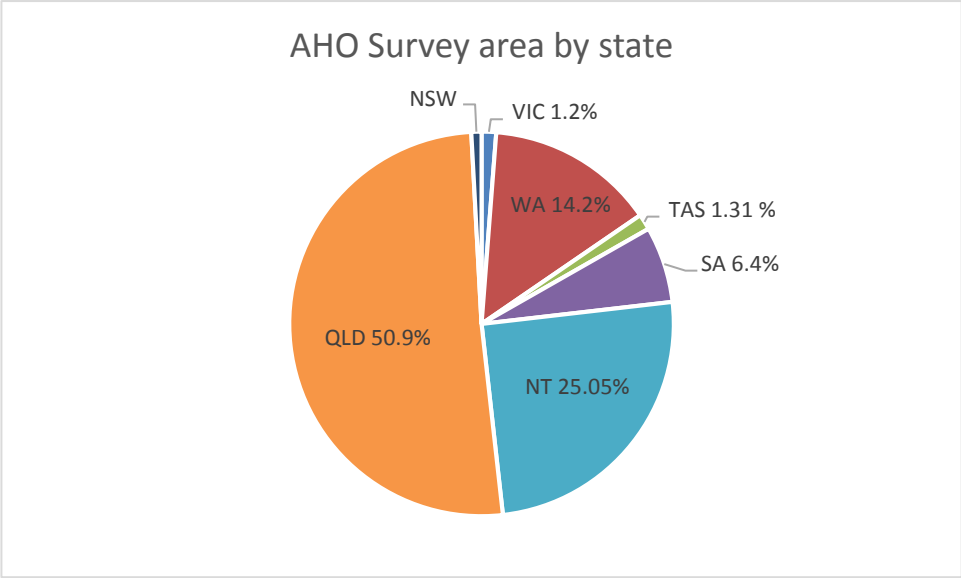


Figure 6. Australian Hydrographic Office survey by state.

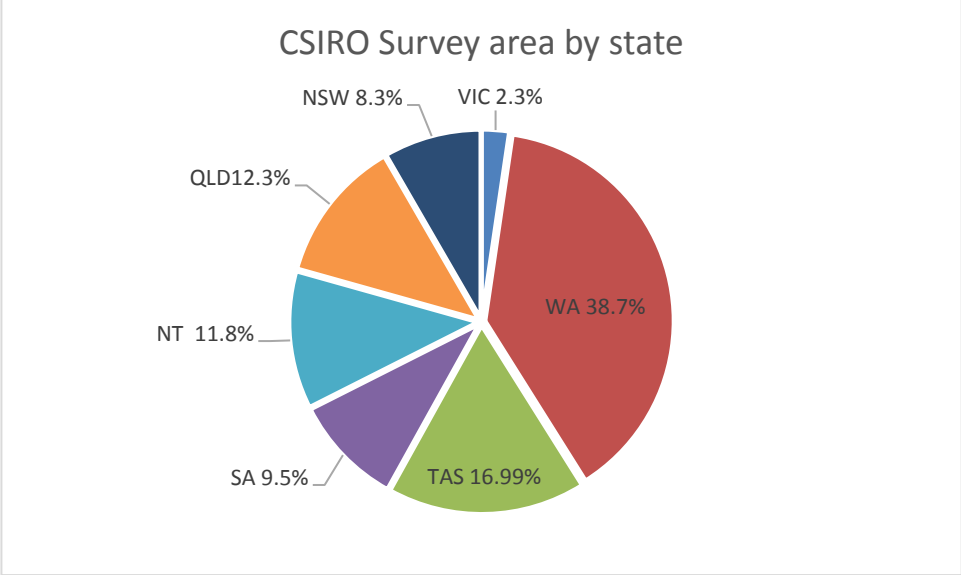


Figure 7. CSIRO survey by state.

CSIRO surveys have been mainly completed (inside of 200 m) in Western Australia (39 %) (Figure 7) and then proportionately across the other states and territory except Victoria which only represents 2 % of the effort in mapping data collected within the continental shelf region.

4.2 Reef-like habitat coverage

From all of the four tiers of data, 25 % of all substrata mapped was reef-like habitat (Table 7). Western Australia, followed by Queensland had the greatest proportions of reef-like habitat as a percentage of total mapping data in continental shelf waters (31 % and 29 %, respectively) (Table 7). Northern Territory, Tasmania and New South Wales have the lowest proportion of mapped reef-like habitat in continental shelf waters (Table 7).

The reef polygons are categorised by TIERS 1-4 representing their data source (and inherently the data resolution and accuracy of the data layer). Figure 8 shows the reef mapping spatial layer as individual classes of AHO reefs, or D3 reef probability predicted from AHO and CSRIO data sets across the north western region.

