Marine Biodiversity Hub

National Environmental Science Programme

Project D1– Ecosystem understanding to support sustainable use, management and monitoring of marine assets in the North and North-West regions - Final Report

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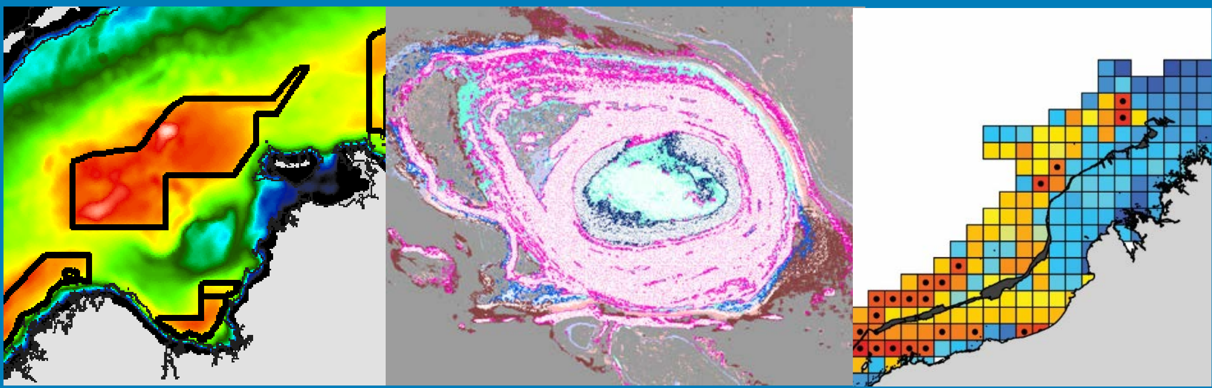

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EXECUTIVE SUMMARY

Effective management of marine assets requires an understanding of ecosystems and the processes that influence patterns of biodiversity. Project D1 of the NESP Marine Biodiversity Hub has been collating and synthesising existing data through 2015/16, focusing on Commonwealth Marine Reserves (CMRs) and Key Ecological Features (KEFs) of the North and North-west regions of Australia's marine estate, with three main objectives:

1. Increase the accessibility of existing research and data products to end users including managers, regulators and the general public
2. Identify knowledge gaps and develop strategies to address these
3. Improve ecosystem understanding of KEFS and CMRS through predictive modelling

Building on the North West Atlas (www.northwestatlas.org) as a communication platform, we collated 179 data sets for the North and NW Regions, and these are now accessible online. Targeted syntheses of knowledge for the Oceanic Shoals CMR and the Ancient Coastline KEF were used to demonstrate the value of this approach for informing marine planning and management and highlighting uncertainty.

Based on collated data sets, we undertook a formal gap analysis across CMRs and KEFs of the North and NW regions to identify those areas for which there exists sufficient data to underpin spatial predictive modelling in future years. Our results highlight the patchiness of available biophysical information, and large differences in coverage among taxa across the CMR network. We considered that the Kimberly CMR was the only area across the North and NW region for which existing data might underpin accurate spatial predictive modelling in the future. Our gap analysis did highlight CMRs and KEFs for which information coverage is greatest, as well as areas in which targeted empirical data collection would both inform future management and planning and enhance our capacity to use predictive models for ecological inference.

We used the Oceanic Shoals CMR as a case study for assessing the value of spatial predictive models in delivering knowledge of habitats and species distributions in remote, unsampled areas. We predicted the distribution of a range of biological and physical characteristics across the entire CMR, including benthic habitats, pelagic species, sponge diversity, and sediment type and hardness. This exercise shows the value of this approach for identifying assets in the marine estate where it is impossible to collect comprehensive data, and is a guide for stakeholders in identifying future data needs and tools required to adopt a similar approach nationally. The Oceanic Shoals predictive modelling example also provides a perspective on how modelling performance needs to be considered in the interpretation of predictive model outputs and maps.

Innovative science continues to support the effective management of Australia's marine estate. In addition to the data collation, synthesis and modelling, the Project D1 team has been developing a range of manuscripts for publication in the peer-reviewed literature. A summary of key findings and progress of eight papers that collectively value-add to past NERP and present NESP research in the North and NW Regions is provided. Novel science discoveries include the identification of pelagic fish hotspots, environmental predictors of flatback turtle behaviour, impacts of cyclones on turtle movements, and descriptions of potential biological and geomorphic values in the Oceanic Shoals CMR.

The work undertaken to date as part of Project D1 has created an easily accessible knowledge framework for the Oceanic Shoals CMR and the Ancient Coastline KEF that will directly inform the development of management and monitoring plans in these areas. We have demonstrated how spatial predictive modelling can be used to fill knowledge gaps and hence form a foundation for the evolution from precautionary management based on minimal information to more effective management based on a more rigorous scientific understanding of ecosystems. We also identified CMRs and KEFs where similar approaches can be implemented easily or with minimal additional investment in field data capture. The methods illustrated here for the North and NW regions provide a template for the application of similar approaches to other regions of Australia, where similar data are available or could be obtained, in particularly for supporting additional KEF characterisation and CMR monitoring and management.

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1. INTRODUCTION

Australia's North and North-West (NW) marine bioregions boast an array of highly diverse ecological communities. Together, they include 29 Key Ecological Features (KEFs) and over 250 species protected under the *EPBC* Act as threatened, migratory or listed. The region also hosts large populations of megafauna, such as whales, turtles and sharks, some of which are endemic to the region (e.g. the flatback turtle which only nests in northern Australia). This diversity and conservation value is reflected in the Commonwealth Marine Reserve (CMR) network, with 21 reserves (out of 58 nationally) established across the North and NW.

The North and NW also support important cultural and economic activities. Traditional owners have deep connections to sea country in the regions. Modern activities include commercial and recreational fisheries, pearling and aquaculture, defence, shipping, petroleum exploration and production, with the latter encompassing Australia's most significant reserves of conventional oil and gas. Geopolitically, the North is Australia's closest continental connection to regional neighbours and the NW is positioned on the Indian Ocean rim. Ensuring ecologically sustainable use of this area is a major national challenge involving multiple government, industry and community stakeholders such as the oil and gas, tourism and fishing sectors, the Wildlife, Heritage and Marine Division of the Department of the Environment and Energy (DOEE), Parks Australia, Department of Industry, Innovation and Science, NOPSEMA, Department of Fisheries and other Commonwealth and State Government agencies.

As highlighted in the National Marine Science Plan 2015-2025, effective management of the marine estate, including the North and NW regions, requires baseline knowledge of assets, their inherent values and their current status. In addition, environmental compliance and risk mitigation across a range of industries (e.g. oil and gas, fishing, tourism) will be strengthened when areas at risk can be assessed in a broader bioregional context, including the rarity/uniqueness of habitats and natural levels of environmental variation.

Recognising the considerable investment in knowledge generation in the North and NW regions through programs such as CERF, NERP, WAMSI, IMOS and joint industry/government research collaborations, NESP Project D1 has been collating and synthesising prior knowledge to achieve three primary goals:

1. Improve access to information that can support decision-making as well as strengthen public engagement and understanding of the value of the marine environment in the North and NW Region through the Northwest Atlas (www.northwestatlas.org).

2. Identify key information gaps relevant to the management of the CMR network and that can be used to prioritise and plan future research activities.

3. Apply and refine existing models generated through CERF, NERP, WAMSI and elsewhere to enable predictions of the extent of benthic habitats, pelagic hotspots, seabed characteristics and connectivity across the Oceanic Shoals CMR. This location was selected as a suitable test case for this approach based on previous Science and Stakeholder Workshops (see Przeslawski et al 2015a, 2016).

This report summarises achievements in Project D1 through to December 2016, and serves as a foundation and example of how similar approaches can be applied in future years across other CMRs and priority areas to underpin the informed management of Australia' marine estate.

2. COLLATION OF AVAILABLE DATA FOR THE NORTH AND NORTH-WEST REGIONS

2.1 Context

A wealth of information exists for the North and NW Regions of Australia, but much of it is not available in a form that is easily accessible to scientists, managers or regulators. Furthermore, there are limited ways in which the public can engage with this information and understand the need for, and importance of, our marine assets and CMR network. As part of Project D1, we have been assessing the utility of existing data sets to inform spatial predictive modelling (see Section 4), and consequently, a diverse range of data has been collated for the North and NW Regions as Project D1 has progressed. In parallel with data collation for modelling we have also been increasing visibility and accessibility of these data sets through the Australian Institute of Marine Science's North West Atlas platform (http://northwestatlas.org/).

The North West Atlas was launched in 2015 through collaboration between AIMS and PTTEP Australasia. The North West Atlas is a web portal that facilitates access and sharing of information and also promotes biodiversity, heritage, value and the way of life for Australia's Northwest region. It is builds on the eAtlas platform; a system originally developed by AIMS to present environmental research data, promote collaboration, and support the work of management agencies, researchers, industries and community groups for the Great Barrier Reef. In a similar way, the North West Atlas provides the infrastructure and tools to promote free and open exchange of information to support science, policy making and public understanding of the Northwest region. AIMS continues to develop the platform, and a regional atlas focusing on the Northern region, and another focussed on MPAs around Australia, is currently under development.

2.2 Data sets provided via the North West Atlas

To date we have provided or enhanced access to 180 datasets through the North West Atlas as part of Project D1. These include 19 for which raw data are not accessible and hence data can only be provided as maps, for example, megafauna tracks and oil spill simulations for the Oceanic Shoals, and unpublished habitat models for Glomar Shoal, Rankin Bank and the various Montara shoals. An additional 64 unpublished datasets have been made viewable in the short term through interactive maps, until such time as they are published and fully accessible via the North West Atlas. Fifty-five additional datasets were already available for interactive use via either the North West Atlas or eAtlas, but access was further facilitated by creating relevant entries in the Interactive Map Gallery (northwestatlas.org/nwa/map/gallery). Finally, we made 42 datasets accessible via the interactive mapping services of the North West Atlas that were previously unpublished on-line in any form. The data sets provided, organised as four geographic categories (covering the entire N and NW region, Oceanic Shoals CMR, Glomar Shoal and Rankin Bank, Montara NW offshore shoals), are summarised in Table 2.1.

Our prioritisation process for delivery of data sets through the North West Atlas was to focus initially on those that would inform the predictive modelling components of Project D1 (see Chapter 4). We subsequently continued to identify and upload data sets as resources allowed, particularly to identify and make accessible relevant spatial data sets that describe the North and NW regions, with a particular focus on CMRs and KEFs. Data that either *will be*, *are planned to be*, or *could be* made available on the North West Atlas through Project D1 in future years are listed in the data delivery schedule (Appendix 1).

Table 2.1. Summary of datasets provided via the North West Atlas as part of D1

	N and NW regions gap analysis	*Oceanic Shoals interactive demo*	*Glomar-Rankin interactive demo*	*Montara shoals interactive demo*	*Total*
Viewable data not allowed to be published any other way	0	5	4	10	19
Viewable data not yet published any other way	0	33	8	23	64
Interact with data online more easily than was previously possible	0	55	0	0	55
Interact with data online that was not previously online	32	10	0	0	42
Total	32	103	12	33	180

2.3 How to interact with spatial data on the North West Atlas

Users can interact with spatial data on the North West Atlas in three basic ways, namely by: 1) creating one's own interactive maps, 2) accessing interactive maps through the Map Gallery and 3) accessing viewable maps and videos through interactive demos for specific regions.

2.3.1 Create your own interactive maps

Any dataset that exists on the North West Atlas can be viewed through the 'Create your own interactive map' link on the 'Interactive Map' menu. A bathymetry dataset is provided as a base data layer, and the user may select as many 'overlay layers' as desired from all the data on the North West Atlas (**Error! Reference source not found.**). This method provides the most flexibility, but may be time-consuming as it requires searching for relevant inputs through the entire database.

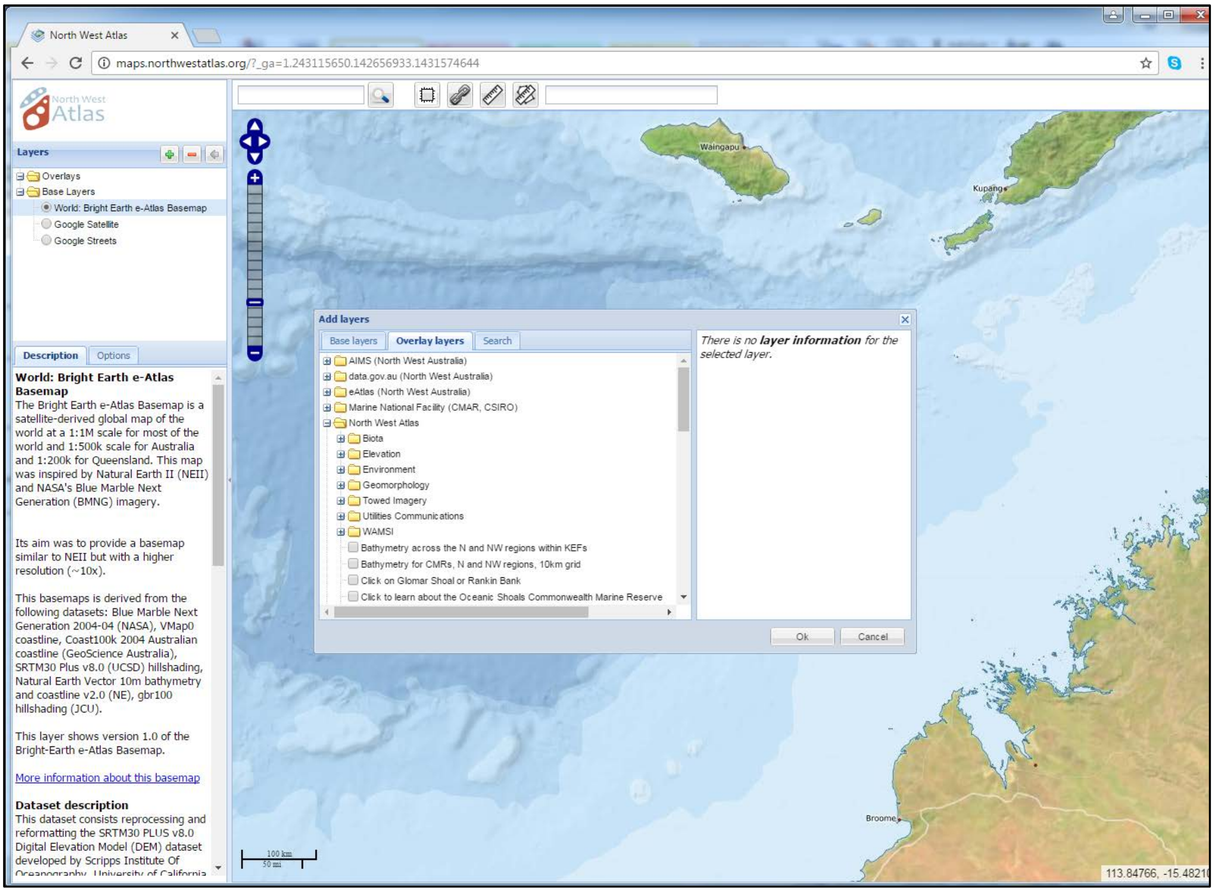

Figure 2.1 Using the 'Create your own interactive map' tool in the North West Atlas.

2.3.2 Interactive map gallery

To make spatial data that are already available on the North West Atlas easier to find, D1 researchers created an Interactive Map Gallery (http://northwestatlas.org/nwa/map/gallery – **Error! Reference source not found.**

Each entry in the Map Gallery provides a brief overview of the spatial datasets that are included and the embedded interactive map (Figure 2.3). Users can zoom in and out of the map and click on features to find out more within the entry, or click on the icon showing four green arrows to open the data inside the full interactive mapping interface. The latter offers additional functions such as distance measurements, selective viewing of data layers, and map construction.

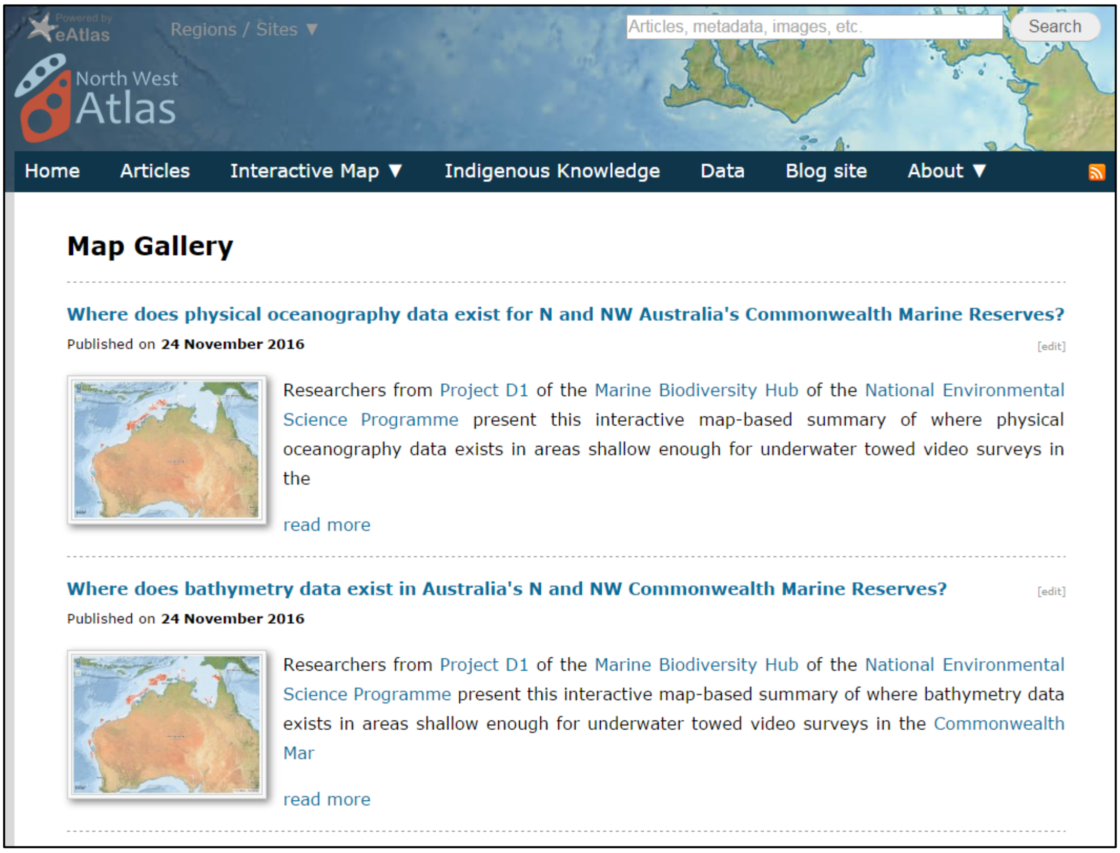

Figure 2.2 Example entries in the Interactive Map Gallery on the North West Atlas.

The number of entries in the Interactive Map Gallery has steadily grown (at 75 as of 19 May 2017), making it harder for users to find a map of interest. A search tool is available at the top right of the NW Atlas interface, but this requires that users know what they are looking for in order to be helpful.

To help users browse sets of entries around a common theme, links to subsets of the Interactive Map Gallery can also be found by clicking on the 'Interactive Map' item on the main NW Atlas menu (see above). These have been created so far for:

- Environmental briefings (NESP)
- North West Banks and Shoals of the Timor Sea (PTTEP)
- Glomar Shoal and Rankin Bank (Woodside)
- Oceanic Shoals CMR (NESP)
- N and NW Australia's CMRs and KEFs (NESP)

2.3.3 Interactive demos for specific regions of interest

Users may often want a summary of all that is known about a particular region of interest. To demonstrate the potential for packaging information to specific regions of interest, D1 researchers developed a comprehensive interactive demo for the Oceanic Shoals CMR (northwestatlas.org/node/1627). This extended similar but less substantial demos developed previously for Glomar Shoal and Rankin Bank (northwestatlas.org/node/1633) and the Montara Shoals (northwestatlas.org/node/1634). These are identified in the Interactive Map Gallery with the prefix ‘Synthesis’. Users can thus type ‘synthesis’ into the Search tool to find all the interactive demos that have been created.

In the Oceanic Shoals demo, users can click on individual fine-scale study areas to enable a menu of tabs, each with views of different data about the study area such as bathymetry, benthic habitats, geomorphology or wildlife abundance. A similar menu of tabs with links to all known published studies about the Oceanic Shoals region (‘Learn more’), and links to interactive maps (‘Explore spatial data’) of relevant datasets both within and outside the North West Atlas, can additionally be enabled by clicking on the entire CMR boundary. Some of the data viewable in the tabs are not published in any form elsewhere and cannot be disseminated any other way. This provides managers with access to key information (such as megafauna locations) that is vital for effective management, but challenging to acquire.

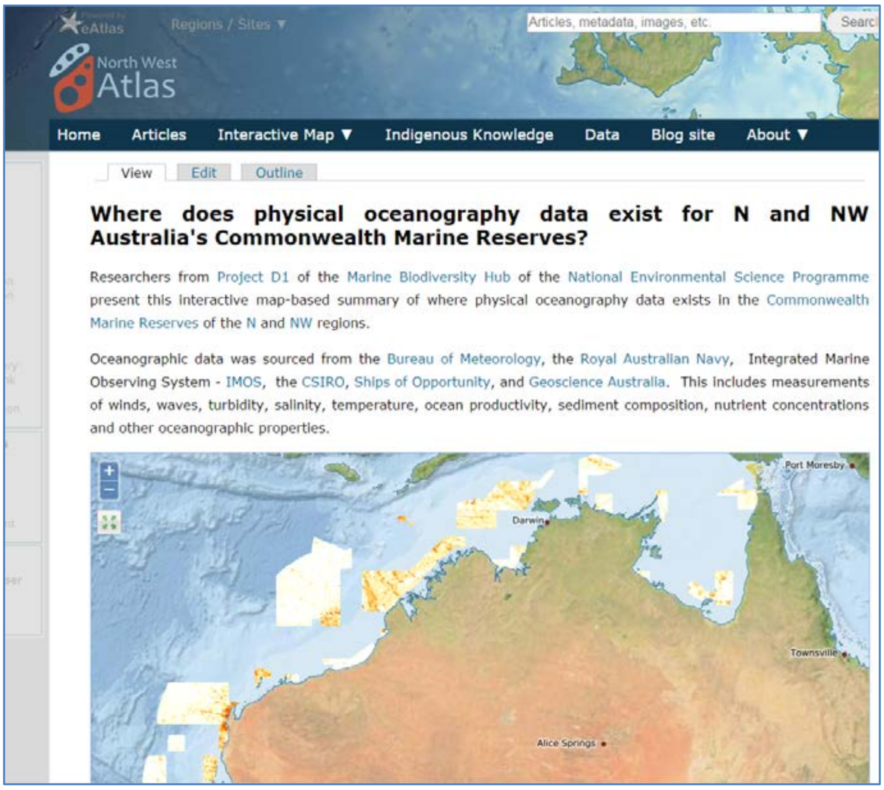

Figure 2. 3 Example of an entry in the interactive Map Gallery on the North West Atlas.

By late 2017, these interactive demos will be migrated from their current 'clickable tabs' format to a large map page with scrollable content on the side of the page. This will make them much easier to interpret and use. It will also make them more reliable by avoiding Java scripts which sometimes lead to problems like content failing to appear when you initially click on it.

2.3.4 Indigenous Knowledge

Recognising the importance of Indigenous knowledge and engagement in the North and NW Regions, and in response to the outcomes of the Stakeholder Workshop held as part of Project D1 in 2016 (Przeslawski et al 2016), we also incorporated a range of interactive maps and spatial layers relevant to Indigenous sea country management, summarised within a general article (northwestatlas.org/node/1707).

Interactive maps provided include:

- Native title http://northwestatlas.org/node/1709
- IPAs http://northwestatlas.org/node/1703
- ILUAs http://northwestatlas.org/node/1704
- RATSIB http://northwestatlas.org/node/1705
- Preferred / alternative names http://northwestatlas.org/node/1706

Links to **approved Indigenous management plans** provided include those for:

- Western Australia http://northwestatlas.org/node/1707#WA_table
- Northern Territory http://northwestatlas.org/node/1707#NT_table
- Queensland http://northwestatlas.org/node/1707#QLD_table

2.4 Synthesis of available data for the Oceanic Shoals CMR

2.4.1 Overview

Australia's North and NW regions cover a vast area, within which 21 Commonwealth Marine Reserves (CMRs) have been declared. One of the largest of these is the Oceanic Shoals, covering more than 70,000 square km. Parks Australia is tasked with managing this vast estate, which ideally requires a solid understanding of the physical and biological assets that lie within the CMR. While various field surveys and scientific investigations have occurred in the Oceanic Shoals CMR (with highlights widely disseminated e.g. exploring-oceanic-shoals-commonwealth-marine-reserve-brochure-fact-sheet) data and outputs have not been summarised or collated for easy access and use by managers.

To address this need, researchers from Project D1 developed a prototype for assembling and communicating such data to researchers and managers via the AIMS North West Atlas for the Oceanic Shoals CMR (Figure 2.4). This area was chosen as a test case to provide proof-of concept of the approach, and because the Oceanic Shoals CMR is among the better studied in the North and NW Regions, particularly through efforts associated with the NERP Marine Biodiversity Hub (Nichol et al. 2013).

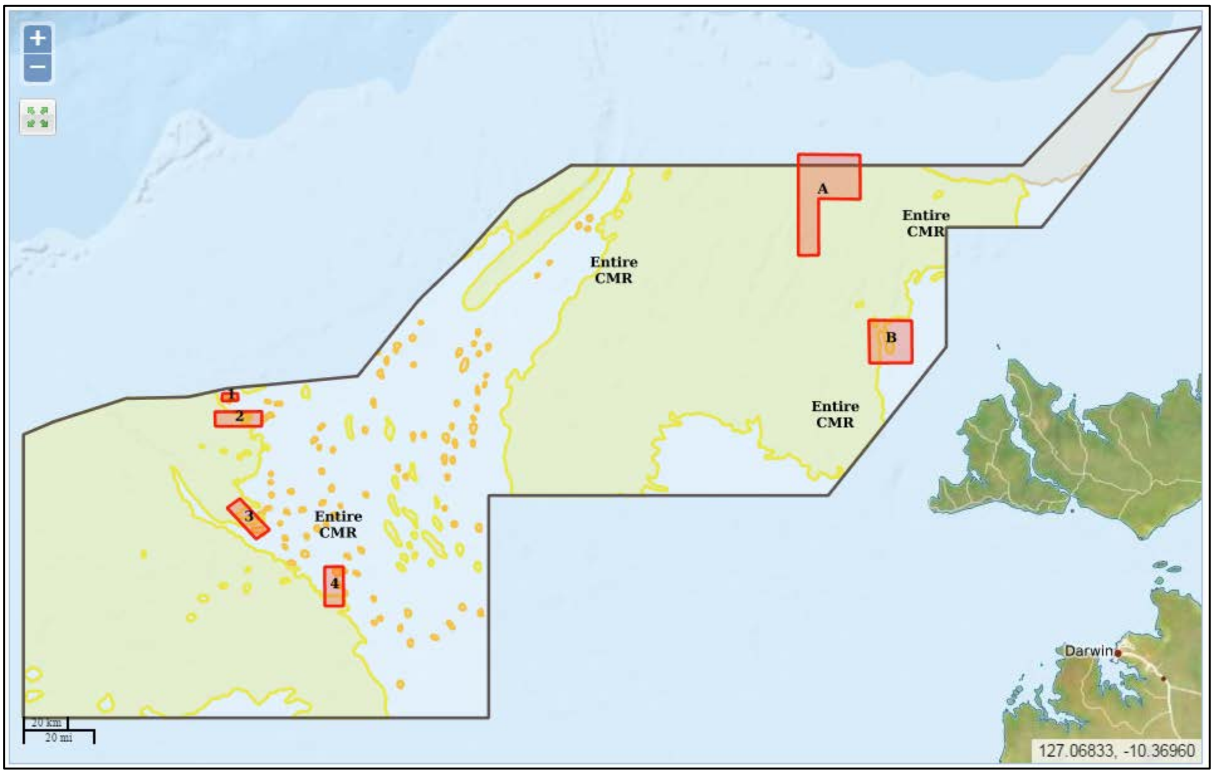

Figure 2.4 Interactive map interface for the prototype summary tool summarising the current state of scientific knowledge about the Oceanic Shoals Commonwealth Marine Reserve.

The Oceanic Shoals data summary prototype is available at northwestatlas.org/node/1627. It contains the following types of information:

- Links to maps, videos and descriptions of in-depth fine-scale field studies of parts of the CMR.
- Links to maps, videos and descriptions of broad-scale CMR-wide data.
- An extensive interactive map gallery of spatial datasets that cover the region.
- An extensive library of published literature that covers the region.

2.4.2 Fine-scale field studies

Each of the six fine scale study areas included in the prototype are shaded red in Figure 2.4. Clicking on any one of the fine scale study areas within the prototype causes a popup box to appear (Figure 2.5), which contains the following tabs:

- **About** - Summary of what is known about the study area's benthic communities and mobile fauna)
- **Depth** - High resolution bathymetry map
- **Geomorphology** - Map of key seafloor features + histogram showing the percent coverage of each geomorphological feature type
- **Example photos** – Photographs of key habitats and geomorphological types
- **What lives there?** – Detailed data on mobile fauna (relative) abundance
- **Key habitats** – Map of predicted/modelled benthic habitats
- **More** – Links to relevant reports and scientific literature

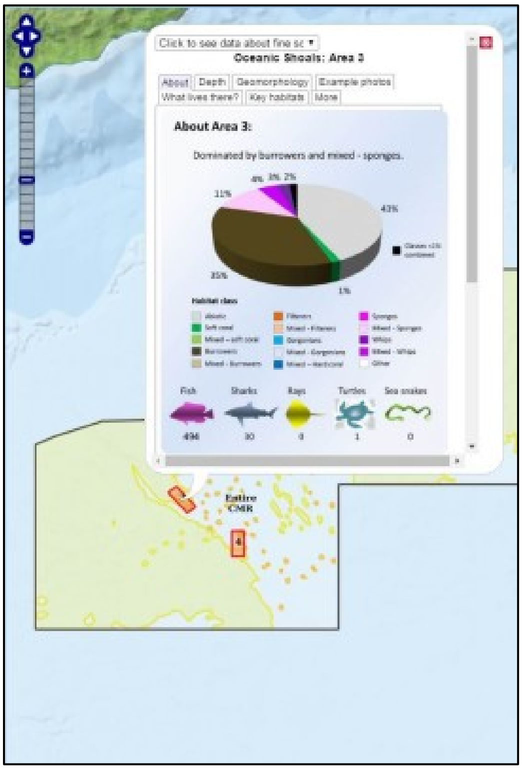

Figure 2.5 An example of the pop-up content available for each of the six fine-scale study areas in the Oceanic Shoals CMR prototype.

2.4.3 Broad-scale CMR-wide data

Clicking anywhere within the boundaries of the Oceanic Shoals CMR within the prototype causes a pop-up box to appear (Figure 2.6) which contains a range of more detailed information about the reserve.

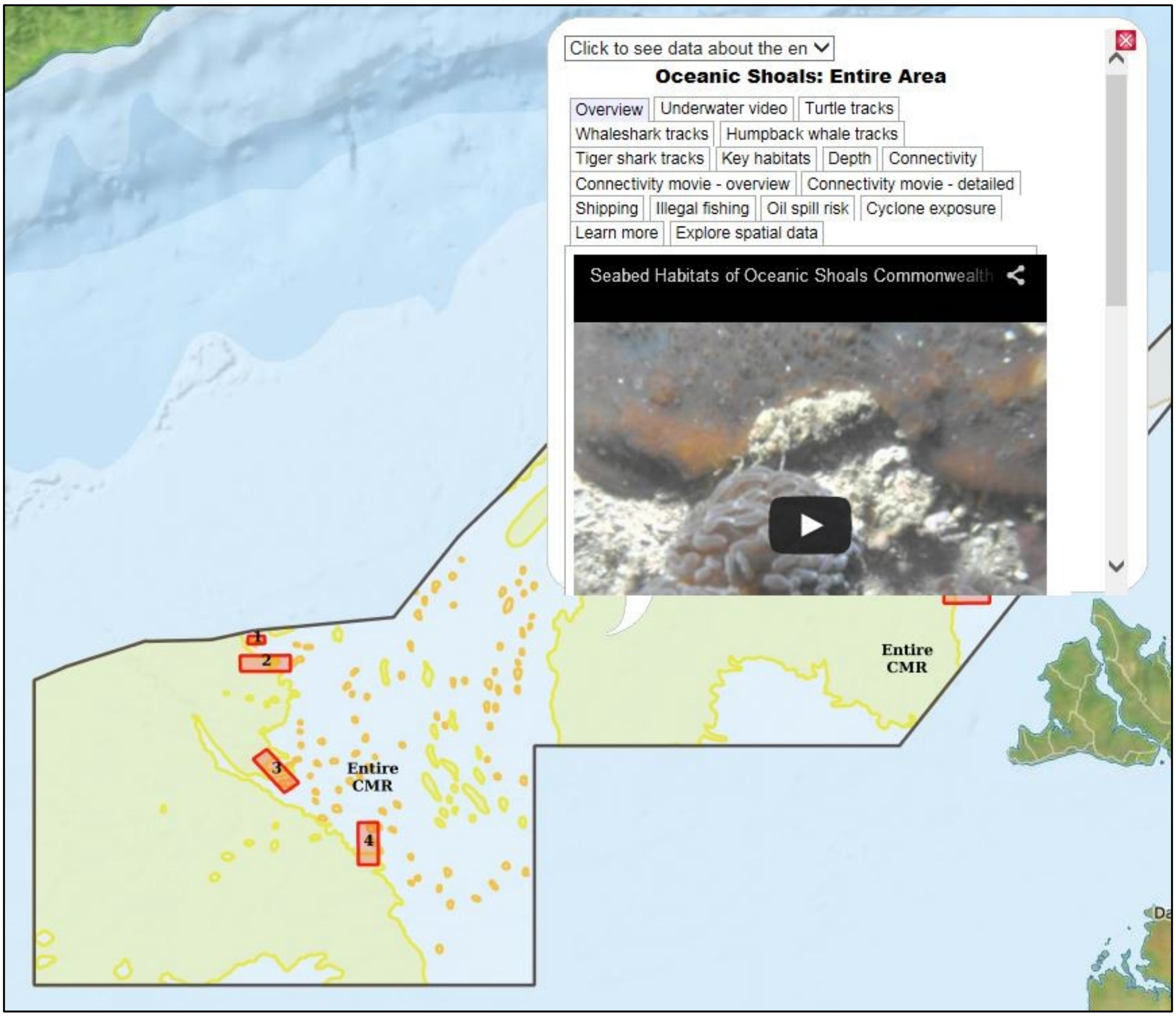

Figure 2.6 An example of the pop-up content available for the entire Oceanic Shoals.

Detailed data summaries provided for the Oceanic Shoals CMR include:

- **Overview** - Watch a movie about the Oceanic Shoals region
- **Underwater video** - Watch a video of undersea mobile fauna in the region
- **Turtle tracks*** - Map of flatback turtle tracks, 2009-2014
- **Whaleshark tracks** – Map of whaleshark tracks, 2005-2008
- **Humpback whale tracks*** – Map of humpback whale tracks, 2006-2010
- **Tiger shark tracks*** – Map of tiger shark tracks, 2008-2016
- **Key habitats** – Maps of potential habitats based on geomorphology
- **Depth** – Map of depth

- **Connectivity*** – Maps of larval connectivity between the Oceanic Shoals and other CMRs
- **Connectivity movie overview*** – Animation of how connected the CMR is to others in the region
- **Connectivity movie detailed*** – Watch individual larvae track through the region to create connectivity patterns
- **Shipping** – Maps of shipping pressure in the CMR over time
- **Illegal fishing** – Map of illegal fishing pressure in the region over time
- **Oil spill risk*** – Model outputs from oil spill scenarios for the region
- **Cyclone exposure** – Maps of typical exposure to cyclone conditions across the region
- **Learn More** – Links to a library of all known published literature as of July 2016
- **Explore spatial data** – Links to interactive maps of spatial data for the region

All of the CMR-wide and fine scale spatial datasets associated with the Oceanic Shoals prototype have been collated and will be uploaded gradually to the NW Atlas. The data sets above marked with a * indicate that they are not available publicly except via the prototype.

2.4.4 Interactive map gallery

Within the entire Oceanic Shoals CMR menu within the prototype, an 'Explore spatial data' tab was created. This included links to datasets in the NW Atlas, the eAtlas and other online data repositories in the following categories:

- Geophysical
    - Current sea state
    - Chlorophyll a
    - SST
    - CTD data
    - Depth contours
    - Australian maritime boundaries
- Biological
    - Home range of dusky whaler shark
    - Bioluminescence observations
    - Turbidity

    - IMCRA bioregions
    - Coral reef ecoregions
    - BIA
    - [Pelagic fish maps are still under development by UWA]
- Threats and pressures
    - Shipping activity
    - Hazardous spills
    - Oil and gas activities
    - Montara oil spill
    - Population density
    - Seismic surveys
- Research expeditions
    - AIMS RV Solander ship tracks
    - RV Southern Surveyor ship tracks

Access to these data sets and summaries was then extended by creating an 'interactive map gallery' in the NW Atlas from which it was much easier for users to discover the information, especially if selecting the sub-gallery 'Oceanic Shoals CMR' at http://northwestatlas.org/nwa/oceanic-shoals-cmr. This includes the following 29 entries, specifically targeted to the Oceanic Shoals CMR:

1. Relative distance to shore http://northwestatlas.org/node/1658
2. Maritime boundaries http://northwestatlas.org/node/1639
3. Density of shipping traffic http://northwestatlas.org/node/1636
4. Dusky whaler sharks http://northwestatlas.org/node/1637
5. Shear stress on the seabed http://northwestatlas.org/node/1662
6. Ocean surface temperature http://northwestatlas.org/node/1655
7. Ocean salinity http://northwestatlas.org/node/1654
8. Voyages RV Southern Surveyor 2013 http://northwestatlas.org/node/1648
9. Voyages RV Southern Surveyor 2012 http://northwestatlas.org/node/1647
10. Voyages RV Southern Surveyor 2010 http://northwestatlas.org/node/1646
11. Voyages RV Southern Surveyor 2007 http://northwestatlas.org/node/1645

12. Voyages RV Southern Surveyor 2006 http://northwestatlas.org/node/1644
13. Voyages RV Southern Surveyor 2005 http://northwestatlas.org/node/1643
14. Voyages RV Southern Surveyor 2003 http://northwestatlas.org/node/1642
15. Voyages AIMS RV Solander http://northwestatlas.org/node/1641
16. Ocean productivity http://northwestatlas.org/node/1659
17. Coral reef ecoregions http://northwestatlas.org/node/1652
18. Marine sediments http://northwestatlas.org/node/1638
19. Geomorphology of the sea floor http://northwestatlas.org/node/1656
20. Bioluminescence http://northwestatlas.org/node/1649
21. Turbidity http://northwestatlas.org/node/1660
22. Seismic surveys, 1976-2010 http://northwestatlas.org/node/1650
23. Hazardous spills, 2009-2013 http://northwestatlas.org/node/1640
24. Seafloor slope http://northwestatlas.org/node/1661
25. Whaleshark migration patterns, 2005-2008 http://northwestatlas.org/node/1657
26. IMCRA regions http://northwestatlas.org/node/1653
27. Petroleum leases and offshore titles http://northwestatlas.org/node/1651
28. Benthic habitat model of the Oceanic Shoals CMR (most likely class) http://northwestatlas.org/node/1710
29. Probability of existence of each of 12 benthic habitat classes across the Oceanic Shoals CMR http://northwestatlas.org/node/5449

2.4.5 Library of published literature

A review of readily available literature found that 18 journal articles, 2 books, 1 book chapter, 9 reports, 2 management plans, and 2 brochures have been published that cover all or part of the Oceanic Shoals CMR, as of July 2016 (Table 2.2). A list of these studies organised by subject area can be found in the 'Learn More' tab of the 'Click to see data about the entire Oceanic Shoals CMR' menu within the prototype. This includes hyperlinks to each study or its metadata record.

Table 2.2 Publications covering all or part of the Oceanic Shoals CMR.

Publication name	Type of publication
Exploring the Oceanic Shoals Commonwealth Marine Reserve	Brochure
Oceanic Shoals Commonwealth Marine Reserve - a guide	Brochure
The Biogeography of the Australian North West Shelf: environmental change and life's response	Book
Marine bioregional plan for the North Marine Region	Management plan
Marine bioregional plan for the North-west Marine Region	Management plan
Moore et al (2016) Improving spatial prioritisation for remote marine regions: optimising biodiversity conservation and sustainable development trade-offs	Journal article
Przeslawski et al (2011) Seabed Habitats and Hazards of the Joseph Bonaparte Gulf, Northern Australia.	Report
Brewer et al (2007) Trophic systems of the North West Marine Region	Journal article
Heyward et al (1997) Big Bank Shoals of the Timor Sea: an Environmental Resource Atlas	Book
Przeslawski et al (2015) Implications of Sponge Biodiversity Patterns for the Management of a Marine Reserve in Northern Australia	Journal article
Przeslawski et al (2014) Sponge biodiversity and ecology of the Van Diemen Rise and eastern Joseph Bonaparte Gulf, northern Australia	Journal article
Field et al (2009) Protein mining the world's oceans: Australasia as an example of illegal expansion-and-displacement fishing	Journal article
McKinnon et al (2011) Determinants of pelagic metabolism in the Timor Sea during the inter-monsoon period	Report
McMahon et al (2007) Satellite tracking reveals unusual diving characteristics for a marine reptile the olive ridley turtle (Lepidochelys olivacea).	Journal article
Meekan and Radford (2010) Migration Patterns of Whale Sharks: A Summary of 15 Satellite Tag Tracks from 2005 to 2008	Report
Rowat and Brooks (2012) A review of the biology, fisheries and conservation of the whale shark Rhincodon typus	Journal article
Whiting et al (2007) Migration routes and foraging behaviour of olive ridley turtles Lepidochelys olivacea in northern Australia	Journal article
Whittock et al (2016) Flexible foraging: Post-nesting flatback turtles on the Australian continental shelf	Journal article
Wilson et al (2006) Movements of whale sharks (Rhincodon typus) tagged at Ningaloo Reef, Western Australia	Journal article
Heap and Harris (2008) Geomorphology of the Australian margin and adjacent seafloor Australian Journal of Earth Sciences	Journal article
Li et al (2016) Selecting Optimal Random Forest Predictive Models: A Case Study on Predicting the Spatial Distribution of Seabed Hardness	Journal article
Nicholas et al (2014) Pockmark development in the Petrel Sub-basin, Timor Sea, Northern Australia: Seabed habitat mapping in support of CO2 storage assessments	Journal article

Publication name	Type of publication
Saqab and Bourget (2015) Controls on the distribution and growth of isolated carbonate build-ups in the Timor Sea (NW Australia) during the Quaternary	Journal article
Wienberg et al (2010) An isolated carbonate knoll in the Timor Sea (Sahul Shelf, NW Australia): facies zonation and sediment composition	Journal article
Yokoyama et al (2001) Shore-line reconstruction around Australia during the Last Glacial Maximum and Late Glacial Stage	Journal article
Kool and Nicholl (2015) Four-dimensional connectivity modelling with application to Australia's north and northwest marine environments, Environmental Modelling and Software	Journal article
Burns et al 2009 Fluxes and fate of petroleum hydrocarbons in the Timor Sea ecosystem with special reference to active natural hydrocarbon seepage	Journal article
Makaraynskyy et al Integrated approach to oil spill assessments: recent case studies in WA, NT and QLD	Report

Since the time the above data was collated, a literature review for all Australia's CMRs has been conducted by JCU. We will use this, combined with new entries using Johnathan Kool's 'Hydroid' search engine, to create an index of research published for every CMR for the upcoming Marine Parks Science Atlas. The data will be stored in a single spreadsheet that can be updated and periodically uploaded to the eAtlas, with its contents automatically displayed on-line in the relevant atlases (including the NW Atlas). This will be searchable by CMR and by a set of 5 to 10 key words describing their content. This new functionality will come on-line by December 2017.

