Review of research and monitoring relevant to natural values in Australia's Commonwealth Marine Reserves

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In responding to a tender from the Department of the Environment and Energy, a team of researchers representing the ARC Centre of Excellence for Coral Reef Studies at James Cook University (JCU) undertook compilation and desktop analyses of published research relating to the natural values of Australia's Commonwealth Marine Reserves. The research team comprised Dr Andrew Hoey and Professor Morgan Pratchett, with assistance by Ms Cassandra Thompson and Mrs Jessica Hoey.

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1 Executive Summary

Context and Purpose

Recognizing the importance of marine protected areas (MPAs) for marine ecosystem protection and conservation; the Australian Government has established a nationwide network of Commonwealth marine reserves (CMRs). The CMR estate was established with substantial scientific input, including through the Marine Bioregional Planning Programme which provided a series of Marine Bioregional Plans for Commonwealth waters. Parks Australia manages CMRs on behalf of the Director of National Parks. Parks Australia commissions research and monitoring in relation to CMRs to assist with management and evaluation of the effectiveness of these reserves. These efforts are complemented by external research and monitoring undertaken by national and international universities, Australian Government institutions (such as the Australian Institute of Marine Science, Geosciences Australia, and the Australian Museum), consultants and private enterprise.

The purpose of this review was to compile the scientific literature (mainly, journal publications and reports) relevant to the natural (biodiversity) values of each of the five Commonwealth Marine Reserve Networks and the Coral Sea Commonwealth Marine Reserve. This includes providing a summary of the scientific literature relevant to each network and how it relates to the *monitoring marine biodiversity*, identifying key research and monitoring knowledge gaps, future research needs, and potential indicators. *Monitoring of marine biodiversity* (as defined by the CMR review expert scientific panel in 2015) not involves only state-base monitoring to establish the range of species that occur in different areas of the CMRs, but also spatial and temporal analyses of the entire suite of processes (e.g., oceanography) that influence these distributions, including threats (e.g., climate change), which could modify species distributions and ecosystem functions.

Extent of Knowledge

This review built upon the 2010 Review of Research and Monitoring in Australia's Commonwealth Marine Protected Areas (Ceccarelli 2011), and identified 1,115 publications and reports (i.e. records) relevant to natural and biodiversity values. All of these records were entered in to the *2016 Commonwealth Marine Reserves Database*. This represents a significant increase from the 363 records included in the 2010 review. Overall, the number of records prior to 2000 was relatively low (121 entries), and grew steadily to 490 entries in 2010, with the majority of records being published in the last six years (2011-2016: 625 entries). Together with this temporal variation, there were substantial differences in the number of records that related to each of the regional networks (from 55 records for the North CMR Network to 302 records for the South-west CMR Network). Similarly, the number of records that related to individual CMRs ranged from 0 records for several CMRs to 109 records for the Lord Howe CMR (and 116 records for the Coral Sea CMR). While these differences in research effort do not directly translate to knowledge of status and trends, they provide a useful proxy. There was limited comprehensive baseline biological, oceanographic, or geomorphological data for the majority of the CMRs. The number of records relevant to, and hence the quantity of research conducted within, individual CMRs is likely to be influenced by a suite of factors, including remoteness and ease of access, logistic and financial constraints of sampling (e.g. deep water benthic communities), relevance to issues of national importance, the local occurrence of specific organisms and habitats, and the general interest of the scientific community and institutions.

Focus of Research Knowledge

A broad scope was taken in this review to include research that was both directly and indirectly (or potentially) relevant to the natural values of CMRs. For example, literature that relates to regional processes that may or may not have been conducted within CMRs, but that may influence the natural values in some way, were included. Overall the majority of research related to ecological communities, with non-coral invertebrates, fish and corals being the most commonly research groups. This was largely consistent among regions, although the relative importance of corals and non-coral invertebrates tended to swap between tropical/subtropical and temperate regions.