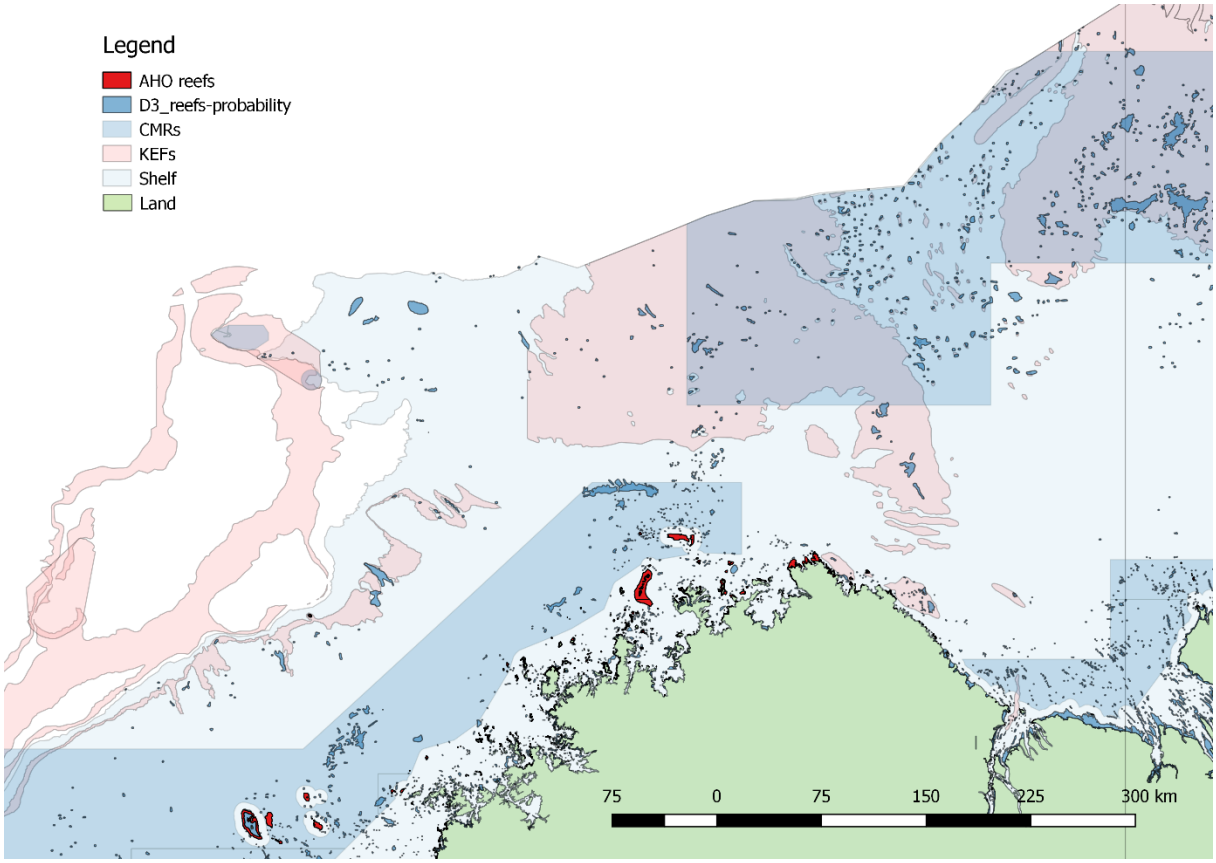


Figure 8. Map showing north western Australia with the AHO reefs and D3 reefs (TIER 2 and TIER 3) shown. TIERS 1-4 can either be visualised as one layer or separated by data source.

Table 7. Summary of mapped reef-like habitat by state.

STATE	Total area of shelf Km^2	Tier 1 (Reef) Km^2	Tier 2 (Reef) Km^2	Tier 3 (Reef) Km^2	Tier 4 (Reef) Km^2	Total (Reef) Km^2	Total reef area surveyed	Reef as a % of total surveyed area
VIC	77500.00	1073.42	81.71	37.17	1201.39	2393.69	9245.01	25.89%
WA	698275.00	1195.79	1947.07	2105.80	13481.86	18730.52	60977.39	30.72%
TAS	104867.00	690.13	529.72	156.07	1378.75	2754.67	17088.89	16.12%
SA	223780.00	1543.20	592.15	258.42	2587.65	4981.42	22727.14	21.92%
NT	404612.00	779.83	952.89	684.62	8750.20	11167.54	71626.26	15.59%
QLD	601734.00	0.04	927.25	27714.48	10331.40	38973.17	135123.05	28.84%
NSW	37372.00	1166.10	201.88	58.40	254.14	1680.52	10128.76	16.59%
Total (km^2)	2148140.00					80681.53	326916.50	
Total area as % of survey type								**24.68%**

Due to the scale of each of the reef products, it was not feasible to produce hard copy maps in this report, but these can be generated on request. A full copy of all maps for the CMRs will be available to download from the SeaMap Australia website at (http://www.seamapaustralia.org/). Appendix C contains a full list of all metadata records to the original data sets used in the creation of these maps. Appendix D lists the collaborators that supplied this data.

4.3 Mapping coverage inside Commonwealth Marine Reserves

Considerably less mapping has occurred within continental shelf waters inside CMRs, with just less than 10 % (9.94 %) of the seafloor within the continental shelf sections of CMRs being mapped (Table 8). Continental shelf waters CMR (< 200 m) within Cod Grounds, Jervis, Perth Canyon and Lord Howe were the most comprehensive mapped at 98%, 97%, 93% and 87% (Table 8). It should be noted that the total area of continental shelf waters represented within these four CMRs is, however, quite small (Table 8).

Of the six CMRs listed in the table below with no data only Cartier Island CMR falls outside of the 200 m shelf D3 reefs mapping zone. Dampier, Murat, Roebuck, Joseph Bonaparte Gulf and Southern Kangaroo Island do not have any AHO, CSIRO or Tier 1 data sets (Table 8, Table 9).

Table 8. Area and percentage of area of Commonwealth Marine Reserves (CMR's) mapped.

Commonwealth Marine Reserve	CMR Area Km^2	Total Area Mapped Km^2	% area of CMR mapped INSIDE 200m depth boundary
Abrolhos	11096.95	165.65	1.49
Apollo	1209.43	0.64	0.05
Arafura	23047.34	86.59	0.38
Arnhem	7475.92	201.70	2.70
Beagle	2995.35	1.91	0.06
Boags	553.96	0.00	0.00
Bremer	1560.69	69.62	4.46
Cartier Island	2.88	0.00	0.00
Central Eastern	2.15	0.00	0.00
Cod Grounds	4.00	3.90	97.65
Coral Sea	186.66	4.83	2.59
Dampier	1237.59	35.42	2.86
Eastern Recherche	5288.50	76.54	1.45
Eighty Mile Beach	10707.33	507.83	4.74
Flinders	818.52	31.77	3.88
Franklin	694.63	7.96	1.15
Freycinet	762.66	63.41	8.31
Gascoyne	2561.44	196.30	7.66
Geographe	964.76	39.40	4.08
Great Australian Bight	22704.68	119.30	0.53
Gulf of Carpentaria	24077.26	439.77	1.83
Hunter	1269.43	110.39	8.70
Huon	1878.45	36.87	1.96
Jervis	93.36	1.80	1.93
Joseph Bonaparte Gulf	8805.89	238.54	2.71