2.5 Synthesis of available data for the NW Ancient Coastline KEF (at 125m contour)

2.5.1 Background

Key ecological features (KEFs) are elements of the Commonwealth marine estate that, based on current scientific understanding, are deemed of particular regional value for the maintenance of ocean biodiversity and the integrity/functioning of natural ecosystems. These may reflect (i) ecologically important species or communities, (ii) areas of enhanced productivity (e.g. upwellings), diversity and endemism, or biological activity (nursing or feeding grounds), or (iii) unique seabed features, with demonstrated or premised ecological properties of regional significance.

To date, 54 such KEFs have been identified around the Australian continent, including 13 within the Northwest marine region (NWMR) (Hayes *et al.* 2012). The submerged Ancient Coastline at 125 m (hereafter 'AC125'[1]) is among these. It can be traced as a ledge or narrow escarpment (ca. 50 km at its widest point, up to 8m high) that extends between the 115m and the 135m isobaths along the Northwest and Sahul Shelves from the Carnarvon Basin to the Bonaparte Archipelago (Falkner *et al.* 2009) (Figure 2.7). The AC125 is the

[1] Also referred to as the 'Holocene strandline' (Falkner *et al.* 2009) or 'paleo-coastline' (Fromont *et al*. 2012), 'palaeoshoreline' (Brooke *et al.* 2017) or 'paleo-coastline' (Fromont *et al*. 2012).

remnant of a relict shoreline landform, which, like numerous similar geological structures in the area (e.g. drowned cliffs, reefs and terraces), reflects sea-level changes during the last glacial maximum and coincides with the well-documented worldwide eustatic lowstand that preceded the Holocene transgression approximately 17-20 ka ago (Jones 1973). Many similar palaeoshoreline structures have been reported at several locations around the globe, each playing a potentially fundamental role in structuring benthic ecosystems at regional to continental scales (Brooke *et al.* 2017).

However, little empirical knowledge of the AC125 currently exists (Falkner *et al.* 2009), with neither the composition nor the distribution of the species assemblages associated with the KEF being described accurately. A conceptual qualitative model of the ecological processes occurring within/around the AC125 is consequently still lacking (Dambacher *et al.* 2012, Hosack *et al.* 2012).

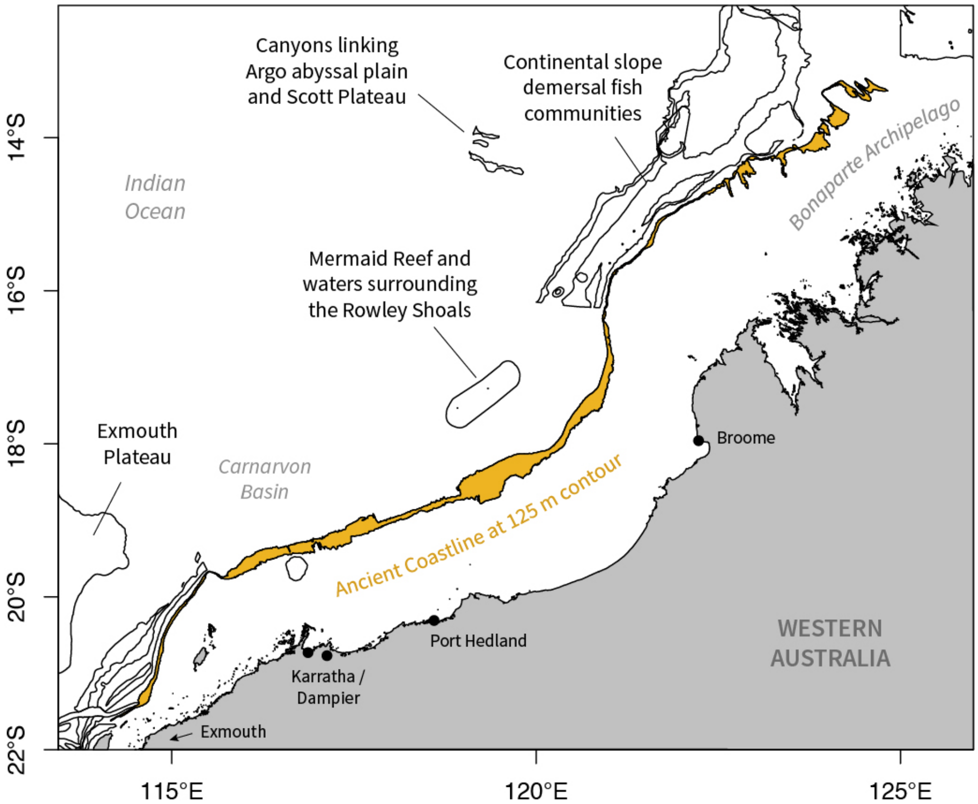

Figure 2. 7 Key ecological features (KEFs) of the Northwest marine region.
The Ancient Coastline at 125 m (AC125) is shown in colour.

The designation of the AC125 as a KEF mostly stems from speculation that its hard substrate, particularly where it emerges as rocky outcrops, may provide crucial habitat for a number of sessile benthic taxa (e.g. sponges, corals, crinoids, molluscs, echinoderms and other invertebrates) in a surrounding environment otherwise broadly dominated by soft sediments **[Hypothesis H1]** (DSEWPaC 2012b, Brooke *et al.* 2017). It is also thought that the AC125 may facilitate vertical mixing in the water column and increase nutrient availability by disrupting internal waves, especially in some locations off the Pilbara (DSEWPaC 2012a) **[Hypothesis H2]**. The resulting enhancement of productivity may in turn attract upper-trophic opportunistic feeders such as cetaceans and large pelagic fish. Lastly, there have been suggestions that the AC125 could act as a migratory pathway and navigation aid for mobile megafauna, including humpback whales (*Megaptera novaeangliae;* C. Jenner, personal communication) and possibly whale sharks (*Rhincodon typus*) (DEWHA 2007, Hayes *et al.* 2012) **[Hypothesis H3].**

Falkner *et al.* (2009) summarised available biophysical information for the AC125 (up to and including the year 2000) and constructed a classification of 'seascapes' designed to confirm whether the KEF met its mandatory criteria of representativeness, uniqueness, vulnerability, and ecological importance. According to their analysis, the AC125 can be separated into a northern section (north of 17°S) characterised by low primary production (likely influenced by the Indonesian Throughflow), and a southern section (south of 17°S) exhibiting high(er) levels of primary production. A focal variety analysis revealed that habitat diversity is moderate along the feature but elevated in adjacent areas, particularly around the abundant shoals, banks and terraces of the upper slope between Exmouth and Broome. Along its entire length, the AC125 mainly intersects a warm, shallow, subtidal depth zone on the margin defined by low mud and high gravel contents, as well as gentle slopes. Biological data are generally sparse, and consist mostly of demersal fish collections gathered and curated by CSIRO and the Northern Territory Museum in the late 1990s. For instance, CSIRO researchers completed 1,019 bottom trawl transects with head rope-mounted cameras around the lower part of the AC125 between 1983 and 1997 (Figure 2.8), although only 57% of these yielded useable photographic data for investigating patterns in benthic communities and seabed cover (Fulton *et al*. 2006). The footage has been annotated for fauna but has not yet been formally analysed or published (F. Althaus pers comm).

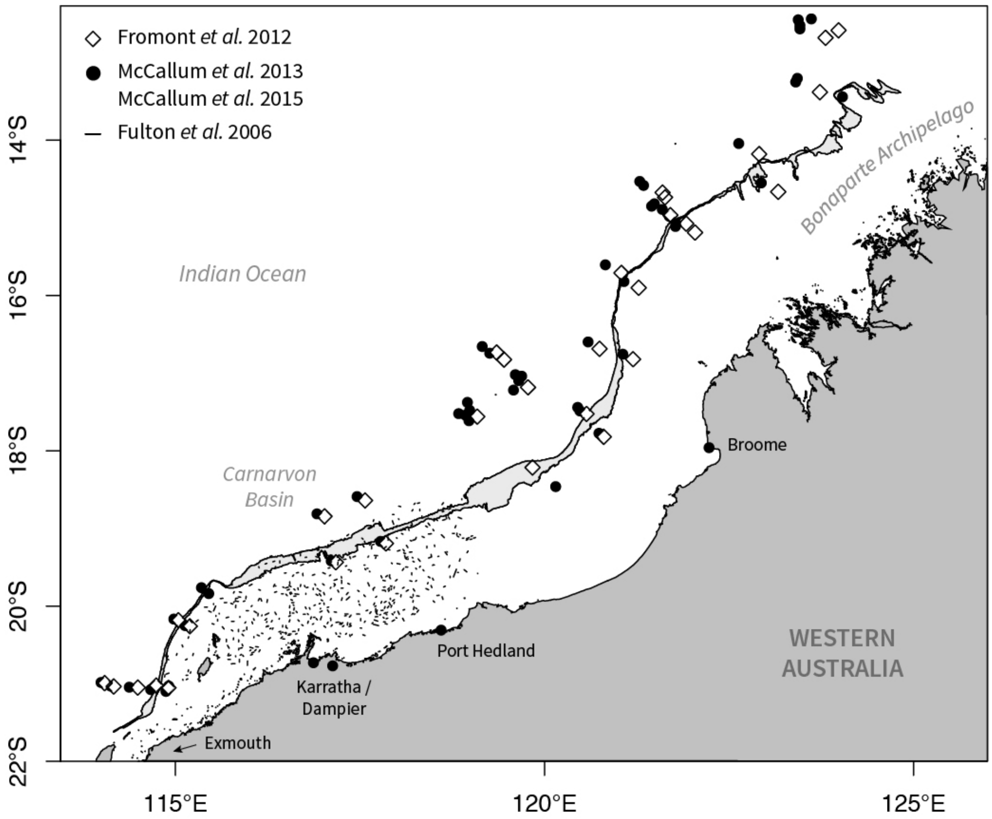

Figure 2.8 Invertebrate/fish sampling stations (grabs and bottom trawls) from four recently published studies across the NWMR. The AC125 is shown in light grey. Note: Locations were obtained by georeferencing maps from the original journal articles/reports and are therefore approximate.

2.5.2 Biological data

Recent field sampling

Additional surveys have been undertaken across various parts of the AC125 since Fulton *et al.* (2006). Notably, Fromont *et al.* (2012) sampled sponges and other benthic invertebrates at a range of depths (100–1100 m) on two cruises aboard the *FRV Southern Surveyor* in 2005 and 2007 (SS10/05 and SS05/07). The former covered Australia's southwestern margin (22°S to 36°S), whereas the latter targeted lower latitudes (12°S to 22°S) (Figure 2.8)**.** Highly speciose assemblages were found to dominate the megabenthic invertebrate biomass in both the southwestern (86%) and northwestern (35%) areas. Video data were gathered during the survey but were not scored (F. Althaus, personal communication). Similarly, McCallum *et al.* (2013) and McCallum *et al.* (2015) collected polychaetes and decapod crustaceans in two bathomes (outer continental shelf at 100 m depth, and upper continental slope at 400 m depth) along a transect stretching between Ashmore reef (13° S, 124° E) and Bald Island (35° S, 119° E). Some knowledge of plankton communities is available from two Continuous Plankton Recorder (CPR) Colour Index Surveys captured on the Australian Region MArine Data Aggregation (ARMADA) repository (Figure 2.9A). The surveys, conducted in 2011 and 2012, concentrated on the southern section of the KEF, much like the demersal trawls performed by various CSIRO vessels since the 1960s (Figure 2.9B). By contrast, singlebeam midwater acoustic samples obtained from the RV *Southern Surveyor* in 2012 and 2013 are predominantly available in the northern KEF section (Figure 2.9C).

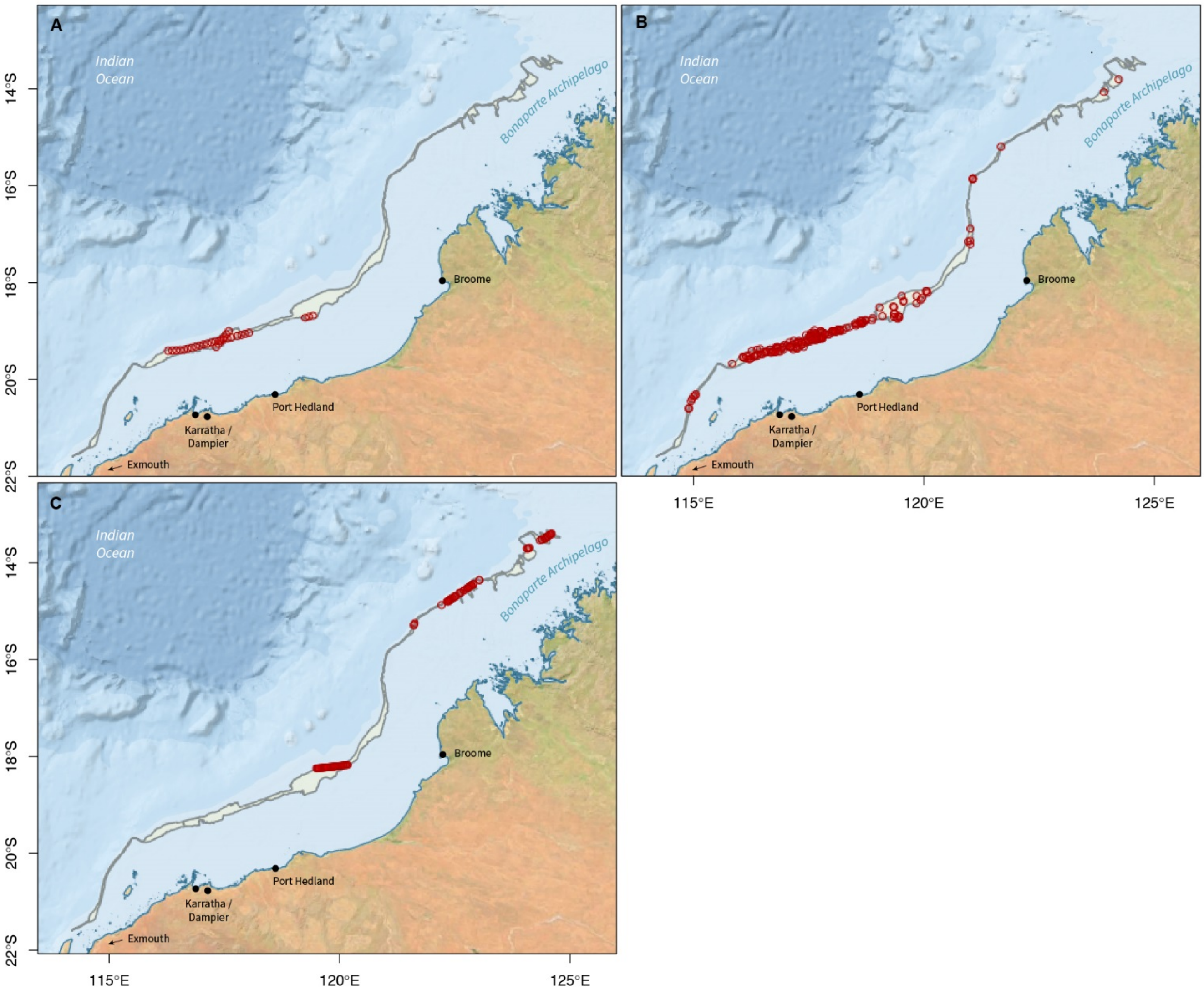

Figure 2.9 Continuous Plankton Recorder (CPR, A), demersal trawl (B) and midwater acoustic (C) samples collected along the AC125. Metadata records are available from the Australian Region MArine Data Aggregation (ARMADA) repository.

Atlas of Living Australia

The Atlas of Living Australia is a digital public-domain repository of distributional information on all marine, freshwater and terrestrial taxa known to occur in Australia. It presently aggregates more than 50 million point records derived from specimen examinations, field observations and on-ground surveys from a wide range of contributors (e.g. museums, herbaria, community groups, government departments, individuals and universities). As of November 8, 2016, running a search query based on the recognised boundary shapefile for the AC125 (available for download here) returns a total of 25,641 valid taxonomic reports (identified to species level) overlapping the KEF or in its close proximity. These represent more than 1,600 species, of which Actinopterygii (ray-finned fishes) make up 85%. The majority of sightings (94.8 %) are confined within the southern section of the AC125 (Figure 2.10).

Moore *et al.* (2016) recently built predictive MaxEnt models for a vast array of organisms (674 taxa from a total of 119 families including fishes, reptiles, crustaceans, echinoderms etc.) in the NWMR, and measured the extent to which species distributions were represented within existing and proposed no-take protected areas. Revisiting these data to conduct a similar assessment focusing on KEFs would likely be a valuable approach to further testing the validity of **H1.**

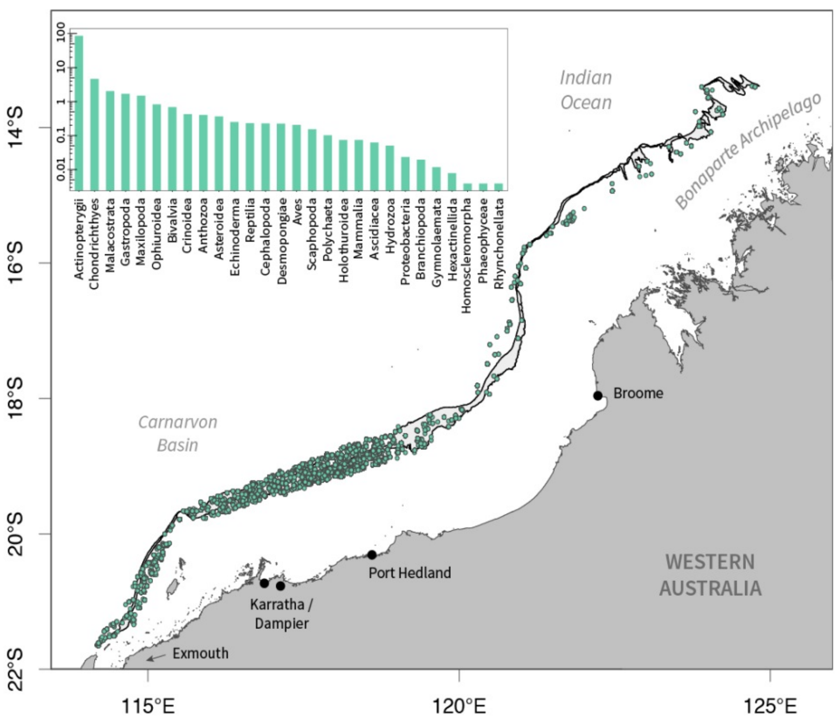

Figure 2.10 Spatially valid (non-duplicated) occurrence records from the Atlas of Living Australia (ALA, **http://www.ala.org.au**) over and adjacent to the AC125 (n= 25,641). The inset illustrates the distribution of percentage contributions (on the log scale) from each taxonomic group.

Sea Around Us Project (SAUP)

Spatial patterns in benthic fish abundance relative to the AC125 were explored using historical commercial landings sourced from the Sea Around Us Project (SAUP, http://www.seaaroundus.org). The data spanned the period 1997-2006 and were those available prior to reconstruction (Pauly and Zeller 2016), filtered to retain only species classified as 'demersal' in the FishBase web database (Froese and Pauly 2016). The analysis closely followed the methods described in Bouchet *et al.* (in press), whereby yearly catches (aggregated over a grid of 0.5 x 0.5° cells) were standardised to derive a relative abundance index based on independent estimates of fishing effort (Figure 2.11).

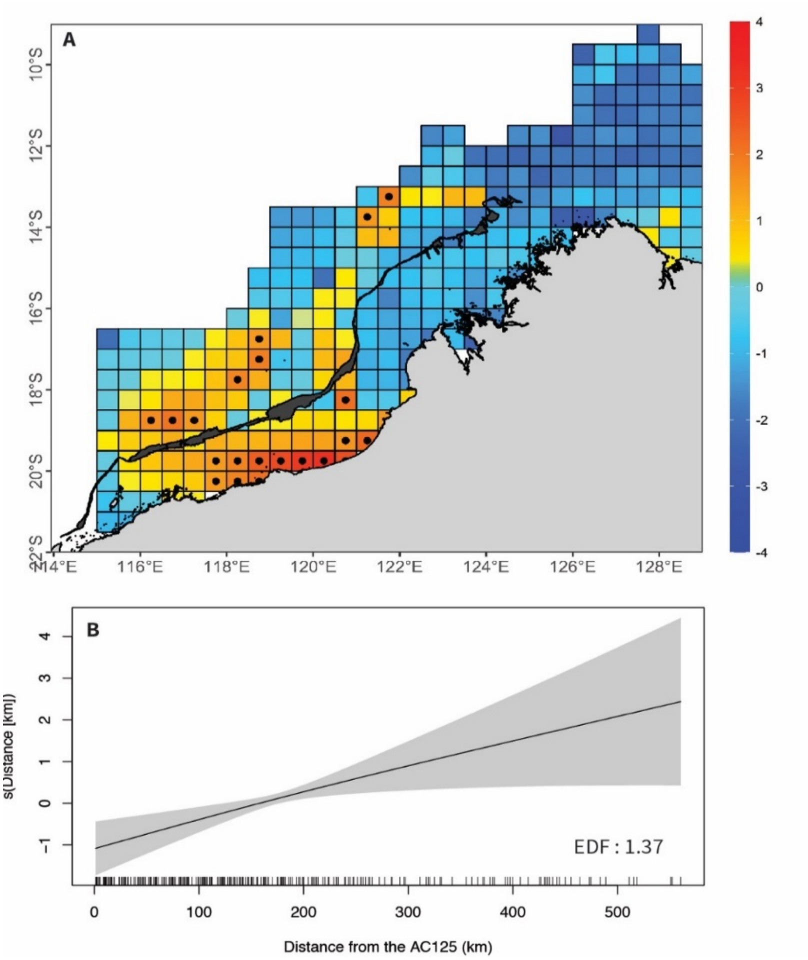

Figure 2.10 (A) Spatial patterns in demersal fish relative abundance in the NWMR inferred from historical commercial catch data. The abundance index is shown on the log scale, and abundance 'hotspots' (predicted from cumulative relative frequency distributions, as per Bouchet *et al.* In press) are marked with black circles. The AC125 is shown in dark grey.
(B) Partial plot of the effect of distance from AC125 on fish relative abundance, according to the GAM model. Shaded areas represent 95% confidence intervals for the fitted relationship.

Standardisation models relied on a measure of species body mass, which can only be obtained conditional on correct species identification. For those taxa only reported at genus, family, order, or class level, this was taken as the median weight (in kg) of all species in the taxonomic group found in the Eastern Indian Ocean and/or around Australia (cross-checked on FishBase). Fish relative abundance was then modelled as a function of the geodesic distance to the centroid of each grid cell in a lognormal generalised additive model, structured as follows:

$$\log(y_i) = \alpha + te(lon_i\,, lat_i) + f(distKEF_i) + \varepsilon_i$$

Where ε_i are i.i.d. normal random variables and y_i the i^{th} value of relative abundance. A tensor product of longitude and latitude (te) and a gamma penalty of 1.4 were considered to mitigate non-isotropic spatial dependence (autocorrelation) (Borchers *et al.* 1997) and overfitting, respectively. An offset term for the log surface area of each grid cell was also included to accommodate cells of differing sizes. f represents a thin-plate spline (with shrinkage) of the distance to AC125. Restricted maximum likelihood (REML) was used to obtain reliable estimates of smooth parameters (Mannocci *et al.* 2016).

Residual plots did not indicate any departures from model assumptions. Spatial correlograms of Moran's I revealed no evidence of residual spatial autocorrelation (Mellin *et al.* 2010). The model explained 65.1% of the deviance and revealed a significant effect of the distance from the AC125 ($p \leq 0.01$), with moderately higher relative abundance in the vicinity of the feature (Figure 2.11). This preliminary analysis therefore suggests that the AC125 may act as an aggregation site for benthic fish communities. This is consistent with Lyne *et al.* (2009), who showed that extensive, elongate biomes of demersal fish exist on the Australian NW shelf in depth zones of 70–100 m and 120–150 m, i.e. overlapping the depths at which the AC125 is found. The coarse spatio-temporal resolution and high level of aggregation of these data, however, preclude habitat relationships from being adequately captured at fine scales. We expect that regional fisheries logbooks (i.e. that report precise GPS coordinates for each catch) will provide valuable additional insights into the use of the AC125 by commercially exploited fish species.

Remote tracking of marine megafauna

A large number of extractive industries are active in the NWMR (Fulton *et al.* 2006), thus numerous telemetry programmes have been - and are still being - implemented by and for the private sector. Data derived from satellite tag deployments, nonetheless, often prove cryptic (e.g. unreleased, only described in internal reports) and their access typically remains a challenge. An examination of the few published studies and public-domain datasets that document the movement patterns of satellite-tagged marine megafauna in the NWMR currently provides limited support for **H3** (Figure 2.12A) for pygmy blue whales (*Balaenoptera musculus brevicauda*). It is possible that whale sharks (*Rhincodon typus*) follow the AC125 on migration, at least throughout the lower half of the feature's southern section (Figure 2.12B). Tiger sharks (*Galeocerdo curvier*) also appear to be relatively closely associated with the AC125 (Figure 2.12C). That said, further dedicated sampling and a more detailed quantitative analysis of available trajectories and other complementary datasets for megafauna (see, for example, the many archives maintained here) are warranted to validate **H3** with greater confidence. It is noteworthy that a number of listening arrays and passive acoustic monitoring stations are operating across the NWMR under the aegis of the Integrated Marine Observing System (IMOS) and its Animal Tracking Facility (formerly the

Australian Animal Tracking And Monitoring System, AATAMS). The data generated by these instruments are almost without exception all archived online and open source, and may help shed light on regional-scale species movements.

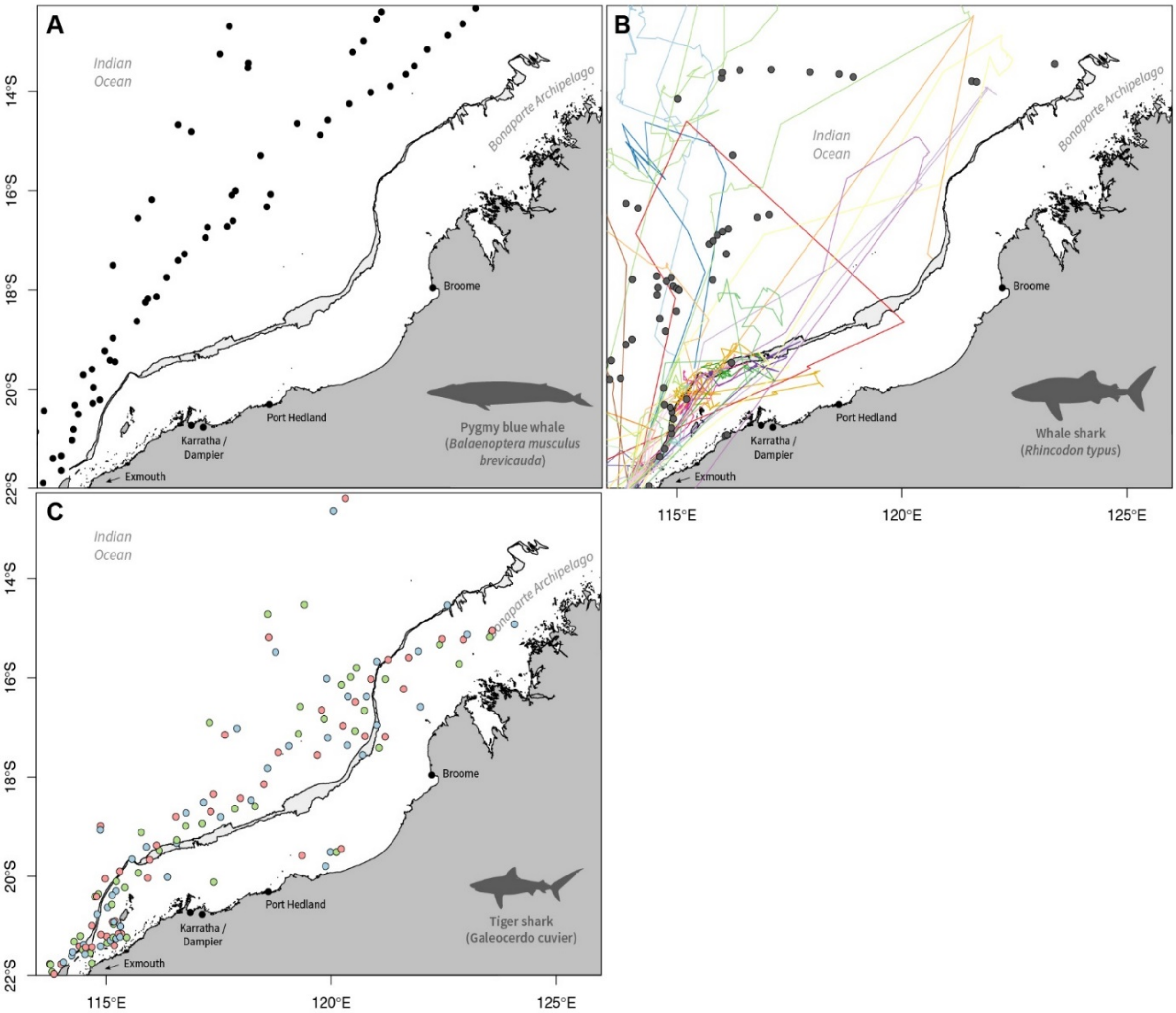

Figure 2.11 Satellite fixes of tagged pygmy blue whales (*Balaenoptera musculus brevicauda*, A), whale sharks (*Rhincodon typus*, B) and tiger sharks (*Galeocerdo cuvier*, C) migrating along the Western Australia coast. **A:** Data extracted from Double *et al.* (2014), with positions georeferenced from published maps and therefore approximate. **B:** Each coloured track represents a different individual. Data provided by the ECOCEAN Project (available for download from ZoaTrack), with dark circles georeferenced positions from Wilson et al. (2006) and therefore approximate. **C:** Each colour represents a different individual. Data sourced from Ferreira *et al.* (2015), with positions georeferenced from published maps and therefore approximate.

2.5.3 Physical data (ocean habitats)

Bathymetry and seabed topography

Though recognised as a complex topographic feature, the bathymetry of the AC125 is poorly documented (especially at high resolution), as only a limited number of narrow multibeam transects have ever been undertaken across its range (Figure 2.13). To better characterise seafloor complexity along the AC125, a series of 20 cross-sections (90 km by 20 km) was performed on the 2009 national digital bathymetric grid of Australian waters (at 9 arc-second resolution or approx. 250 m at the equator) in locations coinciding with existing multibeam datasets (50 m resolution). Three-dimensional models were subsequently constructed and converted to HTML format for interactive click-and-point visualisation. Figure 2.14 illustrates one such swath off the Kimberley coast. The AC125 is relatively heterogeneous, covering a variety of cliffs, terraces, varying slopes or shallow flats.

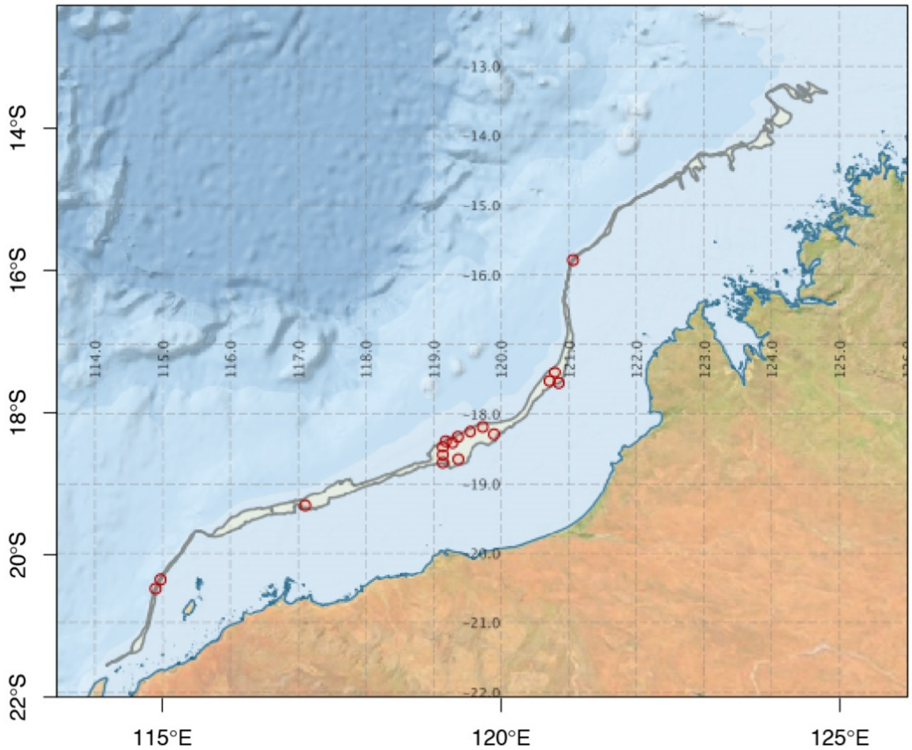

Figure 2.123 Topographic parametric sonar (TOPAS) data available for the AC125 KEF. Metadata records are available from the Australian Region MArine Data Aggregation (ARMADA) repository.

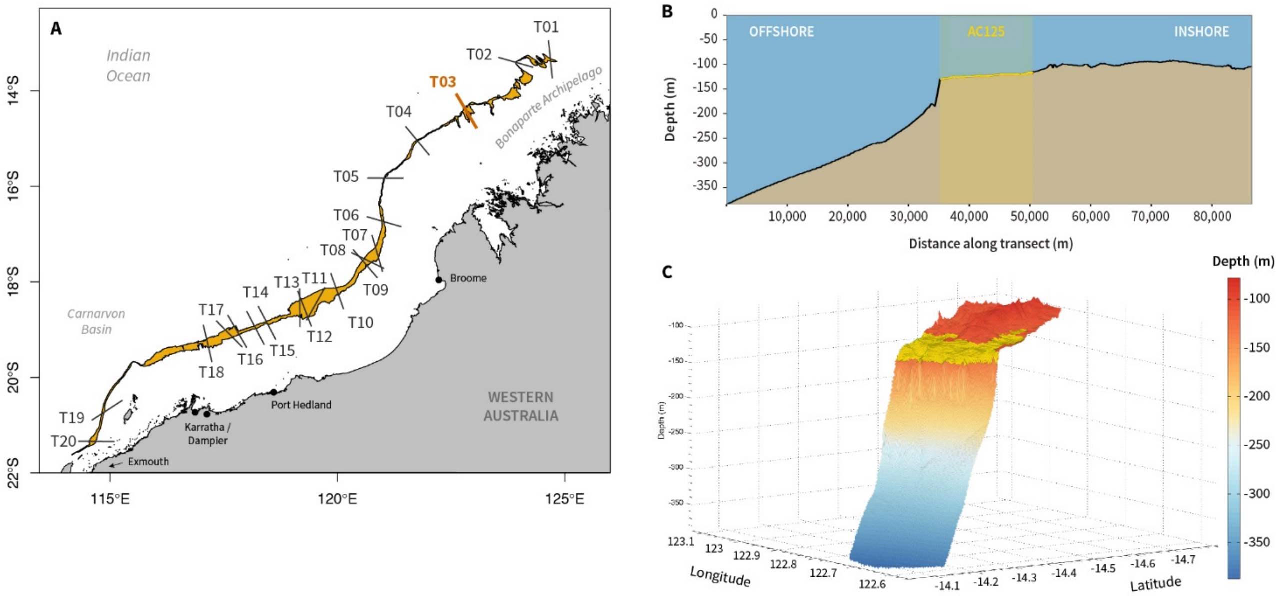

Figure 2.13 Example cross-section of the Ancient Coastline at 125 m KEF. **A:** Location of the twenty transects sampled (T01-T20). The one chosen for illustration (T03) appears in bold. **B:** Depth profile for T03. Bathymetry for the AC125 is plotted from the 50 m multibeam data, whereas the outer portions come from the national 250 m grid. **C:** 3D representation of the bathymetry along T03. The part of the cross-section covered by the AC125 is shown in yellow.

Remote-sensed and interpolated measures of physical environment

The CARS 2009 database from CSIRO's Atlas of Regional Seas was harnessed to test for differences between the physical habitat characteristics of the AC125 and those of its surrounding environment. Three concentric spatial buffers were defined around both the northern and southern sections of the AC125, at distance lags of 10, 25, and 50 km (Figure 2.15). Random samples of points were generated inside the KEF and the inshore and offshore domains of each buffer zone (density: 0.01 points per km^2), and used to extract the values of all environmental covariates described in Huang *et al.* (2010). Raster layers depicting (i) bottom/surface current velocity patterns, derived from Bran 3.5 data and (ii) the spatial distribution of tidal fronts (the boundary between mixed and stratified conditions; courtesy of M. Thums, AIMS), were also included.
The latter were calculated as $S = \log(\frac{h}{U^3})$, where h is the water depth and U the maximum tidal current amplitude (Simpson *et al.* 1981). Many studies have shown that tidal fronts occur when S = 2.7 (e.g. Elizabeth *et al.* 2003).

A non-parametric Kruskal-Wallis analysis of variance was subsequently run to compare covariate medians among groups, and was followed by post-hoc Nemenyi tests where differences were detected.

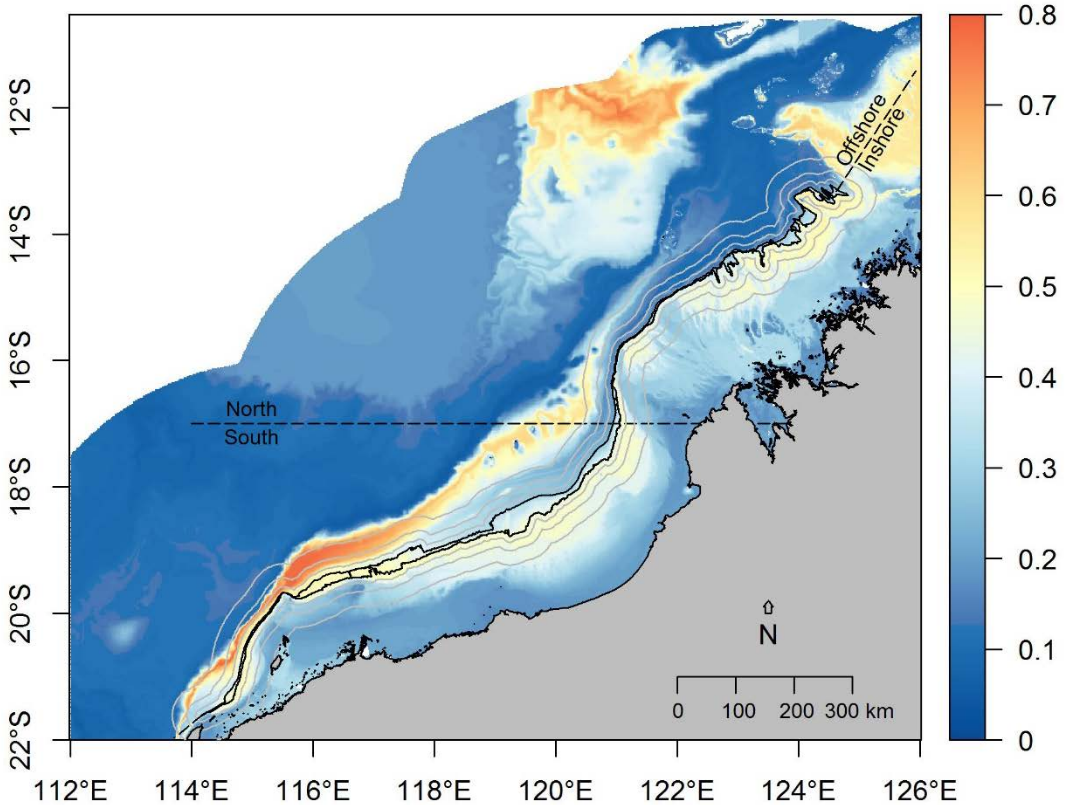

Figure 2.15. Standard deviation of bottom water oxygen concentration (ml/L) in the NWMR in relation to the AC125. The spatial buffers (0-10 km, 10-25 km, and 25-50 km) used in the analysis of habitat characteristics are shown in grey.

Significant differences between the AC125 and at least one spatial buffer were detected for all physical covariates **(Table 1.1)**. Bottom current velocity was the most homogeneous (though the coarsest) variable throughout the NWMR, only departing from the mean of the AC125 in the furthest offshore domain. Overall, the AC125 mostly lies in a ‘transition zone’ characterised by an intermediate ocean signature between inshore and offshore environments (Appendix D). Some habitat gradients appear to break more sharply around the AC125 (e.g. oxygen, temperature), however none were found to peak in the vicinity of the feature. It is possible that tidal fronts may be forming in the northern section of the AC125 (tidal front index range: 2.5-3.4).

Table 2.3 Summary of pairwise comparisons of physical characteristics for the AC125. All combinations of spatial domains (inshore/offshore and 10, 25, 50km buffers) were compared using Nemenyi tests. Only significant results (P-value <0.05) are shown (others are left blank). +/- signs indicate whether variable means are higher/lower over the AC125. BV/SV: Bottom/Surface current velocity; TF: Tidal front index; NO3: nitrate; O2: oxygen; PO4: phosphate; SI: silicate; S: salinity; T: Temperature. m/r/s: mean, range and standard deviation, respectively. For further details, see Huang et al. (2010).