While there are some ongoing monitoring programs within a limited number of individual CMR's, there is currently no systematic research and monitoring program that spans the entire CMR Network, and the number of long-term monitoring programs of biodiversity values directly relevant to management is extremely limited. Considerable research (41% of records) has focused on pressures and threats to biodiversity within and adjacent to CMRs, with the main threats (in terms of number of records) being fishing and climate change. However, the majority of published monitoring programs are too infrequent to detect change or attribute change to pressures, and hence inform and initiate appropriate management actions. Some of the most valuable temporal data series are those that have been commissioned by the Australian Government for some of the offshore shallow tropical and subtropical reefs, namely the ecological surveys of Elizabeth and Middleton Reefs, the terrestrial and marine surveys of the former Coringa-Herald National Nature Reserve, and the reef ecology surveys of Ashmore Reef Commonwealth Marine Reserve. Research through the National Environmental Research

Program has also provided systematic monitoring in deeper temperate waters such the Flinders and Freycinet CMRs in the South-east Network. These time-series allow the status and trends of these locations to be determined, but are also important in informing the likely status of both adjacent areas, and similar habitats elsewhere.

Key Recommendations

Given the size and remoteness of many of the l CMRs, designing a systematic and thorough research and monitoring program will be extremely challenging. Key recommendations arising from this review include:

- Prioritisation of key/important areas for systematic and ongoing monitoring, particularly if these are under pressure or poorly understood. The collection of both environmental and ecological data is critical to allow tracking of status and trend in natural values and assist with attribution of local versus regional or global pressures (e.g. climate change) to any shifts in ecological communities. As a minimum, collect baseline environmental and biological data on the biodiversity values of these key areas (including priority species, habitats, and Key Ecological Features). The development and adoption of standardized methodologies for process-based monitoring to identify vulnerabilities and resilience of communities to ongoing and future pressures
- The establishment of indicator species for a range of ecosystems (e.g. shallow reefs, seamounts) from baseline and monitoring data. This will decrease costs and increase efficiency, directly inform management by allowing comparisons both within and across CMRs, and the identify those areas, habitats, and species that are most vulnerable
- Continued monitoring of those locations for which a long-term temporal series exists (e.g. Ashmore Reef, Elizabeth and Middleton Reefs, Coral Sea, Flinders and Freycinet on-shelf areas). This will not only allow the continued long-term assessment of these areas, but also inform the likely status and trends for comparable habitats exposed to similar pressures
- Shift toward ecological process-based monitoring (e.g. recruitment of corals or kelps), as opposed to current 'state-' (or condition-) based monitoring (i.e. documenting the status and trends in abundance of marine organisms) to understand potential vulnerabilities and resilience of habitats and communities to ongoing and emerging threats
- Initiating and coordinating systematic monitoring of CMRs will be logistically and financially challenging. Initiatives to foster greater

support and collaboration between researchers/research institutions and Parks Australia will be critical in directing management relevant research. Some options to achieve this include: partnering with researchers/research institutions and leveraging direct investment through funding opportunities such as the ARC Linkage program; effective communication of priority science (research and monitoring) needs within CMR's under a clear strategy or policy (e.g. development of a Scientific Information Needs for Management Policy that is regularly updated) for each CMR, each CMR Network, and the estate as a whole.

- The database currently contains 1115 entries and is an invaluable tool. The database should be maintained and updated regularly (at least every 6-12 months), and the information used to update this review.
- One of the major obstacles in compiling data for this review was determining whether a particular study had been conducted within the bounds of a CMR. The Director of National Parks (DNP) should encourage or mandate (through permissions to conduct research within CMRs) that researchers provide copies of all publications and reports relevant to CMRs, and at a minimum provide the citation and the exact location of the research.

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2. INTRODUCTION

Marine Protected Areas (MPAs) are the foremost management tool used in marine systems to conserve and protect marine species and habitats (Graham et al. 2011). Accordingly, the Australian Government has been committed to the establishment of a National Representative System of Marine Protected Areas (NRSMPA) since 1998 (Beeton et al. 2015). The primary goal of the NRSMPA is to establish and effectively manage a comprehensive, adequate and representative system of marine reserves to contribute to the long-term conservation of marine ecosystems and to protect marine biodiversity. In agreement with these policies, a nation-wide network of Commonwealth Marine Reserves (CMRs) was established through a process of Marine Bioregional Planning. This process involved the gathering of background information, the preparation of profiles that describe each marine region and the establishment of a CMR network in each region (Ceccarelli 2011).