Commonwealth Marine Reserve	CMR Area Km²	Total Area Mapped Km²	% area of CMR mapped INSIDE 200m depth boundary
Jurien	1809.52	240.07	13.27
Kimberley	72170.06	2604.69	3.61
Limmen	1424.26	13.72	0.96
Lord Howe	309.44	0.00	0.00
Montebello	3376.76	52.11	1.54
Murat	923.18	2.20	0.24
Murray	4793.15	43.58	0.91
Ningaloo	1574.36	121.12	7.69
Oceanic Shoals	75235.29	4493.83	5.97
Perth Canyon	72.08	1.14	1.58
Roebuck	303.52	2.29	0.75
Shark Bay	7271.89	52.18	0.72
Solitary Islands	148.97	51.47	34.55
Southern Kangaroo Island	630.42	5.95	0.94
South-west Corner	11940.12	163.50	1.37
Tasman Fracture	967.60	26.35	2.72
Twilight	4571.76	14.00	0.31
Two Rocks	866.10	26.03	3.01
Wessel	6196.07	47.10	0.76
West Cape York	16853.19	99.59	0.59
Western Eyre	25890.48	136.91	0.53
Western Kangaroo Island	2335.44	35.21	1.51
Zeehan	746.07	54.47	7.30

Table 9. Area of reef mapped by Tiers 1- 4 for each of the Commonwealth Marine Reserves.

Commonwealth Marine Reserve	Km ^{2} reef mapped in tier 1	Km ^{2} reef mapped in tier 2	Km ^{2} reef mapped in tier 3	Km ^{2} possible reef mapped in tier 4
Abrolhos	0.00	45.70	0.00	121.70
Apollo	0.00	0.00	0.00	0.64
Arafura	0.00	82.39	0.00	4.19
Arnhem	0.00	3.56	0.00	198.41
Beagle	0.00	0.00	0.00	1.63
Boags	0.00	0.00	0.00	0.00
Bremer	1.19	6.70	0.00	0.00
Cartier Island	0.00	0.00	0.00	0.00
Central Eastern	0.00	0.00	0.00	0.00
Cod Grounds	1.07	0.00	0.00	0.73
Coral Sea	0.00	0.42	0.00	4.40
Dampier	0.00	0.00	0.00	35.42
Eastern Recherche	23.59	27.69	0.00	3.78
Eighty Mile Beach	0.00	1.20	0.00	506.63
Flinders	4.38	7.81	0.00	3.43
Franklin	0.00	6.19	0.00	1.77
Freycinet	0.00	17.30	0.00	0.30
Gascoyne	4.89	9.20	0.00	10.73
Geographe	3.18	1.51	0.00	1.18
Great Australian Bight	0.00	81.78	0.21	37.33
Gulf of Carpentaria	0.00	42.02	0.00	403.67
Hunter	18.00	16.13	0.00	6.66
Huon	0.83	31.75	0.00	3.56
Jervis	0.00	1.80	0.00	0.00
Joseph Bonaparte Gulf	0.00	0.00	3.51	235.04
Jurien	94.37	7.40	0.00	73.94
Kimberley	241.24	89.29	64.66	1451.59
Limmen	0.00	0.00	0.00	13.72
Lord Howe	0.00	0.00	0.00	0.00
Montebello	0.00	26.05	1.40	24.77
Murat	0.00	0.00	0.00	2.20
Murray	0.00	42.06	0.00	1.52
Ningaloo	0.07	3.37	0.00	4.98
Oceanic Shoals	662.95	151.17	0.00	2667.31
Perth Canyon	0.00	1.14	0.00	0.00
Roebuck	0.00	0.00	0.00	2.29

Commonwealth Marine Reserve	Km ^{2} reef mapped in tier 1	Km ^{2} reef mapped in tier 2	Km ^{2} reef mapped in tier 3	Km ^{2} possible reef mapped in tier 4
Shark Bay	0.00	45.01	0.00	7.38
Solitary Islands	7.87	0.03	0.00	1.35
Southern Kangaroo Island	0.00	0.00	0.00	5.95
South-west Corner	5.05	90.04	0.00	44.52
Tasman Fracture	6.31	24.03	0.00	0.34
Twilight	0.00	14.00	0.00	0.00
Two Rocks	0.00	21.34	0.00	4.69
Wessel	0.00	29.33	0.00	17.77
West Cape York	0.00	39.75	0.67	59.34
Western Eyre	0.00	5.07	0.00	131.84
Western Kangaroo Island	0.00	15.59	0.00	15.71
Zeehan	0.00	14.48	0.00	40.00

All of the data within the CMRs has been collated into individual QGIS data files that will be downloadable to the public and to the DoE. This will be available from the Australian CMRs Atlas (through developments in D1 Jan –June 2017) and also from the SeaMap Australia site when it is launched in July 2017. An example of the CMRs in south western Australia is shown in Figure 9 .