NORTHERN section (north of 17°S)																	
	Buffer	BV	NO3m	NO3r	NO3s	O2m	O2s	PO4m	PO4s	Sim	Sis	Sm	Ss	SV	TF	Tm	Ts
Inshore	0-10km						-										
Inshore	10-25km		+		+	-	-	+		+			-			-	
Inshore	25-50km		+		+	-		+	+	+	+	-	-	+	+	-	
Offshore	0-10km			+	+		+		+								+
Offshore	10-25km		-	+	+	+	+	-	+	-		-	+		-	+	+
Offshore	25-50km	+	-	+		+	+	-		-	-		+		-	+	+
SOUTHERN section (south of 17°S)																	
	Buffer	BV	NO3m	NO3r	NO3s	O2m	O2s	PO4m	PO4s	Sim	Sis	Sm	Ss	SV	TF	Tm	Ts
Inshore	0-10km		+		+	-		+	+	+	+					-	
Inshore	10-25km		+	+	+	-	+	+	+	+	+	-			+	-	
Inshore	25-50km		+	+	+	-	+	+	+	+	+	-		+	+	-	
Offshore	0-10km										-			-			
Offshore	10-25km		-		-			-		-	-		+	-	-	+	+
Offshore	25-50km	+	-		-	+		-	-	-	-		+	-	-	+	+

Regional connectivity

A four-dimensional (3D × time) object-oriented biophysical dispersal model (Conn4D) was previously developed at Geoscience Australia under the National Environmental Research Program to simulate the movements of marine larvae across the maritime estate and infer connectivity patterns among a number of Commonwealth Marine Reserves (CMRs). The model is currently parameterised to reflect the life history characteristics and dispersal behaviour of ophiuroids (brittle stars), and a full methodological description of the software can be found in Kool and Nichol (2015). To determine whether the AC125 may act as a source/sink for larvae and place it into a regional context relative to other KEFs in the North and Northwest regions, matrices of connectivity values were extracted from the Conn4D relational database and visualised using Chord diagrams **(Figure 2.16).** When integrated over depth (0-5000 m) and time (100 particles released every 30 days commencing January 1st 2009 through until December 31st 2012), results suggest that the AC125 is primarily 'self-seeding' (i.e. particles settle within their release location; average rate of particle settlement: 30.4 %), with only minor contributions from the nearby Glomar Shoals KEF (6.5 %) and to the Continental Slope Demersal Fish Communities KEF (1.1 %). The AC125 makes some contributions to the Exmouth Plateau and Demersal Fish KEFs only at depth (Appendix E).

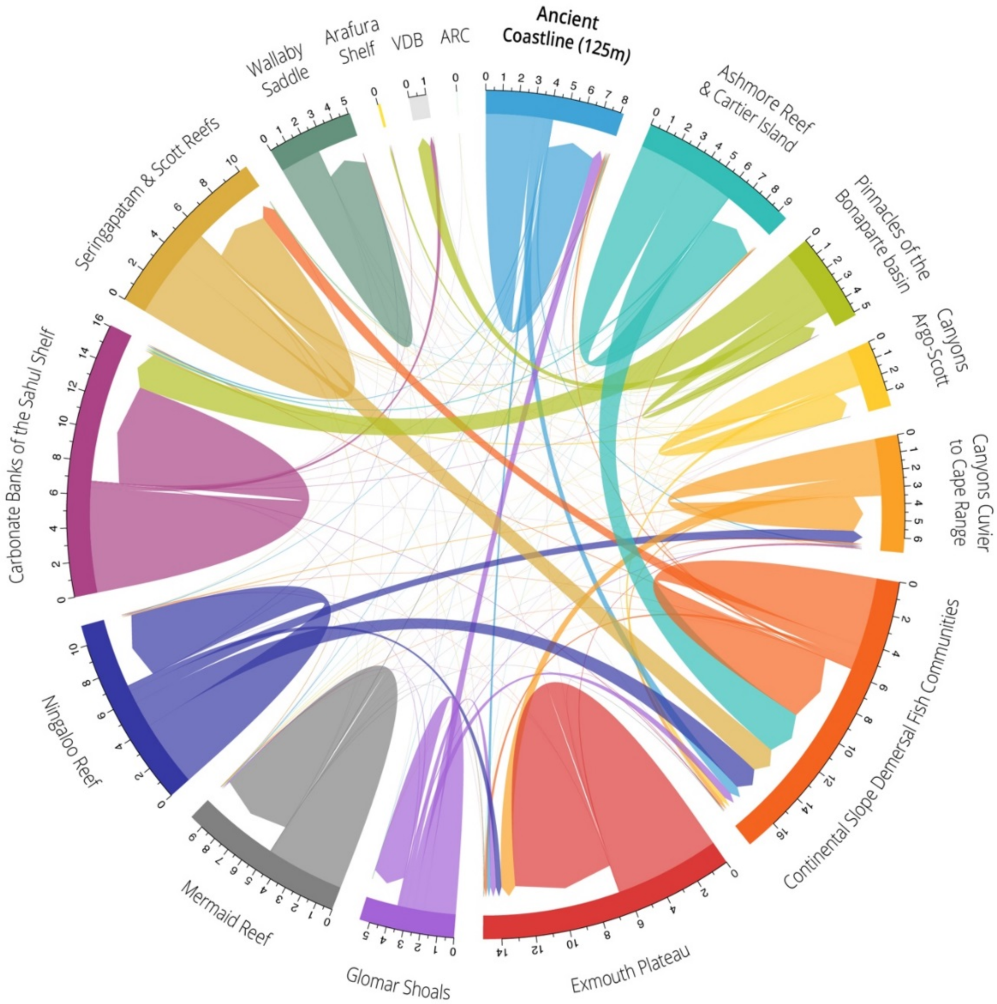

Figure 2.2. Dispersal connectivity between N/NW Key Ecological Features based on Kool and Nichol (2015)'s conn4D model outputs, averaged over time and bathomes. Arrow widths are proportional to connectivity values. The AC125 is shown in bold. ARC: Arafura Canyons; VDB: Van Diemen Banks.

2.5.4 Summary

Our data synthesis has highlighted the poorly known nature of the Ancient Coastline KEF at 125 m, a feature which has received little scientific attention to date. National bathymetric maps (including existing multibeam transects across the continental shelf) indicate varying levels of seabed heterogeneity along the AC125, from gentle slopes to steep cliffs and rocky outcrops. Palaeoshorelines like the AC125 are generally known to form distinct zones of physically complex seabed that can provide shelter, habitat and food (through interactions with currents) for a range of biological communities usually dissimilar to those found on adjacent, unconsolidated sediments (Brooke *et al.* 2017). Available biotic data suggest that a potentially wide array of benthic marine organisms (ray-finned fishes in particular) might occur on or around the KEF, though their distribution and abundance patterns cannot be resolved without targeted data collection in the field. It is possible that some tiger sharks (*Galeocerdo cuvier*) use the KEF as a guiding line on migration, however whether this applies to other species of megafauna (e.g. sea turtles, baleen whales, or whale sharks) remains unclear without a more in-depth analysis of all animal tracks obtained from remote telemetry programmes undertaken throughout the region. This is likely to be a time-consuming and labour-intensive exercise given the number of such tracks that are currently held privately and/or inaccessible. Lastly, the AC125 is primarily self-seeding and shows limited connectivity with other KEFs of the N/NW, possibly because offshore currents tend to be week along the feature (Appendix D). Its upper section (north of 17° S) lies in an environment where tidal fronts and internal waves are likely to form, and could sustain, pulses of high productivity, as evidenced by high total organic carbon (TOC) concentrations recorded in seabed sediments in The Western Timor Sea (Radke *et al.* 2017).

3. IDENTIFYING KNOWLEDGE GAPS

3.1 Introduction

Spatial predictive models can be used to fill in the gaps between areas where field data has been collected, as has been demonstrated for marine environments across Australia and the world. Producing spatial predictive models for CMRs and KEFs of the North and NW Regions requires bathymetric and oceanographic data, and the distribution and abundance of key biota. Thus assessing where such data already exists, including its quality and quantity, will enable identification of areas where modelling may be feasible. We also highlight data 'gaps' in bathymetry that, if filled, would enable the development of additional spatial predictive models of biota.

We addressed this in Project D1 via a detailed 'gap analysis' for the N and NW regions. Our gap analysis considered publically available data sets for the entire region spanning NW Cape to Cape York Peninsula including:

1. Observations of the presence but not absence of 13 key benthic and pelagic taxa,
2. High quality bathymetric datasets,
3. Key oceanographic datasets.

We then examined how these data are distributed specifically in the CMRs and KEFs of the N and NW regions, and addressed the following questions to help determine where it might be possible to build spatial predictive models:

- In which CMRs and KEFs have biota of interest been observed and how often they have been observed?
- In which CMRs and KEFs should we explore the potential for building regional scale predictive models in more detail?
- In which CMRs and KEFs would collecting additional bathymetric data be most useful given existing biological data?

Our results provide a starting point for prioritising future research effort to underpin management and monitoring in CMRs and KEFs both in the context of spatial predictive modelling as well as field expeditions to collect additional data to inform modelling. Notably, future modelling may not necessarily encompass entire CMRs or KEFs and will likely require in-depth scoping beyond what is provided by this report.

3.2 Gap Analysis Methods

Australia's North and NW regions cover a vast area. To facilitate data synthesis, we split the combined region into a regularly-spaced grid where each grid square was 10km x 10 km. We then counted the number of observations of the various types of data in each grid square. This enabled us to map where data exist across the region and compare how data coverage varied within/among individual CMRs and KEFs. A separate interactive map of each data type analysed is provided for CMRs and KEFs in the NW Atlas Interactive Map Gallery http://northwestatlas.org/nwa/n-nw-cmr-kef (or see Appendices B and C for direct links).

3.2.1 Biotic data

We identified broad categories of biota to consider in the gap analysis based both on data availability and knowledge of what biotic groups are important indicators for marine and coastal ecosystems. Based on this, we considered where data existed for the following 13 biotic groups:

1. Hard corals
2. Soft corals
3. Sponges
4. Brittle stars
5. Polychaetes
6. Molluscs
7. Marine mammals
8. Sea turtles
9. Demersal fishes
10. Pelagic fishes
11. Demersal sharks and rays
12. Pelagic sharks and rays
13. Seabirds

Data were obtained from a range of publically available datasets, including:

- The Atlas of Living Australia (http://www.ala.org.au/)
- The Western Australian Museum (www.australianmuseum.net.au/)
- Ocean Biogeographic Information System (http://www.iobis.org/)
- Global Biodiversity Information Facility (http://www.gbif.org/)
- Pelagic BRUVS data from the University of Western Australia (http://www.uwa.edu.au)
- Demersal BRUVS data from the Australian Institute of Marine Science (http://www.aims.gov.au)
- BRUVS from FinPrint (https://globalfinprint.org/)
- Opportunistic observations from the University of Western Australia (http://www.uwa.edu.au)
- Underwater towed video real-time observations from the Australian Institute of Marine Science (http://www.aims.gov.au)
- Satellite tracks of sea turtles from the Australian Institute of Marine Science and Rio Tinto

We reviewed data sources used with relevant NESP partners and the consensus was that no key data sets were missed.

Where multiple data sets were combined for a given taxa, we took reasonable steps to identify and remove duplicate records. The year in which observations were made varied widely within and between the datasets. As our aim in collating this data was to identify locations where various groups had ever been observed, we retained all data regardless of age. Although only very recent data would likely be used to build a spatial predictive model of a given type of biota, examining historic data provides an indication of where various types of biota may be more likely to exist. Furthermore, numerous datasets comprised 'presence-only' data, without documenting the underlying survey effort. This means that the observations may be biased towards locations that have been surveyed more extensively and frequently than others.

We compared CMRs and KEFs based on where each biotic group had been observed frequently, defined whereby a CMR or KEF each contained at least 15% of the total number of observations made across the entire N and NW regions.

Because observations may be concentrated in just a small section of a given CMR or KEF, we also compared CMRs and KEFs by how widespread the distribution of observations of each biotic group was across its entire area. We did this by dividing the number of 10x10 km pixels where at least one observation was made by the total number of 10x10 km pixels in each CMR or KEF. We considered a biotic group to be widespread if at least one-third of the CMR or KEF pixels contained observations of that group. This measure is probably most useful as an indirect proxy of survey effort as it is very sensitive to the size of the CMR or KEF. The CMRs, in particular, vary widely in size. Invariably, observations of biotic groups are the most widespread across the CMRs with the smallest areas because a relatively larger proportion of their total area has been surveyed. Because of this, we also examined how widespread the spatial distribution of each biotic group is by visually examining the detailed maps.

3.2.2 Physical data

We identified where freely-available data describing the physical characteristics of the N and NW regions is known to exist. This included the following:

1. Multibeam bathymetry data held by Geoscience Australia, as at February 17, 2016. These data originated from a range of sources, including GA, CSIRO, RAN and AIMS.
2. RAN bathymetric data, which included bathymetric surveys conducted by the Royal Australian Navy Hydrographic Service (http://www.hydro.gov.au/) using single beam echo-sounder, multibeam echo-sounder and Laser Airborne Depth Sounder (LADS). The year in which bathymetry data were collected ranged from 1989 to 2016.
3. Oceanographic data, sourced from the Bureau of Meteorology (www.bom.gov.au), the Royal Australian Navy (www.hydro.gov.au/), the Integrated Marine Observing System -IMOS (www.imos.org.au/), Ships of Opportunity (imos.org.au/shipsofopportunity.html), Geoscience Australia (www.ga.gov.au), and CSIRO (CTD, ADCP, HYDR – www.csiro.gov.au). This includes measurements of

winds, waves, turbidity, salinity, temperature, ocean productivity, nutrient concentrations and more
4. Sediment composition data held by Geoscience Australia.

We compared CMRs and KEFs based on where each major source of physical data (multi-beam bathymetry, RAN bathymetry, oceanographic and sediment data) was relatively abundant. We defined a data source as relatively abundant within a CMR or KEF when at least 15% of the total number of records from that data source across the entire N and NW regions was present in that CMR or KEF.

Because the location of physical data within a CMR or KEF may be concentrated in just a small section of the CMR or KEF, we also compared CMRs and KEFs by how widespread the distribution of the data holdings of each data type was across its entire area. We did this by dividing the number of 10 x 10 km pixels where at least one dataset exists by the total number of 10 x 10 km pixels in each CMR or KEF. We considered a data type to be widespread across a CMR or KEF if at least one-third of its pixels contained at least one record of that type of data. This measure is probably most useful as an indirect measure of survey effort as it is very sensitive to the size of the CMR or KEF. The CMRs, in particular, vary widely in size. Invariably, observations of data holdings are the most widespread across the CMRs with the smallest areas because a relatively larger proportion of their total area has been surveyed. Because of this, we also examined how widespread the spatial distribution is of each data source by visually examining the detailed maps.

3.3 Results

Knowing where biota have been observed most frequently offers a justification for the effort needed to build a predictive model for a given CMR or KEF, although any model will likely require the collection of recent data to be representative of the current status of the biota. In the interpretation of the results of our gap analyses, we consider biota split into four categories and considered firstly by CMRs and then by KEFs:

1. benthic (hard coral- soft coral – sponge - brittle stars – polychaetes - molluscs),
2. demersal (fish - sharks & rays),
3. pelagic (fish - sharks & rays), and
4. megafauna (marine mammals – sea turtles).

3.3.1 Biota in the CMRs

Benthic biota

By far, observations of benthic biota are most abundant in the Kimberley CMR with 15% or more of the total number of observations across the N and NW regions in all six benthic groups concentrated there (Figure 3.1). This includes 15% of hard coral, 90% of soft corals, 44% of sponges, 25% of brittle stars and 20% of molluscs (Table 3.1). Overall, only 7 CMRs have a relative abundance (at least 15% of all known observations) of at least one benthic group (Arafura – 1, Ashmore Reef – 2, Dampier – 1, Gascoyne – 1, Kimberley-6, Ningaloo – 2, Oceanic Shoals - 1), with no observations of the six benthic biota categories in the remaining 15 CMRS of the North and NW Region (Figure 1, Table 1).

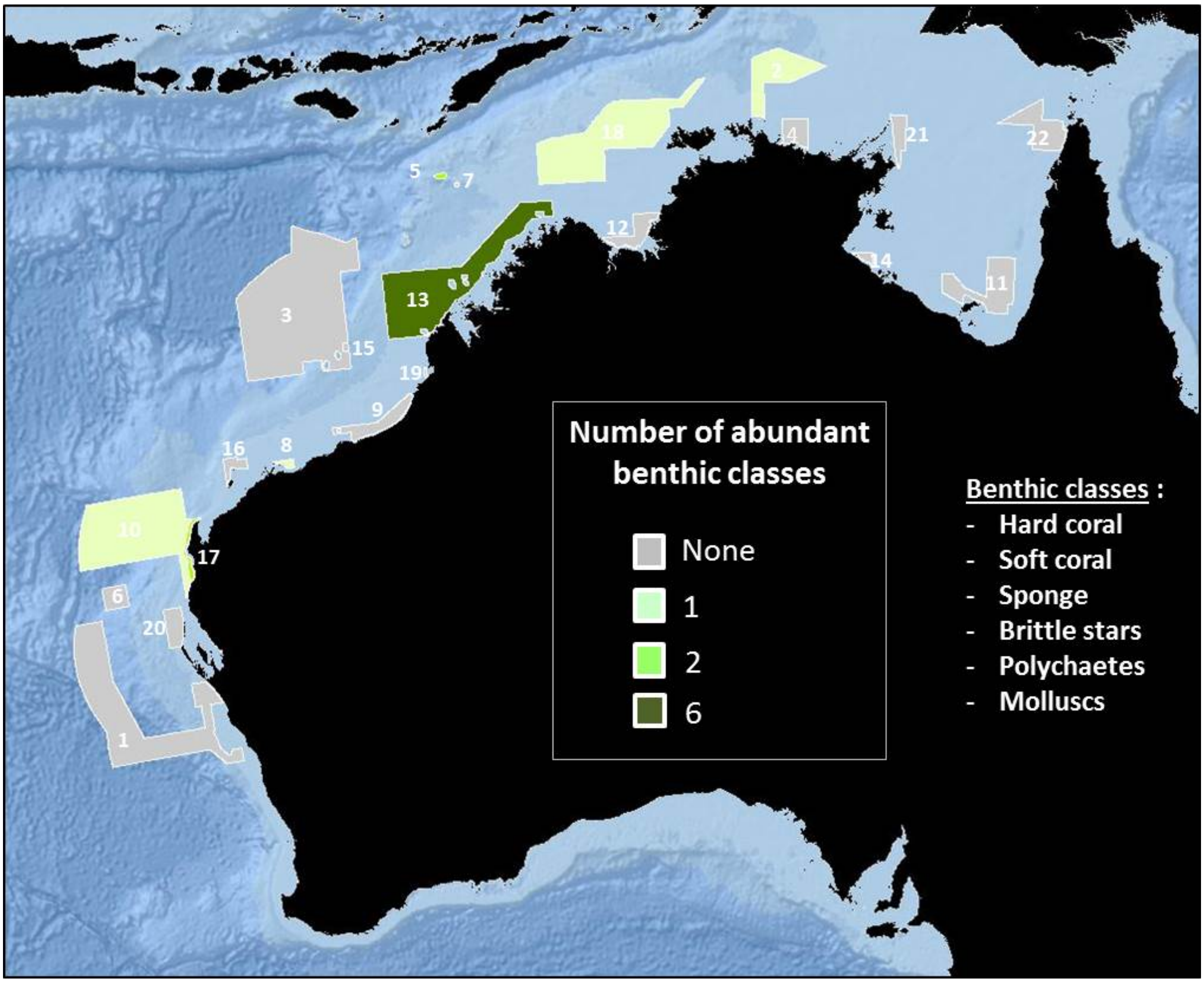

Figure 3.1 Number of benthic classes for which each CMR contains 15% or more of all known observations. We term this as ‘relatively abundant’. CMRs are: 1- Abrolhos, 2- Arafura, 3- Argo-Rowley Terrace, 4- Arnhem, 5- Ashmore Reef, 6- Carnarvon Canyon, 7- Cartier Island, 8- Dampier, 9- Eighty Mile Beach, 10- Gascoyne, 11- Gulf of Carpentaria, 12- Joseph Bonaparte Gulf, 13- Kimberley, 14- Limmen, 15- Mermaid Reef, 16- Montebello, 17- Ningaloo, 18- Oceanic Shoals, 19- Roebuck , 20- Shark Bay, 21- Wessel, and 22- West Cape York.

Table 3.1 Relative % of observations of benthic fauna across the N and NW regions found in each Commonwealth Marine Reserve. Light shaded boxes for a CMR indicate at least 15% of the total observations across the entire region fell within that CMR. The dark shaded box indicates the CMR reaching the 15% target for the highest number of biotic groups – in this case, the Kimberley CMR.

	Relative % of N and NW region						
Commonwealth Marine Reserve	*Hard coral*	*Soft coral*	*Sponge*	*Brittle stars*	*Polychaetes*	*Molluscs*	*# classes > 15%*
Abrolhos	1	0	0	0	0	1	0
Arafura	0	0	0	3	20	1	1
Argo-Rowley Terrace	9	0	0	7	1	3	0
Arnhem	0	0	0	0	2	1	0
Ashmore Reef	6	1	0	16	9	23	2
Carnarvon Canyon	0	0	0	0	0	0	0
Cartier Island	1	6	0	4	8	11	0
Dampier	4	0	0	17	3	8	1
Eighty Mile Beach	0	0	0	2	1	6	0
Gascoyne	2	0	24	3	2	1	1
Gulf of Carpentaria	0	0	0	8	2	3	0
Joseph Bonaparte Gulf	0	0	0	0	0	1	0
Kimberley	15	90	44	25	25	20	6
Limmen	0	0	0	0	0	0	0
Mermaid Reef	6	0	0	4	0	3	0
Montebello	13	0	0	2	0	6	0
Ningaloo	33	1	20	3	1	4	2
Oceanic Shoals	7	0	5	4	25	3	1
Roebuck	0	0	1	0	0	3	0
Shark Bay	2	0	4	1	0	2	0
Wessel	0	0	0	1	0	0	0
West Cape York	0	0	0	0	0	1	0

Below is a summary of where each biotic group was relatively abundant with a link to a detailed map of its distribution (in 10x10 km pixels) within the CMRs:

- **Hard corals** - Ningaloo / Kimberley (http://northwestatlas.org/node/1674)
- **Soft corals** – Kimberley (http://northwestatlas.org/node/1682)
- **Sponges** – Kimberley/Gascoyne/Ningaloo (http://northwestatlas.org/node/1683)
- **Brittle stars** – Kimberley/Dampier/Ashmore Reef (http://northwestatlas.org/node/1671)
- **Polychaetes** – Kimberley/Oceanic Shoals/Arafura (http://northwestatlas.org/node/1679)
- **Molluscs** – Ashmore Reef/Kimberley (http://northwestatlas.org/node/1676)

Observations of benthic organisms covered a high proportion of entire CMRs for only four CMRs; Ashmore Reef, Cartier Island, Mermaid Reef and Ningaloo (Table 3.2). This result is somewhat misleading, however, as most of these CMRs are small and contain far fewer 10x10 km pixels than most of the CMRs. Thus far fewer observations are needed for a relatively high % of the area to be covered. Also, this way of summarising the data gives no indication of how spatially widespread the observations were across the CMR.

Table 3.2 Relative % of each Commonwealth Marine Reserve in the North and NW regions where six groups of benthic organisms were observed. Shaded boxes for a CMR indicate where benthic organisms existed in at least one-third of the 10x10km pixels that define the CMR.

	Relative % of total CMR area					
Commonwealth Marine Reserve	*Hard coral*	*Soft coral*	*Sponge*	*Brittle stars*	*Polychaetes*	*Molluscs*
Abrolhos	1	0	1	0	0	1
Arafura	0	2	0	4	8	4
Argo-Rowley Terrace	1	1	0	1	0	2
Arnhem	0	1	3	1	2	2
Ashmore Reef	40	47	33	47	33	40
Carnarvon Canyon	0	0	0	0	0	0
Cartier Island	50	50	33	50	33	50
Dampier	28	8	32	16	20	28
Eighty Mile Beach	0	1	2	3	1	12
Gascoyne	0	0	3	1	0	2
Gulf of Carpentaria	0	2	12	6	3	11
Joseph Bonaparte Gulf	0	0	0	2	1	7
Kimberley	6	10	11	4	4	9
Limmen	0	0	0	0	0	0

Commonwealth Marine Reserve	Relative % of total CMR area					
	Hard coral	*Soft coral*	*Sponge*	*Brittle stars*	*Polychaetes*	*Molluscs*
Mermaid Reef	31	31	15	31	0	38
Montebello	13	11	11	9	0	29
Ningaloo	34	14	59	12	5	12
Oceanic Shoals	2	1	5	3	5	5
Roebuck	20	0	30	0	0	20
Shark Bay	7	2	7	3	1	12
Wessel	0	0	6	2	1	6
West Cape York	0	0	3	0	0	7

Below is a summary of CMRs in which observations of a benthic biota type were both abundant (Table 3.1) and widespread (Table 3.2), and hence would be most likely to be useful in the context of spatial predictive modelling:

- **Hard corals** – Ningaloo
- **Soft corals** – none
- **Sponges** – Ningaloo
- **Brittle stars** – Ashmore Reef
- **Polychaetes** – none
- **Molluscs** – Ashmore Reef

From the fine-scale maps of benthos (see Appendices B and C for direct links) it is also evident that observations of soft corals and sponges are well distributed spatially throughout the Kimberley CMR. In contrast, in the vast Gascoyne CMR where sponge observations were relatively abundant, known locations were concentrated in the south-west corner and absent elsewhere.

Fish and marine mammals

Observations of demersal fish were only abundant in one CMR (Gulf of Carpentaria) and observations of demersal sharks and rays were not abundant in any CMRs (Figure 3.2, Table 3.3). Six CMRs had observations of demersal fish spread across a large proportion of their area (Ashmore, Cartier, Dampier, Mermaid, Montebello and Ningaloo; Table 3.4), although the spatial distribution of demersal fish observations (northwestatlas.org/node/1672) are widespread in most CMRs (except Argo-Rowley Terrace, Carnarvon Canyon, Eighty Mile Beach and Gascoyne). Furthermore, although only 25% of the area of the Gulf of

Carpentaria CMR has observations of demersal fish (Table 3.4), these observations are actually widespread across the CMR. For demersal shark and rays, five CMRS had observations spread over a large proportion of their area although the number of observations was low (Tables 3.3, 3.4).

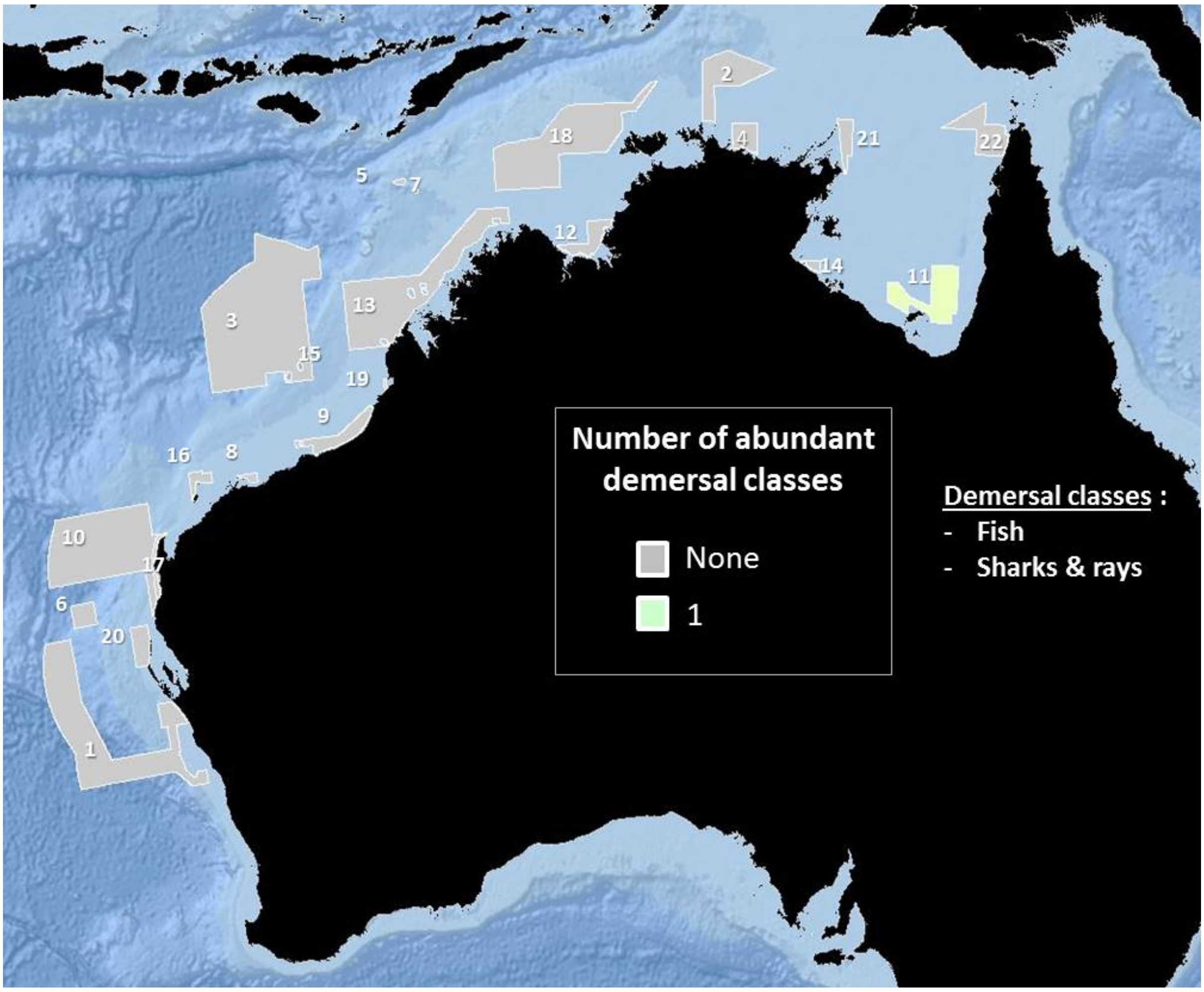

Figure 3.2 Number of demersal fauna classes for which each CMR contains 15% or more of all known observations. CMRs are: 1- Abrolhos, 2- Arafura, 3- Argo-Rowley Terrace, 4- Arnhem, 5- Ashmore Reef, 6- Carnarvon Canyon, 7- Cartier Island, 8- Dampier, 9- Eighty Mile Beach, 10- Gascoyne, 11- Gulf of Carpentaria, 12- Joseph Bonaparte Gulf, 13- Kimberley, 14- Limmen, 15- Mermaid Reef, 16- Montebello, 17- Ningaloo, 18- Oceanic Shoals, 19- Roebuck , 20- Shark Bay, 21- Wessel, and 22- West Cape York.

Table 3.3 Relative % of observations of demersal and pelagic fauna across the N and NW region found in each Commonwealth Marine Reserve. Light shaded boxes for a CMR indicate at least 15% of the total observations across the entire region fell within that CMR. The dark shaded box indicates the CMR reaching the 15% target for the highest number of fish classes – in this case, the Kimberley CMR.

	Relative % of N and NW region							
Commonwealth Marine Reserve	*Marine mammals*	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Sea-birds*	*# classes > 15%*
Abrolhos	8	0	1	13	3	18	13	1
Arafura	1	2	3	5	5	3	1	0
Argo-Rowley Terrace	17	1	5	0	4	2	2	1
Arnhem	4	0	2	3	2	2	2	0
Ashmore Reef	1	0	4	0	9	0	22	1
Carnarvon Canyon	0	0	0	1	0	1	0	0
Cartier Island	0	0	1	0	1	1	0	0
Dampier	1	0	9	1	5	0	3	0
Eighty Mile Beach	2	3	4	1	3	0	7	0
Gascoyne	4	0	2	8	4	17	2	1
Gulf of Carpentaria	2	0	18	21	11	3	0	2
Joseph Bonaparte Gulf	1	0	0	1	1	1	2	0
Kimberley	36	57	9	10	14	3	24	3
Limmen	4	0	0	0	0	0	0	0
Mermaid Reef	1	0	6	0	1	0	0	0
Montebello	6	2	12	2	7	1	4	0
Ningaloo	4	0	11	3	7	17	7	1
Oceanic Shoals	6	31	5	14	9	19	1	2
Roebuck	0	2	0	0	0	0	3	0
Shark Bay	1	0	1	3	2	1	4	0
Wessel	1	0	2	5	5	9	2	0
West Cape York	1	1	4	6	6	2	1	0

Table 3.4 Relative % of each Commonwealth Marine Reserve in the N and NW regions where seven groups of demersal and pelagic fauna were observed to occur. Light shaded boxes for a CMR indicate at least one-third of the total area of that CMR (as divided into 10x10 km boxes) contained at least one observation of that group of fauna.

	Relative % of total CMR area						
Commonwealth Marine Reserve	*Marine mammals*	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Sea-birds*
Abrolhos	5	0	6	4	4	4	48
Arafura	1	23	20	13	13	3	40
Argo-Rowley Terrace	6	4	2	0	1	0	14
Arnhem	12	9	19	15	15	7	10
Ashmore Reef	33	20	73	20	60	13	54
Carnarvon Canyon	0	0	3	3	0	3	0
Cartier Island	0	33	50	17	50	33	0
Dampier	12	76	68	20	52	0	0
Eighty Mile Beach	6	60	10	5	6	0	5
Gascoyne	2	1	4	2	3	3	0
Gulf of Carpentaria	2	2	25	18	17	4	0
Joseph Bonaparte Gulf	2	3	10	7	7	3	3
Kimberley	10	60	13	7	9	1	62
Limmen	38	5	10	10	5	5	0
Mermaid Reef	15	31	38	0	23	0	0
Montebello	23	75	73	32	66	9	1
Ningaloo	21	40	52	21	41	45	4
Oceanic Shoals	2	27	9	7	7	3	3
Roebuck	0	70	20	0	0	0	1
Shark Bay	3	1	27	17	13	3	6
Wessel	4	3	26	20	26	17	100
West Cape York	2	11	25	16	22	3	20

Like demersal fish, pelagic fish observations are only relatively abundant in one CMR – the Gulf of Carpentaria (Figure 3.3, Table 3.3) where they are also reasonably widely distributed (http://northwestatlas.org/node/1677) even though they've been observed over a relatively low % total area of the CMR. While observations of pelagic fish cover a low proportion of the total area of every CMR (Table 3.4), some observations of them exist in nearly every CMR except the Argo Rowley Terrace, Eighty Mile Beach and Gascoyne.

Observations of pelagic sharks and rays are the most abundant in the Abrolhos, Gascoyne, Ningaloo and Oceanic Shoals CMRs (Figure 3.3, Table 3.3). These observations are sparsely distributed across the CMRs (northwestatlas.org/node/1678), though a relatively high proportion of Ningaloo and Cartier Island CMRs have observations of pelagic sharks and rays (Table 3.4).

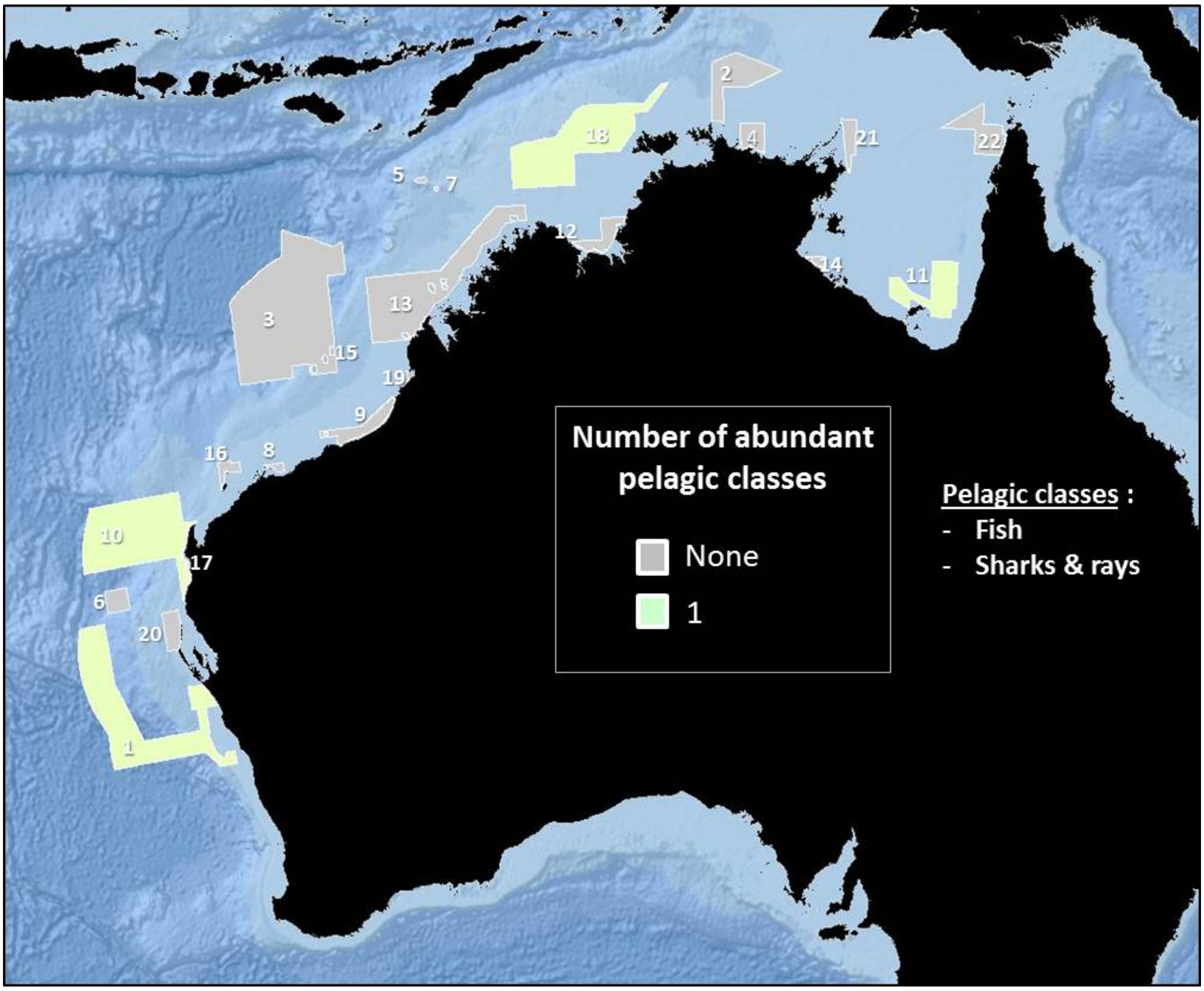

Figure 3.3 Number of pelagic fauna classes for which each CMR contains 15% or more of all known observations. CMRs are: 1- Abrolhos, 2- Arafura, 3- Argo-Rowley Terrace, 4- Arnhem, 5- Ashmore Reef, 6- Carnarvon Canyon, 7- Cartier Island, 8- Dampier, 9- Eighty Mile Beach, 10- Gascoyne, 11- Gulf of Carpentaria, 12- Joseph Bonaparte Gulf, 13- Kimberley, 14- Limmen, 15- Mermaid Reef, 16- Montebello, 17- Ningaloo, 18- Oceanic Shoals, 19- Roebuck , 20- Shark Bay, 21- Wessel, and 22- West Cape York.

Marine mammals are relatively abundant in the Kimberley and Argo Rowley Terrace CMRs (Table 3.3, Figure 3.4) where they are distributed widely in all but the northernmost parts of the CMRs (http://northwestatlas.org/node/1675). However, it is the Ashmore Reef and Limmen CMRs for which observations of marine mammals cover the largest proportion of their total area (Table 3.4). Sea turtle observations, in contrast, are by far the most abundant in the Kimberley (57%) and the Oceanic Shoals (31%) CMRs (Table 3.3), though they have been observed across a large proportion of the area of Dampier (76%), Eighty Mile Beach (60%), Kimberley (60%), Montebello (75%), Ningaloo (40%), and Roebuck (70%) CMRs (Table 3.4; http://northwestatlas.org/node/1680).

It is in the Kimberley CMR where observations of marine mammals and sea turtles are both relatively abundant and widely distributed. However, as our analysis is limited to freely available data sets, different patterns may emerge should additional datasets (e.g. held privately by industry) were to be included.

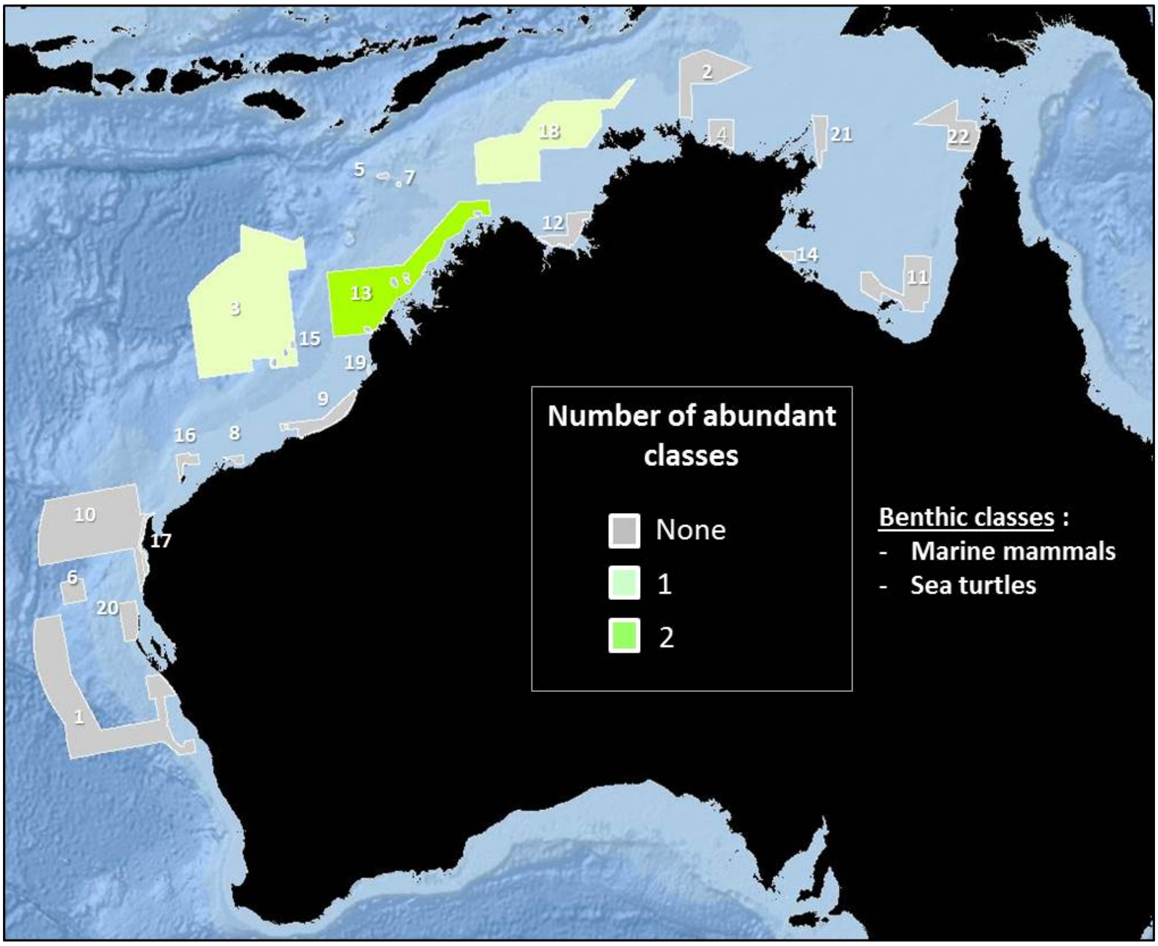

Figure 3 4 Number of megafauna classes for which each CMR contains 15% or more of all known observations. CMRs are: 1- Abrolhos, 2- Arafura, 3- Argo-Rowley Terrace, 4- Arnhem, 5- Ashmore Reef, 6- Carnarvon Canyon, 7- Cartier Island, 8- Dampier, 9- Eighty Mile Beach, 10- Gascoyne, 11- Gulf of Carpentaria, 12- Joseph Bonaparte Gulf, 13- Kimberley, 14- Limmen, 15- Mermaid Reef, 16- Montebello, 17- Ningaloo, 18- Oceanic Shoals, 19- Roebuck , 20- Shark Bay, 21- Wessel, and 22- West Cape York.