The Director of National Parks (DNP), under the EPBC Act is responsible for managing all Commonwealth reserves. The only exception is the Great Barrier Reef Marine Park, which is managed under separate legislation. Parks Australia manage 58 of the 59 CMRs on behalf of the DNP, while the Australian Antarctic Division manages one (Heard Island and McDonald Island). Only CMRs managed by Parks Australia are within the scope of this review.

In 2007 the first network of CMRs was proclaimed with the establishment of 14 reserves in the South-east Marine Region. In November 2012, 40 new CMRs were proclaimed in the South-west, North-west, North, Temperate East and Coral Sea, finalising the Australian Government's contribution to the NRSMPA with a total of 60 MPAs making up the system (including the GBRMP).

The CMR estate that is managed by Parks Australia is broadly divided into 5 major Networks and the Coral Sea Commonwealth Marine Reserve (Figure 2.1):

1. The North-west Commonwealth Marine Reserve Network
2. The North Commonwealth Marine Reserve Network
3. The Coral Sea Commonwealth Marine Reserve
4. The Temperate East Commonwealth Marine Reserve Network
5. The South-east Commonwealth Marine Reserve Network
6. The South-west Commonwealth Marine Reserve Network

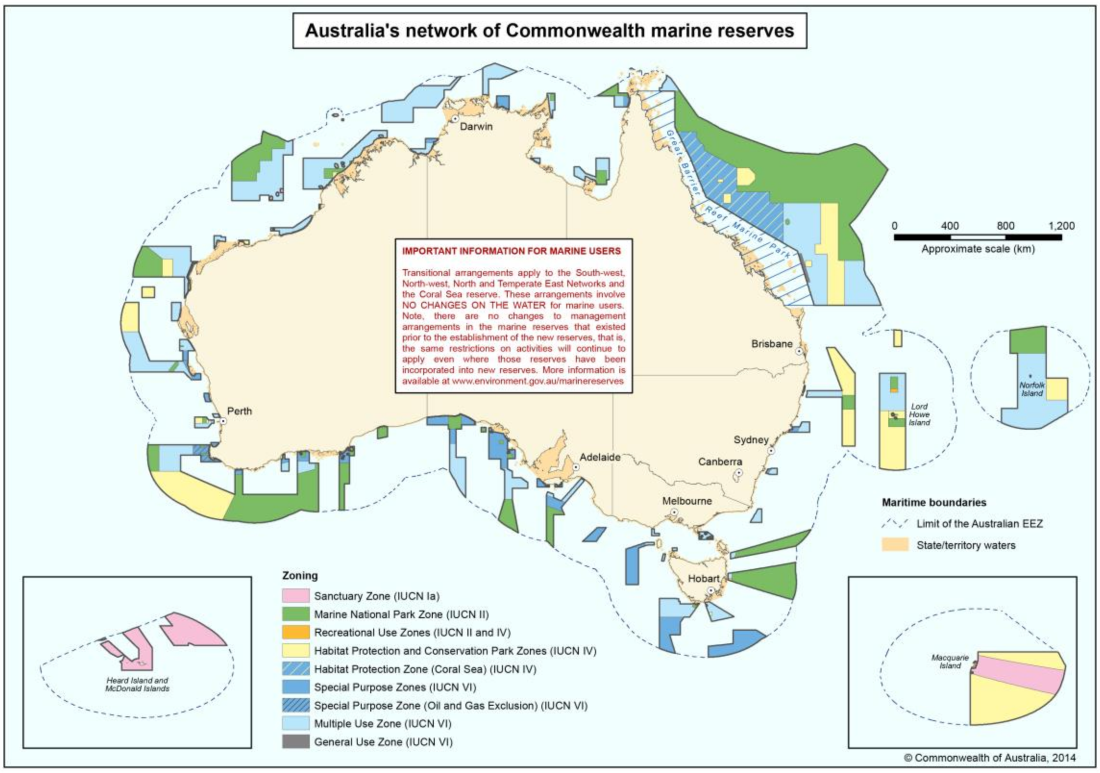

Figure 2.1 – Map of Australia showing the location, size and zoning of Commonwealth CMRs.