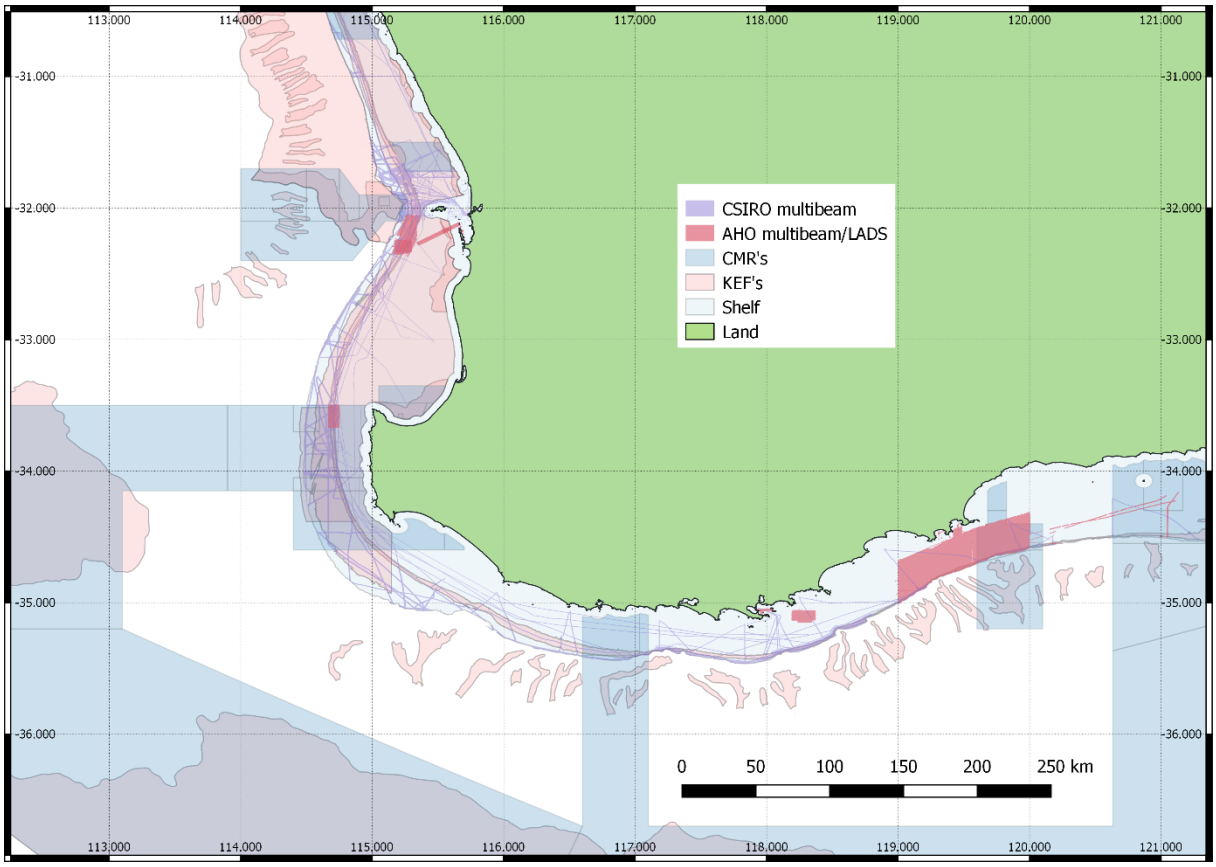


Figure 9. Example of the data summaries by acoustic data source (e.g. CSIRO multibeam, Australian Hydrographic Office multibeam or LADS), overlapped with key ecological feature (KEF), the Commonwealth Marine Reserve (CMR) boundary and the shelf boundary.

4.4 GIS-based collation of the underlying mapping data

As part of the data collation process for Project D3, 70 unique habitat mapping datasets have been collated (Appendix C). At least 50 of these will be published on the Australian Online Data Network (AODN) (with metadata generated for each), or in instances where data has been published elsewhere, linked back to the Project D3 record in the AODN. In addition to the "new" derived data product generated by D3 (national reef habitat map), the project has collated a vast body of existing data that was previously unpublished, and made it publicly available for discovery and download in a central searchable location.

A next phase of this project is to more specifically generate maps to visualise the extent and nature of mapping coverage within shelf waters of the CMR network, to identify the priority gaps in this coverage, and to collate associated biological data from temperate CMRs to improve our overall description of these areas. The results will be published through the report Monk et al. (2017); *Current knowledge of the status of Australia's Commonwealth Marine Reserves Network.*

5. DISCUSSION

This project has made a significant step forward in the collation and access to a wide range of mapping products held by a diverse range of research institutions across Australia, in addition to the Australian Hydrographic Office (AHO). Such a compilation was necessary to begin the process of quantitatively delineating the nature and extent of shelf reef habitats nationally, but perhaps more importantly, it was necessary to inform our knowledge of the very significant gaps in our understanding and mapping of these to assist in the prioritisation of future mapping programs. By compiling these datasets, and improving their discovery via links to these datasets on the AODN, we have made an important first step towards a framework for increases sharing and access to mapping data, to inform both the research and management communities.

For the central project focus of improving our understanding of the distribution of reef habitat across the shelf, the primary outcome has been the successful collation of 71 separate datasets to produce a single synthesis mapping product. This gives an indication of the likelihood of the presence of reef based on four tiers of data reflecting different levels of data density, type and validation. Access to the AHO data set provided us with 12% of the 15% of the overall mapping coverage of the continental shelf and therefore was an overwhelming contribution to this project. Despite this, only a small proportion of the AHO mapping was based on modern MBS mapping that may more reliably identify areas of seabed than historical sounding methods. Likewise, while MBES datasets contributed by CSIRO were used to generate estimates of reef coverage using automated processes, the lack of backscatter data, at times coupled with noisy bathymetry data, means that there remains an unquantified error in our estimates of reef cover that requires future validation. Indeed, even with the best quality MBES and backscatter data, differentiating low profile reef in areas prone to sand inundation can be very difficult as found during NERP Hub surveys in the Flinders CMR (Lucieer et al. 2013), hence certainty is highest in areas with high relief reef and good backscatter coverage.
It is also important to note that Tiers 2-4 represent inferred reef-like features, which may consist of sloping sediment bodies (such as edge of sand banks). Only Tier 1 data contains validated reef habitat, where mapping is accompanied with some form of accuracy assessment. Despite these short comings we determined that ~ 15% of continental shelf waters have been mapped, with the majority of this outside CMRs and typically in State waters as part of State mapping programs. Importantly, only 1% of the overall mapping is currently based on validated mapped using contemporary, peer-reviewed habitat characterisation methods (such MBES and towed video).