3.3.2 Biota in the KEFs

Benthic biota

Five (of 26) KEFs contain relatively abundant observations of at least one benthic class (Figure 3.5), with the 'Continental Slope and Demersal Fish Communities' KEF (#11) relatively abundant in five of six classes (Table 5).

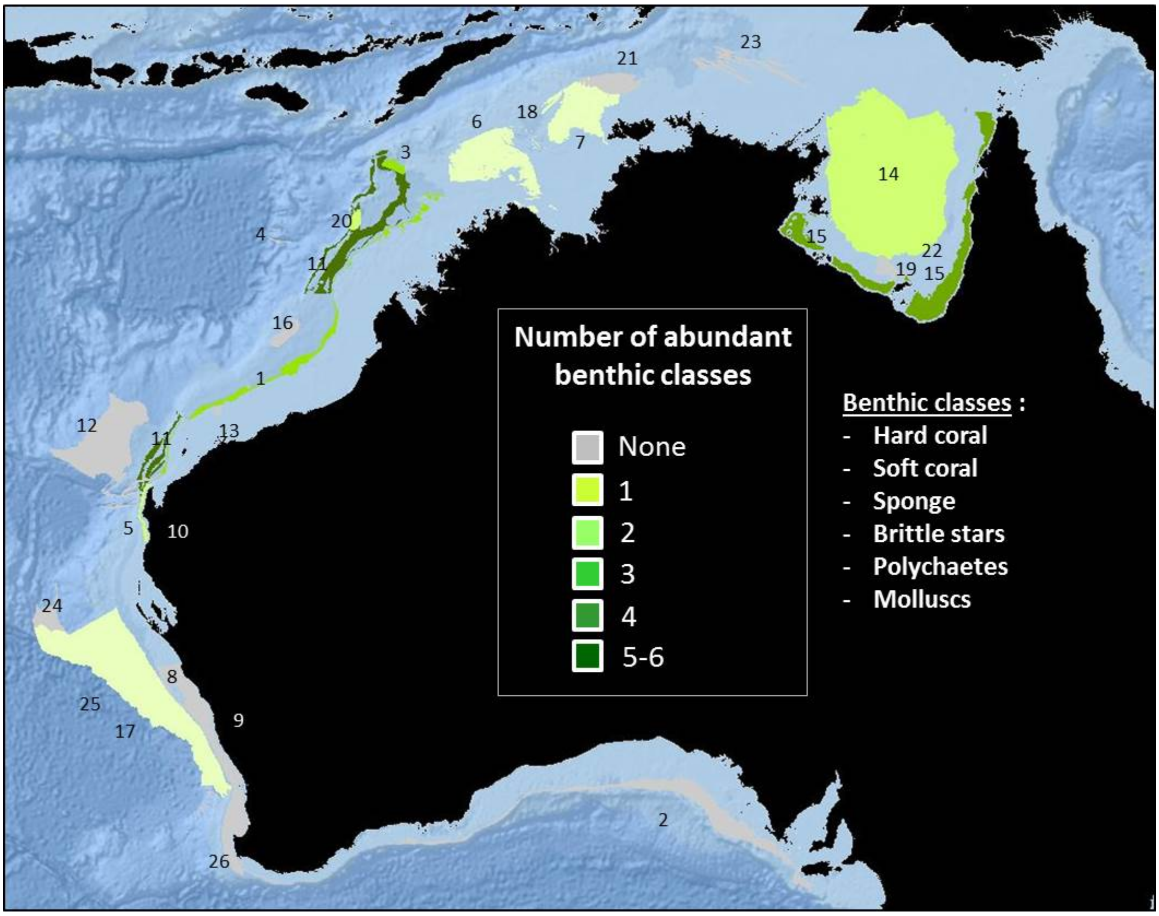

Figure 3.5 Number of benthic classes for which each KEF contains 15% or more of all known observations. KEFs are: 1- Ancient coastline at 125 m depth contour, 2- Ancient coastline at 90-120m depth, 3- Ashmore Reef and Cartier Island and surrounding Commonwealth waters, 4- Canyons linking the Argo Abyssal Plain with the Scott Plateau, 5- Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula, 6- Carbonate bank and terrace system of the Sahul Shelf, 7- Carbonate bank and terrace system of the Van Diemen Rise, 8- Commonwealth marine environment surrounding the Houtman Abrolhos Islands, 9- Commonwealth marine environment within and adjacent to the west coast inshore lagoons, 10- Commonwealth waters adjacent to Ningaloo Reef, 11- Continental Slope Demersal Fish Communities, 12- Exmouth Plateau, 13- Glomar Shoals, 14- Gulf of Carpentaria basin, 15- Gulf of Carpentaria coastal zone, 16- Mermaid Reef and Commonwealth waters surrounding Rowley Shoals, 17- Perth Canyon and adjacent shelf break, and other west coast canyons, 18- Pinnacles of the Bonaparte Basin, 19- Plateaux and saddle north-west of the Wellesley Islands, 20- Seringapatam Reef and Commonwealth waters in the Scott Reef Complex, 21- Shelf break and slope of the Arafura Shelf, 22- Submerged coral reefs of the Gulf of Carpentaria, 23- Tributary Canyons of the Arafura Depression, 24- Wallaby Saddle, 25- Western demersal slope and associated fish communities, and 26- Western rock lobster.

Below is a summary of where observations of each benthic group were relatively abundant (>15% of all records; Table 3.5) with a link to a detailed map of the distribution of observations of each benthic group within the KEFs.

- **Hard corals** – Seringapatam/Scott Reef, Continental Slope Demersal Fish Communities, Ningaloo Reef (http://northwestatlas.org/node/1690)
- **Soft corals** – Seringapatam/Scott Reef, Ningaloo Reef (http://northwestatlas.org/node/1691)
- **Sponges** – Ningaloo Reef, Ancient coastline at 125 m depth contour (http://northwestatlas.org/node/1692)
- **Brittle stars** – Continental Slope Demersal Fish Communities (http://northwestatlas.org/node/1693)
- **Polychaetes** – Ashmore Reef and Cartier Island, Continental Slope Demersal Fish Communities (http://northwestatlas.org/node/1694)
- **Molluscs** – Continental Slope Demersal Fish Communities, Ashmore Reef and Cartier Island

Examination of the spatial distribution of observations of benthic biota within the 10x10 km cells shows that hard coral observations are most widespread across the Scott Reef Complex (Table 3.6). This is the case for sponges, which also have widespread observations across the Scott Reef Complex, but have also observed across a high proportion of the area within Ningaloo and adjacent waters, and the submerged reefs of the Gulf of Carpentaria (Table 3.6). Molluscs have also been observed across a high proportion of the area of Scott Reef Complex, as well as Ashmore and Cartier, and Mermaid Reef. In contrast, observations of soft corals, brittle stars and polychaetes are not widely distributed spatially across any KEF.

Table 3.5 Relative % of observations of benthic fauna across the North and NW regions found in each Key Ecological Feature (KEF). Light shaded boxes for a KEF indicate at least 15% of the total observations across the entire region fell within that KEF. The dark shaded box indicates KEF reaching the 15% target for the highest number of biotic classes.

	Relative % of N and NW region						
KEF	*Hard coral*	*Soft coral*	*Sponge*	*Brittle stars*	*Polychaetes*	*Molluscs*	*# biotic classes > 15%*
1 Ancient coastline at 125 m depth contour	3	3	23	10	3	4	1
2 Ancient coastline at 90-120m depth	0	0	0	0	0	0	0
3 Ashmore Reef and Cartier Island and surrounding Commonwealth waters	5	6	2	8	24	30	2
4 Canyons linking the Argo Abyssal Plain with the Scott Plateau	0	0	0	0	0	0	0

KEF	Relative % of N and NW region: *Hard coral*	*Soft coral*	*Sponge*	*Brittle stars*	*Polychaetes*	*Molluscs*	*# biotic classes > 15%*
5 Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	0	0	8	5	2	1	0
6 Carbonate bank and terrace system of the Sahul Shelf	4	0	4	3	7	1	0
7 Carbonate bank and terrace system of the Van Diemen Rise	4	0	2	8	13	3	0
8 Commonwealth marine environment surrounding the Houtman Abrolhos Islands	3	0	1	0	0	0	0
9 Commonwealth marine environment within and adjacent to the west coast inshore lagoons	0	0	0	0	0	0	0
10 Commonwealth waters adjacent to Ningaloo Reef	19	1	40	5	2	4	2
11 Continental Slope Demersal Fish Communities	17	30	11	32	22	32	5
12 Exmouth Plateau	0	0	0	0	0	0	0
13 Glomar Shoals	1	0	0	1	0	0	0
14 Gulf of Carpentaria basin	0	0	0	2	1	2	0
15 Gulf of Carpentaria coastal zone	0	0	0	8	4	3	0
16 Mermaid Reef and Commonwealth waters surrounding Rowley Shoals	12	0	0	5	0	6	0
17 Perth Canyon and adjacent shelf break, and other west coast canyons	0	0	0	0	0	0	0
18 Pinnacles of the Bonaparte Basin	0	0	5	1	6	0	0
19 Plateaux and saddle north-west of the Wellesley Islands	0	0	0	0	0	1	0
20 Seringapatam Reef and Commonwealth waters in the Scott Reef Complex	29	59	1	8	1	12	2
21 Shelf break and slope of the Arafura Shelf	1	0	0	0	0	0	0
22 Submerged coral reefs of the Gulf of Carpentaria	0	0	1	2	0	0	0
23 Tributary Canyons of the Arafura Depression	0	0	0	4	14	0	0
24 Wallaby Saddle	0	0	0	0	0	0	0
25 Western demersal slope and associated fish communities	0	0	0	0	0	0	0
26 Western rock lobster	2	0	1	0	0	0	0

Table 3.6 Relative % of each KEF in the North and NW regions where six groups of benthic fauna were observed to occur. Light shaded boxes for a KEF indicate at least one-third of the total area of that KEF (as 10x10 km pixels) contained at least one observation of that group of fauna.

	Relative % of KEF					
KEF	*Hard coral*	*Soft coral*	*Sponge*	*Brittle stars*	*Polychaetes*	*Molluscs*
1 Ancient coastline at 125 m depth contour	2	3	7	6	3	14
2 Ancient coastline at 90-120m depth	10	0	25	0	0	10
3 Ashmore Reef and Cartier Island and surrounding Commonwealth waters	25	29	21	40	29	35
4 Canyons linking the Argo Abyssal Plain with the Scott Plateau	0	0	0	0	0	0
5 Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	0	3	13	8	4	13
6 Carbonate bank and terrace system of the Sahul Shelf	3	0	3	1	3	3
7 Carbonate bank and terrace system of the Van Diemen Rise	4	2	6	5	6	10
8 Commonwealth marine environment surrounding the Houtman Abrolhos Islands	17	3	38	0	0	0
9 Commonwealth marine environment within and adjacent to the west coast inshore lagoons	21	0	0	0	0	0
10 Commonwealth waters adjacent to Ningaloo Reef	33	15	60	18	11	18
11 Continental Slope Demersal Fish Communities	5	6	9	12	4	16
12 Exmouth Plateau	0	0	0	0	0	1
13 Glomar Shoals	25	6	13	13	0	31
14 Gulf of Carpentaria basin	0	0	2	0	0	3
15 Gulf of Carpentaria coastal zone	0	1	2	3	2	10
16 Mermaid Reef and Commonwealth waters surrounding Rowley Shoals	21	24	15	21	3	34
17 Perth Canyon and adjacent shelf break, and other west coast canyons	0	0	0	0	0	0
18 Pinnacles of the Bonaparte Basin	3	0	9	2	9	3
19 Plateaux and saddle north-west of the Wellesley Islands	0	2	17	0	3	14
20 Seringapatam Reef and Commonwealth waters in the Scott Reef Complex	55	33	31	34	10	47
21 Shelf break and slope of the Arafura Shelf	2	2	0	1	0	12
22 Submerged coral reefs of the Gulf of Carpentaria	0	0	46	12	0	7
23 Tributary Canyons of the Arafura Depression	0	2	0	4	8	3
24 Wallaby Saddle	0	0	0	0	0	0
25 Western demersal slope and associated fish communities	0	0	1	0	0	0
26 Western rock lobster	10	1	12	0	0	2

KEFs in which observations of a benthic biota type were both abundant (Table 3.5) and widespread (Table 3.6), and hence would be most likely to be useful in the context of spatial predictive modelling include:

- **Hard corals** – Commonwealth waters adjacent to Ningaloo Reef (#10), Seringapatam Reef and Commonwealth waters in the Scott Reef Complex (#20)
- **Soft corals** – Seringapatam Reef and Commonwealth waters in the Scott Reef Complex (#20)
- **Sponges** – Commonwealth waters adjacent to Ningaloo Reef (#10)
- **Brittle stars** – none
- **Polychaetes** – none
- **Molluscs** – Ashmore Reef and Cartier Island and surrounding Commonwealth waters (#3)

Fish and marine mammals

Observations of demersal fish and demersal sharks & rays were concentrated in just three KEFs: Gulf of Carpentaria basin (#14), Gulf of Carpentaria coastal zones (#15) and along the Ancient coastline at 125 m depth - #1 (Figure 3.7).

Below is a summary of where demersal fish and demersal sharks and rays were relatively abundant (Table 3.7), with a link to a detailed map of its distribution within the KEFs divided into 10x10 km cells:

- **Demersal fish** - Gulf of Carpentaria coastal zone, Ancient coastline at 125 m depth contour (http://northwestatlas.org/node/1699)
- **Demersal sharks and rays** – Ancient coastline at 125 m depth contour, Gulf of Carpentaria basin, Gulf of Carpentaria coastal zone (northwestatlas.org/node/1700)

Observations of demersal organisms covered a high proportion of entire KEFs for several KEFs and demersal classes (Table 3.8):

- **Demersal fish** at Glomar Shoals, waters adjacent to Ningaloo Reef, Scott Reef Complex, Ashmore/Cartier and Ancient Coastline at 125m contour
- **Demersal sharks & rays** at Glomar Shoals, waters adjacent to Ningaloo Reef and Ashmore/Cartier

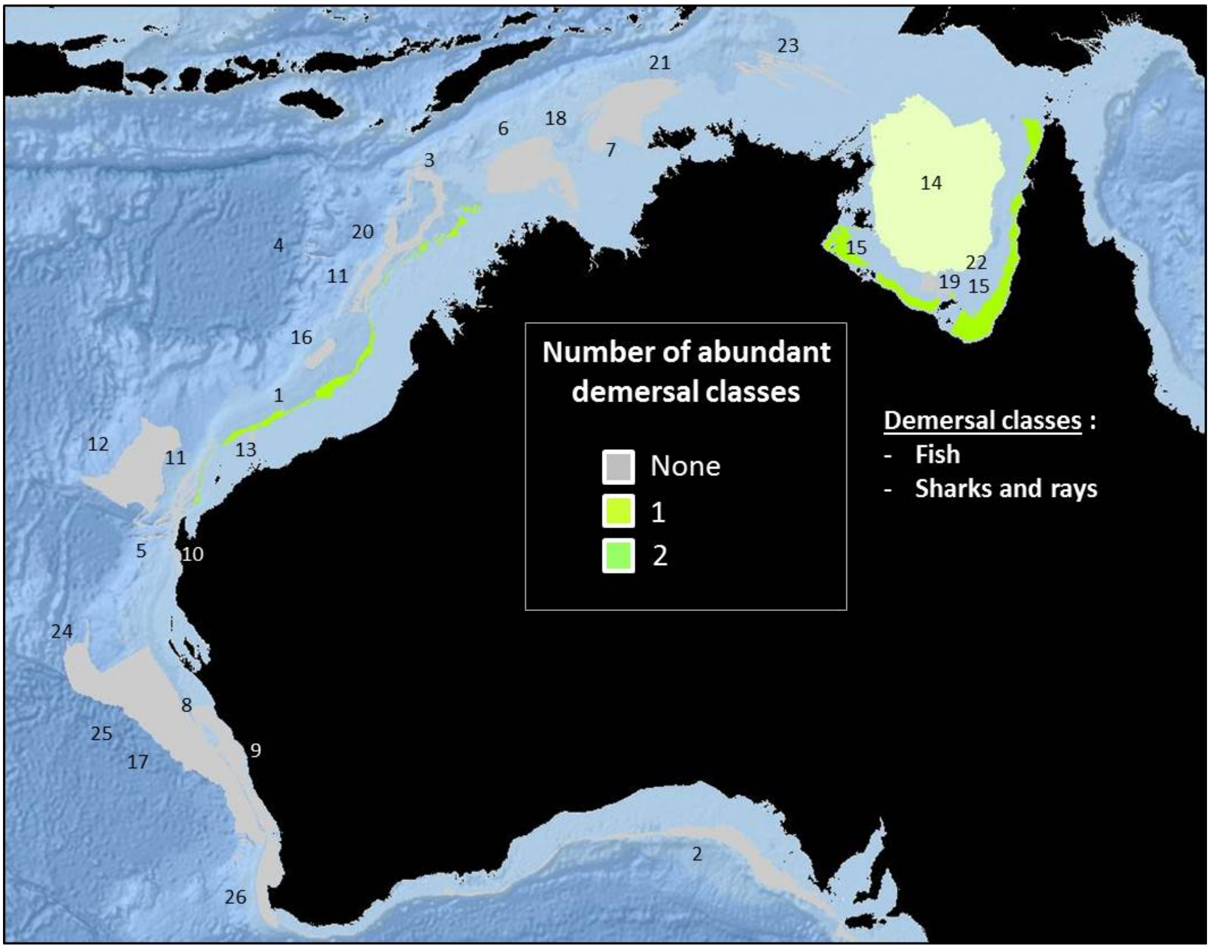

Figure 3.6 Number of demersal classes for which each KEF contains 15% or more of all known observations. KEFs are: 1- Ancient coastline at 125 m depth contour, 2- Ancient coastline at 90-120m depth, 3- Ashmore Reef and Cartier Island and surrounding Commonwealth waters, 4- Canyons linking the Argo Abyssal Plain with the Scott Plateau, 5- Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula, 6- Carbonate bank and terrace system of the Sahul Shelf, 7- Carbonate bank and terrace system of the Van Diemen Rise, 8- Commonwealth marine environment surrounding the Houtman Abrolhos Islands, 9- Commonwealth marine environment within and adjacent to the west coast inshore lagoons, 10- Commonwealth waters adjacent to Ningaloo Reef, 11- Continental Slope Demersal Fish Communities, 12- Exmouth Plateau, 13- Glomar Shoals, 14- Gulf of Carpentaria basin, 15- Gulf of Carpentaria coastal zone, 16- Mermaid Reef and Commonwealth waters surrounding Rowley Shoals, 17- Perth Canyon and adjacent shelf break, and other west coast canyons, 18- Pinnacles of the Bonaparte Basin, 19- Plateaux and saddle north-west of the Wellesley Islands, 20- Seringapatam Reef and Commonwealth waters in the Scott Reef Complex, 21- Shelf break and slope of the Arafura Shelf, 22- Submerged coral reefs of the Gulf of Carpentaria, 23- Tributary Canyons of the Arafura Depression, 24- Wallaby Saddle, 25- Western demersal slope and associated fish communities, and 26- Western rock lobster.

Table 3.7 Relative % of observations of demersal and pelagic fauna across the North and NW region found in each Key Ecological Feature (KEF). Light shaded boxes for a KEF indicate at least 15% of the total observations across the entire region fell within that KEF. The dark shaded box indicates the KEF reaching the 15% target for the highest number of biotic classes.

	Relative % of N and NW region							
KEF	*Marine mammals*	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Sea-birds*	*# biotic classes > 15%*
1 Ancient coastline at 125 m depth contour	5	2	15	11	17	5	1	2
2 Ancient coastline at 90-120m depth	0	0	0	0	0	0	0	0
3 Ashmore Reef and Cartier Island and surrounding Commonwealth waters	2	0	5	0	7	1	20	1
4 Canyons linking the Argo Abyssal Plain with the Scott Plateau	0	0	0	0	0	0	0	0
5 Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	0	0	0	2	1	6	0	0
6 Carbonate bank and terrace system of the Sahul Shelf	8	62	1	4	3	8	2	1
7 Carbonate bank and terrace system of the Van Diemen Rise	0	28	2	2	2	1	0	1
8 Commonwealth marine environment surrounding the Houtman Abrolhos Islands	1	0	1	0	1	0	8	0
9 Commonwealth marine environment within and adjacent to the west coast inshore lagoons	2	0	0	0	0	0	2	0
10 Commonwealth waters adjacent to Ningaloo Reef	4	1	5	2	4	12	4	0
11 Continental Slope Demersal Fish Communities	12	1	10	4	9	11	25	1
12 Exmouth Plateau	6	0	0	0	0	0	0	0
13 Glomar Shoals	0	0	4	1	4	0	0	0
14 Gulf of Carpentaria basin	2	1	11	19	15	12	4	2

KEF	Relative % of N and NW region							# biotic classes > 15%
	Marine mammals	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Sea-birds*	
15 Gulf of Carpentaria coastal zone	39	2	21	38	16	11	9	4
16 Mermaid Reef and Commonwealth waters surrounding Rowley Shoals	2	0	8	0	3	1	1	0
17 Perth Canyon and adjacent shelf break, and other west coast canyons	0	0	0	1	0	1	0	0
18 Pinnacles of the Bonaparte Basin	1	0	0	3	1	6	0	0
19 Plateaux and saddle north-west of the Wellesley Islands	1	0	3	1	1	1	0	0
20 Seringapatam Reef and Commonwealth waters in the Scott Reef Complex	1	0	7	0	3	0	6	0
21 Shelf break and slope of the Arafura Shelf	0	0	1	1	2	0	0	0
22 Submerged coral reefs of the Gulf of Carpentaria	0	0	1	1	0	0	0	0
23 Tributary Canyons of the Arafura Depression	0	3	1	2	2	1	0	0
24 Wallaby Saddle	2	0	0	1	0	3	0	0
25 Western demersal slope and associated fish communities	5	0	1	7	6	18	4	1
26 Western rock lobster	4	0	1	0	1	0	12	0

Table 3.8 Relative % of each KEF in the North and NW regions where seven groups of demersal and pelagic fauna were observed to occur. Light shaded boxes for a CMR indicate at least one-third of the total area of that CMR (as divided into 10 by 10 km boxes) contained at least one observation of that group of fauna.

	Relative % of KEF						
KEF	*Marine mammals*	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Sea-birds*
1 Ancient coastline at 125 m depth contour	4	16	42	29	31	8	2
2 Ancient coastline at 90-120m depth	0	0	5	5	10	5	10
3 Ashmore Reef and Cartier Island and surrounding Commonwealth waters	13	13	44	12	33	13	19
4 Canyons linking the Argo Abyssal Plain with the Scott Plateau	0	0	0	0	0	0	0
5 Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	1	4	14	3	11	13	0
6 Carbonate bank and terrace system of the Sahul Shelf	3	55	8	5	6	3	3
7 Carbonate bank and terrace system of the Van Diemen Rise	0	14	16	7	9	2	0
8 Commonwealth marine environment surrounding the Houtman Abrolhos Islands	5	0	14	6	12	5	15
9 Commonwealth marine environment within and adjacent to the west coast inshore lagoons	29	0	14	14	7	0	21
10 Commonwealth waters adjacent to Ningaloo Reef	18	40	53	19	38	49	18
11 Continental Slope Demersal Fish Communities	4	7	16	5	10	6	10
12 Exmouth Plateau	5	0	2	0	1	0	0
13 Glomar Shoals	6	0	100	69	100	13	0
14 Gulf of Carpentaria basin	0	0	12	9	10	3	1
15 Gulf of Carpentaria coastal zone	11	7	24	19	18	6	3
16 Mermaid Reef and Commonwealth waters surrounding Rowley Shoals	7	10	28	3	28	7	7

	Relative % of KEF						
KEF	*Marine mammals*	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Sea-birds*
17 Perth Canyon and adjacent shelf break, and other west coast canyons	0	0	5	5	5	5	2
18 Pinnacles of the Bonaparte Basin	3	9	9	14	7	8	0
19 Plateaux and saddle north-west of the Wellesley Islands	3	1	29	14	11	10	0
20 Seringapatam Reef and Commonwealth waters in the Scott Reef Complex	3	3	45	7	22	7	21
21 Shelf break and slope of the Arafura Shelf	1	7	31	9	17	0	0
22 Submerged coral reefs of the Gulf of Carpentaria	2	0	27	12	10	5	0
23 Tributary Canyons of the Arafura Depression	0	27	18	13	12	3	1
24 Wallaby Saddle	6	0	5	4	1	4	0
25 Western demersal slope and associated fish communities	3	0	8	5	8	5	1
26 Western rock lobster	6	0	9	5	8	1	14

Below is a summary of where observed locations of demersal organisms covered at least one-third of the total area of KEFs (Table 3.8) and where observations of that group was also relatively abundant (>15% of all observations across KEFs; Table 3.7). These areas could be considered further for predictive modelling for these taxa:

- **Demersal fish** – Ancient coastline 125m depth (#1)
- **Demersal sharks and rays** – none

Examining the detailed maps, however, shows that demersal fish records are also widely distributed across the vast KEFs in the Gulf of Carpentaria, even though there were relatively few observations across the KEF.

Observations of pelagic fish and pelagic sharks & rays were abundant in only three KEFs – again two in the Gulf of Carpentaria (basin - #14 and coastal zone - #15) and the Western Demersal Slope (#25) in the far south-east (Figure 3.7, Table 3.7).

- **Pelagic fish** – Gulf of Carpentaria basin, Gulf of Carpentaria coastal zone (http://northwestatlas.org/node/1702)

- **Pelagic sharks and rays** – Western demersal slope and associated fish communities (http://northwestatlas.org/node/1701)

Observations of pelagic organisms covered a high proportion of the Commonwealth waters adjacent to Ningaloo - #10 and Glomar Shoals - #13 (Table 3.8).

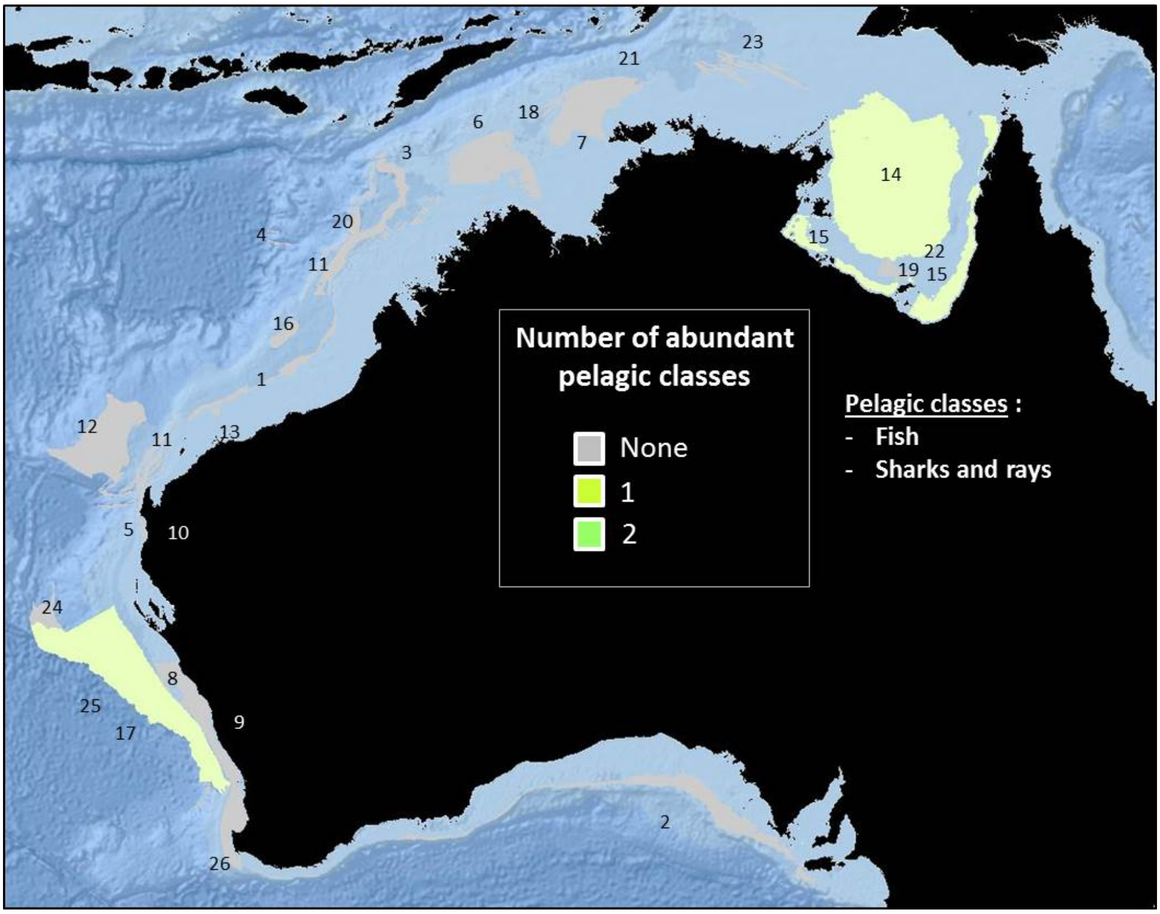

Figure 3.7 Number of pelagic classes for which each KEF contains 15% or more of all known observations. We term this as 'relatively abundant'. Pelagic classes are: fish and sharks & rays. KEFs are: 1- Ancient coastline at 125 m depth contour, 2- Ancient coastline at 90-120m depth, 3- Ashmore Reef and Cartier Island and surrounding Commonwealth waters, 4- Canyons linking the Argo Abyssal Plain with the Scott Plateau, 5- Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula, 6- Carbonate bank and terrace system of the Sahul Shelf, 7- Carbonate bank and terrace system of the Van Diemen Rise, 8- Commonwealth marine environment surrounding the Houtman Abrolhos Islands, 9- Commonwealth marine environment within and adjacent to the west coast inshore lagoons, 10- Commonwealth waters adjacent to Ningaloo Reef, 11- Continental Slope Demersal Fish Communities, 12- Exmouth Plateau, 13- Glomar Shoals, 14- Gulf of Carpentaria basin, 15- Gulf of Carpentaria coastal zone, 16- Mermaid Reef and Commonwealth waters surrounding Rowley Shoals, 17- Perth Canyon and adjacent shelf break, and other west coast canyons, 18- Pinnacles of the Bonaparte Basin, 19- Plateaux and saddle north-west of the Wellesley Islands, 20- Seringapatam Reef and Commonwealth waters in the Scott Reef Complex, 21- Shelf break and slope of the Arafura Shelf, 22- Submerged coral reefs of the Gulf of Carpentaria, 23- Tributary Canyons of the Arafura Depression, 24- Wallaby Saddle, 25- Western demersal slope and associated fish communities, and 26- Western rock lobster.

Marine mammals and sea turtles were also abundant in only three KEFs (Figure 3.8).

- **Marine mammals** - Gulf of Carpentaria Coastal zone - #15 (northwestatlas.org/node/1696)
- **Sea turtles** – Carbonate Banks of the Sahul Shelf - #6 and Carbonate Banks of the Van Diemen Rise - #7 (http://northwestatlas.org/node/1697)

Observations of marine mammals were generally sparse across all KEFS, although observations of sea turtles covered a high proportion of the Carbonate Banks of the Sahul Shelf - #6 and waters adjacent to Ningaloo Reef - #10 (Table 3.8).

Examining the detailed maps for marine mammals illustrates how sparsely distributed their known positions are even in KEFs where they have been observed relatively frequently. In contrast, sea turtles have been observed throughout all but the south-eastern section of KEF #6 (Carbonate Banks of the Sahul Shelf).However, they are only present in a few patches in KEF #7 (Carbonate Banks and Terraces of the Van Diemen Rise).

Below is a summary of where observed locations of pelagic organisms covered at least one-third of the total area of KEFs (Table 3.8) and where observations of that group were also relatively abundant (>15%; Table 3.7):

- **Pelagic fish** – none
- **Pelagic sharks and rays** – none
- **Marine mammals** – none
- **Sea turtles** – Carbonate Banks of the Sahul Shelf - #6

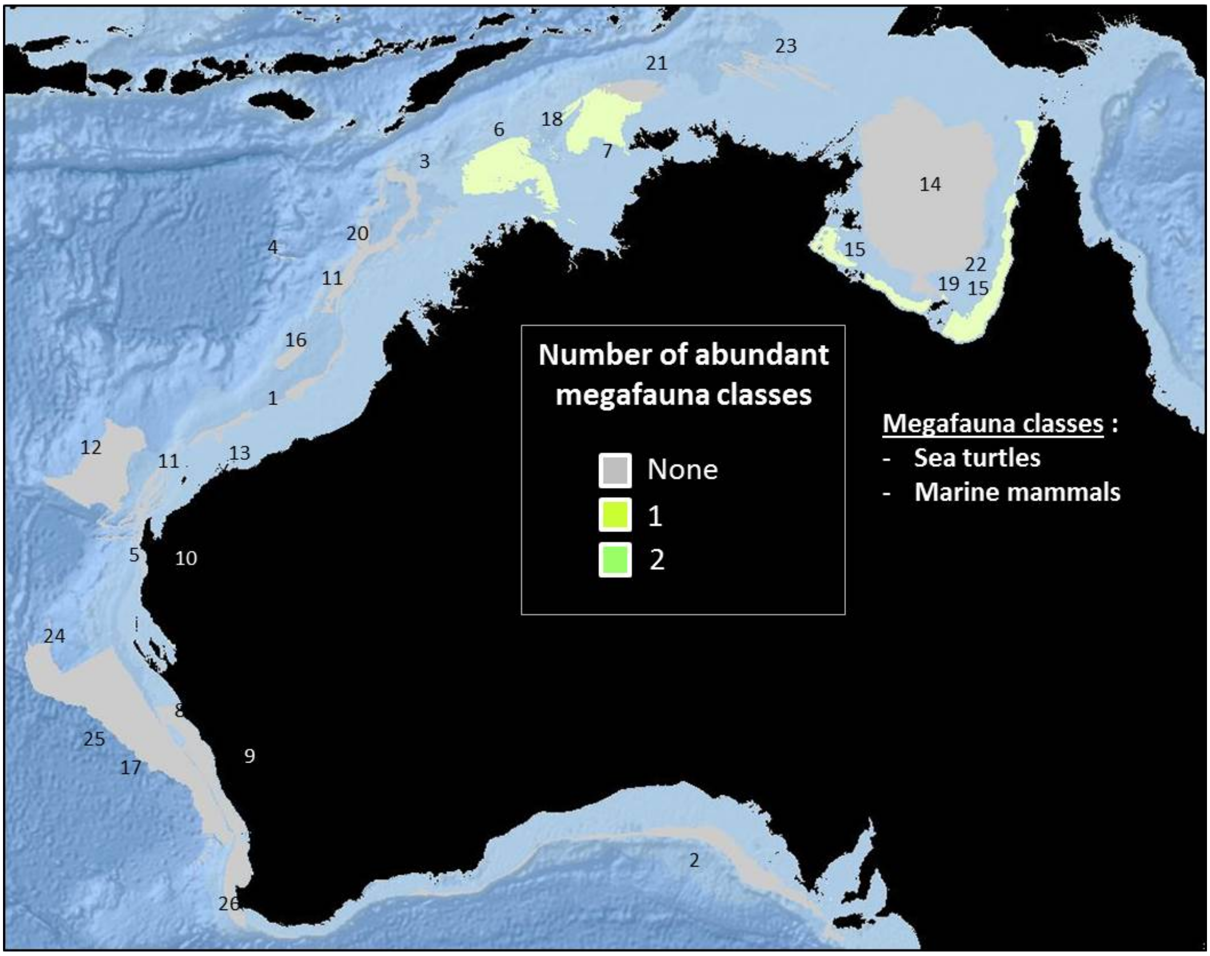

Figure 3.8 Number of marine megafauna classes for which each KEF contains 15% or more of all known observations. KEFs are: 1- Ancient coastline at 125 m depth contour, 2- Ancient coastline at 90-120m depth, 3- Ashmore Reef and Cartier Island and surrounding Commonwealth waters, 4- Canyons linking the Argo Abyssal Plain with the Scott Plateau, 5- Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula, 6- Carbonate bank and terrace system of the Sahul Shelf, 7- Carbonate bank and terrace system of the Van Diemen Rise, 8- Commonwealth marine environment surrounding the Houtman Abrolhos Islands, 9- Commonwealth marine environment within and adjacent to the west coast inshore lagoons, 10- Commonwealth waters adjacent to Ningaloo Reef, 11- Continental Slope Demersal Fish Communities, 12- Exmouth Plateau, 13- Glomar Shoals, 14- Gulf of Carpentaria basin, 15- Gulf of Carpentaria coastal zone, 16- Mermaid Reef and Commonwealth waters surrounding Rowley Shoals, 17- Perth Canyon and adjacent shelf break, and other west coast canyons, 18- Pinnacles of the Bonaparte Basin, 19- Plateaux and saddle north-west of the Wellesley Islands, 20- Seringapatam Reef and Commonwealth waters in the Scott Reef Complex, 21- Shelf break and slope of the Arafura Shelf, 22- Submerged coral reefs of the Gulf of Carpentaria, 23- Tributary Canyons of the Arafura Depression, 24- Wallaby Saddle, 25- Western demersal slope and associated fish communities, and 26- Western rock lobster.

3.3.3 Physical data in CMRs and KEFs

The previous section established the CMRs and KEFs for which a relative abundance and widespread distribution of records of biota of various types may justify developing spatial predictive models. This section considers the feasibility of building such models in those locations given the availability of relevant bathymetry and oceanographic data.

Of all the physical data that exists across the N and NW regions, most has been collected in 4 CMRs: Argo-Rowley Terrace, Gascoyne, Kimberley, and the Oceanic Shoals (Table 3.9). It is worth noting, however, that recording the existence of physical datasets in 10x10 km pixels can exaggerate how comprehensive the spatial coverage of the data is (see maps of the data at 5x5 km pixels at http://northwestatlas.org/node/1708).

Table 3.9 Relative % of bathymetry and oceanographic data that exists across the North and NW regions that is found in each Commonwealth Marine Reserve (CMR). Light shaded boxes for a CMR indicate at least 15% of the total observations across the entire region fell within that CMR. The dark shaded box indicates the CMR reaching the 15% target for the most different types of data.

	Relative % of N and NW region			
Commonwealth Marine Reserve	*Multi-beam bathymetry*	*RAN bathymetry*	*Oceanographic data*	*# classes > 15%*
Abrolhos	10	10	10	0
Arafura	3	3	5	0
Argo-Rowley Terrace	16	17	15	3
Arnhem	0	2	1	0
Ashmore Reef	0	1	1	0
Carnarvon Canyon	1	1	1	0
Cartier Island	0	0	0	0
Dampier	0	1	0	0
Eighty Mile Beach	0	0	0	0
Gascoyne	15	15	14	2
Gulf of Carpentaria	2	3	5	0
Joseph Bonaparte Gulf	0	0	1	0
Kimberley	12	16	21	2
Limmen	0	0	0	0
Mermaid Reef	0	0	0	0
Montebello	1	1	1	0
Ningaloo	2	2	2	0
Oceanic Shoals	12	18	17	3
Roebuck	0	0	0	0
Shark Bay	2	2	2	0
Wessel	1	1	1	0
West Cape York	1	5	3	0

High resolution multi-beam bathymetry is completely absent in the Dampier, Joseph Bonaparte Gulf and Limmen CMRs, and nearly so for Eighty Mile Beach (Table 3.10). Smaller CMRs generally have more widespread coverage (eg, Cartier Island, Mermaid Reef, Ningaloo – 100%), with notable exceptions (Limmen – 0%, Ashmore Reef – 50%). For some CMRs, coverage of lower resolution RAN bathymetry is notably more widespread than that of multi-beam – such as Arnhem (65% vs 11%), Ashmore Reef (100% vs 50%), Limmen (38% vs 0%), Montebello (98% vs 68%), Oceanic Shoals (84% vs 56%), and West Cape York (84% vs 19%). Oceanographic data exists to some degree across every CMR, with 100% coverage at Ashmore Reef, Cartier Island, Mermaid Reef and Ningaloo. For all but the Eighty Mile Beach CMR (11%), at least one-third of the total area contains some oceanographic data.

Table 3.10 Relative % of each Commonwealth Marine Reserve in the North and NW regions for which bathymetric and oceanographic data exists. Light shaded boxes indicate that at least 75% of the total area of the CMR contain at least one data point for a given dataset.