Management plans for these new reserves were drafted following their proclamation. However, the Australian Government re-proclaimed the reserves in December 2013, which had the effect of setting aside the management plans. This was the first step in the Government's commitment to reviewing the new reserves and how they were to be managed. The Commonwealth Marine Reserves Review (the CMR Review) commenced in August 2014 with the release of the terms of reference and announcement of the appointment of panel members. The CMR Review had two interrelated streams: (i) The Expert Scientific Panel (ESP) addressed the science underpinning the current CMRs and their future management, and (ii) The Bioregional Advisory Panels (BAP) enhanced consultation with stakeholders about the CMRs (Beeton et al. 2015).

The Director of National Parks (DNP) is responsible, under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), for preparing marine reserve management plans. At the time of this report, the DNP was preparing draft management plans for consideration by the minister for public comment.

The Australian Government (mainly the Department of the Environment and Energy) encourages and supports research and monitoring within the CMRs to better understand natural values, the condition of those values, and the effectiveness of, and requirements for altered management. However, there is also a large amount of research undertaken by national and international universities, Australian Government institutions (such as the Australian Institute of Marine Science, Geosciences Australia, and the Australian Museum), consultants and private enterprise. The objectives of this independent research are highly varied and not necessarily aligned with the research and monitoring objectives for the CMRs, but may nonetheless inform and greatly advance knowledge of the geology and oceanography of CMRs (e.g., Kool and Nichol 2015), status and trends in abundance of marine species and habitats (Prince and Chaloupka 2012), patterns of biological and hydrographical connectivity (Underwood et al. 2013), and/ or major and emerging threats to CMRs (e.g., Fuentes et al. 2009)

This report brings together this disparate body of work as it relates to each major Network and Coral Sea CMR, as well as providing preliminary analyses of the alignment of the region-specific literature against research and monitoring requirements outlined by the CMR review expert scientific panel (Beeton et al. 2016; Table 2.1). In doing so, this report identifies key knowledge gaps that should represent future research and monitoring priorities both within each of the CMRs and major bioregions, and across the entire CMR estate. In addition, the following report builds upon and updates the previous literature review conducted by Dr Ceccarelli in 2010 and 2011. Dr Ceccarelli's reviews, commissioned by the Department, provided an overview of research conducted within the Commonwealth Marine Reserve estate prior to the proclamation of new marine reserves and covered some 363 research papers.

2.1. CONSERVATION BENEFITS OF MARINE PROTECTED AREAS

It has been shown that MPAs that include zones that prohibit or restrict extractive (e.g., fishing) activities, lead to higher density and biomass of fish within fully protected MPAs (i.e., IUCN II and IUCN Ia categories) relative to comparable fished areas (Edgar et al. 2014). The purported benefits of MPAs increasingly extend well beyond the protection of fisheries target species (e.g., Roberts and Hawkins 2000). Most notably, MPAs are expected to confer increased resilience to marine systems (Hughes et al. 2003, West & Salm 2003, Game et al. 2008), though the mechanistic basis and empirical support for increased resilience within MPAs is highly equivocal (Graham et al. 2011). There is also ongoing controversy over the extent to which removal or reduction in fishing take in some MPA zones has a 'spill over' benefit to surrounding areas. Harrison et al. (2012) showed that MPAs in the southern Great Barrier Reef (GBR) provide a significant recruitment subsidy to surrounding fished habitats, but such effective demonstration of larval spill over and connectivity across seascapes is extremely limited.