For the CMRs themselves, we identified three CMRs that remain entirely unmapped- Boags, Central Eastern and Cartier Islands, while a further 43 CMRs have < 5 % of their continental shelf waters mapped. As this mapping was rarely part of focussed campaigns to understand habitat distribution, a significant effort is still required to provide even the most rudimentary understanding of the nature of shelf habitats within them, including reef features. While a priority remains to focus mapping efforts on regions of CMRs where little or no mapping has been undertaken, this really applies to the vast majority of CMRs. Monk et al. (2017, in preparation) includes a synthesis of the current mapping within each CMR that can be used as a basis to assist in the prioritisation of such future surveys.

5.1 Outcomes of this project

The main project outcomes can be measured against the NESP research priorities for the Marine Biodiversity Hub.

1. *Develop and trial decision making tools that will support managers to define and prioritise management actions in Commonwealth Marine Reserves*.

   This research here has provided a robust baseline understanding of shelf reef systems (a Key Ecological Feature) and importantly their representation in the CMR network. This information is critical to evaluating the management actions within the CMR network necessary to adequately protect the ecological values of this KEF.

This project has delivered essential information on the physical assets contained within Commonwealth and adjacent State waters on the continental shelf; specifically, the location, extent and nature of rocky reef habitats within mapped areas, as these are currently poorly known. In addition, it has collated all available mapping data in shelf waters to place in perspective our understanding of reef extent in context with the limited available overall coverage of seabed mapping nationally. This information, gained through collation and analysis of existing data and targeted gap filling studies, is critical to development of management planning for CMRs, implementation of regional marine plans, and ensuring fisheries are managed on an ecologically sustainable basis (via links with the Australian Fisheries Management Authority (AFMA)). It identifies the types of assets that need to be managed, and by furthering our understanding of the regional variability in biological assets within these reef system, allows refinement and development of appropriate monitoring programs for CMRs and regional areas, providing information essential to adaptive management.

5.2 The value of this project

The project is the beginning of the process of identifying the values of the marine environment across the shelf. Currently, many shelf areas within the Commonwealth marine estate have little to no mapping, including within existing and newly established CMRs. By identifying physical assets and their underlying biological values, we have added significant measurable value to all aspects of this estate, including conservation values managed through the Department of Environment (DOE) and fisheries values managed through AFMA. Moreover, through refining and developing inventory and monitoring approaches through new surveys in the future and approaches to analysing acquired data, we will establish the mechanism through which these values can be benchmarked through time and tracked through State of Environment reporting using national standard approaches and collaboration around the nation.

Next steps:

In addition to the reef mapping, the overall collation and improved access to the datasets used in this project is a major step forward in the sharing of nationally important bathymetry datasets and the identification of gaps in these to assist in prioritisation of future surveys regardless of the end users.

Along the way, we have identified a range of significant issues that need addressing if this process is to be fruitful and efficient.

The first of these is data access. Whilst many research agencies are increasingly willing to share such data at varying levels of detail (from raw MBS data to processed xyz data, to post-processed habitat maps), we made no progress with regard to similar datasets held by consultants and industry, despite these being generated by Environmental Impact Studies (EIS) as part of environmental approvals. It is recommended that where bathymetry data is collected as part of mandatory EIS requirements, this data be generated at a minimum prescribed standard, be made publically available via a nationally agreed data portal, and with data stored on an appropriate national database.

The second issue is data standards. Currently bathymetry is derived from a range of sources including single beam sonar and multibeam sonar (or equivalent). The raw data generated from these systems is then usually post processed into data (xyz or similar) that is able to be utilised in GIS platforms. This is often then post processed to produce end products such as maps that cannot be further interrogated for the detail they contain. The agencies and organisations contributing to this project have provided data at various levels of this process, but where it is the latter, the data has limited value for use in GIS platforms to generate new mapping outputs. It is recommended that there is a national review of data standards by leading agencies to facilitate minimum standards, particularly for new MBS data acquisition. As a minimum, it would be ideal for xyz data to be made available at the best resolution of the system in use, and at best, a protocol be in place for sharing of raw sonar outputs and associated ship files, such that end users could process the data at the resolution required for a particular need, rather than the resolution at which a particular agency decides to supply.

Related to data standards is the acquisition of backscatter information. Historically, some agencies have not collected MBS derived backscatter data, both because of storage issues relating to the volume of data generated, and a focus on describing bathymetry rather than habitats in shelf waters. However, with an increasing focus on the need to understand the nature of such habitats, particularly within CMRs, backscatter information is critical to full interpretation of bathymetry data, particularly with respect to seabed hardness. It is recommended that future acquisition programs collect backscatter data wherever possible and national data storage facilities include the capacity to store such information for subsequent post-processing where required.

The third issue is data storage. Currently there is no single central facility for storage of bathymetric data, particularly high resolution MBES datasets. Some information is held by the AHO, some by CSIRO, some by Geoscience Australia (including deposits by other agencies), some by state agencies, and some by universities. There are also indications that some valuable MBES datasets have been deleted once post-processed products have been developed to save storage space. While this project has identified many of these datasets, and can point to them via AODN metadata records, it has not had the resources, or agency permission in several cases, to make all of these datasets available from one location for easy access by end users. While an initial aim of the project was to make such data more accessible by hosting copes of major datasets (gridded xyz data and/or post-processed polygon-based GIS files), the issue of data access permissions precluded the availability of several major datasets at the time. Despite this, most major data holders are now moving to open public access, and this data is likely to be available in the near future and accessed via metadata on the AODN portal. Now that such data access issues are becoming resolved, there is a significant need, and real opportunity, to develop an agreed national storage and archive that can safely hold all the nations mapping products from raw sonar data to post-processed products. It is recommended, that as a priority, all agencies engaged in seabed

mapping and management agree on an appropriate national facility and provide the support to get it operational.