	Relative % of total CMR area			
Commonwealth Marine Reserve	*Multi-beam bathymetry*	*RAN bathymetry*	*Oceanographic data*	*# classes > 50%*
Abrolhos	52	52	51	0
Arafura	35	43	55	0
Argo-Rowley Terrace	41	43	38	0
Arnhem	11	65	39	0
Ashmore Reef	50	100	100	2
Carnarvon Canyon	63	63	47	0
Cartier Island	100	100	100	3
Dampier	0	100	37	1
Eighty Mile Beach	4	8	11	0
Gascoyne	65	66	64	0
Gulf of Carpentaria	31	37	61	0
Joseph Bonaparte Gulf	0	6	40	0
Kimberley	54	69	91	1
Limmen	0	38	86	1
Mermaid Reef	100	100	100	3
Montebello	68	98	95	2
Ningaloo	100	100	100	3
Oceanic Shoals	56	84	78	2
Roebuck	30	30	60	0
Shark Bay	85	87	97	3
Wessel	27	32	54	1
West Cape York	19	84	60	1

Multi-beam survey effort across the entire extensive N and NW regions has not been concentrated within any single KEF (Table 3.11). Indeed, no single KEF contains at least 15% of the known data. The largest concentration (9%) is found in KEF #25: Western demersal slope and associated fish communities. However, every KEF contains at least some multi-beam data. There is no major difference in coverage for RAN bathymetry versus multi-beam. Similarly, oceanographic data is found in all KEFs and is not concentrated in any particular KEFs.

Table 3.11 Relative % of bathymetry and oceanographic data that exists across the N and NW regions that is found in each Key Ecological Feature (KEF). Light shaded boxes for a KEF indicate at least 15% of the total observations across the entire region fell within that KEF. The dark shaded cells indicate the KEFs reaching the 15% target for the most different types of data.

	Relative % of N and NW region			*# classes > 15%*
KEF	*Multibeam bathymetry*	*RAN bathymetry*	*Oceanographic data*	
1	3.0	4.6	4.7	0
2	0.2	0.2	0.2	0
3	0.9	1.1	1.1	0
4	0.3	0.3	0.1	0
5	1.7	1.7	1.6	0
6	3.4	5.3	5.8	0
7	2.8	4.9	4.8	0
8	0.7	0.7	0.9	0
9	0.1	0.1	0.2	0
10	1.0	1.0	1.0	0
11	6.9	7.7	7.8	0
12	1.9	1.9	2.0	0
13	0.1	0.2	0.2	0
14	2.9	4.6	10.1	0
15	0.3	2.1	4.2	0
16	0.9	1.0	1.0	0
17	0.5	0.5	0.5	0
18	0.9	1.2	1.2	0
19	0.8	0.8	0.9	0
20	1.4	1.4	1.4	0
21	0.6	1.3	1.4	0
22	0.5	0.5	0.5	0
23	1.0	1.2	2.0	0
24	0.4	0.4	0.8	0
25	9.0	9.0	6.6	0
26	1.5	1.5	1.9	0

For 4 KEFs, multi-beam bathymetry has been collected within each 10km cell (Table 3.12 – values of 100%): #2 (Ancient coastline at 90-120m depth), #10 (Commonwealth waters adjacent to Ningaloo Reef), #17 (Perth Canyon), and #22 (Submerged coral reefs of the Gulf of Carpentaria). However, for 6 KEFs, such data exists for less than one-third of its total number of 10 by 10 km cells: #12: Exmouth Plateau, #14: Gulf of Carpentaria basin, #15: Gulf of Carpentaria coastal zone, #21: Shelf break and slope of the Arafura Shelf, #23: Tributary Canyons of the Arafura Depression, and #24: Wallaby Saddle. For some of these areas, coverage is greater for RAN bathymetry compared to multi-beam - particularly #1, #6, #7, #13, and #21. Oceanographic data is widespread across 17 KEFs, but is present in less than one-third of the total area of 2 KEFs: #4 and #12.

Table 3.12 Relative % of bathymetry and oceanographic data that exists across the N and NW regions that is found in each Key Ecological Feature (KEF). Light shaded boxes for a KEF indicate at least 15% of the total observations across the entire region fell within that KEF. The dark shaded boxes indicate the KEFs reaching a 15% target for the most different types of data.

	Relative % of total KEF area			*# classes > 15%*
KEF	*Multibeam bathymetry*	*RAN bathymetry*	*Oceanographic data*	
1	60	92	94	2
2	100	100	100	3
3	79	100	100	3
4	79	79	21	2
5	93	95	86	3
6	47	73	80	1
7	47	84	82	2
8	79	81	97	3
9	64	64	100	1
10	100	100	100	3
11	82	92	93	3
12	28	28	29	0
13	56	100	100	2
14	11	17	37	0
15	4	26	53	0
16	93	98	100	3
17	100	100	90	3
18	64	86	82	2
19	62	62	74	0
20	96	96	100	3
21	25	51	55	0
22	100	100	93	3
23	31	38	61	0
24	21	21	42	0
25	89	89	65	2
26	78	78	99	3

In summary, the bulk of physical data in the N and NW regions has been collected in only 4 CMRs (Argo-Rowley Terrace, Gascoyne, Kimberley, and the Oceanic Shoals). Because these CMRs are vast in size, however, this does not equate to anywhere near full coverage (Argo-Rowley Terrace – 41%, Gascoyne – 65%, Kimberley – 54%, Oceanic Shoals – 56%). In contrast, some relatively small CMRs have much greater coverage (Cartier Island, Mermaid Reef, Ningaloo). However, even CMRs with 100% coverage will still have gaps in coverage within the 10 by 10 km pixels (see http://northwestatlas.org/node/1708 - turn on the CMR data layer and zoom in to any CMR of interest). Bathymetry data is particularly lacking in the Dampier, Joseph Bonaparte Gulf, Limmen and Eighty Mile Beach CMRs. Oceanographic data exists for every CMR to some degree, with by far the worst coverage in Eighty Mile Beach.

In contrast, physical data as a whole is generally more widely available across the KEFs because they are smaller in size. No KEFs lack it completely. The worst coverage is for Gulf of Carpentaria KEFs (#14, 15).

3.4 Options for spatial predictive modelling based on existing data

3.4.1 Benthic spatial predictive models

The distribution of benthic organisms is typically highly correlated to the bottom topography. Thus, building benthic spatial predictive habitat models requires up-to-date observations of the distribution and abundance of biota as well as high resolution (multi-beam) bathymetry data that might explain these observations. Below we identify the CMRs and KEFs across the North and NW Regions for which the potential to build regional-scale (eg, CMR or KEF wide) models should be explored. Note however, that the lack of biological presences recorded in some CMRs and KEFs may just reflect a lack of survey effort. Unfortunately we have no way to account for this at present.

For CMRs:

Benthic habitat modelling would be a daunting task for the following CMRs as no bathymetry data exists and very little biological data has ever been recorded (Table 3.13):

- Arnhem,
- Carnarvon Canyon,
- Eighty Mile Beach,
- Joseph Bonaparte Gulf
- Roebuck.

Similarly, such modelling would be problematic for the following CMRs where no bathymetry data exists and minimal biological data has ever been recorded (Table 3.13):

- Abrolhos,
- Arafura,
- Gulf of Carpentaria,
- Limmen
- Wessel.

The **most likely candidates** for building CMR-wide benthic habitat models are:

- Ningaloo (particularly for hard corals, sponges, demersal fish, and demersal sharks & rays)
- Cartier Island (for all benthic and demersal types)
- Mermaid Reef (particularly for molluscs and demersal fish)

Such models **could also be attempted** for CMRs where multi-beam bathymetry is less widespread by using coarser scale (250m) RAN bathymetry, such as:

- Kimberley (all benthic types)
- Oceanic Shoals (particularly polychaetes)
- Ashmore Reef (all benthic types)

Further, in late 2017, a new 100m resolution bathymetry dataset for the NW shelf will be released. This will improve prospects for modelling the above CMRs.

Indeed, the next chapter in this report explores the implications of building such a model across the entire Oceanic Shoals CMR for a range of benthic classes. This CMR was selected because extensive field data exists – the CMR is just so large that the data still only represents a small proportion of the entire CMR.

For KEFs:

In contrast, only 6 KEFs fail to meet the 33% coverage benchmark (#s 12, 14, 15, 19, 21, 23 and 24) – Table 3.14. All but two of these also have minimal to no recorded biological data. However, demersal fish and demersal sharks and rays are relatively abundant and uniformly distributed across the two Gulf of Carpentaria KEFs (#14 and 15).

The **most likely candidates** for building KEF-wide benthic habitat models are:

- #3 (Ashmore Reef and Cartier Island) – particularly molluscs
- #10 (Ningaloo) – particularly hard coral and sponge
- #11 (Continental Slope Demersal Fish Communities) – particularly hard coral, soft coral, brittle starts, polychaetes and molluscs
- #20 (Scott Reef Complex) – particularly hard coral and soft coral

Such models **could be attempted** for KEFs where multi-beam bathymetry is less widespread by using coarser scale RAN bathymetry, such as:

- #1 (Ancient coastline 125m) – particularly demersal fish, demersal sharks & rays
- #13 (Glomar Shoals) - particularly demersal fish, demersal sharks & rays

Our analysis establishes where various types of biota have ever been observed – but predictive models will require current observations. In depth examination of the relevant data sets will be required to assess whether such models can be built 'as is' or whether additional biological observations are required. As such, the above results provide a guide for targeting which biota to survey and where.

Table 3.13. CMRs for which data is relatively abundant across the entire N and NW regions (contain 15+% of the bathymetry and oceanographic data and at 33+% of the observed biota) are shaded medium orange. CMRs for which data is widespread within the CMR (data exists in more than 75% of their 10 by 10 km cells) are shaded light orange. CMRs for which data is both relatively abundant and widespread are shaded dark orange.

Commonwealth Marine Reserve	*Multi-beam bathy-metry*	*RAN bathy-metry*	*Oceano-graphic data*	*Hard coral*	*Soft coral*	*Sponge*	*Brittle stars*	*Poly-chaetes*	*Molluscs*	*Marine mammals*	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Seabirds*
Abrolhos																
Arafura																
Argo-Rowley Terrace																
Arnhem																
Ashmore Reef																
Carnarvon Canyon																
Cartier Island																
Dampier																
Eighty Mile Beach																
Gascoyne																
Gulf of Carpentaria																
Joseph Bonaparte Gulf																
Kimberley																
Limmen																
Mermaid Reef																
Montebello																
Ningaloo																
Oceanic Shoals																
Roebuck																
Shark Bay																
Wessel																
West Cape York																

Table 3.14 KEFs for which data is relatively abundant across the entire N and NW regions (contain at least 15% of the bathymetry and oceanographic data and at least one-third of the observed biota) are shaded medium orange. KEFs for which data is widespread within the KEF (data exists in more than 75% of their 10 by 10 km cells) are shaded light orange. KEFs for which data is both relatively abundant and widespread are shaded dark orange.

KEF	*Multi-beam bathy-metry*	*RAN bathy-metry*	*Oceano-graphic data*	*Hard coral*	*Soft coral*	*Sponge*	*Brittle stars*	*Poly-chaetes*	*Molluscs*	*Marine mammals*	*Sea turtles*	*Demersal fish*	*Pelagic fish*	*Demersal sharks & rays*	*Pelagic sharks & rays*	*Sea-birds*
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3.4.2 Other spatial predictive models

Spatial predictive models of mobile biota (pelagic fish, sharks and rays, marine mammals, turtles, seabirds) may not require high resolution multi-beam bathymetry as long as lower resolution bathymetry and oceanographic data is available.

For CMRs, such models look the **most promising** for:

- Ashmore Reef – particularly seabirds
- Kimberley – particularly seabirds and sea turtles
- Ningaloo – particularly pelagic sharks and rays

For KEFs, such models look the **most promising** for:

- #6 (Carbonate bank and terrace system of the Sahul Shelf) – particularly pelagic sharks and rays

Again, a detailed examination of the relevant data is needed to determine whether additional biological data must be collected in order to build these models. And some CMRs and KEFs may have been rarely visited resulting in a lack of presences even if various biota are prevalent in reality. The above provides a guide for targeting future biological surveys given these limitations.

3.5 Prioritizing field surveys to collect high resolution bathymetry data

The previous section highlighted where collecting current biological data would add the most value to building spatial predictive models for CMRs and KEFs given existing bathymetry and oceanographic data. This section considers how to prioritise the collection of additional high resolution multi-beam bathymetry data.

Collecting multi-beam bathymetry is very resource intensive, making it impossible to achieve complete coverage across even a single CMR / KEF at biologically important scales (eg, 2-5 m) even for small CMRs / KEFs. Two key questions to consider when prioritising future data collection are:

- Should we collect multi-beam data in CMRs and KEFs where it is most lacking, realising that we will only ever be able to partially fill the gaps?

OR

- Should we collect data in locations where it would make the biggest difference to enabling spatial predictive modelling? That is, by filling in a key small gap where key types of biota are known to be prevalent.

It will be important, however, to also dedicate some field time to collecting biological data. While bathymetry and bathymetry-derived variables play a large role in prediction the distribution of benthos, the relationships are complex and vary spatially. Physical proxies derived from bathymetry have limited value without in situ field data to interpret their ecological meaning. And – some of the CMRs and KEFs have likely rarely been surveyed.

3.5.1 Major multi-beam data gaps

CMRs and KEFs that lack multi-beam data completely (or nearly so) and also lack RAN bathymetry (Table 3.10 – CMRs, Table 3.11 – KEFs have the most severe data gap. We thus ranked CMRs and KEFs based on this trade-off by calculating a bathymetry-gap index where (% CMR coverage + [% RAN coverage / 2])/100, where the lowest values have the greatest data gap. We considered CMRs or KEFs with index values of 0.5 or less as major data gaps.

For CMRs

The CMRs most in need of multi-beam data in priority order are:

- Joseph Bonaparte Gulf 0% multi-beam, 6% RAN
- Eighty Mile Beach 4% multi-beam, 8% RAN
- Limmen 0% multi-beam, 38% RAN
- Arnhem 11% multi-beam, 65% RAN
- Wessel 27% multi-beam, 32% RAN
- Roebuck 30% multi-beam, 30% RAN
- Gulf of Carpentaria 31% multi-beam, 37% RAN
- Dampier 0% multi-beam, 100% RAN

For KEFs

The KEFs most in need of multi-beam data in priority order are:

- #15 (Gulf of Carpentaria coastal) 4% multi-beam, 26% RAN
- #14 (Gulf of Carpentaria basin) 11% multi-beam, 17% RAN

- #24 (Wallaby Saddle) 21% multi-beam, 21% RAN
- #12 (Exmouth Plateau) 28% multi-beam, 28% RAN
- #21 (Arafura shelf) 25% multi-beam, 51% RAN

3.5.2 Strategic multi-beam data gaps

We define strategic gaps as locations that met benchmarks for the relative abundance and % prevalence of biota within a CMR (Table 3.13) or KEF (3.14) that also scored as data deficient on the bathymetry-gap index from section 3.5.1. Filling these gaps would likely have the added benefit of enabling spatial predictive modelling of key types of biota that require multi-beam data for modelling.

For CMRs, in priority order these are:

- **Gulf of Carpentaria***: Demersal fish - relatively abundant + widespread, multi-beam – 31%, RAN – 37%

- **Kimberley:** Hard coral, soft coral, sponge, brittle stars, polychaetes, molluscs – relatively abundant, multi-beam – 54%, RAN – 69%

- **Ashmore Reef**:** All types widespread, brittle stars + molluscs also relatively abundant, multi-beam – 0%, RAN – 100%

- **Dampier:** Brittle stars relatively abundant, multi-beam – 0%, RAN – 100%

- **Arafura:** Polychaetes relatively abundant, multi-beam – 35%, RAN – 43%

* examining the maps (see http://northwestatlas.org/nwa/n-nw-cmr-kef) shows the fish are widespread even though they don't score that way in terms of % of total pixels

** collecting bathymetry data here is complicated due to complex terrain and shallow depths.

For KEFS, in priority order these are:

- **#15 (Gulf of Carpentaria – coast*)** Demersal fish, sharks and rays relatively abundant and widespread, multi-beam – 4%, RAN – 26%

- **#14 (Gulf of Carpentaria - basin)** Demersal sharks and rays relatively abundant and widespread, multi-beam – 11%, RAN – 17%
- **#1 (Ancient coastline 125 m)** Demersal fish relatively abundant and widespread, sponge and demersal sharks and rays widespread, multi-beam – 60%, RAN – 92%

*examining the maps (see http://northwestatlas.org/nwa/n-nw-cmr-kef) shows the fish are widespread even though they don't score that way in terms of % of total pixels

4. APPLICATION OF PREDICTIVE MODELS TO ADDRESS KNOWLEDGE GAPS

4.1 Introduction

Effective management of marine resources requires baseline data on the distribution and abundance of biota combined with regular monitoring of their status. For remote and large CMRs and KEFs, collection of comprehensive data across large areas to inform management and monitoring is logistically difficult. As a starting point to focus the collection of such data, spatial predictive models use data that describe potential drivers of the distribution of biota with observations of the spatial distribution of those biota to create maps of where biota are likely located in areas not surveyed (Brown et al 2011, Holmes et al 2008). Although bathymetry is a primary driver of where many benthic biota can exist, it alone is insufficient as a surrogate for their spatial distribution.

Such models can be widely useful to scientists and managers, for example to:

- determine the spatial heterogeneity of the benthic environment and key classes of organisms,
- evaluate the physical and biological controls on individual and joint habitat distributions,
- discover relationships among habitats and various species of interest,
- investigate how habitats and organisms respond to disturbance from human activities,
- help prioritise areas for field surveys and design such surveys, and
- help communicate the attributes of an area to the public.

Ideally, a spatial predictive model for a given type of organism is developed at the spatial scale at which the organism responds to the abiotic factors used to predict its distribution. For many benthic marine organisms, however, this requires modelling at very local scales (5 m or less). Further, field observations of biota would ideally be evenly spread across the area to be modelled. The gap analysis from the previous section demonstrates that such fine scale modelling and extensive field data is not feasible, and perhaps will never be, for entire CMRs or KEFs. Yet, managers require information on where fauna and habitats exist across entire CMRs and KEFs. To address this, D1 aimed to explore the extent to which lower resolution models (eg, 250m pixel) with incomplete field observations can provide data of value to managers despite the uncertainties that this introduces. We use the Oceanic Shoals CMR as a case study because field campaigns have collected high resolution survey data in six study areas within the Oceanic Shoals, but these studies collectively cover only a small fraction of the total area of the CMR. Below we present preliminary results for a set of models, but more work remains to be done. In addition, we developed a model based on sponge richness, but this model is presented separately (see Section 5.6) due to its main objective being to compare different statistical approaches.

4.2 Benthic Habitats

4.2.1 Methods

Benthic spatial predictive habitat models aim to map the spatial distribution of types of bottom-dwelling organisms across an area of interest in as much spatial detail as robustly possible. In producing such models for NESP, we aim to ensure they are:

- Ecologically meaningful on relevant spatial and temporal scales,
- Sufficiently accurate for the intended use, and
- Communicated to stakeholders clearly so that their limits and likely errors and uncertainties are clearly understood.

To that end, we built a spatial benthic habitat model for the entire Oceanic Shoals CMR, and compared the resulting data to that from six fine-scale, local-extent models that each only cover a small part of the CMR.

We built the models following the basic process outlined in Figure 4.1.

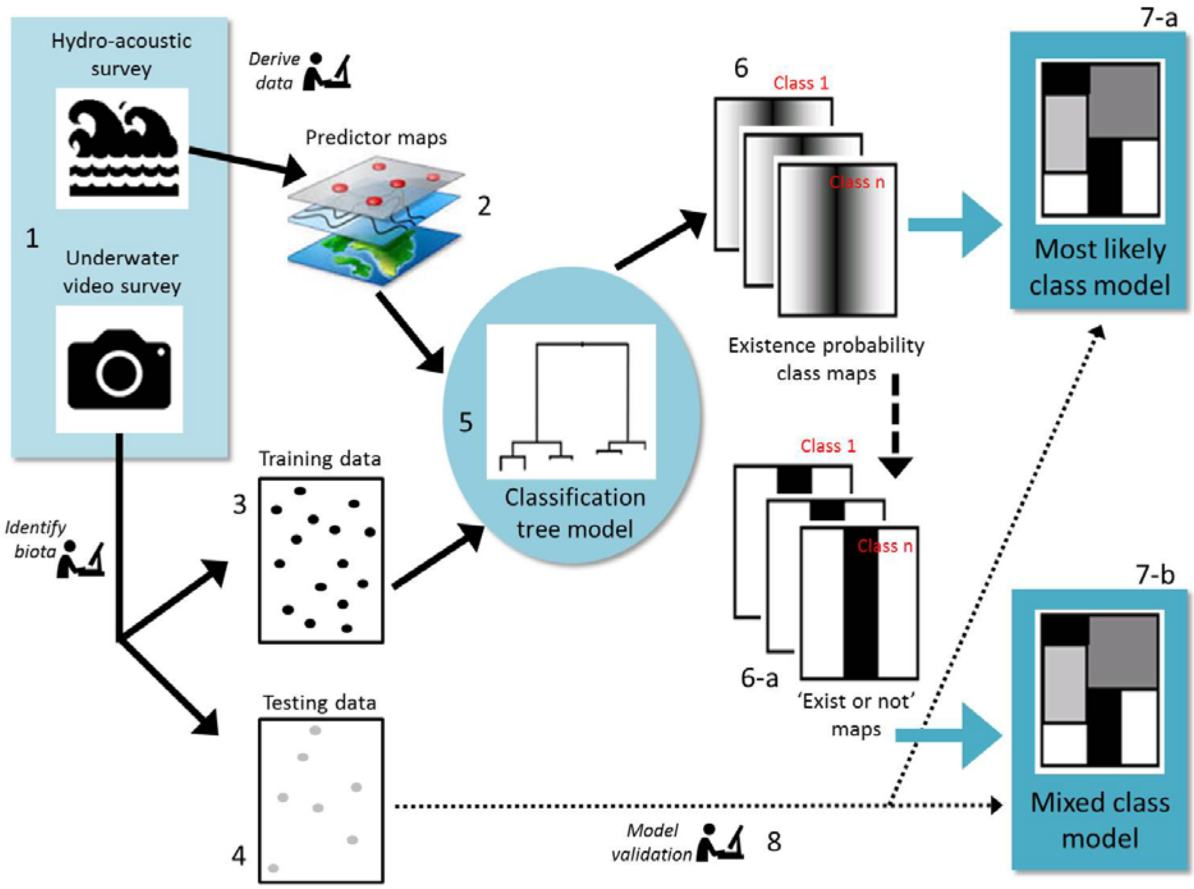


Figure 4.1 Diagram illustrating the process of producing a spatial benthic prediction model from field data (step 1), with two options: most likely class model (step 7-a) or mixed class model (step 7-b). All models are validated with testing data (step 4) held out from the training data (step 3) used to build the model.

Developing predictors

Developing environmental surrogates to attempt to predict the existence and abundance of classes of benthic organisms (step 2, Figure 4.1) is possible with high resolution bathymetric data (Brown et al 2011). Where such data do not exist in an area of interest, they can be developed from multi-beam sonar data via hydro-acoustic surveys (Holmes et al 2008, Lehmann et al. 2002- step 1 on Figure 4.1). Within the Oceanic Shoals CMR, hydro-acoustic data has been collected at six locations (Figure 4.2) – we used these data to build the smaller extent, 2m bathymetry grids. For the entire CMR, we used Geoscience Australia's 250 metre national bathymetric grid.

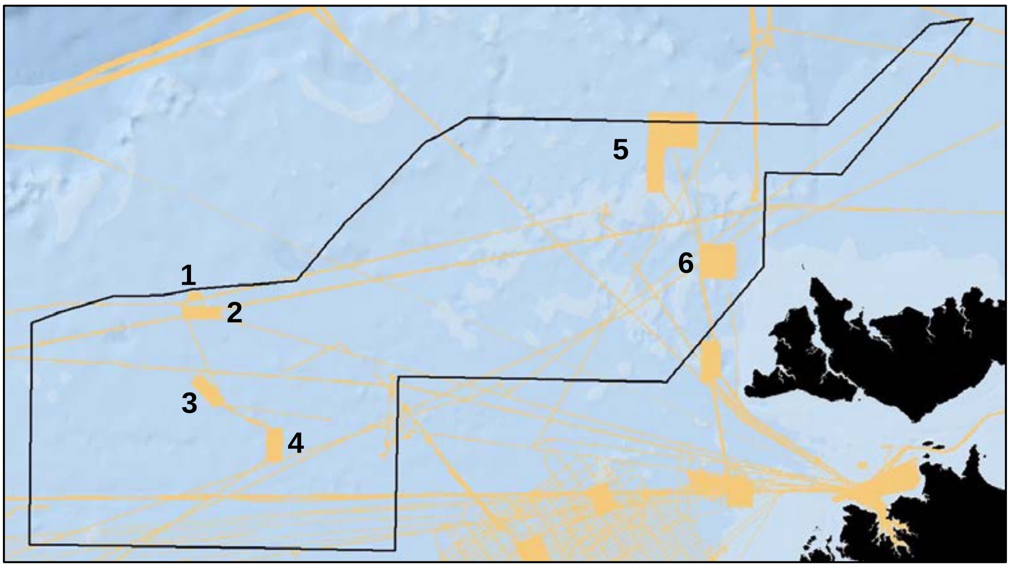


Figure 4.2 Very high resolution multi-beam sonar coverage of the Oceanic Shoals CMR. The CMR is outlined in black. High resolution multi-beam data coverage is shown in orange. Data courtesy of Geoscience Australia. Spatial benthic habitat models were built for the entire CMR at 250m resolution and for each fine-scale study area within the CMR at 2m resolution.

From the bathymetric data at both spatial scales (2m and 250m), we developed the following potential predictors of benthic habitat (Figure 4.1, step 2):

- Depth
- Aspect
- Overall curvature
- Profile curvature
- Plan curvature
- Depth range (5, 10, 25, 50 m windows)
- Standard deviation of depth (5, 10, 25, 50 m windows)
- Mean depth (5, 10, 25, 50 m windows)

Although ocean parameters are also important drivers of benthic community composition and structure (Brown et al 2011), relevant data were not available at spatial and temporal scales sufficient to justify inclusion in this instance. Further, such data are more readily incorporated into predictive models at biogeographic scales, rather than the regional scales covered by CMRs (Williams et al 2010).

Developing training and test data

Building predictive models is not possible without verified field data to document where biota of various types actually occur. The data we used to build and test a given model (Figure 4.1 – steps 3 & 4) came from towed video surveys (Figure 4.1, step 1) conducted as part of the NERP Marine Biodiversity Hub (Nichol et al 2013) and includes a combination of real-time classification of habitat types from forward-facing video footage and quantitative data from downward facing high-resolution still photos (Figure 4.3). The location of towed video transects within the study area was determined using a GRTS (Generalized Random Tesselation Stratified) sample design structured to spread transects across *a priori* classes of habitat complexity while ensuring they were evenly distributed spatially (https://science.nature.nps.gov/im/datamgmt/statistics/r/advanced/grts.cfm). The CATAMI classification scheme (http://catami.org/classification) was used to assign benthic categories both for real-time video and for still images.

We withheld a random sample of one-third of the field data to use for model performance estimates (testing set) and used two-thirds of it to establish how benthic classes of organisms vary with the potential predictors (training set) to enable building a model. When establishing the testing and training sets, we also tested for spatial autocorrelation. Where spatial autocorrelation existed, we retained a representative data point for each cluster of auto-correlated points. After each model was built with the training data, we used the testing data to assess its performance (step 8, Figure 4.1) based on the AUC – ‘area under curve’ parameter in ROC analysis (Faucet 2006). Models whose AUC values are less than 0.7 were discarded.

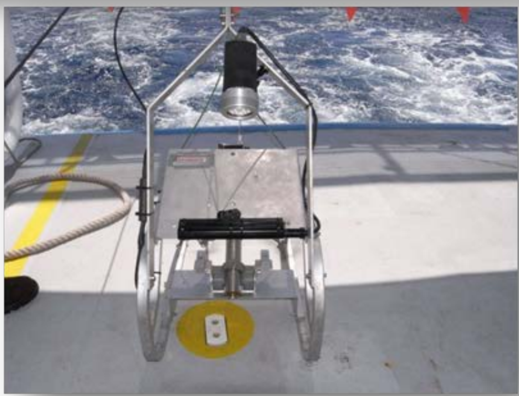


Figure 4.3 The AIMS towed video system tow body with mounted video camera and down-ward facing camera for stills (lower), with an example of a still photo taken just above the sea floor (above).

Building models and mapping habitats

The statistical relationship between the predictors and testing data was explored using a non-parametric statistical method - classification trees (Figure 4.1, step 5 – Breiman et al 1984). We used an innovative version of this called random forest (Breiman 2001, Cutler et al 2007). A random forest model first builds hundreds of classification trees that identify all the unique combinations of variables that could predict the distribution of a given benthic class. Those trees that are not useful in predicting that class cancel each other out. This method outperforms standard classification trees that are defined *a priori* because it ensures that valid relationships in the data are not missed (Cutler et al 2007).

Typically, we build a separate model for each class of benthos that predicts the likelihood of a class existing (Figure 4.1, step 6) in each pixel across the study area from 0 (no chance it exists) to 1 (100% certainty that it exists). Below is an example for sponges from one of the fine scale, limited extent models (Figure 4.4).

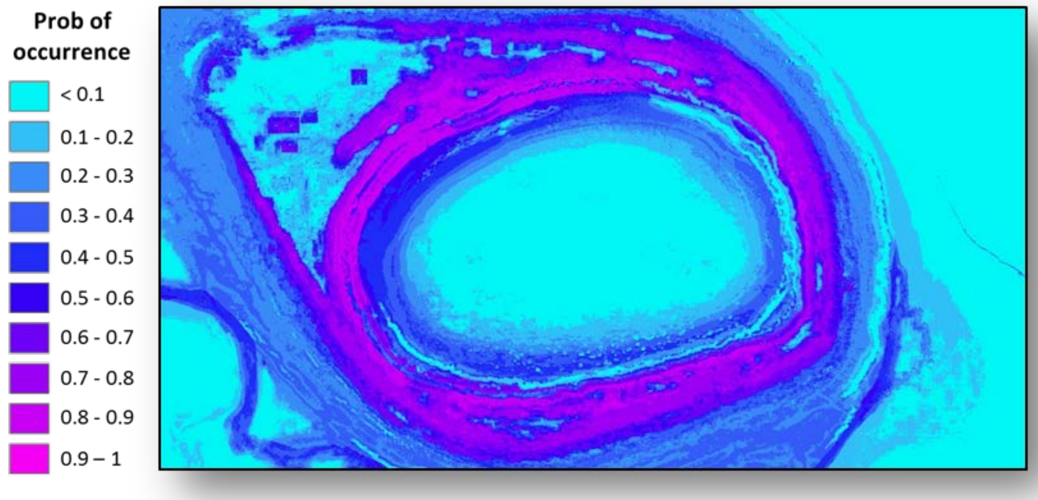


Figure 4.4 An example of a ‘probability map’ of sponges for part of the Oceanic Shoals CMR at a 2m spatial resolution. Sponge is most likely to exist in pixels shaded bright pink, and least likely to exist in pixels shaded turquoise.

From the ‘existence probability’ maps, we can then identify for each pixel which class is most likely to exist - the ‘most likely class’ model (step 7-a, Figure 4.1). This approach is particularly appropriate when different benthic classes are unlikely to be found in close proximity to one another. However, as the pixel size used in the model becomes increasingly coarse, the chance of missing a class completely in a given pixel even though it actually exists increases, particularly for benthic classes that are typically found in close proximity to other benthic classes.

An alternate approach – the ‘mixed class model’ (step 7-b, Figure 4.1) avoids this by allowing for more than one class to be assigned to a given pixel. This requires that we first identify a threshold probability of existence for each habitat class at which errors in misclassifying pixels are balanced between incorrectly assuming the biota doesn’t exist (false negative or ‘misses’) and incorrectly assuming the biota does exist (false positives or false ‘hits’). For each biota, we can use this threshold probability to simplify the data into two classes: 1 – where the biota might exist and 2 – where the biota is unlikely to exist. This creates a binary map for each class of biota (Figure 4.1, step 6a). Combining all the binary maps enables us to identify where different classes may co-exist in the same pixel, and where single ‘pure’ pixels of only one class of biota may exist. Below is an example for a limited extent, fine-scale study area within the Oceanic Shoals CMR (Figure 4.5). Note that no pixels were predicted to contain Hard Coral or Gorgonians or Sponges except in combination with other classes. In contrast, multiple ‘pure pixels’ were predicted for whips, Alcyons (octocorals), Filterers and Burrowers.

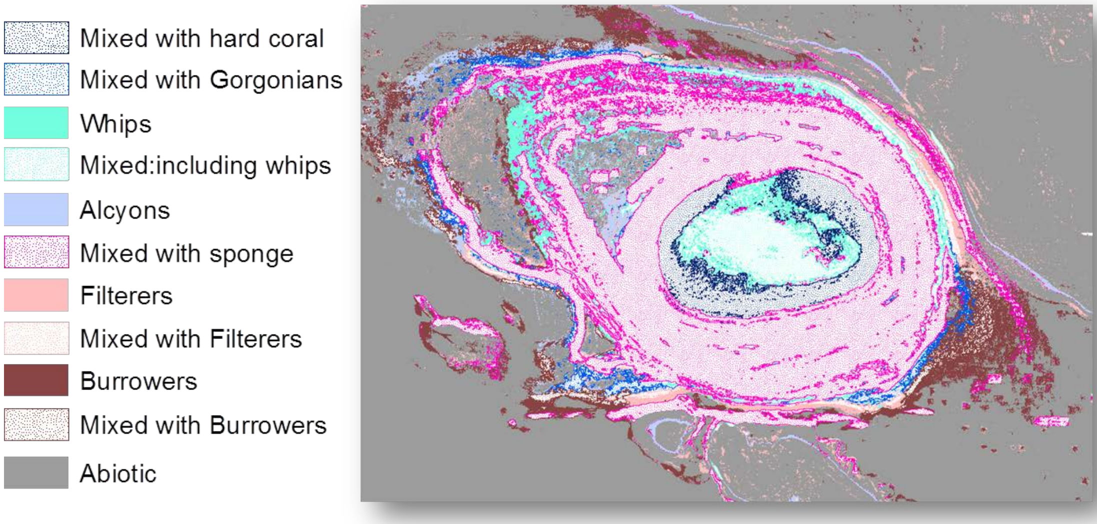


Figure 4.5An example of a 'mixed category map compilation' (Figure 4.1, step 7) for part of the Oceanic Shoals CMR at a 2 metre spatial resolution. Note that living organisms that burrow below the surface may exist in the 'abiotic' class, but were not detectable using survey methods and thus modelled as abiotic.

A downside to the 'mixed class' model approach is that judgement calls must be made when deciding what statistical measure to use in simplifying the existing probability maps (step 6, Figure 4.1) into 'exist or not' maps (step 7, Figure 4.1). Further, combining the benthic class 'exist or not' maps often yields hundreds to thousands of unique combinations. Determining how best to coalesce these potential mixed classes into a reasonable number (<10) is time consuming and unavoidably somewhat arbitrary. One way we currently address this problem is to only retain mixed classes that cover at least 5% of the study area. Nonetheless, these issues mean that generating a 'mixed class' model requires orders of magnitude more time than a 'most likely class' model. Tests are currently underway at present to address these concerns by assessing the training data for spatial correlation at the scale of a given model to determine which, if any, benthic classes tend to be found together during field surveys. This would enable us to identify the most appropriate mixed classes from the field data before generating the existence probability maps and remove the need to create 'exist or not' maps. Instead, we'd coalesce field data from correlated classes into mixed classes and generate existence probability maps for mixed and pure classes to produce a 'most likely class' model that takes into account the likely co-existence of classes in a given pixel. If this approach works, it would make the process run much faster, but more importantly, make the analysis more robust and repeatable. We are in the process of testing it on multiple datasets and the results will be a deliverable for NESP in 2017-8.

This is important because the two approaches can produce very different results (Figure 4.6). Where many classes are likely to co-exist in a given location, the most likely class model will tend to predict a greater area where no biota is detected (longer grey bar to the left) while the mixed class model will predict a greater area of most biotic classes (longer coloured bars to the right).

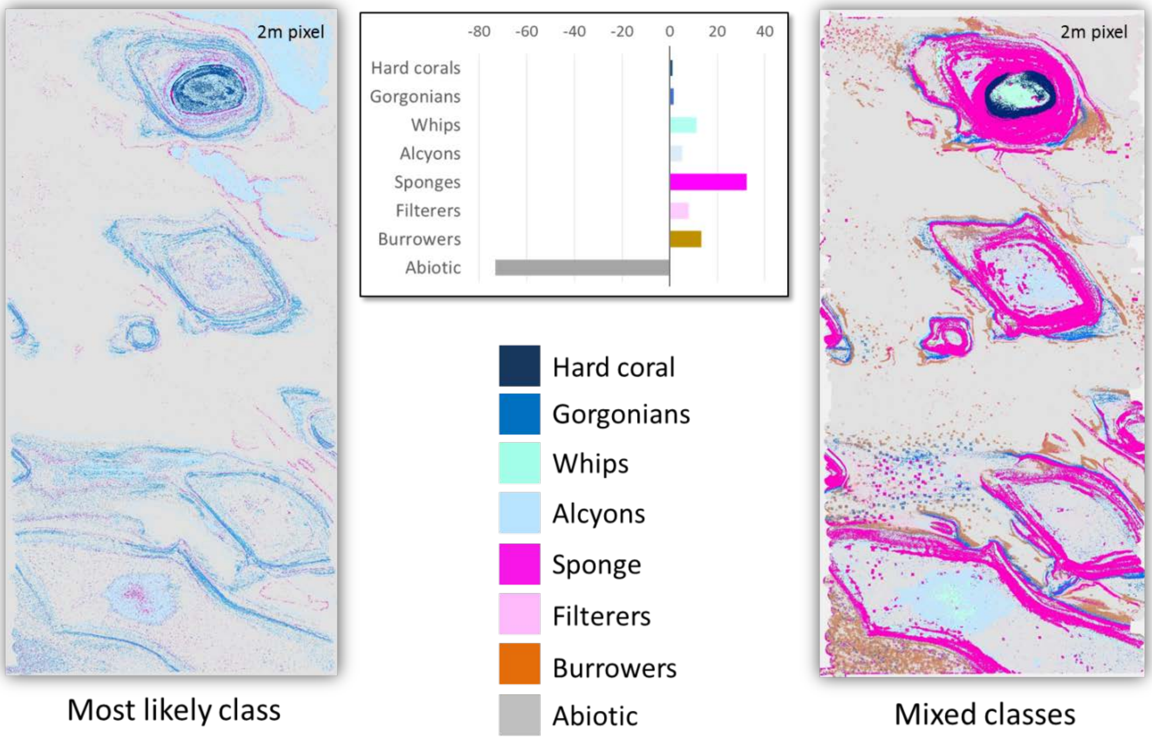


Figure 4.6 Comparison of a 'most likely class' model (left) versus a 'mixed class' model for part of the Oceanic Shoals CMR at a 2m resolution. The graph in the centre shows the % area difference between the two models for each of 7 classes. The class names when applied to the mixed class model indicate the dominant biota in the mixed assemblage.

For the Oceanic Shoals CMR as a whole, we have thus far only run the 'most likely class' model for a 280 m pixel. This is slightly coarser than the 250 m pixel of the input bathymetry data – some resolution was lost due to the use of a kernel to generate some of the predictors and by projecting the data into flat map coordinates. This is available on the NW Atlas at: http://northwestatlas.org/node/1710. A set of existence probability maps is also available at: http://northwestatlas.org/node/5449. In the latter, some classes were combined to speed processing.

Assessing map accuracy

Once we build a statistical model and used it to predict where a class or classes of biota occur across a study area, it is vital to estimate the accuracy of those predictions (Mumby & Harborne 1999; Holmes at al., 2008; Gray 2001). This is done using the testing data points we randomly withheld when building the model (step 4, Figure 4.1). For each point, we know what actually exists (the observed value), and we know what the model predicts should exist (the predicted value). Plotting these by benthic class yields what is called a 'confusion matrix' (Figure 4.7). In the confusion matrix, the number of data points where the observed class matches the predicted class is shown for each class in the boxes along the black diagonal. All the other boxes in the diagram (that are not on the diagonal) indicate misclassification errors – essentially showing all the ways in which the model failed, broken down by class. For example, for the 'hard coral' row below, values in the boxes other than on the diagonal show the number of test data points where the benthic class was actually hard coral, but the model predicted something else (misses). Most commonly this was either Alcyon (octocorals) or Abiotic. For the 'hard coral' column, values in the non-diagonal boxes show the number of test data points where the model predicted hard coral, but the benthic class was actually something else (false hits). Most commonly this was Alcyon (octocorals). The relative proportion of false positives and misses given the sample size can be used to estimate overall accuracy of the classification.

Observed \ Predicted	Alycon	Burrowers	Filter Feeders	Gorgonians	Hard Corals	Abiotic	Sponges	Whips
Alycon	923	0	1	43	29	163	42	3
Burrowers	0	18	0	0	0	5	0	0
Filter Feeders	0	0	33	5	0	19	0	0
Gorgonians	53	0	3	524	0	152	18	6
Hard Corals	44	0	0	0	176	12	2	0
Abiotic	98	6	2	99	6	3712	21	6
Sponges	59	0	2	15	2	74	214	4
Whips	12	0	0	18	1	29	1	57
Total accuracy	78	75	80	74	82	**89**	72	75
% false hits	23	22	42	31	25	**6**	42	52
% missed	22	25	20	26	18	**11**	28	25

33 Predicted = Observed

False hits

Misses

Total accuracy balances hits and misses.

Confusion matrix

Figure 4.7 Example of a confusion matrix for a most likely class model of part of the Oceanic Shoals. The top two-thirds of the diagram show how well the observed (rows) versus predicted (columns) values at each of the testing data points matched for each of eight benthic classes. The black diagonal line indicates the number of testing data points for each class where the predicted class matched what was observed (eg, the model was correct). Each box not on the diagonal line indicates a misclassification error.

When this is done for a 'mixed class' model, a misclassification may be less significant than it appears as it may only be that the model predicted multiple classes to exist but the error was made in which class was assigned as dominant. This issue may be reduced by creating a priori mixed classes from the training data before running the model.

4.2.2 Results

We successfully modelled 10 benthic classes across the entire Oceanic Shoals CMR, with each class identified by its most likely member:

1. Alcyons (octocorals)
2. Gorgonians
3. Soft corals
4. Hard corals
5. Halimeda
6. Macroalgae
7. Seagrasses
8. Filterers
9. Burrowers
10. Abiotic

Explore the CMR-wide model (280 m pixel) online at: http://northwestatlas.org/node/1710.