Increasing emphasis on management for resilience (Game et al. 2008), as well as improved understanding of key processes (e.g., connectivity) that support ecological resilience (Almany et al. 2009), provides new directions for research and monitoring in MPAs. Importantly, we need to move away from simply documenting the status and trends in abundance of marine organisms of particular conservation concern. Rather, consideration of demographic responses of organisms to changes in ecological and environmental conditions, combined with improved understanding and forecasting of local conditions, will provide much greater capacity to effectively manage important and emerging threats to population, communities and ecosystems. For example, quantifying the recruitment of corals will provide an indication of the capacity of the population to recover following a disturbance that causes mortality of adult corals. Accordingly, Beeton et al. (2016) argue that research priorities to support effective management of the CMRs must include a research that not only documents the distribution and abundance of focal species, but also considers the ecological processes that influence species' distributions as well as accounting for temperal changes in such process (Table 2.1)

Table 2.1 – Foremost research and monitoring requirements related to natural values to facilitate "*robust, evidence-based decision-making for the management of* [Commonwealth] *marine reserves*" as identified by Beeton et al. (2016)

Research that contributes to increased understanding of values of the reserves and that provides for establishing baselines and ongoing reporting of the condition of the values of the reserves, as required under legislation, and national and international agreements:
1. Systematic bathymetry mapping
2. Stratified random sampling of the benthos, particularly habitat forming benthos such as sponges and corals
3. Comprehensive surveys of biological assemblages associated with geomorphic features or habitats
4. Comprehensive surveys of native species
5. Research into oceanographic features and processes that influence biodiversity patterns
6. Development of indicators for use in long-term monitoring to detect changes in ecosystem condition and attribution to pressures
7. Estimating populations and monitoring trends of threatened species
8. Research and monitoring to contribute to the development and implementation of other recovery plans, action plans, Threat Abatement Plans and character assessment of Ramsar wetlands
9. Studies to better understand biological and hydrographical connectivity within and among CMRs.
Research and monitoring to further understand the impacts of human activities in and around the reserves and management strategies that will prevent or minimize those

impacts:
1. Monitoring the spatial extent and character of human disturbances
2. Monitoring changes in the degree to which anthropogenic threats affect threatened and other key species
3. Identification of key impacts within and among CMRS
4. Surveys to determine the presence and extent of invasive species
5. Investigate the possible impacts on native biota of invasive species
6. Investigating the cumulative impacts of human activities, and identifying vulnerable species, habitats and areas
7. Identifying the pathways for and mitigation of risk of invasive species

3. Objectives and Scope

The purpose of this review was to provide an overview of scientific research and monitoring being undertaken within each of the 5 CMR Networks and the Coral Sea Reserve, thereby updating the 2010 Review of Research and Monitoring in Australia's Commonwealth MPAs (Ceccarelli 2011). This study considered a range of publicly available publications and reports, including i) journal articles, ii) books and book chapters, iii) conference proceedings, iv) technical reports, and v) reports commissioned by Australian Commonwealth and State governments. As this review was intended to provide an update to the 2010 review, priority was given to information published after 2010. Attention was further restricted to research and monitoring activities that were directly relevant to natural values pertaining to one or more of the Networks and MPAs, as well as adjoining State MPAs, where relevant.

A national overview of the entire CMR Network is provided, followed a summary of research and monitoring within each of the 5 CMR Networks and the Coral Sea CMR. Finally, reserve specific case studies are provided for six individual reserves, one from each network and the Coral Sea, to provide a more detailed characterisation of the reserve and, where possible, analysis of temporal trends.

4. NATIONAL SUMMARY

4.1. OVERVIEW

Australia's Commonwealth Marine Reserve Estate is composed of five regional networks (North-west, North, Temperate East, South-east, and South-west) and the Coral Sea CMR that collectively cover over 2.75 million km^2 (Table 4.1). The area of the individual CMR networks varies from 157,484 km^2 in the North CMR Network to 508, 605 km^2 in the South-west CMR Network, and 989,842 km^2 for the Coral Sea CMR. The level of protection within the CMR Networks is dominated by IUCN categories VI (46.9%), II (34.8%), and IV (23.3%), with only 2.1% of the estate protected under IUCN category I.