The final issue is data visualisation, while this project has collated the majority of the national mapping datasets (excluding AHO MBS data at this stage), and we are able to generate specific area/scale maps for core stakeholders such as Parks Australia on request, as there is currently no way, other than agency staff developing significant GIS expertise, that most agencies and individuals could easily interrogate current mapping datasets as needed. Historically some tools have been developed for access to post-processed maps, including the excellent but outdated CSIRO developed viewer of National Facility-based MBS and backscatter data (http://www.marine.csiro.au/geoserver/index.html). However, there is no tool that synthesises all the existing data available across agencies and is up to date with available data, nor one that can be used to generate new maps at scales appropriate to the question of interest, including at the finest scale that data can be made available, and the ability to rescale depth information to reflect the gradient in the area of interest. It is recommended that significant investment be made in the parallel development of a national data storage and access facility for bathymetric data, and the necessary tools for visualisation and manipulation of this data at multiple spatial scales. Such tools are readily within the reach of existing technology.

5.3 Future mapping

Whilst this project was nominally focussed on developing our understanding of reef systems around Australia (and the current gaps in this knowledge), by default it also collated data on all forms of marine habitat mapping along the way that can be readily used to identify existing gaps across a range of habitats, depths and jurisdictions. For the majority of Australian shelf waters the overall gaps are so significant that there are no clear guidelines for prioritisation of future surveys based on infilling these. While state agencies in some areas (notably NSW and Vic) have made significant progress in this area, the same cannot be said for commonwealth waters on the shelf. The vast majority of mapping in this areas has been along the shelf break and slope, leaving a substantial gap between there and state waters. The new CMR network offers a real opportunity to address this, by providing both a bioregional framework on which to structure an ongoing program, and a significant management driver-the need to understand the assets within each CMR to ensure management plans are adequate. This study has shown quantitatively that the existing mapping within the vast majority of CMRs on the shelf is typically less than 5 %, and occasionally completely absent. Given that most of this is also due to unplanned transits, or related to shelf-break mapping, it is currently completely inadequate to infer the extent and nature of habitats within these CMRs, or to provide sufficient information on which to base subsequent biological surveys. It is recommended that a priority for ongoing management of the CMR network be a focus on gathering sufficient mapping within each CMR to adequately characterise the extent and nature of key habitats within each, to underpin subsequent biological surveys. Given the extent of this task, a priority should be given to balanced regional representation of CMRs that may support nodes within national monitoring programs, and that through time, the remaining CMRs be mapped as part of an ongoing and sustained focus on understanding the shelf assets of both the CMR network and Australia's overall marine estate. This task would be significantly enhanced by closer cooperation and coordination between government agencies and the AHO, and a national focus on developing the capability to safely store, and share future mapping outputs.

6. CONCLUSION

In this project we have taken a stepwise approach to filling the knowledge gaps of where survey data has been collected to characterise continental shelf reef-like habitat around the nation. Into the future this database can be employed to further develop and refine appropriate survey and monitoring protocols to inform effective management of the commonwealth's marine estate. We have quantified the fact that such surveys are particularly sparse on the shelf, particularly in commonwealth waters and CMRs, and provide an information base on which to enable discussions on the future prioritisation of such information needs.

The project has made significant inroads towards building collaboration across agencies to share habitat mapping data for the public good, as well as furthering discussions on mechanisms to making data more widely available, In addition to data access (IP vs open access), we have made a number of recommendations relating to the need for data standards, central data storage, and tools for data visualisation. All of these recommendations are readily achievable, and discussions are progressing on all fronts, including visualisation of much of the data collated through this project by the AODN via its SeaMap Australia project (in development). Successful adoption of the recommendations will significantly enhance the planning process for future surveys across all jurisdictions and management needs, as well as the uptake of such information into future spatial management. Critically, if the CMR network is to form the backbone of a national integrated monitoring program that includes shelf waters, these processes, and the information generated by appropriately targeted surveys, are going to be essential to underpin planning of biological surveys to ensure they are regionally relevant and representative of important habitat features.

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APPENDIX A

A targeted baseline survey of the Hunter Commonwealth Marine Reserve was conducted as part of research within Theme D of the NESP Marine Biodiversity Hub. We refer to the report by (Davies 2016). This NESP funded priority survey was conducted in December 2015 and January 2016 to identify the key reef features within the Hunter CMR (Figure A1)