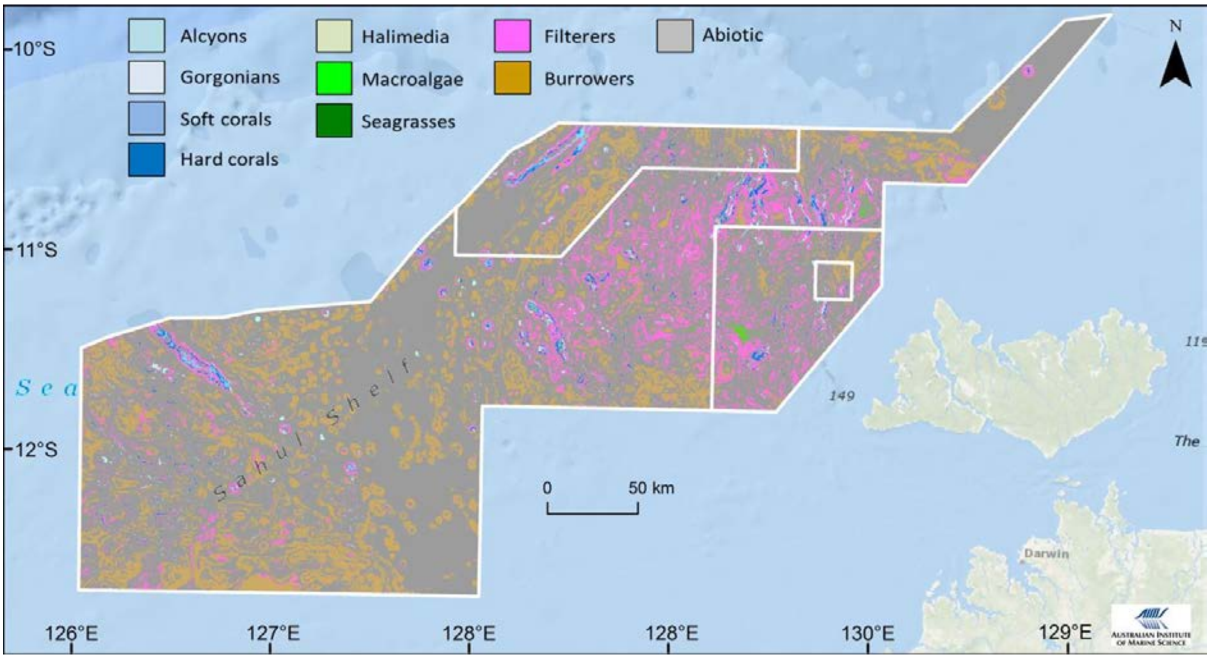


Figure 4.8 Spatial predictive model of the Oceanic Shoals Commonwealth Marine Reserve for ten classes of biota. Note that living organisms that burrow below the surface may exist in the 'abiotic' class, but were not detectable using survey methods and thus modelled as abiotic. White outlines within the CMR indicate recent zoning designations.

Across all classes, the model accuracy for the CMR-wide 'most likely class' model was high (82.97% total accuracy, 0.76 of 1 when adjusted for sample sizes to generate a Kappa statistic). Despite this, examining the confusion matrix (Figure 4.9) shows that total accuracy estimates for four individual classes was poor. These are abiotic, filter feeders, macroalgae and seagrasses. Data points that were actually abiotic were most often mistakenly predicted to be whips. Those that were actually filter feeders were most often mistakenly predicted to be sponges. Those that were actually macroalgae were most often mistakenly predicted to be Halimeda. Those that were actually seagrass were most often mistakenly predicted to be filter feeders. These misses should be kept in mind when using the model outputs.

		Predicted											
		Abiotic	Alcyon	Burrowers	Filter Feeders	Gorgonians	Halimeda	Hard Corals	Macro algae	Soft Corals	Seagrass	Sponges	Whips
Observed	Abiotic	1040	1	96	225	0	185	22	35	3	7	433	51
	Alcyon	0	4942	174	0	0	0	0	0	1	0	390	2
	Burrowers	1	119	13042	0	8	1461	48	162	0	0	1708	7
	Filter Feeders	183	0	31	1268	0	37	1	6	0	22	371	101
	Gorgonians	0	0	42	0	383	410	4	36	0	0	314	0
	Halimeda	203	0	747	1	73	42194	66	633	47	0	1468	0
	Hard Corals	8	0	61	0	0	21	1419	0	0	0	184	0
	Macroalgae	9	0	145	0	75	1081	22	2341	0	0	241	0
	Soft Corals	0	0	0	0	0	607	0	0	169	0	24	0
	Seagrass	66	0	3	132	0	63	0	0	0	54	71	15
	Sponges	188	182	1522	357	12	2906	252	302	5	29	27085	19
	Whips	241	22	161	206	0	0	0	0	0	0	212	506
	Total accuracy	54 X	94	81	58 X	70	86	77	67 X	75	48 X	83	72
	% false hits	46	6	19	42	30	14	23	33	25	52	17	28
	% misses	50	10	21	37	68	7	16	40	40	87	18	62

Figure 4.9 Confusion matrix of the 'most likely class' model of benthic classes across the entire Oceanic Shoals CMR. Note that living organisms may exist in the 'abiotic' class, but were not detectable using survey methods. Red x's denote classes with unacceptable classification accuracy (less than 75%).

Despite the relatively high overall classification skill of the CMR-wide model, it is important to realise that the training and testing observed data points were not evenly distributed across the study area (Figure 4.10). This means that it is possible that model quality may be lower in areas far from testing and training data points if the relationship between the benthic classes and the predictor variables is not uniform across the CMR. The extent to which this is the case can only be determined by collecting additional field data to validate the model.

In 2017-18 we plan to test the importance of the spatial distribution of data points by carrying out a comprehensive study in the Geographe Bay CMR where extensive field data that is relatively uniformly distributed across a fine-scale study area already exists. We can do thousands of simulations to explore how classification accuracy changes for the model when the spatial configuration of testing and training data is altered. The aim of would be to identify spatial configurations of testing and training data that lead to predictable distortions in classification accuracy. These could then be used to estimate a level of uncertainty associated with any benthic habitat model in any study area, based on its spatial configuration of testing and training points.

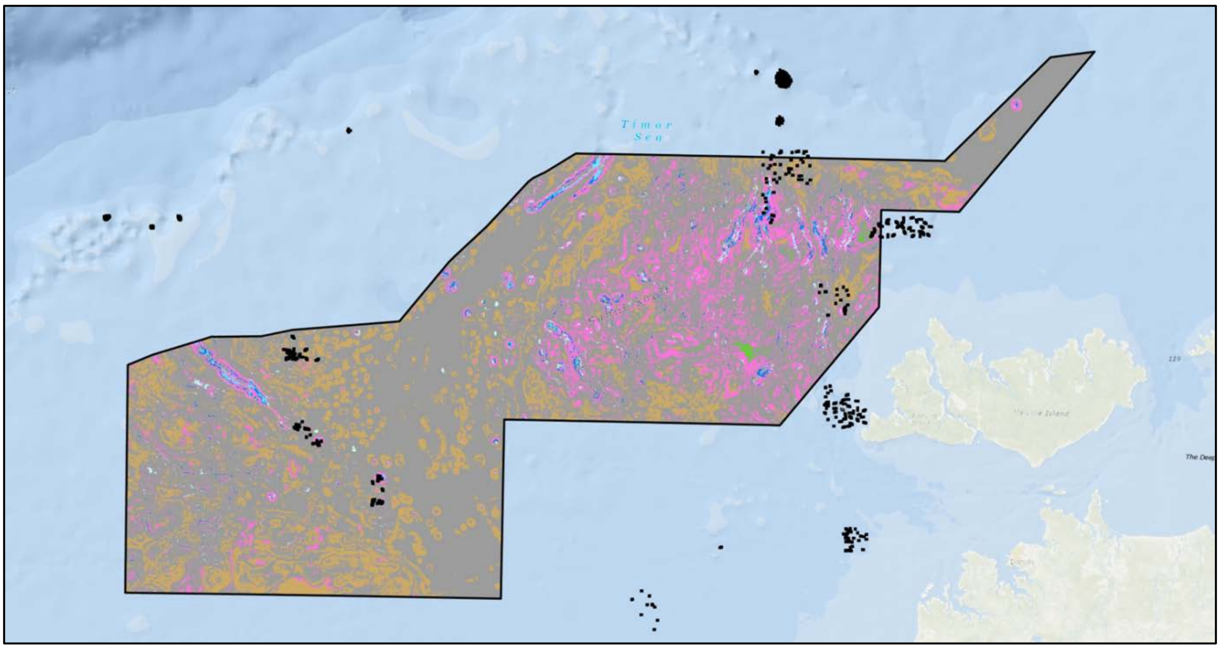


Figure 4.10 Location of field data used for model building and testing (black dots) for the Oceanic Shoals CMR.

It is also important to consider the spatial scale (pixel size) at which we were able to model the Oceanic Shoals CMR. Due to vast size of the CMR, fine scale bathymetry was too sparse to build a high resolution bathymetric model of the study area. The most detailed dataset covering the entire study area was at a spatial resolution of 250 m. Comparing this for selected areas where fine scale existed (and for which high resolution models were built) illustrates the implications of using the coarser scale bathymetry data (Figure 10).

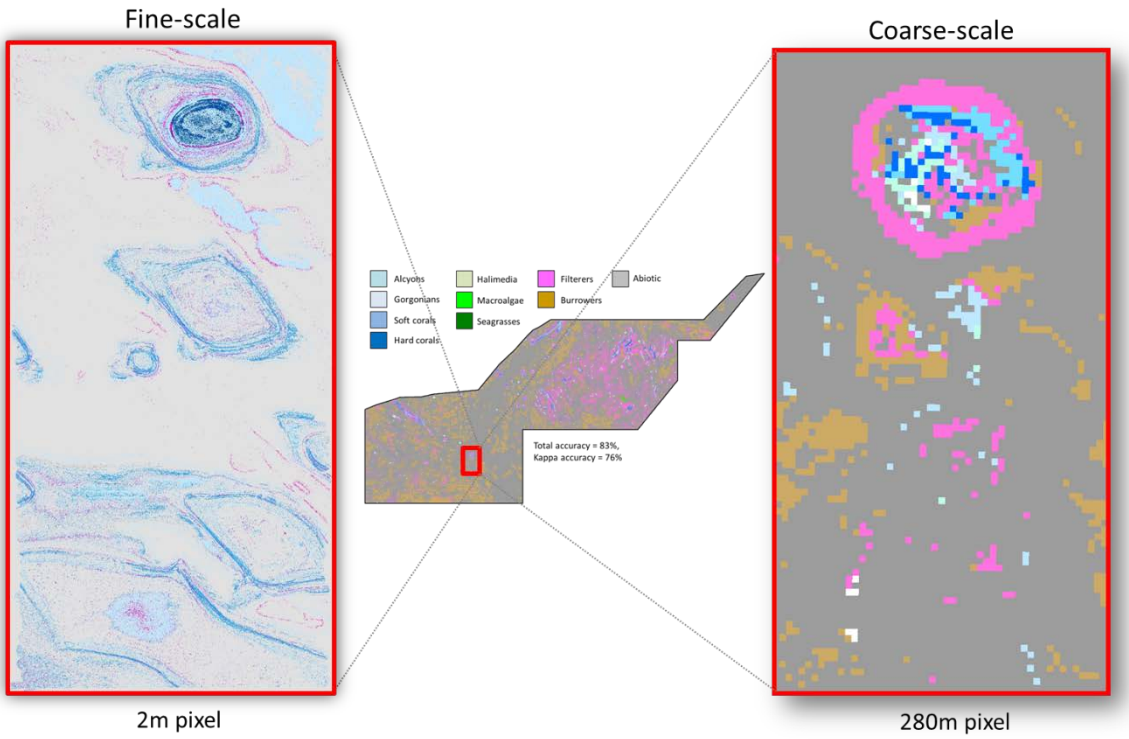


Figure 4.11 Comparison of fine scale versus coarse scale habitat 'most likely class' model results for a small section of the Oceanic Shoals CMR.

Most notably, the coarse-scale data not only predict a different relative proportion of the class types, but misses entire features evident in the fine-scale data. The coarse-scale model is still useful, but the implications of using it need to be kept in mind. In particular, if designing a monitoring program based on the coarse scale model, multiple samples should be taken within a given 280 by 280 metre pixel classified as 'sponge', for example, to ensure that at least one of those observations contains sponge.

A new approach currently being trialled at AIMS is to define *a priori* mixed classes from the training data geared specifically to the spatial scale of the intended model to help reduce distortion in the relative proportion of class types. Ultimately, though, if it is not possible to model benthos at spatial scales appropriate to their environmental response, features will be missed. Given that the cost and time required to collect fine-scale multi-beam across entire CMRs and KEFs will likely mean that many CMRs and KEFs must be modelled at coarse scales: this may still be better for managers than no information at all. It is important in these cases to carry out some fine-scale investigations as well to enable an estimation of the likely implications of the coarse resolution for that particular CMR or KEF. Indeed, the existence of the CRM-wide model can help target such fine scale investigations.

4.2.3 Recommendations for using the Oceanic Shoals benthic habitat model

- This coarse-scale habitat map of the entire Oceanic Shoals should be used to target future field surveys in areas of particular interest where validation data is currently missing to collect additional field data. This will enable the development of fine scale habitat models of higher quality.
- The current 'most likely class' model may underestimate the spatial prevalence of some benthic classes that may exist in mixed assemblages. We will develop and test a new version of a 'most likely class' model using 'a priori' defined mixed classes (as described above) to address this.
- Decisions about poorly modelled habitat types (abiotic, filter feeders, macroalgae and seagrasses) should be made with care, and should consider how the model typically misclassified these types, as shown in the confusion matrix.
- Single class probability models of benthic classes of particular interest have been created and published via the NW Atlas: http://northwestatlas.org/node/5449.
- A more detailed analysis of the ecological processes driving the spatial distribution of different habitat types would help to understand the risks posed by various stressors, and aid in the development of appropriate monitoring strategies.

4.3 Pelagic diversity

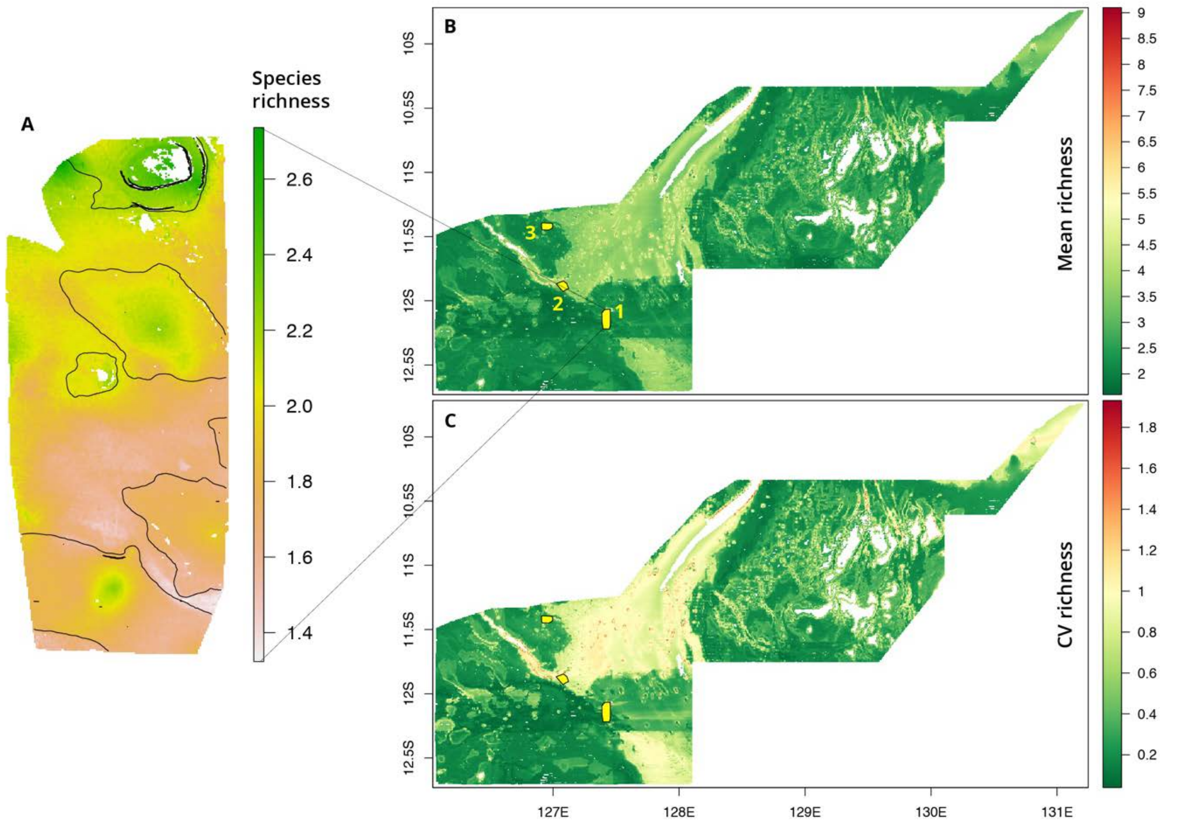
High-order mobile predators such as marine mammals or large pelagic fish (e.g. billfish, tuna, or marlin) and sharks play a key role in maintaining biodiversity and are recognised as key sentinels of ocean resilience and health (Fossi *et al.* 2012). As such, they are often used as ecosystem indicators to guide spatial planning efforts (e.g. the placement and zoning of protected areas). To support the management of the newly established Oceanic Shoals CMR (ca. 127.5°E, 11.5°S), a 21-day interdisciplinary field expedition (GA0339/SOL5650) was jointly undertaken on the *RV Solander* by the Australian Institute of Marine Science, Geoscience Australia, the University of Western Australia and the Museum and Art Gallery of the Northern Territory in Sept-Oct 2012. Pelagic baited remote video systems ('pelagic stereo-BRUVS') were deployed at 116 sites across three sampling areas in the western part of the reserve (Nichol *et al.* 2013). Footage of oceanic sharks, fishes, turtles and cetaceans was collected at each site and is analysed in Bouchet *et al.* (In prep.) (see also section 4.2).

4.3.1 Methods

Pelagic diversity (expressed as species counts) was modelled as a function of seafloor characteristics in each sampling area using 'hybrid' generalised linear models with ordinary kriging (RKglm) (Li and Sanabria 2015), assuming a Poisson distribution and a log link function (O'Hara and Kotze 2010). Explanatory variables consisted of an array of geomorphometrics chosen to reduce multicollinearity (Mellin *et al.* 2010) and computed from high-resolution (1 m), full-coverage multibeam swath maps acquired concurrently during the survey. These were grouped into five candidate predictor categories (i.e. seabed curvature, aspect, hardness, complexity and topography), of which all possible combinations were considered during model fitting. All competing model formulations were ranked on the basis of their second-order Akaike's Information Criterion scores (AICc) and included an offset term for effort (duration of the video clip, in min) as well as a three-way *area x latitude x longitude* interaction. Spatial correlograms of Moran's I were used to check for residual non-independence. Ordinary kriging was then performed on the model residuals to improve predictions. Following Wenger *et al.* (2013), uncertainty due to model selection and parameter estimation was quantified by bootstrapping the original data (with replacement) 1,000 times and repeating model construction upon every iteration. To mitigate mathematical extrapolation, spatial predictions were constrained within both the convex hulls and univariate ranges of the data points in each area (Zurell *et al.* 2012). In a second step, outputs from the RKglms were used as response variables in whole-of-CMR ensemble models comprised of generalised additive models (GAMs) and boosted regression trees (BRTs), two techniques favoured in published transferability studies (Duncan *et al.* 2009, Mannocci *et al.* 2016). The choice of predictors was driven primarily by the need to compromise reasonable explanatory power against optimal geographic coverage. Only three covariates were retained under these constraints: depth, slope and gravel content. Model selection proceeded as before for the GAM (thin plate splines of rank 10), whereas all three covariates systematically entered the BRT (tree complexity = 2, learning rate = 0.01, bag fraction = 0.5, number of trees = 8050). To ease computational burden, the data were resampled to a common resolution of 250 m, and bootstrap runs capped at n=100. Final predictions were obtained by weighted-averaging those of the best GAM/BRT. Inference was only sought within the univariate range of input predictors.

4.3.2 Results

The GLMs that included terms from either the hardness or topography categories received highest support according to the AICc (weights of 0.388 and 0.372 respectively). Bootstrap models explained an average of 31% (maximum of 60%) of the deviance across resampling iterations. Predicted species richness generally increased in the vicinity of carbonate bank summits within each sampling area (Figure 4.12). The GAM model structure containing all three explanatory terms (depth, slope, gravel content) was consistently selected as it minimised the AICc at each bootstrap run. BRTs performed better than GAMs, with an average deviance explained of 69.8% compared to 47.1% respectively. CMR-wide predictions suggest that species richness is greater along the northern section of the Malita Shelf Valley and throughout eastern half of the Sahul Shelf, peaking on carbonate banks (pinnacles). However, these results should be interpreted with care, as these areas are also where model predictions exhibit the largest degree of uncertainty (Figure 4.12, bottom panel).



- Figure 4.12 Spatial patterns in pelagic diversity within the Oceanic Shoals Commonwealth Marine Reserve (CMR). Predictions of species richness for sampling area #1 are shown in A, with the outline of carbonate banks overlaid. The bootstrap mean and coefficient of variation of species richness for the entire CMR are shown in B and C, respectively.

4.4 Connectivity

Modelling of potential connectivity between the Oceanic Shoals CMR and other reserves in the North and North-West marine regions, the following key points emerge (Note: these modelling results are based on brittle star life-history characteristics):

- Based on a narrow subset of species and passive dispersal, the Oceanic Shoals CMR may be to a large extent self-seeding with respect to larval dispersal (i.e. 77% chance of a larva being retained in its area of origin);
- The model suggests that the Oceanic Shoals receives larvae from the Argo Rowley Terrace, Mermaid Reef, Kimberley, Ashmore Reef, Cartier, Joseph Bonaparte Gulf, Arafura, Arnhem, Wessel and West Cape York CMRs.

- The model also suggests that the Oceanic Shoals contribute larvae to the Montebello, Argo-Rowley Terrace, Mermaid Reef, Kimberley, Ashmore Reef, Cartier, Joseph Bonaparte Gulf, Arafura and Arnhem CMRs.
- Analysis of modelled connectivity among CMRs suggests that the Oceanic Shoals CMR is a keystone of the north and northwest network because it links to the Kimberley, Arafura and Arnhem CMRs.

4.4.1 Methods

Model outputs from Kool & Nichol (2015) were used to examine the probabilities of dispersal specifically in the Oceanic Shoals CMR. The model simulates the dispersal of larvae by embedding artificially intelligent particles within realistic ocean current fields (three spatial dimensions + time), and tracing the paths that they follow. The results are stored within an RDBMS environment (PostGRESQL), and the particle paths can be summarised for analysis. The ocean currents used in the simulation were produced using the Hybrid Isopycnal COordinate Model (HYCOM – http://www.hycom.org). The basis of the simulation is an offline Lagrangian dispersal model, using interpolation and integration of velocity values as the simulated particles move through the current fields. Biological responses of the simulated organisms are added on the basis of values obtained from scientific literature – e.g. a daily mortality value of 0.6 (Lefebvre et al., 2003; Rumrill, 1990), and a maximum pelagic larval duration (PLD) of 90 days.

4.4.2 Results

Most particles released within the CMR are retained locally and there is limited dispersal outside of the CMR (Figure 4.14). There are, however, weak external connections with other CMRs (e.g. Montebello, Argo-Rowley Terrace, Mermaid Reef, Kimberley, Ashmore Reef, Cartier, Joseph Bonaparte Gulf, Arafura and Arnhem CMRs) (Figure 4.15). In the southwest corner and central northern portion of the CMR, there appears to be a natural convergence of the simulated larvae on the basis of transport by currents.

Dispersal appears to be particularly restricted at depth, and most dispersal in deep water appears to coincide with the central channel that divided the eastern and western sections of the CMR suggesting there may be limited connectivity across the CMR (Figure 4.16).

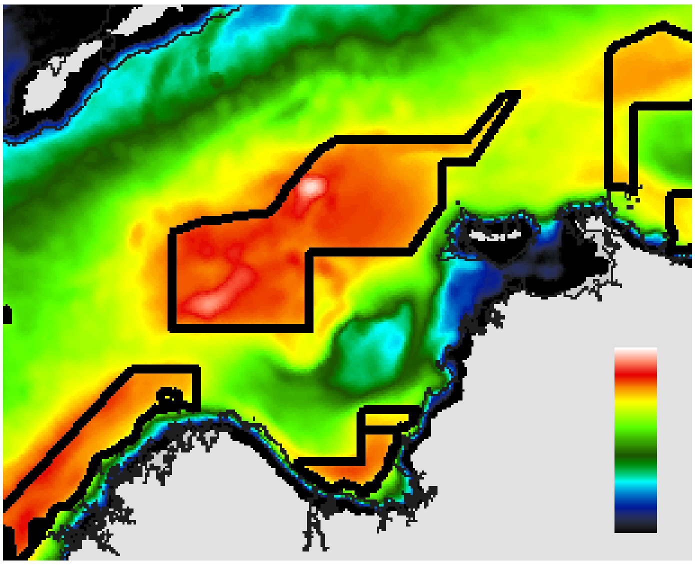


Figure 4.13 Probability of particle releases (dispersal) from the Oceanic Shoals CMR (integrated over depth). Modified from Kool & Nichol (2015)

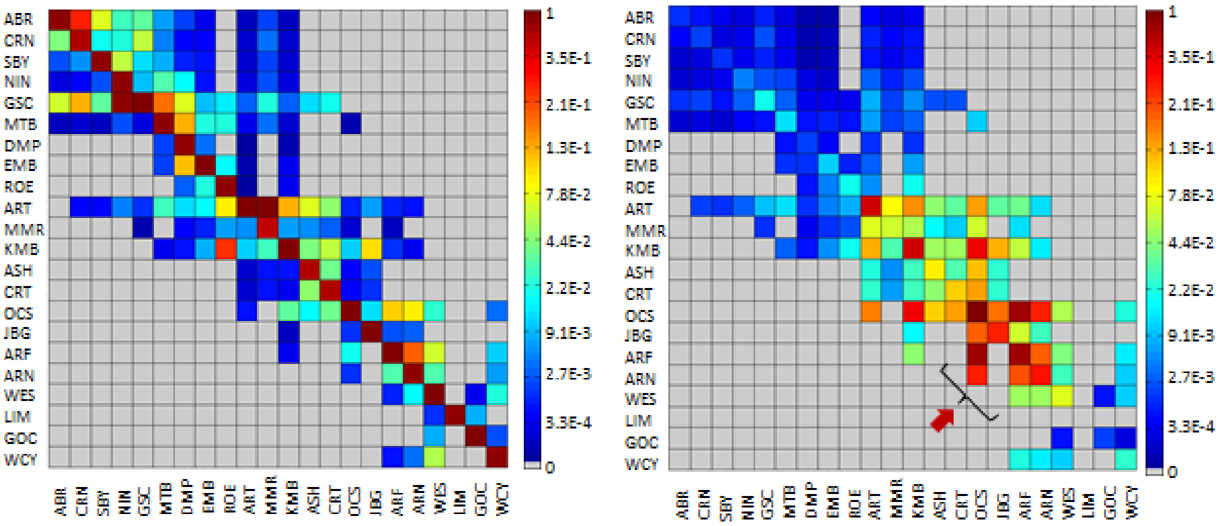


Figure 4.14. A) Connectivity matrix showing the strengths of connections among north and north-west Commonwealth Marine Reserves. Red indicates areas that are relatively well-connected, and blue indicates a weak connection. Values indicate likelihood of connection. CMRs are indicated as follows: ABR=Abrolhos, SBY=Shark Bay, CRN=Carnarvon Canyon, NIN=Ningaloo Reef, GSC=Gascoyne Canyon, MTB=Montebello, DMP=Dampier, EMB=Eighty Mile Beach, ROE=Roebuck, ART=Argo-Rowley Terrace, KMB=Kimberley, ASH=Ashmore Reef, OCS= Oceanic Shoals, JBG = Joseph Bonaparte Gulf, ARF=Arafura, ARN=Arnhem, WES=Wessel, LIM=Limmen, GOC=Gulf of Carpentaria, WCY=West Cape York. B) The elasticity of the original matrix shows the connections that are likely to have the greatest impact on the entire system. Here, the results show that changes occurring in the Oceanic Shoals region – specifically with Arafura are likely to generate the most significant changes.

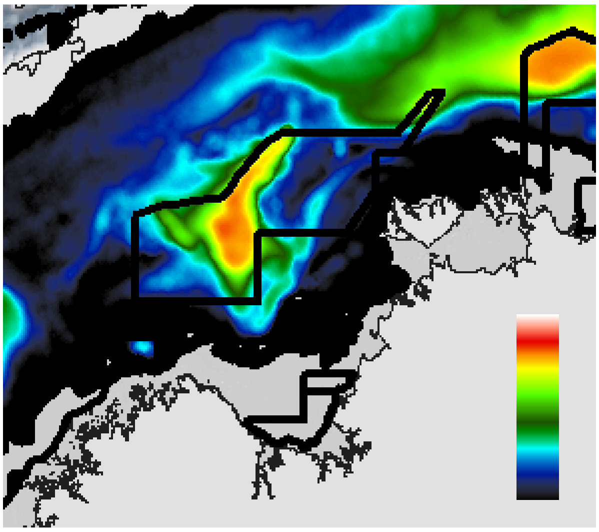


Figure 4.15 Dispersal from CMRs released between 75 and 100 m depth and integrated over time

4.5 Seabed Substrate (sediments and hardness)

4.5.1 Methods

Owing to the location of the Oceanic Shoals CMR near exit points of the Indonesian throughflow (Wyrtki 1987), as well as the tendency for currents to shift in direction from east to west to east to west in the Australian summer and winter respectively in association with monsoons, this area is a critical junction point within the CMR network. Impacts taking place in this CMR are likely to have a unidirectional influence on other areas. This is suggested by the results of analysing the elasticity of the connectivity matrix. Although the results may only be from simulations, they do provide a case for field research to test the model results against empirical data.

Seabed sediment data is important baseline environmental information for identifying benthic habitat types because sediment type influences the colonisation, formation and distribution of benthic communities and the abundance of organisms within those communities (e.g. McArthur et al. 2010). However, data representing seabed sediment typically comprises point observations (derived from samples) meaning that spatially continuous information must be predicted from this often sparse, unevenly distributed point data. Seabed hardness is an additional characteristic of seabed substrate that potentially influences the nature of attachment of an organism to the seabed (Williams and Leach 1999). A spatially continuous prediction of seabed hardness would be a significant aid in predicting the spatial distribution of benthic marine communities. In this study, we aim to select the most accurate model to predict the spatial distribution of seabed sediments and seabed hardness. The most accurate model was used to predict their spatial distribution, and the predictions were examined visually.

4.5.2 Methods

Study region

Seabed sediments were modelled for the North and Northwest marine regions. In this study, we use the Timor Sea and Joseph Bonaparte Gulf areas as an example (Figure 4.17). This study area comprises mostly continental shelf and a small area of slope in water depths ranging from 0 to 378 m. In total, 237 samples of seabed sediments from shelf depths were considered for this area following data quality control (Li et al. 2010, Li et al. 2012) and further checks to ensure location information suitable for predictions at 250 m resolution. Sample density is very low (1.04 samples per 1000 km^2) and highly clustered within sampling areas. For modelling, sediment texture is represented by three classes: mud, sand and gravel (Li et al. 2010).

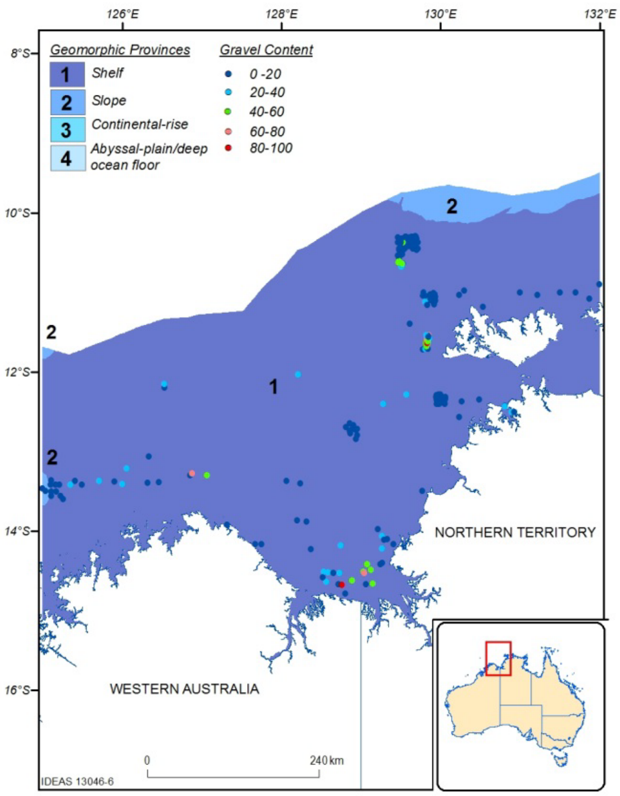


Figure 4.16 Spatial distribution of sediment samples using gravel content as an example and their occurrence in the geomorphic provinces.

For seabed hardness modelling, the study area is located in the eastern Joseph Bonaparte Gulf within four areas (A - D) that were surveyed in 2009 (Heap et al. 2010) and 2010 (Anderson et al. 2011). Within each area, high-resolution multibeam bathymetry and backscatter data and co-located underwater video transects were acquired. The areas comprise a spatially complex suite of geomorphic features including shallow flat-topped banks, terraces, ridges, deep valleys and plains.

Estimation of substratum composition and seabed hardness classification

The seabed and associated epibenthos were recorded along underwater video transects using a forward-facing towed-video system. The video footage was analysed based on a 15-second window for each transect to classify substratum composition (Anderson et al. 2008b). The substratum composition was visually estimated to 5% precision (Mortensen and Buhl-Mortensen 2004) in terms of seven size-class categories of rock, boulders, cobble, rubble, gravel, sand and mud as defined by (Wentworth 1922). We grouped substratum composition into two categories: soft and hard materials. Anything larger than gravel (i.e. rubble, cobbles, boulders and bedrock) was classified as 'hard' material, while mud, sand and gravel were classified as 'soft' material according to Stein *et al*. (1992). The presence of epibenthic communities provides additional information to correctly classify substratum. For instance, biota/benthic organisms (i.e. sessile organisms like sponges, hard corals and octocorals) that require hard substratum for growth (Warwick and Davies 1977, Newell et al. 2001, Thrush et al. 2001, Post et al. 2006, Buhl-Mortensen et al. 2012) were found in amongst soft substratum according to the video data alone.

On the basis of Stein *et al*. (1992), we developed a new system to classify the seabed substrate into four categories: hard, hard-soft, soft-hard and soft. If a substratum consisted of ≥90% hard material, it was classed as 'hard'. If it consisted of <90% and >50 % hard material, it was classed as 'hard-soft'. If it consisted of <50 % and >10% hard material, it was classed as 'soft-hard'. And if it consisted of ≤ 10% hard material, it was classed as 'soft'. This system is hereinafter referred to as 'hard90'. In total, 140 samples of seabed hardness were considered in this study. Of the 140 samples, 6 samples were recorded as hard, 14 hard-soft, 9 soft-hard and 111 soft based on hard90 systems respectively. The resultant datasets were used to predict seabed hardness, with hardness classes based on hard90 presented in Fig 4.6.1b.

Predictive variables

For seabed sediments, a range of predictors could be used as secondary information to improve the spatial prediction of marine environmental data. However, only six predictors that were justified and used in previous studies (Li et al. 2011b, Li et al. 2012) were employed here based on their availability for the study region at the resolution required. These predictors are: bathymetry (bathy), distance-to-coast (dist.coast), seabed slope (slope), seabed relief (relief), latitude (lat) and longitude (long). Of these predictors, bathymetry data was based on Whiteway (2009), and seabed slope and relief were derived from the bathymetry data. All datasets of these variables were generated in ArcGIS at a 250 m resolution using the methods detailed by Li et al. (2010, 2012). The coordinates system for this study was based on WGS84 as explained in previous studies (Li et al. 2011b, Li et al. 2011c). Besides these six variables, 15 derived variables (i.e. $bathy^2$, $bathy^3$, $dist.coast^2$, $dist.coast^3$, $slope^2$, $slope^3$, $relief^2$, $relief^3$, lat^2, $long^2$, lat*long, $lat*long^2$, $long*lat^2$, lat^3 and $long^3$) were used as predictors.

For seabed hardness, following a preliminary analysis based on data availability and the relationships with seabed hardness, 41 predictive variables (i.e. features) were initially selected for this study. They are:

1) Easting,
2) Northing,

3) Bathymetry (bathy): a measure of depth of bodies of water,

4) Local Moran I of bathymetry(bathy.moran): a measure of local spatial autocorrelation in bathymetry,

5) Planar curvature (planar.curv): a curvature of the surface perpendicular to the slope direction (second derivative of bathymetry),

6) Profile curvature (profile.curv): a curvature of the surface in the direction of slope (second derivative of bathymetry),

7) Topographic relief (relief): a measure of difference between the highest and the lowest points (variance) in the surrounding cells,

8) Seabed slope (slope): slope gradient (first derivative of bathymetry),

9) Surface area (surface): the ratio of the “true” surface area and its “planar” surface area,

10) Topographic position index (tpi): a measure of difference between a cell elevation and the average of the elevation values in the surrounding cells,

11-37) Backscatter (bs10 to bs36): a diffused reflection of acoustic energy due to scattering process back to the direction from which it's been generated, measured as the ratio of the acoustic energy sent to a seabed to that returned from the seabed, normalised to incidence angles between 10^o and 36^o,

38) Homogeneity of backscatter (homogeneity): a measure of closeness of the distribution of elements in the Gray-Level Co-occurrence Matrix (GLCM) to the GLCM diagonal,

39) Variance of backscatter (variance): a measure of the dispersion of the values around the mean within the GLCM,

40) Local Moran I of backscatter (bs.moran): a measure of local spatial autocorrelation in backscatter, and

41) Prock: the probability of hard substrate.

Acquisition and processing of multibeam bathymetry, backscatter and their derived variables, and prock have been detailed in previous studies (Siwabessy et al. 2013) and in relevant online metadata (Li et al. 2016). All these variables were available at each grid cell to a 10 m resolution in the four study areas for generating the spatial predictions of seabed hardness. These 41 variables were also available at 140 sample locations for developing models to predict seabed hardness. The dataset for developing predictive models in this paper is from (Li et al. 2016).

Preliminary selection of predictive variables for seabed hardness

There were strong correlations among some predictive variables based on Spearman’s rank correlation that was used due to non-linear relationships between some variables. We removed 21 backscatter (bs) variables that were perfectly correlated with other variables or with a ρ=0.99, which is usually called a correlation-based filter FS method (Saeys et al. 2007, Janecek et al. 2008). The selection was also according to their relation with the total hard (i.e., whether they displayed a better relationship with total hard) and their correlation coefficients with other bs variables. The bs25 should have been removed according to the above selection criteria, but was retained because it was used in a previous study (Li et al. 2013). The remaining 20 variables are listed in Table 4.1.

Table 4.1 Predictive variables and their corresponding number

No.	Predictive variable	No.	Predictive variable
1	easting	11	tpi
2	northing	12	bs13
3	prock	13	bs21
4	bathy	14	bs25
5	bathy.moran	15	bs27
6	planar.curv	16	bs32
7	profile.curv	17	bs35
8	relief	18	homogeneity
9	slope	19	variance
10	surface	20	bs.moran

Application of predictive methods

For seabed sediments, random forest (RF), the hybrid methods of RF with inverse distance weighting (IDW) (RFIDW) or ordinary kriging (OK) (RFOK) were used. Two most commonly compared methods, IDW and OK, were used. The residuals of RF were then interpolated using IDW with a searching window size of 5, and using OK with a Spherical model and a searching window size of 5 separately. For RF, the predictors used are identical to those used in the RF component in RFOK and RFIDW. For IDW, a distance power of 2 and a searching window size of 12 were used. For OK, log transformation was applied, and a Spherical variogram model and a searching window size of 12 were used. All these predictors and parameters were chosen based on our previous findings for predicting the seabed gravel content in AEEZ (Li et al. 2011d).

For seabed hardness, only RF was used for hardness classification. RF as briefly described in (Li et al. 2013), is an ensemble machine learning method that combines many individual regression or classification trees in the following way: from the original sample, many bootstrap samples and portions of predictive variables are drawn, and an unpruned regression or classification tree is fit to each bootstrap sample using the sampled variables. From the complete forest, the status of the response variable is usually predicted either as an average of the predictions of all trees for regression or as the class with the majority vote for classification (Breiman 2001, Strobl et al. 2007). The R function, *randomForest* by Liaw and Wiener (2002), was employed to develop a model to predict the spatial distribution of seabed hardness. The default values of *mtry*, *ntree* and *nodesize* are often good options (Liaw and Wiener 2002, Diaz-Uriarte and de Andres 2006) that were also observed in marine environmental sciences (Li et al. 2012, Li et al. 2013), so the default values were used for these parameters.

Model selection

For seabed sediments, the variable importance (VI) was used to select predictors for RF.

For seabed hardness, the model selection was based on a procedure developed for RF in previous studies (Li 2013b, a, Li et al. 2013), which involved two steps. One step was to select predictors to form a model that is often termed as feature selection, and the other was to estimate the predictive accuracy of the model formed that is addressed in the next section. To select predictive variables, we adopted the same principle used in *rfcv*, a cross-validation function in the randomForest package (Liaw and Wiener 2002), that is, identifying and removing the least important variables based on the importance of predictive variables. Five feature selection (FS) methods were used to select predictors in this study based on all 140 samples. These methods are: 1) the variable importance (VI), 2) averaged variable importance (AVI), 3) knowledge informed AVI (KIAVI), 4) Boruta and 5) RRF. The first method (i.e., VI) was based on the procedure in a previous study (Li et al. 2013) was applied to hard90 data with 20 variables.

Model validation and accuracy assessment

For seabed sediments, to compare the performance of these methods, a 10-fold cross-validation was employed. Randomness associated with the 10-fold cross-validation may lead to each method receiving different samples. To reduce such influence, we repeated the 10-fold cross-validation 100 times. Relative mean absolute error (RMAE) and relative root mean square error (RRMSE) (Li and Heap 2011) were used to assess the performance of the methods tested and to compare with findings in previous studies. The predictive errors were assessed based on the average of 100 iterations of 10-fold cross-validation. The modelling was implemented in R 2.15.1 (R Development Core Team, (2012), using packages 'raster' for extracting data from different data layers, 'gstat' for geostatistical modelling and 'randomForest' for random forest modelling. Predictions were corrected by resetting the faulty estimates to the nearest bound of the data range (i.e. 0 or 100%) if applicable (Goovaerts 1997).