Table 4.1 – Summary of the spatial extent of Australia's Commonwealth Marine Reserve Estate. *Note the GBRMP and Heard Island and McDonald Islands CMR are managed by the GBRMPA and Australian Antarctic Division, respectively, and fall outside the scope of this review

CMR	Total Area (km^2)	Level of protection – IUCN Category			
		I	II	IV	VI
Total CMR estate	**2,763,184**	**59,262**	**961,120**	**645,603**	**1,295,719**
North-west CMR Network	335,437	1,262	105,552	17,680	210,934
North CMR Network	157,484		16,977		140,507
Temperate East CMR Network	383,352		60,264	140,083	183,004
South-East CMR Network	388,464	58,000	96,046	104,712	129,703
South-West CMR Network	508,605		179,627	94,473	234,505
Coral Sea CMR	989,842		502,654	288,655	198,533

A total of 1,115 publications and reports broadly relevant to Australia's Commonwealth Marine Reserves (*including 43 records that relate specifically to the Heard Island and McDonald Islands CMR*) were entered in to the *2016 CMR Literature Review Database.* The number of entries related to each CMR Network ranged from 55 entries for the North CMR Network to 302 entries for the South-west CMR Network (Figure 4.1). The North-west, South-west, South-east, Temperate East CMR Networks had broadly similar number of entries (230 to 302 entries), while the Coral Sea CMR and North CMR

Network had considerable fewer entries (116 and 55 entries, respectively). The number of entries relevant to the Australia's CMR Networks has more than doubled since 2010, driven primarily by a marked increase in the number of journal articles (Figure 4.2).

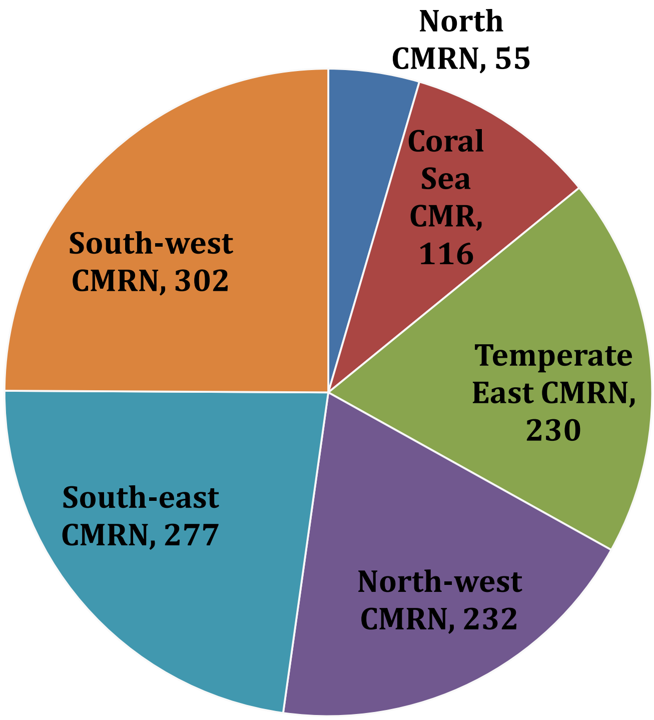

Figure 4.1 – The total number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of the five CMR Networks and the Coral Sea CMR. Note that several publications were relevant to multiple CMR Networks.