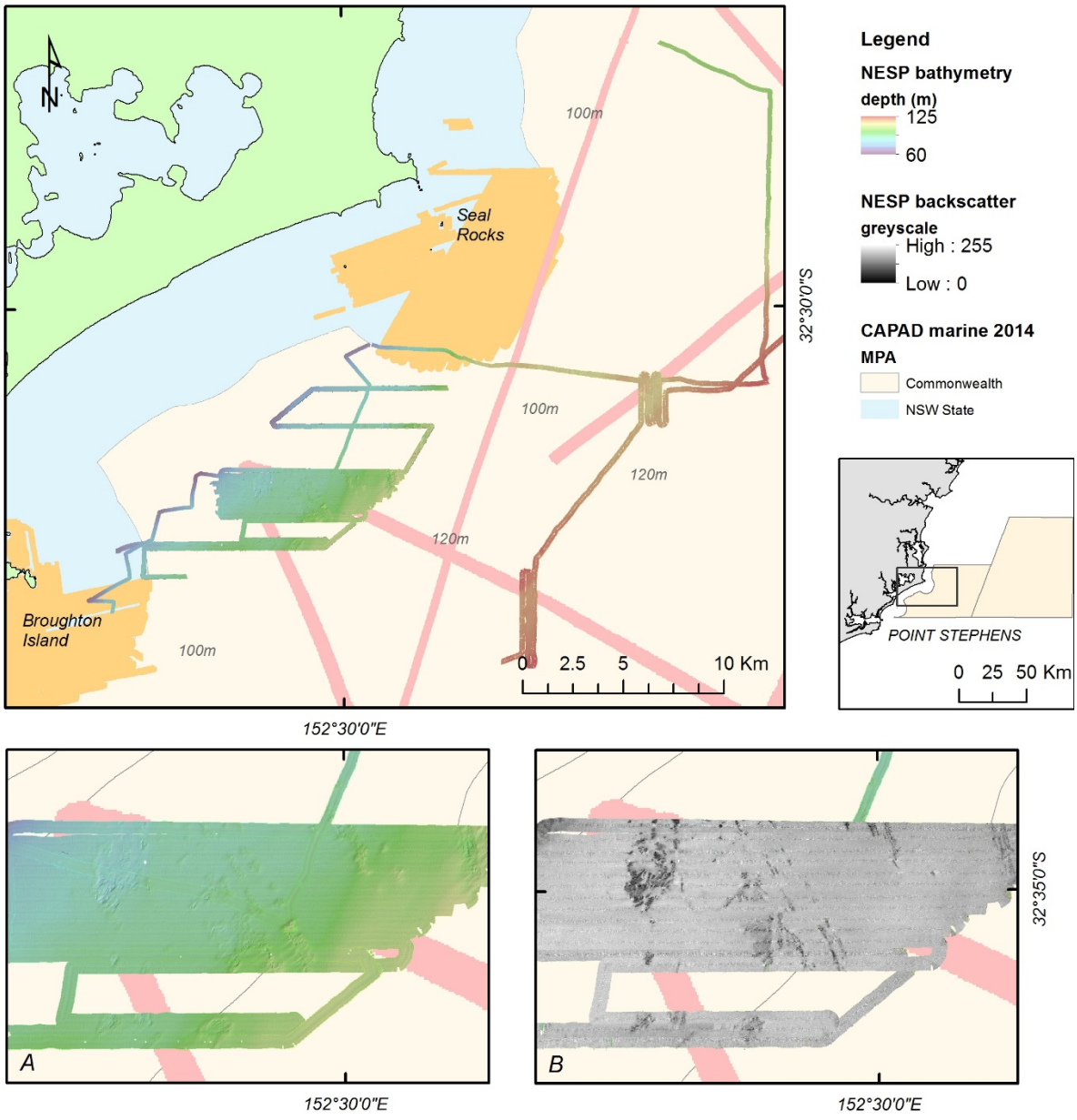

Figure A1. Map showing the NESP collected acoustic data from a survey within the Hunter CMR in 2015/16.

APPENDIX B

Python script used for extracting reef-like features from the CSIRO and Royal Australian Navy bathymetric data products.

```
from qgis.core import *
import qgis.utils
import processing
import time
import os


#LIST LAYERS IN QGIS PROJECT
##-------------------------
print "Layers in project..."
for layer in QgsMapLayerRegistry.instance().mapLayers().values():
    print layer.name()
    #inputlayer = QgsVectorLayer("/home/rick/Share/scratch-
csiro/scratch/%s" % (layer), "%s" % (layer), "ogr")
    #selectlayer = QgsVectorLayer("/home/rick/Share/scratch-
csiro/ss%s.shp"% (d), "ss%s.shp" % (d), "ogr")
    inputlayer = layer
    print inputlayer.name()
    print c
    name = layer.name()
    ##SET ACTIVE
    ##-----------
    qgis.utils.iface.setActiveLayer(inputlayer)
    qgis.utils.iface.zoomToActiveLayer()

    if os.path.isfile('%s' % dir + 'g'+'%s' % name + '.shp'):
        print '%s' % dir + 'g'+'%s' % name + '.shp' + '....exists'
    else:
        print '%s' % dir + 'g'+'%s' % name + '.shp'  + '....not
exists'
        for d in range(-210, -5, 5):
            print d
            print '------------------------'
            print 'Processed....'+'%s' % c
            print '------------------------'
            print time.strftime("%Y-%m-%d %H:%M")
            processing.runalg('qgis:selectbyexpression', inputlayer,
'GRID_CODE = %s' % (d), 0)
            print '     Selected features...'

            print '------------------------'
            print 'Processed....'+'%s' % c
            print '------------------------'
            processing.runalg('qgis:saveselectedfeatures',
inputlayer, '%s' % dir + 'ss'+'%s.shp' % d)
            print '     Saved features...'
```

```
            selectlayer = QgsVectorLayer('%s' % dir + 'ss'+'%s.shp'
% d, 'ss%s.shp' % d, "ogr")
            print selectlayer.name()
            print inputlayer.name()
            QgsMapLayerRegistry.instance().addMapLayer(selectlayer)

            print '------------------------'
            print 'Processed....'+'%s' % c
            print '------------------------'
            processing.runalg('qgis:selectbylocation', inputlayer,
selectlayer, u'touches', 1)
            print '     Selected by touch...'

            processing.runalg('qgis:selectbyexpression', inputlayer,
'GRID_CODE >= %s' % (d), 2)
            print '     Targeted deeper features...'


QgsMapLayerRegistry.instance().removeMapLayer(selectlayer.id())

            #SELECTLAYER Shapefile removal
            #-------------------------------
            #file = '/home/xx/Share/scratch-csiro/scratch/ss%s.' % d
            file = '%s' % dir + 'ss'+'%s.' % d
            exts = ['shp','shx','dbf','prj','qpj']
            for ext in exts:
                print '%s' % file + '%s' % ext
                if os.path.isfile('%s' % file + '%s' % ext):
                    os.remove('%s' % file + '%s' % ext)

            ##DELETE ALL - VECTORISED - works
            #-------------------------------
            inputlayer.startEditing()
            selection = inputlayer.selectedFeatures()
            ids = [f.id() for f in selection]
            inputlayer.dataProvider().deleteFeatures(ids)
            inputlayer.commitChanges()
            print '     Features deleted...'

        processing.runalg('qgis:selectbyexpression', inputlayer,
'GRID_CODE > -100000', 0)
        processing.runalg('qgis:saveselectedfeatures', inputlayer,
'%s' % dir + 'g'+'%s' % name)
        c = c + 1
```