To identify the most accurate predictive model, we need to know the accuracy of each model formed from the above FS methods. To achieve this, we used *rf.cv* that validates one model with fixed predictive variables for all iterations for a given number of predictive variables (Li et al. 2013). This function allows variations in datasets generated by cross-validation and ensures the model select relevant predictors from a list of the fixed predictive variables. Given that the response variable is categorical, the correct classification rate (*ccr*) (Fielding and Bell 1997) and *kappa* (Cohen 1960) were used to measure the accuracy of the predictive model and were calculated using the built-in functions in *rf.cv*. To assess the predictive ability of each model, we used 10-fold cross-validation (Hastie et al. 2009). To deal with the random error associated with each 10-fold cross validation (Li 2013b, a, Li et al. 2013), the cross validation procedure was repeated 100 times. The choice of this iteration number was based on findings in previous studies (Li 2013b, Li et al. 2013) and that the dynamics of the predictive accuracies with iterations of relevant models in this study suggested that averaged accuracies stabilised after 20-80 iterations. The final results were based on the average of 100 iterations of the cross validation. Finally, the most accurate predictive model for hard90 data was used to predict seabed hardness at each 10m grid cell in the study areas. All relevant computing work was implemented in R 2.15.2 (Team 2012).

Relevant maps were then produced using ArcGIS (ESRI ® ArcMap ™ 10.0) (Inc 2002).

4.5.3 Results

Model performance for seabed sediments

For seabed gravel, mud and sand content, similar modelling approaches were used. Here we use gravel content as an example to illustrate the predictive model selection results. The predictive error varied with the methods in terms of RMAE and RRMSE (Figure 4.6.3). RF, RFOK and RFIDW were the most accurate methods. They were significantly more accurate than the most commonly compared SIMs (i.e. IDW and OK), based on Mann-Whitney test for IDW in terms of RRMSE, based on t-test for IDW in terms of RMAE, and based on t-test for OK in terms of both RMAE and RRMSE (all with a p value < 0.0001). Of these three methods, RFIDW was significantly less accurate than RF and RFOK in terms of both RMAE and RRMSE based on paired t-test (with a p value < 0.0001). RF was significantly less accurate than RFOK in terms of RMAE based on paired t-test (with a p value < 0.0001), while there was no significant difference between RF and RFOK in terms of RRMSE based on paired t-test (with a p value = 0.2146). Overall, RFOK is preferred over RF and RFIDW.

Model performance for seabed hardness

The most accurate predictive model was selected based on the five model selection methods, with a mane *ccr* of 89.78% (Table 4.2) and *Kappa* of 0.6753. Overall, this model was relatively more accurate than other all models in terms both of *ccr* and *kappa* and contained 15 predictors (Li et al. 2016).

Table 4.2 Confusion matrix between the observed and predicted values of four hardness classes based on the average of 100 times of 10-fold cross validation using the most accurate predictive model (i.e., model 40) for hard90.

		Observed					
		Hard	Hardsoft	Softhard	Soft	Total	User's accuracy
Predicted	Hard	4	1	0.42	0	5.42	73.80
	Hardsoft	0	6.84	0.86	1.89	9.59	71.32
	Softhard	0	0	5.87	0.13	6	97.83
	Soft	2	6.16	1.85	108.98	118.99	91.59
	Total	6	14	9	111	140	
	Producer's Accuracy	66.67	48.86	65.22	98.18		89.78

Spatial predictions of seabed sediments

For seabed sediments, the spatial distributions of gravel, mud and sand content are illustrated in Figure 4.6.4. Accuracy of predictions varies based on density of underlying data and level of seabed complexity. Artefacts occur in these predictions as a result of insufficient samples in some areas and the surrogate predictors used. For example, the influence of latitude and longitude is clear in the predictions for the Gulf of Carpentaria. These sediment predictions are therefore intended primarily for use at the regional scale, such as to depict increased mud content beyond the shelf break and higher sand content on the inner shelf. To obtain the most accurate interpretation of sediment distributions at finer spatial scales in these areas, additional samples are clearly required so that the predictions can be updated. Relevant metadata information can be found in Li 2013a for seabed gravel content, in Li 2013b for seabed mud content and in Li 2013c for seabed sand content. Furthermore, some detailed information on how the predictive model was developed for gravel was documented in Li 2013d.

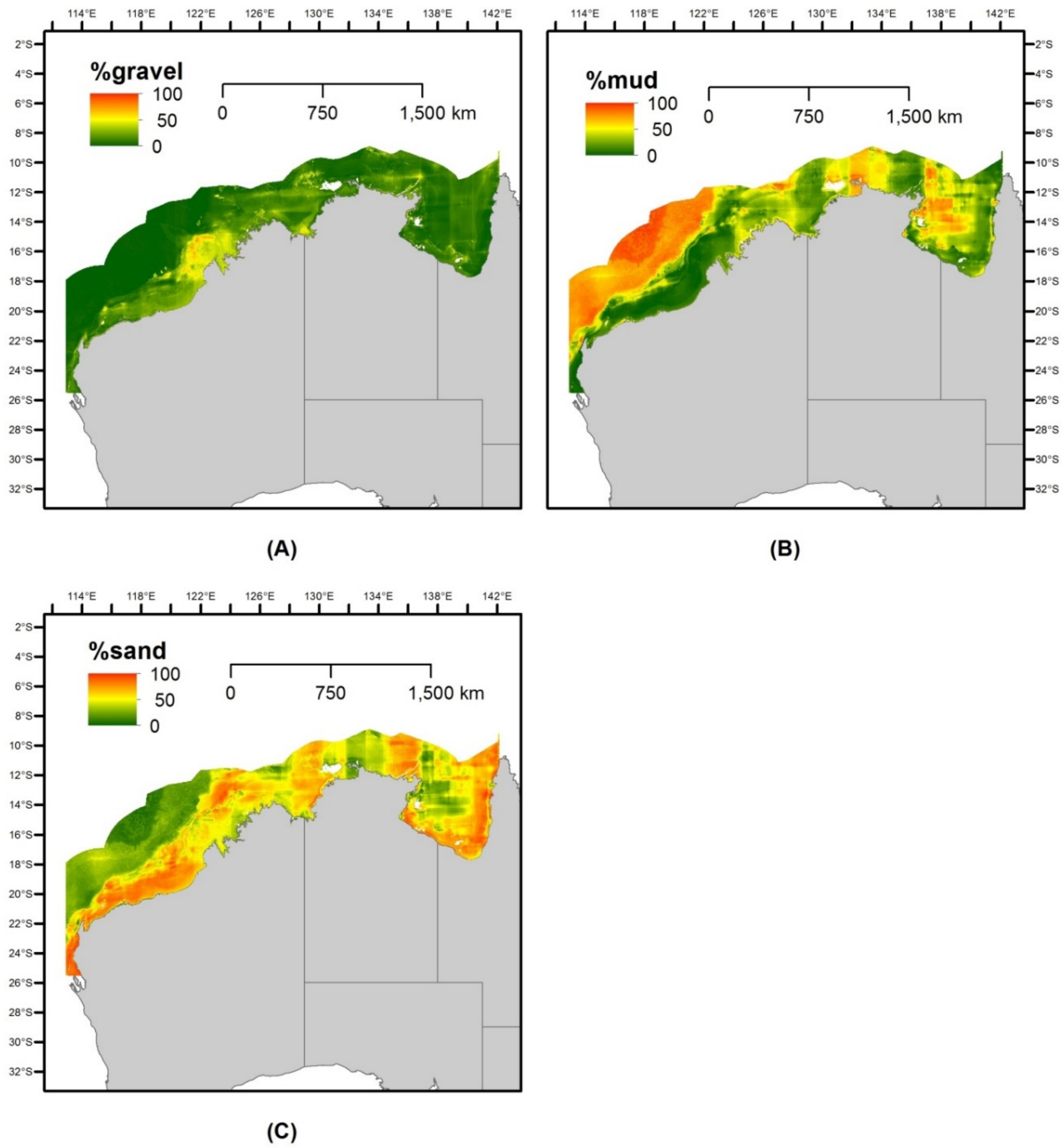


Figure 4.17 Spatial predictions of seabed sediments for the North and North-west Marine Regions. Note the presence of artefacts in some areas (e.g. Gulf of Carpentaria) that are driven by predictors such as latitude and longitude.

Spatial predictions of seabed hardness

The predicted values for seabed hardness based on the most accurate model and the observed values matched well for most classes in terms of both user's accuracy and producer's accuracy, although producer's accuracy was poor for the hard-soft class (Table 4.2). When the hard-soft and soft-hard classes are merged into the hard class, the model accuracies are improved, especially for the user's accuracy for the hard class (Table 4.3). The user's accuracy was higher than the producer's accuracy for non-soft classes (Tables 4.2, 4.3). Non-soft classes, particularly hard-soft, were under-predicted while the soft class was over-predicted.

The spatial predictions for hard90 were similar with the predictions based on two hardness classes (Li and Siwabessy 2013, Li et al. 2013). The match rates were 92.06% when the predictions of hard, hard-soft and soft-hard were pooled into one category (i.e. hard) for hard90.

Table 4.3 Confusion matrix between the observed and predicted values of two hardness classes based on the average of 100 times of 10-fold cross validation using the most accurate predictive model (i.e., model 40) for hard90.

		Observed			
		Hard	Soft	Total	User's accuracy
Predicted	Hard	18.99	2.02	21.01	90.39
	Soft	10.01	108.98	118.99	91.59
	Total	29	111	140	
	Producer's Accuracy	65.48	98.18		91.41

Spatial predictions of the most accurate models for hard90 are shown in Fig 4.6.5 for survey areas located in the Oceanic Shoals CMR and the carbonate banks and terraces of the Van Diemen Rise KEF. In these areas, hard substrates are predicted for bank geomorphic features where acoustic backscatter is high. The intermediate classes of hard-soft and soft-hard substrates are predicted to occur mostly on banks as well as on portions of terraces, consistent with increased water depths for these features. In contrast, soft substrates are predicted to occur mostly in the deeper parts of valleys that were often associated with the lowest backscatter values; portions of terraces were also predicted as soft.

In sum, this study shows that where high resolution bathymetry and acoustic backscatter data are available it is possible to derive (with high levels of accuracy) maps that define areas of hard and soft seabed. Importantly, these maps are at a resolution that is meaningful for interpreting patterns in benthic biodiversity and for providing the requisite baseline information for ongoing monitoring of benthic communities.

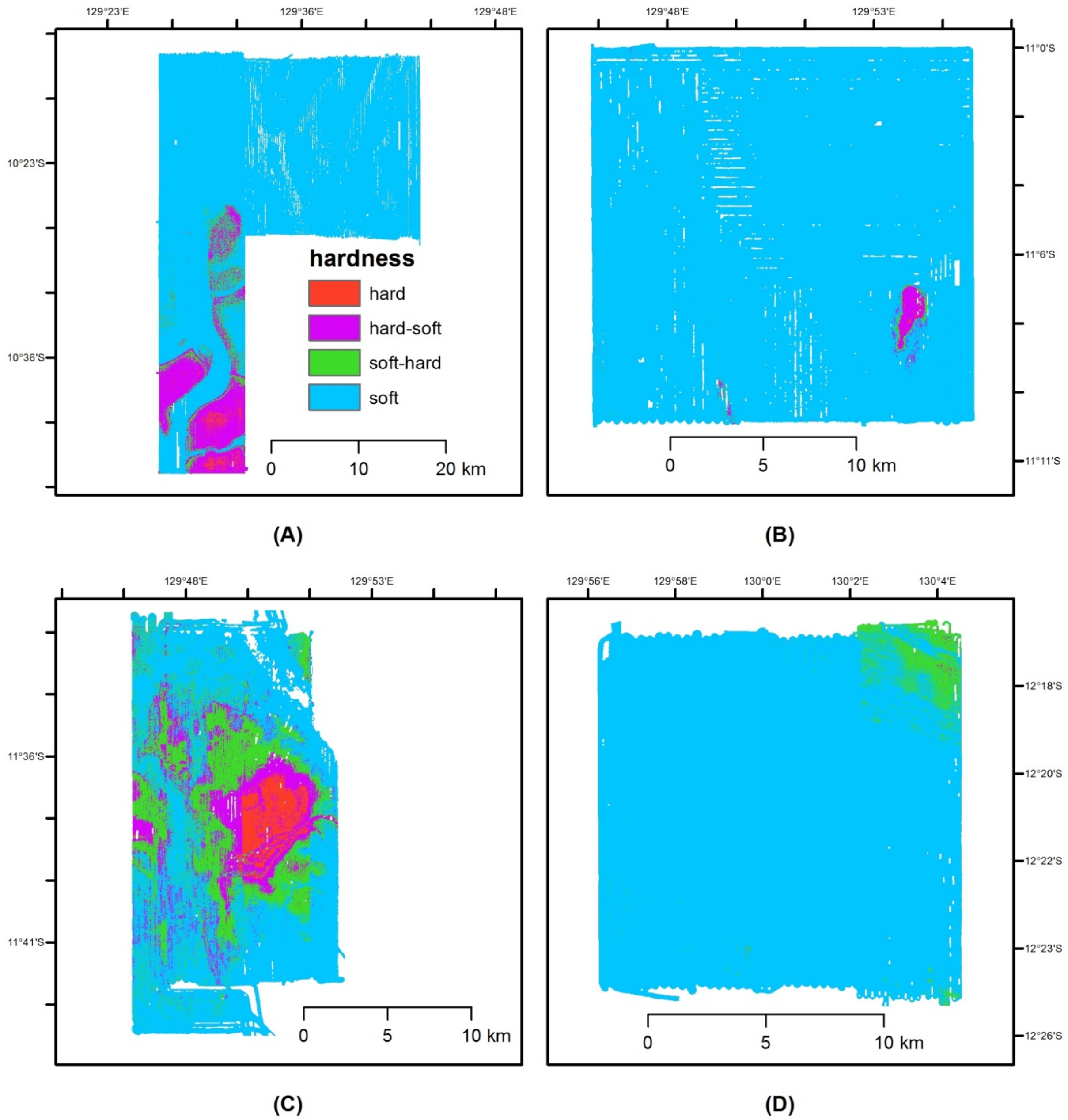


Figure 4.18 Spatial predictions of seabed hardness for four survey areas in eastern Joseph Bonaparte Gulf, North Marine Region. Areas A and B are located within the Oceanic Shoals CMR; Area C is located on the carbonate banks and terraces of the Van Diemen Rise KEF; Area D is on soft sediment plains to the south of Area C and outside the KEF. See 4.2 for location map

5. NEW SCIENCE DISCOVERIES

In addition to the predictive models and visualisation tools described earlier in this report, Project D1 has also yielded several new science discoveries relevant to the management of the CMR network. Some of these projects are completed (e.g. accepted for publication), while others are still in various stages of preparation (e.g. scoping). Here, we describe the associated key findings and significance to marine monitoring and management.

5.1 Continental-scale Hotspots of Pelagic Fish Abundance Inferred from Commercial Catch Records

RESEARCHERS: Phil Bouchet, Jessica Meeuwig, Zhi Huang, Tom Letessier, Scott Nichol, Julian Caley, Reg Watson

SUMMARY: Although marine protected areas have become key strategies in the modern conservation planning toolbox, their design and implementation in pelagic environments has been hampered by a limited understanding of wildlife dynamics on macro-ecological scales. Based on ten years of commercial fishing records from the *Sea Around Us* Project, we modelled the distribution of an assemblage of large bodied open-water predators (e.g. tunas, marlins, mackerels) and tested whether topography and prominent seabed features such as submarine canyons were useful physical proxies of their relative abundance patterns. We determined the location of abundance 'hotspots' around Western Australia on a 0.5 x 0.5° spatial grid and assess how well these overlapped with Australia's proposed national network of Commonwealth Marine Reserves.

KEY FINDINGS:

- Three regional pelagic hotspots were identified in the North, West and South bioregions, which were congruent with the results of previous studies.
- The occurrence and density of canyons were the best predictors of regional fish abundance in the North.
- Pelagic hotspots are under-represented in Australia's marine reserve network.

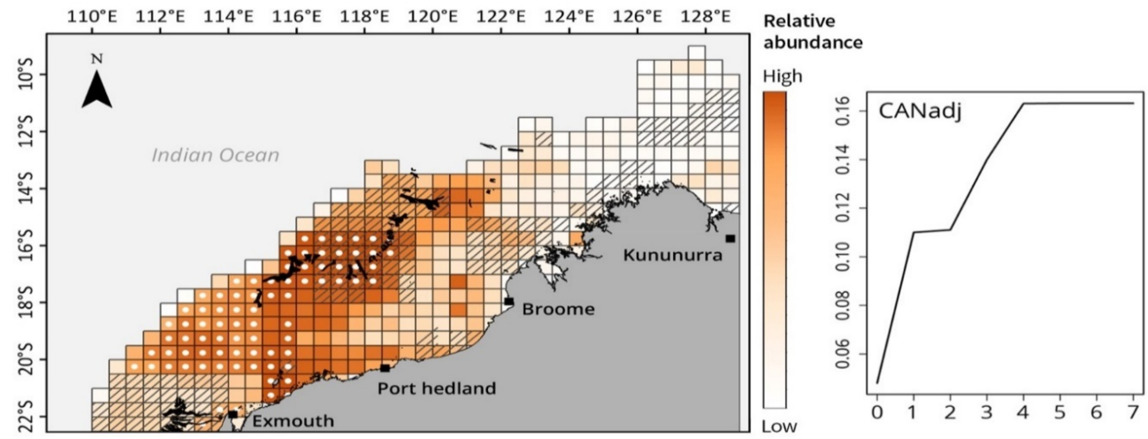


Figure 5.1**.** (left) Inferred spatial patterns in the relative abundance of pelagic fish across the North bioregion. Submarine canyons appear in black. Hotspot locations are marked with white circles and shown relative to the distribution of Commonwealth Marine Reserves (striped fill). (right) Partial dependence plot of the marginal effect of canyon density (number of canyons in the neighbourhood of a focal grid cell) on relative fish abundance. Values normalised to the [0-1] range.

SIGNIFICANCE: This study highlights the relevance of harnessing static topography as a blueprint for ocean zoning and spatial management.

STATUS: The manuscript has been accepted for publication in *Global Ecology and Biogeography*.

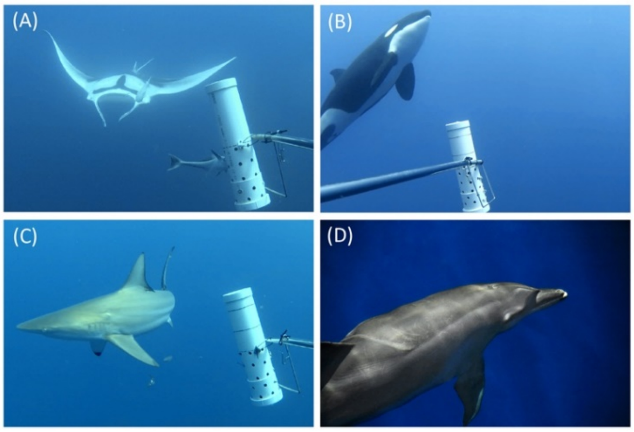
5.2 Spatial Dimensions of Pelagic Diversity in a Geodiverse Offshore Seascape

RESEARCHERS: Phil Bouchet, Tom Letessier, Julian Caley, Jan Hemmi, Jessica Meeuwig, Scott Nichol

SUMMARY: Broad-scale assessments of biodiversity in remote marine habitats often pose immense financial and technical challenges that constrain decision-making to proceed with only limited ecological information. This study reports on the first dedicated pelagic sampling programme undertaken within the Oceanic Shoals Commonwealth Marine Reserve using a novel baited videography technology. Underwater cameras were deployed at 116 sites to generate baseline information on the composition, richness and distribution of vertebrate species across a topographically complex seascape. Statistical methods were used to both estimate the total number of species likely occupying the survey region and produce forecasts of pelagic diversity within CMR boundaries.

KEY FINDINGS:

- Video footage of 32 species from 13 families was recorded, ranging from small bait fishes to large sharks, manta rays, sea turtles, sea snakes and cetaceans.
- We estimate that between 22 and 59 species (best estimate: 40) make up the pelagic assemblage of the region.
- Pelagic communities associated with carbonate banks were distinct from those found elsewhere, with possible size-mediated niche partitioning occurring between shark species.
- Predictive models highlighted the Malita Valley and the eastern part of the Sahul Shelf as being among areas of elevated species diversity. Species richness is expected to peak in the vicinity of raised topographic features.



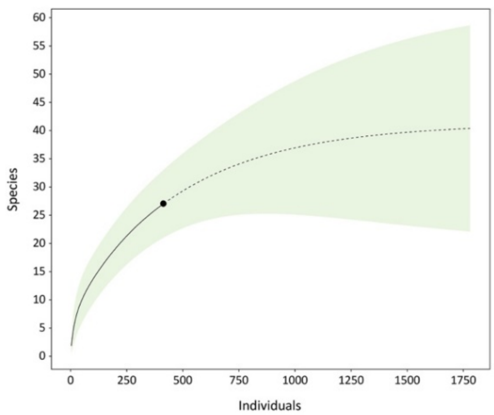


Figure 5.2 (left) Examples of higher-order predators encountered during the survey. (right) Estimated individual-based rarefaction (solid line) and extrapolation (dashed line) curves for pelagic species richness in the Oceanic Shoals CMR (shaded area: 95% confidence interval).

SIGNIFICANCE: The study provides urgently needed baseline data on the biodiversity values of the poorly-explored Oceanic Shoals CMR and illustrates the successful early management of a rich and still relatively pristine environment under extreme data deficiency.

STATUS: The manuscript is final stages of preparation and will be submitted to *Conservation Biology* in the second half of 2017.

5.3 Environmental Predictors of Foraging and Transit Behaviour in Flatback Turtles

RESEARCHERS: <u>Michele Thums, </u>Zhi Huang

SUMMARY: Flatback turtles migrate between nesting beaches and foraging grounds, but little is known about the cues they use to direct these migrations, and the habitats that define their foraging grounds. This study used animal-borne satellite transmitters to document movement patterns of these animals from the Lacepede Islands, in the Kimberley region of Western Australia. We then used statistical methods to objectively identify foraging grounds and migratory pathways and determine the key physical (e.g. tidal fronts, turbidity) and habitat (e.g. geomorphology, sediment type) variables that influence their movement patterns. We also quantified the area used in each behavioural mode (foraging, nesting, transiting) to quantitatively identify these biological important areas and assess how well the existing system of marine reserves encompassed these areas.

KEY FINDINGS:

- The turtles migrated to foraging grounds on the mid-Sahul Shelf, 135 ± 35 km from shore.
- Flatback turtles preferred foraging and transiting in clear waters (total suspended material < 0.06 g m^{-3}), 60 – 90 m deep and in association with complex, benthic geomorphology (banks, shoals, terraces, deep holes and valleys) thought to support a high abundance of sessile invertebrates, the likely targets of their foraging.
- Distance to the tidal front was also a strong predictor of turtle migratory behaviour, with the turtles potentially following tidal fronts along the Kimberley Coast.
- Whilst the nesting grounds and transitory pathways to the nesting grounds were well encompassed by the Commonwealth Marine Reserves Network, only around half of the core foraging area was encompassed although 70% of their time was spent there.

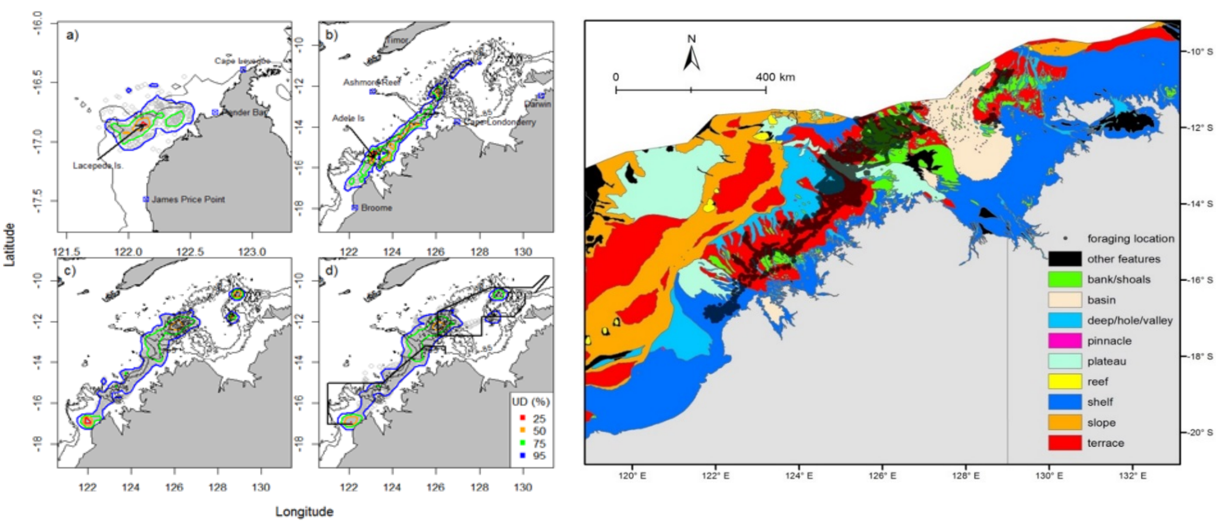


Figure 5.3. Left plot: the 25% (red), 50% (orange), 75% (green) and 95% (blue) home range cores for all flatback sea turtles during a) the nesting season, showing the 25 m depth contour in black, b) the outward transit, c) foraging and d) all phases combined. Also shown in thick black lines are two Commonwealth Marine Reserves; the Oceanic Shoals (top) and Kimberley (bottom). Right plot shows the geomorphic features overlayed with turtle foraging positions.

SIGNIFICANCE: The study identified both critical habitats for this species and the environmental variables that predict their migration and foraging. This information is essential to aid spatial planning of conservation for this data-deficient species that is endemic to northern Australia.

STATUS: Thums, M., Waayers, D., Huang, Z., Pattiaratchi, C., Bernus, J., & Meekan, M. (2017). Environmental predictors of foraging and transit behaviour in flatback turtles Natator depressus. Endangered Species Research, 32, 333-349.

5.4 The Impact of Tropical Cyclones on Migrating Flatback Turtles

RESEARCHERS: Michele Thums, Marji Puotinen

SUMMARY: Tropical cyclones generate heavy seas that regularly cause physical damage to marine and coastal tropical ecosystems, such as NE Australia's Kimberley region. Their detrimental effects on sea turtle nesting beaches have been well documented, however our understanding of the effects on the sea turtle post-nesting phase remains largely unexplored. We modelled maximum likely wave heights every hour during tropical cyclones over three seasons along the migratory paths taken by 35 satellite tracked flatback turtles from nesting beaches in the Dampier region of Western Australia to foraging grounds in the Kimberley. The aim was to quantify the extent to which heavy seas during cyclones disrupted turtle trajectories and exposed them to cool water.

KEY FINDINGS: The analysis is ongoing, but so far has revealed the following:

- 56% of migrating turtles may have been exposed to extreme conditions during a single cyclone, with potential impacts from several others.
- A detailed reconstruction of maximum possible seas (significant wave height - Hs) along the migratory path of one turtle below (Figure) showed that the turtle deviated notably from its northward migration just as conditions worsened (Hs up to 8m), and then returned to its route once conditions returned to normal.
- Analysis of the CTD data from the turtle's tag showed that during this time the turtle dived deeply and was exposed to cooler water resulting from mixing by the cyclone (Figure).

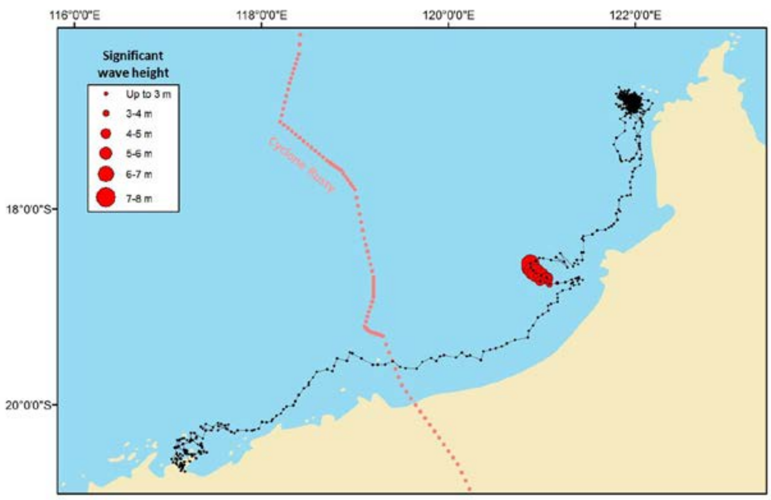


Figure 5.4 Satellite track of a flatback turtle overlaid with the path of Cyclone Rusty and significant wave height.

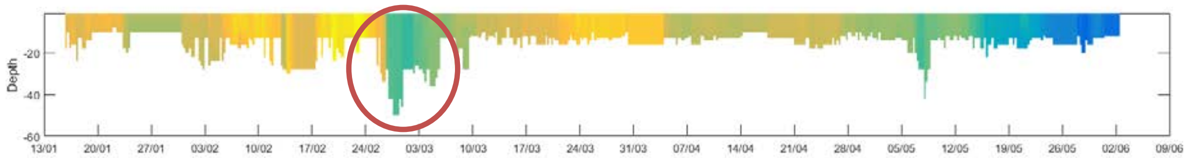


Figure 5.5 Dive depth of the turtle (y-axis) by time (x-axis) colour coded by sea temperature (darker colours = cooler). The cyclone causes the turtle to dive more deeply as indicated by the red circle, and the water column to cool (through mixing).

SIGNIFICANCE: Deviation from their migratory path will delay their arrival at foraging grounds. In addition, cyclones mix and cool the water column and as turtles are ectotherms, time spent in cooler water may have an energetic impact. Both effects could be compounded by the fact that turtles are energetically weakened by the breeding season.

STATUS: A manuscript will be completed and submitted to a peer reviewed journal in mid 2017.

5.5 Marine Worms of the Oceanic Shoals CMR region

RESEARCHERS: Rachel Przeslawski, Chris Glasby, Scott Nichol

SUMMARY: The aim of this study was to characterise the polychaete biodiversity and ecology of the Joseph Bonaparte Gulf and Timor Sea using biological samples collected on four surveys in the region. Since management decisions may be based on biological data collected from only one taxonomic group or habitat, we will also relate these findings to previous work undertaken on other taxonomic groups (e.g. sponges) to assess the generality of ecological patterns among different groups.

KEY FINDINGS: The comparative analysis between polychaetes and sponges is still pending, but analysis of polychaete biodiversity has revealed the following:

- The collection included 50 families and 368 species, with at least ten confirmed new species and three possible new genera, indicating that the Oceanic Shoals CMR and its surrounding region may be a hotspot for polychaete biodiversity.
- There were significant differences in species assemblages among all surveys, including those from the same area in the eastern Oceanic Shoals regions (2009 and 2010 surveys) (Figure). These differences were not observed at the family level, reflecting the need for high taxonomic resolution in biodiversity surveys (or at least appropriate interpretation at coarser resolution).
- Polychaete assemblages were only weakly related to depth, substrate hardness and various sediment characteristics, suggesting that there is no strong environmental predictor for infaunal biodiversity in this region.

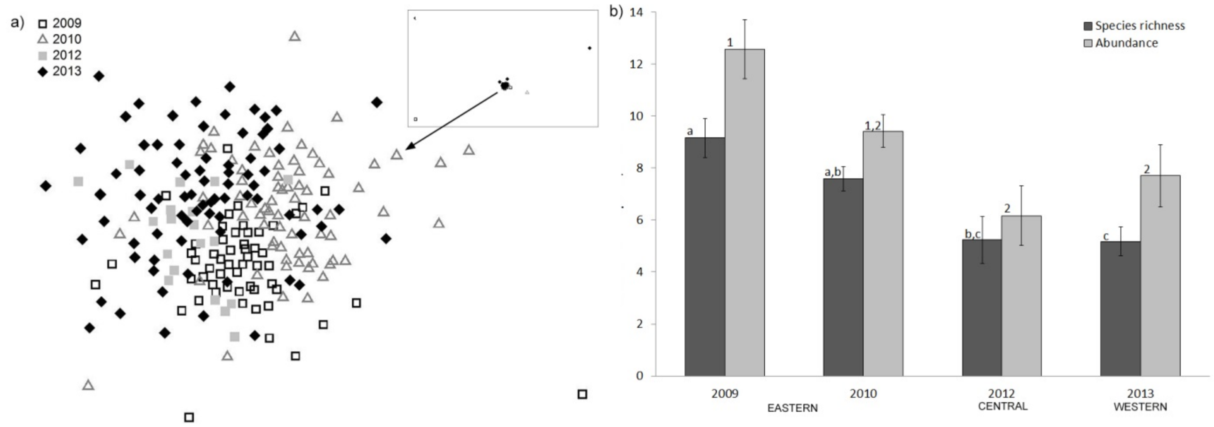


Figure 5.6 Spatiotemporal variation in a) species assemblages as shown by a n-MDS (stress = 0.09) in which each point represents an assemblage from a given grab, and the distance between points represents similarity between assemblages (outliers included in inset), and b) species richness and total abundance in which different letters or numbers represent significant differences as determined by Tukeys HSD multiple comparisons. Error bars are SEMs.

SIGNIFICANCE: Results of this study will provide valuable baseline data on the Oceanic Shoals Commonwealth Marine Reserve, as well as inform future marine management plans and associated monitoring programs. Specifically, we recommend that target measures of biodiversity need to be decided, appropriate gear identified, and qualified taxonomists engaged prior to any marine survey or monitoring program. If possible, preliminary data should be acquired to determine the target organisms and optimal combination of gear types used to sample that region and address a given hypothesis. Temporal variability must also be accounted for in marine biodiversity and monitoring studies that include small macrofauna or infauna.

STATUS: The manuscript associated with this study is in the final stages of writing and will be submitted to *Ocean & Coastal Management* in early 2017.

5.6 Sponge Species Richness Predictive Modelling in the Oceanic Shoals CMR region

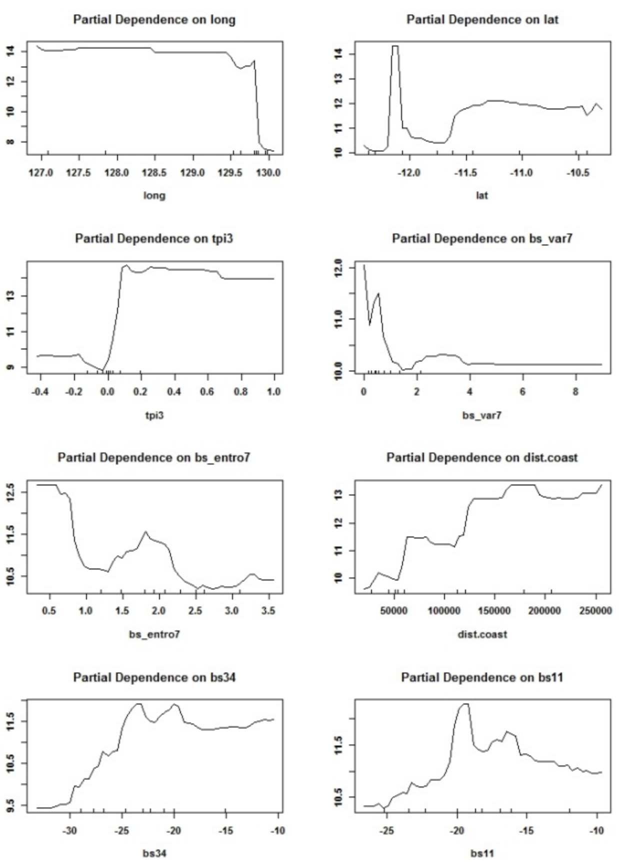
RESEARCHERS: Jin Li, Belinda Alvarez, Justy Siwabessy, Maggie Tran, Zhi Huang, Rachel Przeslawski, Lynda Radke, Floyd Howard, Scott Nichol

SUMMARY: In this study, we aim to predict the spatial distribution of sponge species richness (SSR) within the Oceanic Shoals CMR in the Timor Sea offshore, northern Australia, based on samples of SSR using the hybrid method of random forest (RF) and geostatistics (RFOKRFIDW), acoustic multibeam data and their derived variables. The spatially continuous data of SSR and the relationships between SSR and environmental variables are of important conservation values for the CMR. However, they are either not readily available or largely unknown. Predictive models for SSR may address the spatial data gaps and could be used to investigate the ecological relationships.

KEY FINDINGS: The predictive modelling of SSR has revealed the following findings.

- The prediction accuracy (VEcv) of RFOKRFIDW was 45.41%, which is higher than the average accuracy of predictive models published in the environmental sciences.
- Eight predictors were found to be important predictors and their importance was: longitude > latitude > distance to coast > bs11 > tpi3 > bs34 > bs_entro7 > bs_var7.
- The relationships of SSR with the predictors were non-linear (Figure a).
- The predicted SSR was found to be high on banks and terraces and low on plains and valleys, as being illustrated in Figure b.

(b)



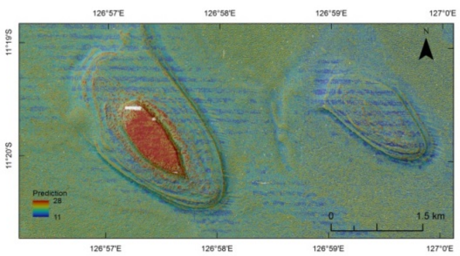


Figure 5.7. a) the relationships of SSR to the eight predictors and b) spatial predictions of sponge species richness.

SIGNIFICANCE: The hybrid methods of RF and geostatistical methods can effectively model count data and are not data-type specific; and they can effectively deal with the global trend either spatially, environmentally or both and with non-linear relationships with predictors, and with local variations if the residuals contain useful information of local variation. The accurate predictive model based on proxy predictors can not only produce reliable spatial predictions, but also provide clues for identifying causal variables. The relationships of SSR with the predictors are non-linear, rather than linear as previously assumed. Moreover, these findings largely delineate the region where habitats of SSR are likely to be found, providing important information for future monitoring design and highlighting areas where management and conservation of sponge gardens should be focused.

STATUS: The manuscript associated with this study has been submitted to *Environmental Modelling and Software* in April 2016 and is under review.

5.7 Banks and Shoals of the Oceanic Shoals CMR

AUTHORS: Kim Picard, Ben Radford, Marji Puotinen, Rachel Przeslawski, Dave Williams, Scott Nichol, Lynda Radke, Floyd Howard, Zhi Huang, Jin Li

SUMMARY: Data collected during a 2012 NERP survey to the Oceanic Shoals CMR revealed a greater number of banks and pinnacle features that had been previously identified and also provided new insights into geomorphic processes on the seabed that may influence fine-scale patterns of biodiversity. In this study, we use the bathymetry and backscatter data to derive a suite of morphometrics (depth, backscatter intensity, seabed slope, bank/pinnacle area and aspect) for bank and pinnacle features as a quantitative basis for exploring the relationship between these features and the predicted distribution of benthic biological communities. We also evaluate the exposure of banks to tidal currents by using the direction of pockmark scours that surround the banks as a proxy, and validated against a local hydrodynamic model.

KEY FINDINGS:

- Three distinct groups of banks can be defined based on a cluster analysis of morphometric data (5.8a). Group 2 and 3 are similar, but different from each other by one (group 2) having the least steep flanks.

- Pockmark scour directions indicate that seabed currents are predominantly bidirectional and aligned in a WNW to ESE direction, consistent with local hydrodynamic model results. Variability from this general trend likely reflects local turbulence caused by the banks (Figure 3b). This ‘scattering’ is especially obvious in close proximity to banks that have an irregular to asymmetrical shape.

- Based on the observed scour directions, we estimate that on average only about 5% (1-sigma deviation around the mean flow direction, i.e. ~92° to 107° and 282° to 297°) of the surface area of a bank is directly exposed to currents that flow along the WNW-ESE vector. However, this exposure increases to 38 ± 12% at the 2-sigma range (i.e ~ 45° to 140° and 242° to 330°)

- Predictive models of suspension-feeding communities (soft and hard corals, sponges, gorgonians and sea whips) will be used to assess differences among and within banks.

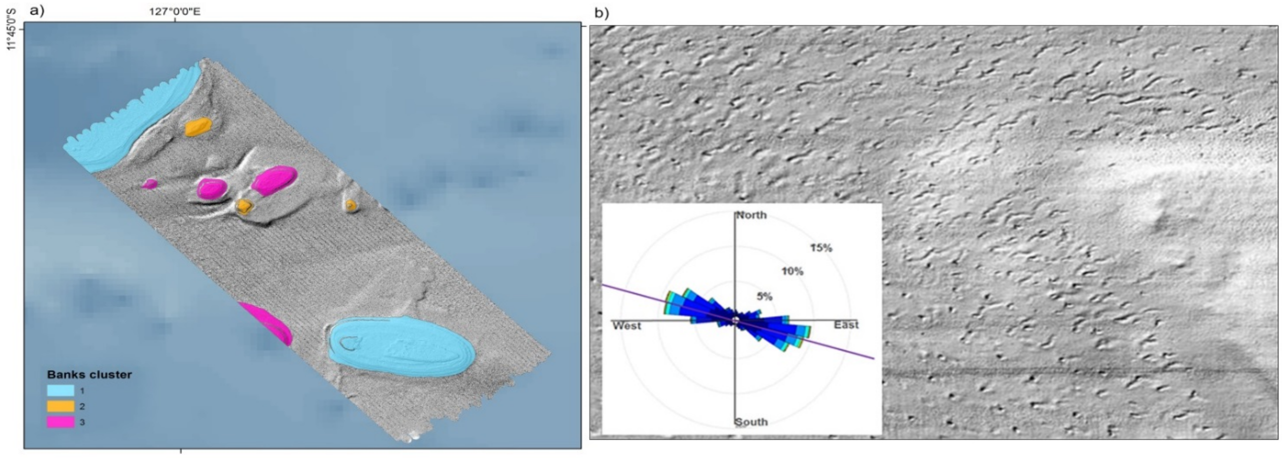


Figure 3 a) Map showing how the banks from the Area II cluster morphometrically. b) Seabed image created from multibeam bathymetry data showing the pockmarks and their associated scour marks on the plains surrounding the banks. Inset shows distribution of the scour directions for all survey areas. The purple line shows the modelled current direction for the region.

SIGNIFICANCE: This study highlights the need to consider heterogeneity among geomorphic features when assessing their conservation values. For the carbonate bank and pinnacle KEFs, variability in depth and aspect are key distinguishing characteristics that appear to influence their relative habitat potential. In addition to providing fundamental baseline data for monitoring CMR performance, this information can guide the setting of priorities by allowing a focus on seabed features with the greatest habitat potential.

STATUS: The manuscript associated with this study is currently being drafted.

5.8 Connectivity of Northern Australia

RESEARCHERS: Rachel Przeslawski, Johnathan Kool, Karen Miller

SUMMARY: This project scoped the application of the 4-D connectivity model developed in NERP to existing sponge and polychaete data in the Oceanic Shoals CMR region. As part of this, the life histories of these groups are generalised and related to ophiuroids to determine if the existing model is appropriate or if a new one should be developed. In addition, potential differences in sponge and polychaete assemblages between the east and west CMR are examined in relation to the existing connectivity model.