APPENDIX C

Spatial data contributions to the D3 project and associated metadata links

Data collection no.	Metadata title	Region	Metadata URL	Intellectual Property owner	Custodian
1	Seabed environments and shallow geology of the Leveque Shelf, Browse Basin, Western Australia - interpreted geomorphic map	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=fefed6a4-2284-333c-e044-00144fdd4fa6	Geoscience Australia (GA)	Geoscience Australia (GA)
2	Oceanic Shoals Commonwealth Marine Reserve (Timor Sea) Biodiversity Survey (GA0339/SOL5650) - Interpreted Geomorphic Map	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=23c589ee-e3d9-c448-e053-10a3070abc3f	Geoscience Australia (GA)	Geoscience Australia (GA)
3	Petrel Sub-basin Marine Survey (GA-0335 / SOL5463) (NLECI Program) - interpreted geomorphic map	NT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=fefe36ac-f4fc-5eae-e044-00144fdd4fa6	Geoscience Australia (GA)	Geoscience Australia (GA)
4	Carnarvon Shelf Reef Polygons	WA	http://www.ga.gov.au/metadata-gateway/metadata/record/101464	Geoscience Australia (GA)	Geoscience Australia (GA)
5	Browse Shelf Reef Polygons	WA	http://www.ga.gov.au/metadata-gateway/metadata/record/101465	Geoscience Australia (GA)	Geoscience Australia (GA)
6	Jervis Bay Reef Polygons	NSW	http://www.ga.gov.au/metadata-gateway/metadata/record/100680	Geoscience Australia (GA)	Geoscience Australia (GA)
7	Vlaming Shelf reef polygons	WA	http://www.ga.gov.au/metadata-gateway/metadata/record/101463	Geoscience Australia (GA)	Geoscience Australia (GA)

Data collection no.	Metadata title	Region	Metadata URL	Intellectual Property owner	Custodian
8	Seabed Habitat New South Wales State Waters	NSW	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=78096d8e-66d7-4644-bf1c-4cf3261f0204	Office of Environment and Heritage (OEH), NSW Government	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
9	Darwin Harbour marine habitats	NT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=2e754ed7-caab-4640-a133-5ead9e077edb	NT Government	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
10	SA DEWNR - State Marine Benthic Habitats - South Australia	SA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=cbe02d9e-2450-4364-ad76-c1d27f030943	Department of Environment, Water and Natural Resources (DEWNR), SA Government	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
11	SeaMap Tasmania Habitat Data	TAS	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=7a6751e0-1ad5-11dc-9e36-00188b4c0af8	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
12	Marine Futures Project - Abrolhos Islands - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=7dfa419a-f641-4f3c-9e31-d6030e0f45b2	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
13	Marine Futures Project - Broke Inlet - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=0ec64a97-1128-46a6-9417-6ef4964a00c7	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
14	Marine Futures Project - Geographe Bay - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=275f62b0-0b6c-4514-90c7-deeae423ab23	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
15	Marine Futures Project - Jurien Bay - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=cf19f228-16b9-4cc2-9852-de02933718dc	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
16	Marine Futures Project - Middle Island - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=2ec08dd9-a409-4451-bc81-509fedae2bff	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)

Data collection no.	Metadata title	Region	Metadata URL	Intellectual Property owner	Custodian
17	Marine Futures Project - Mount Gardner - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=1d6c8927-55b9-42f3-84c3-9eea559482a1	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
18	Marine Futures Project - Point Ann - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=595c11cf-5427-4dd3-a1a7-0b6eb4f3a158	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
19	Marine Futures Project - Rottnest Island - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=b718e793-3773-47da-97e6-f176a1f7d9af	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
20	Marine Futures Project - Southwest Capes - reef habitat	WA	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=7c1fe290-727d-441a-b2a9-8bf4d52782d8	Centre for Marine Futures (UWA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
21	Great Barrier Reef Features	QLD	http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=33b58caf-6dab-4c2f-84d3-9a4db064664f	Great Barrier Reef Marine Park Authority (GBRMPA)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
22	Index of Australian Hydrographic Office (AHO) 1 degree, 10 degree and 30 degree S57 files for Australian EEZ	NAT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=91a344bf-e55f-4747-826c-70190780947b	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
23	State boundary area of the Australia continental shelf (including Lord Howe Island)	NAT	http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=15cf5eeb-0899-4e8a-bbd2-d3c904940bd4	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
24	Contours (1m and 5m interval) of the Australian continental shelf and Lord Howe Island shelf	NAT	http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=e9624e55-1a14-4267-a8b1-12652e1e33b2	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)

Data collection no.	Metadata title	Region	Metadata URL	Intellectual Property owner	Custodian
25	Depth areas on the Australian continental shelf and Lord Howe Island shelf derived and aggregated from Australian Hydrographic Offices (AHO) depth area features in the 1 degree S57 file series	NAT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=29135c1e-697f-4e24-9118-367bd17be81b	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
26	Intertidal area of the Australian continental shelf and Lord Howe Island shelf derived and aggregated from Australian Hydrographic Office's (AHO) depth area features in the 1 degree S57 file series	NAT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=47338884-1f4f-4335-bc35-414370b815bd	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
27	Raised features on the Australian continental shelf derived and aggregated from Australian Hydrographic Offices (AHO) depth area features in the 1 degree S57 file series	NAT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=81fcb9e3-76fd-4c29-99ed-28ee411f75cb	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)

Data collection no.	Metadata title	Region	Metadata URL	Intellectual Property owner	Custodian
28	Australian land and coastline (including Lord Howe Island) at lowest astronomical tide (LAT) datum	NAT	http://catalogue.aodn.org.au/geonetwork/srv/en/metadata.show?uuid=358afb92-4977-4f9f-9c74-e66ad7a6c65a	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
29	Seabed area on the Australian continental shelf and Lord Howe Island shelf derived and aggregated from Australian Hydrographic Offices (AHO) seabed area features (sbdare_a) from the 1 degree S57 file series.	NAT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=f56d4f73-7444-4335-8c46-dce34db915f9	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)
30	Reef features on the Australian continental shelf derived and aggregated from Australian Hydrographic Offices (AHO) seabed area features (sbdare_a) from the 1 degree S57 file series	NAT	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=2e53d926-5d97-4997-b192-dc7dec66943d	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)	Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS)

APPENDIX D

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