KEY FINDINGS:

- Sponge larvae are generally passively transported particles, but they have a shorter pelagic larval duration (PLD) and reduced mortality rate compared to ophiuroids. Polychaete larval parameters are unable to be generalised at the class level.
- The current model is suitable to examine patterns in sponges, as the model can readily be truncated to account for a pelagic larval duration of two days for sponges. Due to the diversity of larval characteristics represented by polychaetes, the model can only be applied to particular families in this group that share larval characteristics with ophiuroids (i.e. negligible vertical swimming capability, neutral larval buoyancy) and that are also well-represented in the biological collections (e.g. Capitellidae, Spionidae, Pilargidae, Syllidae).
- The connectivity model suggests moderate population or assemblage differences between east and west CMR may occur even in groups with relatively long larval durations (e.g. 90 days for ophiuroids). However, previous studies have shown that sponge assemblages show

no significant differences between east and west of the CMR, and spatiotemporal variations in polychaete assemblages cannot be definitively linked to east-west differences. Further applications of the model should investigate effects of timing and depth of particle release points.

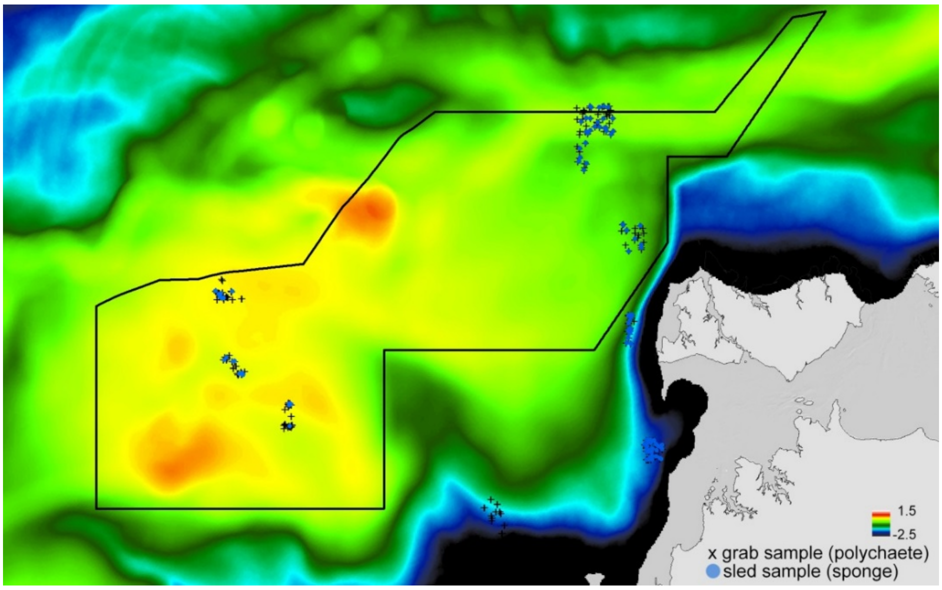


Figure 5.9 Connectivity map of Oceanic Shoals CMR (black outline) with biological sample locations shown. Connectivity values are Log_{10} simulated particle densities for a 12 km radius around a 1 km cell from June 30th 2009, integrated over depth.

SIGNIFICANCE: Application of the model to actual biological collections will be relevant to marine zoning and management to identify potential sinks and sources. This effort represents the first time that the Conn4D model is used to explain biodiversity patterns using biological samples in a discrete CMR. The approach may be adopted in other CMRs and may inform future refinements of connectivity models.

STATUS: This project was a scoping exercise and will be further pursued if resources become available.

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APPENDIX A – DATA DELIVERY SCHEDULE

NESP Marine Biodiversity Hub Project D1: *Ecosystem understanding to support sustainable use, management and monitoring of marine assets in the North and North-west regions*								
Brief description of data product (title)	**Metadata record created? (Y/N)**	**Metadata URL (if published)**	**Format of data product**	**Expected publication date of data (if not yet published)**	**Data publication status (overdue / in progress / on time)**	**Contact responsible for publishing project data**	**Additional notes/comments**	**Data Categorisation (1A, 1B, 2A, 2B - see cell comment)**
NESP MB Project D1: Ecosystem understanding to support sustainable use, management and monitoring of marine assets in the North and North-west regions	Y	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=d150240e-3cb7-437f-90ca-b9fafe700a19	N/A	N/A		Emma Flukes (Hub Data Manager)	Project record for linking data outputs in AODN	
Extensive interactive map gallery with pop-up content 'What do we know about the Oceanic Shoals Commonwealth Marine Reserve?'	Y	Various - see NW Atlas description field.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A, 1B, 2A, 2B
Extensive interactive map gallery with pop-up content 'What do we know about Glomar Shoal and Rankin Bank?'	Y	Various - see NW Atlas description field.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A, 1B, 2A, 2B
Extensive interactive map gallery with pop-up content 'What do we know about the NW banks and shoals of the Timor Sea?'	Y	Various - see NW Atlas description field.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A, 1B, 2A, 2B

Interactive map gallery 'Modelling what substrates make up the NW shoals of the Timor Sea'	N	Pending	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1B
Interactive map gallery 'How has the density of shipping through the Oceanic Shoals CMR changed over time?'	N	Data provider needs to fix broken link in their Geoserver to enable metadata to display in the NW Atlas.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Dusky Whaler sharks and the Oceanic Shoals CMR'	N	Data provider needs to fix broken link in their Geoserver to enable metadata to display in the NW Atlas.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'Marine sediments in the Oceanic Shoals CMR'	Y	http://eatlas.org.au/data/uuid/865e5c88-b2db-44a4-a0d7-d0299141bbf6	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'Maritime boundaries and the Oceanic Shoals CMR'	Y	See description in the NW Atlas for each data layer in the map gallery.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'Hazardous spills in NW Australia, 2009-2013'	N	Data provider needs to fix broken link in their Geoserver to enable metadata to display in the NW Atlas.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Voyages of the AIMS RV Solander in the Oceanic Shoals CMR'	Y	http://data.aims.gov.au/metadataviewer/uuid/525475b0-cbcc-4099-893a-04d2df733d41	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map	1A

							gallery of the NW Atlas	
Interactive map gallery 'Voyages of the RV Southern Surveyor in the Oceanic Shoals CMR, 2003'	Y	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!59cd26d6-764d-4a9d-a9f0-ce2049a7db66	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Voyages of the RV Southern Surveyor in the Oceanic Shoals CMR, 2005'	Y	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!35ead766-ae4f-448f-a59e-330c9ed243f8	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Voyages of the RV Southern Surveyor in the Oceanic Shoals CMR, 2006'	Y	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!8c7025cd-8a14-4ea7-94ed-c4360eba2978	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Voyages of the RV Southern Surveyor in the Oceanic Shoals CMR, 2007'	Y	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!0c9feb07-6e37-45dc-8e36-18eadbc4ddeb	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Voyages of the RV Southern Surveyor in the Oceanic Shoals CMR, 2010'	Y	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!bc1b3741-e7e5-5039-e044-00144f7bc0f4	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Voyages of the RV Southern Surveyor in the Oceanic Shoals CMR, 2012'	Y	See description in the NW Atlas for each data layer in the map gallery.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A

Interactive map gallery 'Voyages of the RV Southern Surveyor in the Oceanic Shoals CMR, 2013'	Y	See description in the NW Atlas for each data layer in the map gallery.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Observations of bioluminescence in the Oceanic Shoals CMR'	N	Data provider needs to fix broken link in their Geoserver to enable metadata to display in the NW Atlas.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Seismic surveys within the Oceanic Shoals CMR, 1976-2010'	N	Data provider needs to fix broken link in their Geoserver to enable metadata to display in the NW Atlas.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Petroleum leases and offshore titles near the Oceanic Shoals CMR'	N	Data provider needs to fix broken link in their Geoserver to enable metadata to display in the NW Atlas.	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Coral reef ecoregions of the Oceanic Shoals CMR and beyond'	Y	http://spatial.ala.org.au/ws/layers/view/more/australian_coral_ecoregions	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'IMCRA regions and the Oceanic Shoals CMR'	Y	http://spatial.ala.org.au/ws/layers/view/more/imcra_meso	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'How does ocean surface salinity vary across the Oceanic Shoals CMR?'	Y	http://spatial.ala.org.au/ws/layers/view/more/marspec_11	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map	2A

							gallery of the NW Atlas	
Interactive map gallery 'How does ocean temperature vary across the Oceanic Shoals CMR and beyond?'	Y	http://spatial.ala.org.au/ws/layers/view/more/marspec_16	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Geomorphology of the seafloor within and beyond the Oceanic Shoals CMR'	Y	http://spatial.ala.org.au/ws/layers/view/more/geo_feature	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'Migration patterns of whalesharks from 2005-2008 and the Oceanic Shoals CMR'	Y	http://data.aims.gov.au/metadataviewer/uuid/6c763a30-1603-4be2-b38f-a18c7eb283cf	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'Relative distance to shore of the Oceanic Shoals CMR'	Y	http://spatial.ala.org.au/ws/layers/view/more/marspec_05	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'Ocean productivity within and beyond the Oceanic Shoals CMR'	Y	http://spatial.ala.org.au/ws/layers/view/more/swchlo_mean	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A
Interactive map gallery 'Average turbidity within and beyond the Oceanic Shoals CMR'	Y	http://spatial.ala.org.au/ws/layers/view/more/swk490_mean	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	2A

Interactive map gallery 'How steep is the seafloor in the Oceanic Shoals CMR?'	Y	http://spatial.ala.org.au/ws/layers/view/more/marspec_06	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Interactive map gallery 'Shear stress on the seabed in the Oceanic Shoals CMR and beyond'	Y	http://data.gov.au/dataset/469dbf04-9bc9-48e4-95cf-1293c8d8e862	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	N/A	Published	Marji Puotinen, AIMS	Data already existed but has been made more accessible through the interactive map gallery of the NW Atlas	1A
Most likely benthic class habitat model for the Oceanic Shoals CMR	N	TBA	NW Atlas short article and interactive maps: see http://northwestatlas.org/nwa/map/gallery	Dec-16	Published	Marji Puotinen, AIMS		1B
Combined benthic class habitat model for the Oceanic Shoals CMR	N	TBA	Interactive map TBA	Dec-16	In progress	Marji Puotinen, AIMS		1B
Hard coral probability habitat model for the Oceanic Shoals CMR	N	TBA	Interactive map TBA	Dec-16	In progress	Marji Puotinen, AIMS		1B
Gorgonian probability habitat model for the Oceanic Shoals CMR	N	TBA	Interactive map TBA	Dec-16	In progress	Marji Puotinen, AIMS		1B
Alcyon probability habitat model for the Oceanic Shoals CMR	N	TBA	Interactive map TBA	Dec-16	In progress	Marji Puotinen, AIMS		1B

Whips probability habitat model for the Oceanic Shoals CMR	N	TBA	Interactive map TBA	Dec-16	In progress	Marji Puotinen, AIMS		1B
Sponge coral probability habitat model for the Oceanic Shoals CMR	N	TBA	Interactive map TBA	Dec-16	In progress	Marji Puotinen, AIMS		1B
Burrowers probability habitat model for the Oceanic Shoals CMR	N	TBA	Interactive map TBA	Dec-16	In progress	Marji Puotinen, AIMS		1B
The 25%, 50%, 75% and 95% kernel utilisation distribution of telemetry data from 11 flatback sea turtles from the Lacepede Islands for each of the main turtle phases of turtle life history; inter-nesting, transit to foraging grounds and foraging	N	TBA	Interactive map TBA	Dec-16	In progress	Michele Tums, AIMS		1B
Map of high resolution bathymetry that exists across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1684	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of high resolution bathymetry that exists across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1689	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of all bathymetry that exists across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1685	Dec-16	Published	Marji Puotinen, AIMS		1B

Map of all bathymetry that exists across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1688	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of a range of oceanographic datasets that exists across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1686	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of a range of oceanographic datasets that exists across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1687	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of hard coral across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1674	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of hard coral across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1690	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of soft coral across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1682	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of soft coral across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1691	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of sponges across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1683	Dec-16	Published	Marji Puotinen, AIMS		1B

Map of observed occurrences of sponges across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1692	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of brittle stars across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1671	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of brittle stars across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1693	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of polychaetes across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1679	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of polychaetes across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1694	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of molluscs across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1676	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of molluscs across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1695	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of marine mammals across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1675	Dec-16	Published	Marji Puotinen, AIMS		1B

Map of observed occurrences of marine mammals across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1696	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of sea turtles across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1680	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of sea turtles across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1697	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of seabirds across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1681	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of seabirds across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1698	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of demersal fish across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1672	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of demersal fish across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1699	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of demersal sharks and rays across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1673	Dec-16	Published	Marji Puotinen, AIMS		1B

Map of observed occurrences of demersal sharks and rays across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1700	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of pelagic sharks and rays across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1678	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of pelagic sharks and rays across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1701	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of pelagic fish across the N and NW regions by CMR, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1677	Dec-16	Published	Marji Puotinen, AIMS		1B
Map of observed occurrences of pelagic fish across the N and NW regions by KEF, divided into 10 by 10 km squares	N	TBA	http://northwestatlas.org/node/1702	Dec-16	Published	Marji Puotinen, AIMS		1B
Where has multibeam data been collected near Australia?	Y	http://services.ga.gov.au/site_3/rest/services/Multibeam_Coverage_Extents_2016/MapServer/	http://northwestatlas.org/node/1708	Dec 16	Published	Marji Puotinen, AIMS		
Sea Around Us Project - Relative pelagic fish abundance inferred from commercial catch data, Western Australia (1997-2006)	Y	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=16501b1f-4b29-4b52-82d1-2e5c4d536acc	Shapefile/raster	December 2016	In progress	Phil Bouchet (UWA), Jessica Meeuwig (UWA)		1B
Sea Around Us Project - Relative demersal fish abundance inferred from commercial catch data, northwestern Australia (1997-2006)	Y	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=e90f84bd-a1c8-4943-ac6a-dbfee0cc313e	Shapefile/raster	December 2016	In progress	Phil Bouchet (UWA), Jessica Meeuwig (UWA)		1B

Juvenile shark occurrence inferred from baited remote underwater video surveys Northwest Australia (2003-2013)	Y	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=5af57072-c4c2-4a5a-bc72-62486dc6d73e	Shapefile/raster	December 2016	In progress	Beverly Oh (UWA / AIMS), Jessica Meeuwig (UWA)		1B
Oceanic Shoals Commonwealth Marine Reserve - Pelagic baited camera surveys (stereo-BRUVS)	Y	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=ef452136-c42c-4f0a-98b3-f38a000a3752	Excel	December 2016	In progress	Phil Bouchet (UWA), Jessica Meeuwig (UWA)	Delivered to AIMS	1B
Oceanic Shoals Commonwealth Marine Reserve - Opportunistic visual surveys of marine megafauna	Y	http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=99208235-d68e-4039-bf77-362549a7aa48	Excel	published	-	Phil Bouchet (UWA), Jessica Meeuwig (UWA)		1B
Oceanic Shoals Commonwealth Marine Reserve - Predicted pelagic diversity	N	TBA	Raster	December 2016	In progress	Phil Bouchet (UWA), Jessica Meeuwig (UWA)		1B
Oceanic Shoals/Wessel Islands Sponge species ids	N	http://journals.plos.org/plosone/article/asset?unique&id=info:doi/10.1371/journal.pone.0141813.s002; http://journals.plos.org/plosone/article/asset?unique&id=info:doi/10.1371/journal.pone.0141813.s003	Excel	Metadata to come Nov 2016		Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Polychaete species ids	N			Nov 2016		Zhi Huang		1B
Petrel Basin Infaunal morphospecies ids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75010/	Excel			Zhi Huang		1B
Petrel Basin Underwater video and still images	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/74672/	Images and Videos			Zhi Huang		1B
Petrel Basin High Resolution Bathymetry Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/74866/	Geotif, ArcGIS grid, XYZ ascii			Zhi Huang	has been delivered to AIMS	1B

Petrel Basin High Resolution Backscatter Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75004/	Geotif, ArcGIS grid, XYZ ascii			Zhi Huang	has been delivered to AIMS	1B
Petrel Basin Seabed Geochemistry -- Porewater TCO2 and TCO2 flux	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/74979/	Excel			Zhi Huang		1B
Petrel Basin Seabed GeoChemistry -- Chlorins	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/74988/	Excel			Zhi Huang		1B
Petrel Basin Seabed GeoChemistry -- Chlorophyll abc and pheaophytin	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75003/	Excel			Zhi Huang		1B
Petrel Basin Seabed Geochemistry -- Sediment Oxygen Demand	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75006/	Excel			Zhi Huang		1B
Petrel Basin Seabed Geochemistry -- TOC, TN and carbon and nitrogen isotopes	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75005/	Excel			Zhi Huang		1B
Petrel Basin Seabed Geochemistry -- Specific surface area and total carbonate	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75007/	Excel			Zhi Huang		1B
Petrel Basin - Geomorphology	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_81955	shapefile			Zhi Huang	has been delivered to AIMS	1B
Petrel Basin Seabed Sediment Grain Size Data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75037/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin AUV still images	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82983/	Images			Zhi Huang		1B
Browse Basin Caswell Sub-basin High Resolution AUV Backscatter Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83919/	Geotif, ArcGIS grid, XYZ ascii, ESRI ascii, KML			Zhi Huang		1B
Browse Basin Caswell Sub-basin AUV sub-bottom profiler data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83930/	segy			Zhi Huang		1B

Browse Basin Caswell Sub-basin AUV Sidescan Sonar Data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/84545/	tif, xtf			Zhi Huang		1B
Browse Basin Caswell Sub-basin Total sediment metabolism, bulk carbonate, mineral specific surface area, major and trace elements and carbon and nitrogen concentrations and isotopes of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83179/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin Sediment Porosity and Chlorins	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83639/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin Sediment Grain Size Data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89782/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin High Resolution Bathymetry Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83696/	ArcGIS grid, geotif, kml, xyz ascii			Zhi Huang		1B
Browse Basin Caswell Sub-basin Shipboard Sub Bottom Profiler Data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83955/	segy			Zhi Huang		1B
Browse Basin Caswell Sub-basin Organic Geochemistry of Core Sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83843/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin Sediment oxygen demand in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83178/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin Shipboard Multibeam Backscatter Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83918/	ESRI ascii, ArcGIS Grid, Geotiff, KML, xyz ascii			Zhi Huang		1B
Browse Basin Caswell Sub-basin Remotely Operated Vehicle (ROV) imagery	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89921/	video			Zhi Huang		1B

Browse Basin Caswell Sub-basin p-rock (Probability of Rock) Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83920/	ArcGIS grid, geotif, kml, xyz ascii			Zhi Huang		1B
Browse Basin Caswell Sub-basin Standard Multi-Sensor Core Logger Data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89741/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin Total oxygen uptake and TCO2 release from core incubation experiments on marine sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83165/	Excel			Zhi Huang		1B
Browse Basin Caswell Sub-basin Chlorophyll a, b, c and Pheaophytin a concentrations in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83197/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Polychaete morphospecies ids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83720/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf High Resolution Bathymetry Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/79576/	ArcGIS grid, XYZ ascii, tif			Zhi Huang	has been delivered to AIMS	1B
Browse Basin Leveque Shelf High Resolution Backscatter Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/79033/	ArcGIS grid, XYZ ascii, tif, ESRI ascii, kml			Zhi Huang	has been delivered to AIMS	1B
Browse Basin Leveque Shelf Seabed Sediment Grain Size Data by Sieve measurement	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83638/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Interpreted Geomorphic Map	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/81956/	shapefile			Zhi Huang	has been delivered to AIMS	1B
Browse Basin Leveque Shelf Sediment total chlorin concentrations and chlorin indices	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78817/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Sediment Chlorophyll a, b, and c and phaeophytin a	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78818/	Excel			Zhi Huang		1B

Browse Basin Leveque Shelf Sediment Major and trace elements	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78820/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Sediment Total sediment metabolism and porewater pH and Salinity	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78824/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Sediment %Carbonate and specific surface area	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78825/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Sediment Oxygen Demand	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78826/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Sediment Porosity measurements	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78827/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Processed multichannel sub bottom profiler data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78880/	segy			Zhi Huang		1B
Browse Basin Leveque Shelf Sediment Total organic carbon and total nitrogen concentrations and isotopes	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78965/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Sediment Oxygen uptake and CO2 release based on core incubation experiments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/78819/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf underwater video and still images	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/77504/	Excel			Zhi Huang		1B
Browse Basin Leveque Shelf Seabed Sediment Grain Size Data by Laser Measurement	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83637/	Excel			Zhi Huang		1B
Oceanic Shoals Chlorin data from seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78786	Excel			Zhi Huang	has been delivered to AIMS	1B

Oceanic Shoals Sediment oxygen demand data from seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78788	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals %Carbonate and specific surface area of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78789	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Chlorophyll a, b and c and phaeophytin a concentrations in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78790	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Bulk organic carbon and nitrogen concentrations and isotopes in seabed sediment	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78791	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Oxygen consumption and dissolved organic carbon production rates in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78793	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Major and trace elements of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78794	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Organic carbon and nitrogen concentrations and isotopes and specific surface areas of the mud fraction of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78795	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Porosity measurements on seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78796	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Total sediment metabolism (Dissolved Inorganic Carbon production) and TCO2 pools of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_78798	Excel			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Sediment Grain Size Data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_79005	Excel			Zhi Huang	has been delivered to AIMS	1B

Oceanic Shoals High Resolution Multibeam Sonar Bathymetry Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_79006	ArcGIS grid, ESRI ascii, xyz ascii, kml, tif			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals High Resolution Multibeam Acoustic Backscatter Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_79007	ArcGIS grid, ESRI ascii, xyz ascii, kml, tif			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Interpreted Geomorphic Map	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89764/	shapefile			Zhi Huang	has been delivered to AIMS	1B
Oceanic Shoals Inorganic element data from the fine fraction (<63um) of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/79257/	Excel			Zhi Huang		1B
Oceanic Shoals (SOL5650) underwater video and still images	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75879/	video			Zhi Huang		1B
Joseph Bonaparte SOL4934 Gulf Videos and images	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/70206/	video, image			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Inorganic chemistry of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82523/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Mineral specific surface areas of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82556/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Backscatter Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76340/	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Joseph Bonaparte the eastern Timor Sea Probability of Seabed Hardness Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76347/	ArcGIS grid			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Bathymetry Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76400/	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B

Joseph Bonaparte the eastern Timor Sea Hardness Prediction Grids	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76401/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Hardness Classification Data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76402/	shapefile			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Slope	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76714/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Relief	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76715/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Surface Area	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76716/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Topographic Position Index	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76717/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Planar Curvature	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76721/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Profile Curvature	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76722/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Bathymetry Local Moran I	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76723/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Backscatter Homogeneity	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76725/	ArcGIS grid			Zhi Huang			1B
Joseph Bonaparte the eastern Timor Sea Backscatter Variance	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76726/	ArcGIS grid			Zhi Huang			1B

Joseph Bonaparte the eastern Timor Sea Backscatter Local Moran I	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76727/	ArcGIS grid			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Multibeam Sonar Angular Response Curves	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/76736/	shapefile			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Mineralogy of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82526/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea P-speciation in the fine-fraction of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82528/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Extractable elements in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82529/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Chlorophyll a,b,c and pheaophytin a concentrations in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82531/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Total chlorin concentrations and chlorin indices of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82549/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Sediment oxygen demand of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82550/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Total organic carbon (TOC), Total nitrogen (TN) and organic carbon and nitrogen isotopes of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82552/	Excel			Zhi Huang		1B
Joseph Bonaparte the eastern Timor Sea Total metabolism of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/82553/	Excel			Zhi Huang		1B

Joseph Bonaparte Gulf SOL5117 Videos and images	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/70902/	video, image			Zhi Huang		1B
Backscatter Grid of Darwin Harbour From Survey Onboard the Matthew Flinders - 2011	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_74916	ArcGIS grid, ESRI ascii, tif, kml			Zhi Huang	has been delivered to AIMS	1B
Bathymetry Grid of Darwin Harbour From Survey Onboard the Matthew Flinders - 2011	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_74915	ArcGIS grid, ESRI ascii, tif, kml			Zhi Huang	has been delivered to AIMS	1B
Rugosity Grid of Darwin Harbour	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75393/	ArcGIS grid			Zhi Huang		1B
Topographic Aspect Grid of Darwin Harbour	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75389/	ArcGIS grid			Zhi Huang		1B
Local Moran I Grid of Darwin Harbour	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75391/	ArcGIS grid			Zhi Huang		1B
Topographic Slope Grid of Darwin Harbour	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75390/	ArcGIS grid			Zhi Huang		1B
Benthic Position Index Grid of Darwin Harbour	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/75392/	ArcGIS grid			Zhi Huang		1B
Outer Darwin Harbour Porosity and Chlorins in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89835/	Excel			Zhi Huang		1B
Outer Darwin Harbour High resolution bathymetry grid	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/100093	ArcGIS grid, ESRI ascii, geotiff, kml, xyz ascii			Zhi Huang		1B
Outer Darwin Harbour High resolution backscatter grid	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/101200	ArcGIS grid, ESRI ascii, imagery, kml			Zhi Huang		1B
Seascape classification layer from the Darwin	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/83951/	kml, shapefile, geotif			Zhi Huang		1B

Harbour 2011 Marine Survey (GA0333)								
Outer Darwin Harbour Sediment oxygen demand data on seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89836/	Excel			Zhi Huang		1B
Outer Darwin Harbour Grain size data of seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89840/	Excel			Zhi Huang		1B
Outer Darwin Harbour TCO2 production and total oxygen uptake of seabed sediments from core incubation experiments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89832/	Excel			Zhi Huang		1B
Outer Darwin Harbour Total sediment metabolism, mineral specific surface area, carbonate and element concentrations and C and N isotopes in seabed sediments	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/89837/	Excel			Zhi Huang		1B
p-rock (probability of rock) grids from the Darwin Harbour 2011 Marine Survey (GA0333)	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_83950	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Complete Bathymetry Grid of Darwin Harbour from Various Surveys onboard the Matthew Flinders in 2010 and 2011	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_83182	ArcGIS grid, ESRI ascii, tif, kml, xyz ascii			Zhi Huang	has been delivered to AIMS	1B
Carnarvon Shelf Infaunal Diversity	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/72014/	Excel			Zhi Huang		1B
Sediment Data for Carnarvon Shelf	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/72039/	Excel			Zhi Huang		1B
Seabed exposure grid of Carnarvon Shelf	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/72030/	ArcGIS grid			Zhi Huang		1B
Carnarvon Shelf species level infauna data	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/72012/	Excel			Zhi Huang		1B
CERF Underwater video and stills from Carnarvon Shelf	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/72044/	mdb			Zhi Huang		1B
Video and still images from SOL4769 Carnarvon Shelf	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/70202/	video			Zhi Huang		1B

Carnarvon Infauna images	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/72009/	images			Zhi Huang		1B
Backscatter grids of Carnarvon Shelf	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_72001	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Bathymetry grids of Carnarvon Shelf	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_72005	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Geomorphic Features 2006	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_69797	shapefile			Zhi Huang	has been delivered to AIMS	1B
Australian Bathymetry and Topography Grid, June 2009	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_67703	xyz ascii, ER Mapper ers files, ER Mapper Raster images, ArcGIS grid, ascii BIL files			Zhi Huang	has been delivered to AIMS	1B
Bathymetry derived topographic aspect grid	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_76991	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Bathymetry derived topographic slope grid	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_76992	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Bathymetry derived topographic relief grid	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_76993	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Bathymetry derived topographic rugosity grid	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_76994	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Predicted seabed gravel content in the north-northwest region of the Australian continental EEZ 2013	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_76997	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Predicted seabed mud content in the north-northwest region of the Australian continental EEZ 2013	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_76998	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B

Predicted seabed sand content in the north-northwest region of the Australian continental EEZ 2013	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_76999	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Percentage of time the Shields parameter exceeds 0.25	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77000	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
The integrated Shields parameter exceeding 0.25 divided by the integrated total Shields parameter	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77001	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Average time between events when the Shields parameter exceeds 0.25	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77002	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
Ecological disturbance index	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77003	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
MODIS derived Chlorophyll a datasets	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77004	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
MODIS derived Coloured Dissolved Organic Matter (CDOM) datasets	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77005	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
MODIS derived Total Suspended Materials (TSM) datasets	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77006	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
MODIS derived K490 datasets	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77007	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
MODIS derived Euphotic Depth (Zeu) datasets	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77008	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B
MODIS derived Sea Surface Temperature (SST) datasets	Y	http://www.ga.gov.au/metadata-gateway/metadata/record/gcat_77009	ArcGIS grid			Zhi Huang	has been delivered to AIMS	1B

APPENDIX B – MAPS OF BIOLOGICAL DATA USED FOR GAP ANALYSIS

Detailed maps for each class of biota considered in the Gap Analysis are available on the North West Atlas. These maps show the CMRs and KEFs divided into squares 10km by 10km. For a given biotic class, each square is shaded red if at least one organism of that biotic class has ever been observed there and white if it has not. To see the total number of organisms known to exist in a given square, click on that square and read the value for 'count' in the table that pops up. Note that you may need to zoom in to ensure you click on the desired square and not a nearby square.

For CMRs:

- Pelagic fish: http://northwestatlas.org/node/1677
- Pelagic sharks & rays: http://northwestatlas.org/node/1678
- Demersal sharks & rays: http://northwestatlas.org/node/1673
- Demersal fish: http://northwestatlas.org/node/1672
- Seabirds: http://northwestatlas.org/node/1681
- Sea turtles: http://northwestatlas.org/node/1680
- Marine mammals: http://northwestatlas.org/node/1675
- Molluscs: http://northwestatlas.org/node/1676
- Polychaetes: http://northwestatlas.org/node/1679
- Brittle stars: http://northwestatlas.org/node/1671
- Sponges: http://northwestatlas.org/node/1683
- Soft corals: http://northwestatlas.org/node/1682
- Hard corals: http://northwestatlas.org/node/1674

For KEFs:

- Pelagic fish: http://northwestatlas.org/node/1702
- Pelagic sharks & rays: http://northwestatlas.org/node/1701
- Demersal sharks & rays: http://northwestatlas.org/node/1700
- Demersal fish: http://northwestatlas.org/node/1699
- Seabirds: http://northwestatlas.org/node/1698
- Sea turtles: http://northwestatlas.org/node/1697
- Marine mammals: http://northwestatlas.org/node/1696
- Molluscs: http://northwestatlas.org/node/1695
- Polychaetes: http://northwestatlas.org/node/1694
- Brittle stars: http://northwestatlas.org/node/1693
- Sponges: http://northwestatlas.org/node/1692
- Soft corals: http://northwestatlas.org/node/1691
- Hard corals: http://northwestatlas.org/node/1690

APPENDIX C – MAPS OF PHYSICAL DATA USED FOR GAP ANALYSIS

Detailed maps for three types of physical oceanography data are available on the North West Atlas. These maps show the CMRs and KEFs divided into squares 10km by 10km, except for bathymetry data (5 by 5 km). For bathymetry data, each square is shaded red if a dataset exists. For physical oceanography data, squares are shaded according to how many data sets they contain. Click on any square to see the data – note that you may need to zoom in to ensure you click on the desired square and not a nearby square.

For the entire Australian region:

Location of all bathymetry data as of Dec 2016 from Geoscience Australia:
http://northwestatlas.org/node/1708

For CMRs:

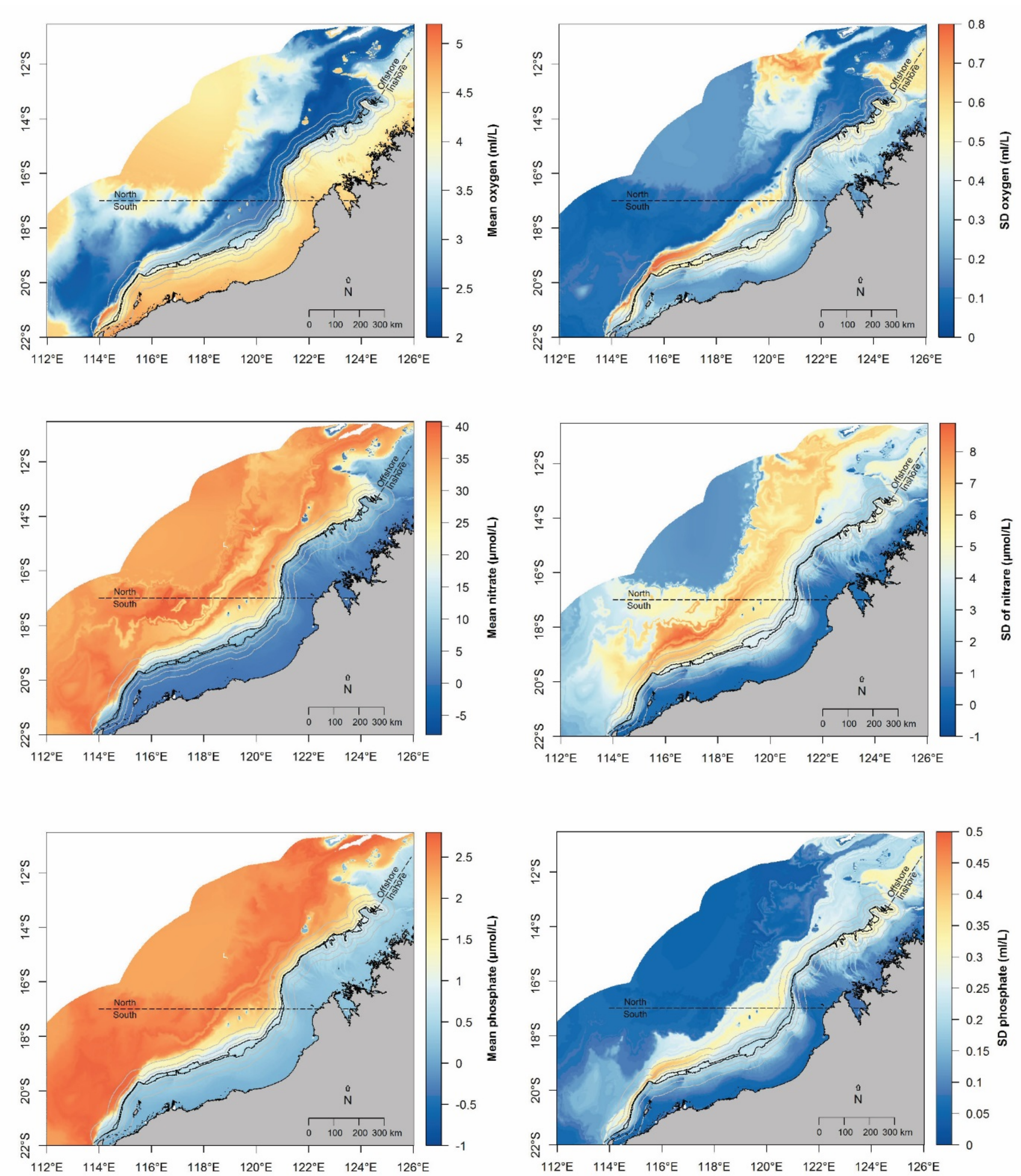
Multi-beam bathymetry data: http://northwestatlas.org/node/1684
RAN Bathymetry data: http://northwestatlas.org/node/1685
Physical Oceanography data: http://northwestatlas.org/node/1686

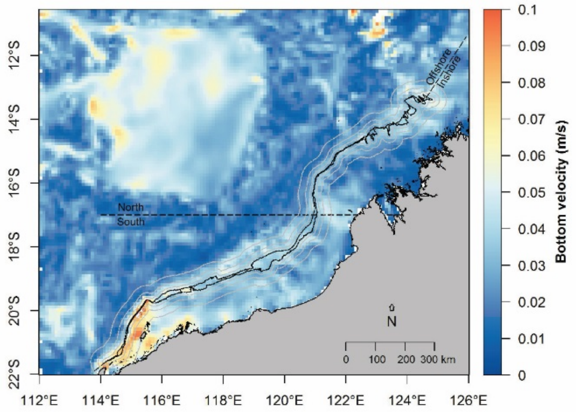
For KEFs:

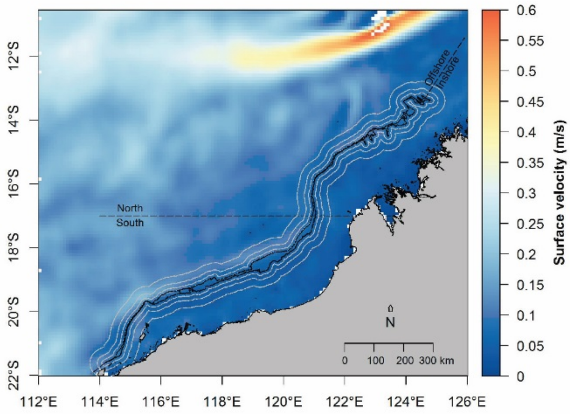
Multi-beam bathymetry data: http://northwestatlas.org/node/1689
RAN Bathymetry data: http://northwestatlas.org/node/1688
Physical Oceanography data: http://northwestatlas.org/node/1687

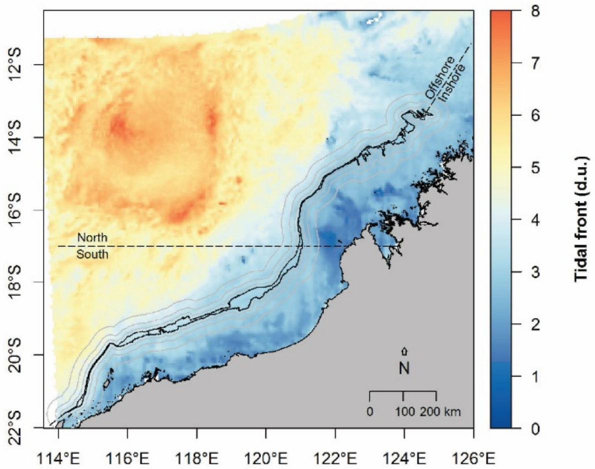
APPENDIX D – MAPS OF CARS DATA (SECTION 2.5.3)

Below are maps of the CARS variables (means and standard deviations) included in the analysis described in section 2.5.3.



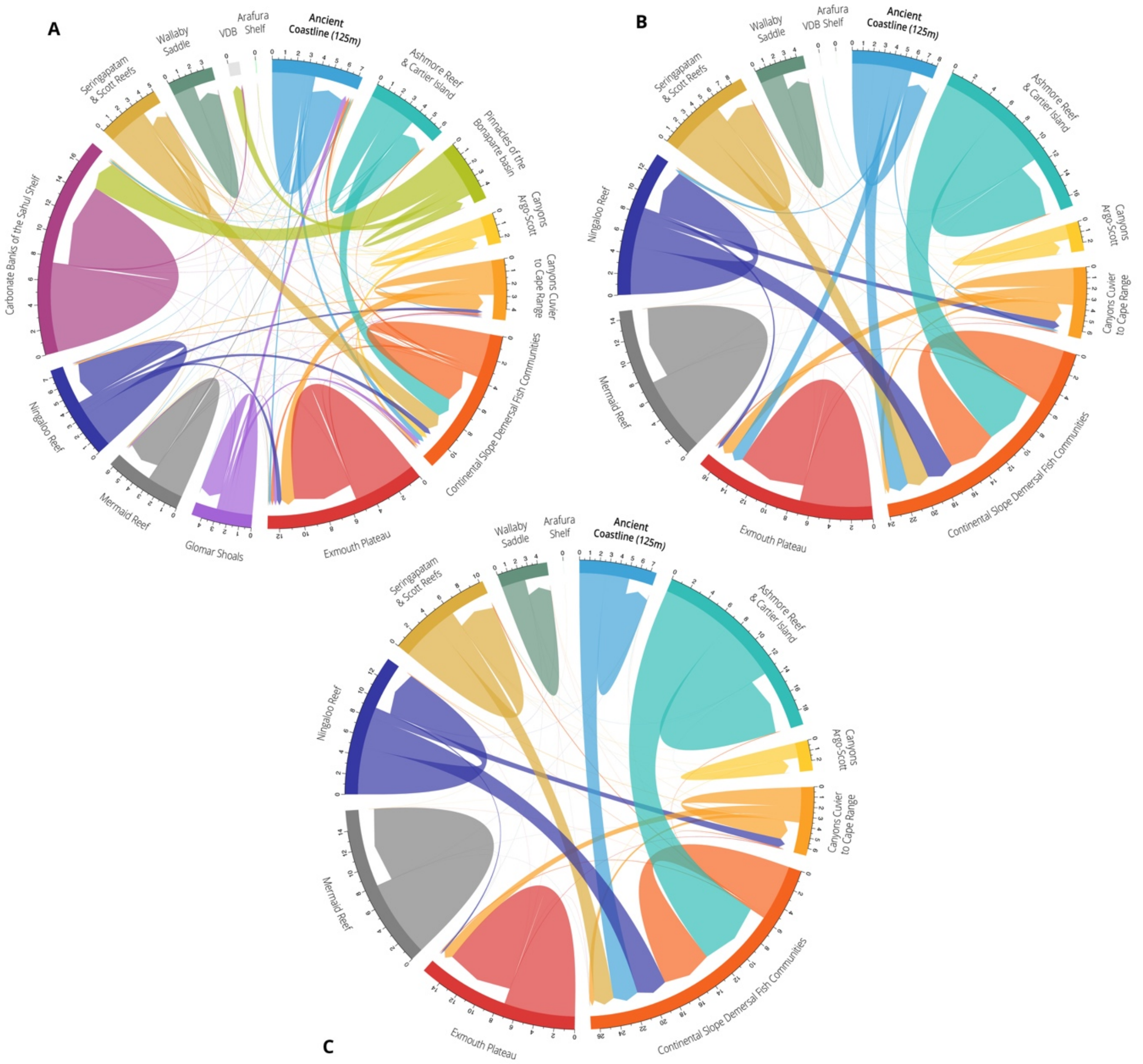

Bottom velocity (m/s)
North
South
Offshore
Inshore
N
0 100 200 300 km
12°S
14°S
16°S
18°S
20°S
22°S
112°E 114°E 116°E 118°E 120°E 122°E 124°E 126°E
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1


Surface velocity (m/s)
North
South
Offshore
Inshore
N
0 100 200 300 km
12°S
14°S
16°S
18°S
20°S
22°S
112°E 114°E 116°E 118°E 120°E 122°E 124°E 126°E
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6


Tidal front (d.u.)
North
South
Offshore
Inshore
N
0 100 200 km
12°S
14°S
16°S
18°S
20°S
22°S
114°E 116°E 118°E 120°E 122°E 124°E 126°E
0 1 2 3 4 5 6 7 8

APPENDIX E – KEF CONNECTIVITY IN THE NW

The plots below are a complement to Figure 2.16 and show the degree of connectivity between several NW KEFs within a range of bathomes (A: 30-50 m; B: 200-250 m; C: 250-300 m). Connectivity was modelled using conn4D (Kool and Nichol, 2015). Arrow widths are proportional to connectivity values. The AC125 appears in bold.



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