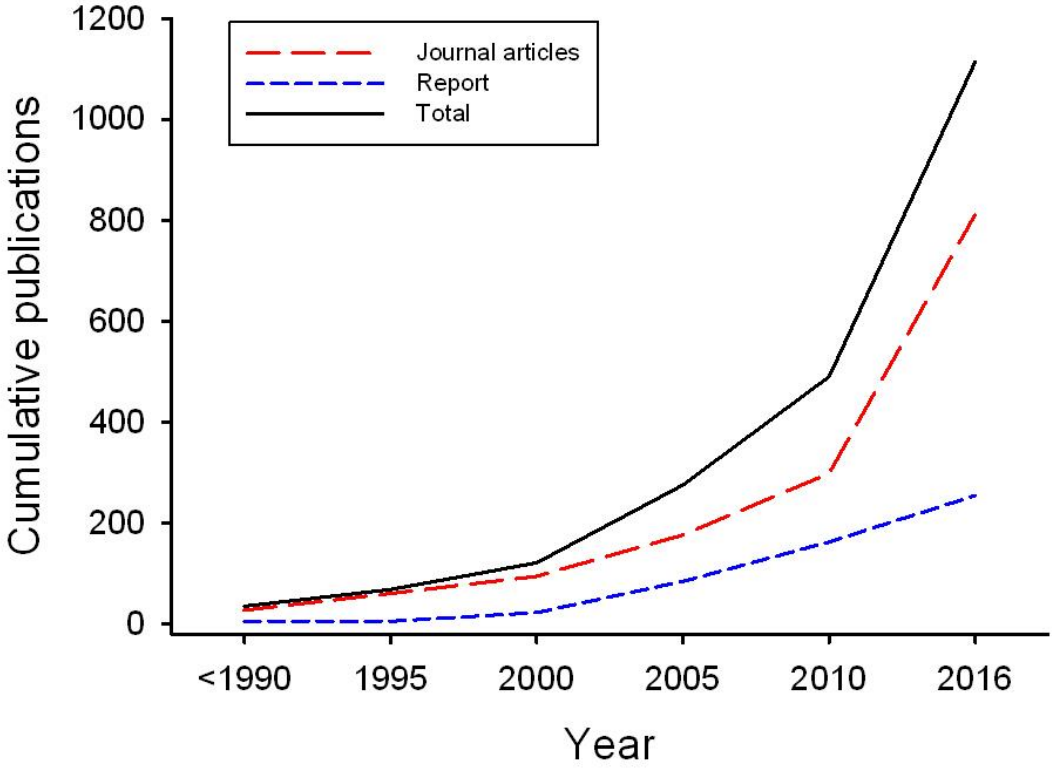

Figure 4.2 – The number of publications relevant to Australia's Commonwealth Marine Reserve estate. Lines show the increase in the number of journal articles (red), reports (blue), and total publications (black) from 1990 to 2016

4.2. BIODIVERSITY VALUES

4.2.1 Key Ecological Features (KEFs)

Fifty-five KEFs are identified within Australia's Commonwealth Marine Estate, with the number of KEFs within each individual CMR network ranging from 3 in the Coral Sea CMR to 15 in the South-west CMR Network. The number of entries in the *2016 CMR Literature Review Database* relating to individual KEFs ranged from 0 to 39 entries, with the most commonly researched KEFs being the Seamounts south and east of Tasmania (South-east CMRN, 39 entries), Ashmore Reef and Cartier Island and surrounding Commonwealth waters (North-west CMRN, 33 entries), Elizabeth and Middleton Reefs (Temperate East CMRN, 19 entries), and the Lord Howe seamount chain (Temperate East CMRN, 14 entries). There were less than 10 entries relating to each of the remaining 51 KEFs.

4.2.2. Significant marine species

Australia's Commonwealth Marine Estate encompasses critical marine and terrestrial habitats that support numerous significant, threatened or endangered species, endemic species, as well as many exploited species. Of these species, the most commonly researched were the Grey Nurse Shark (13 entries), Australian Sea Lion (12 entries), Western Rock Lobster (11 entries), White Shark (10 entries), Pygmy Blue Whale, Southern Right Whale, Blue Whale (6 entries each), Green Turtle and Flatback Turtle (5 entries each) and the Black Cod (5 entries).

4.2.3. Biological communities and species groups

Of the entries that reported on biological communities and species the majority focused on non-coral invertebrates (313 entries) and bony fish (219 entries), intermediate numbers focused corals (140 entries), seabirds (113 entries), sharks (111 entries) and marine mammals (102 entries), with relatively few entries relating to marine plants (74 entries) and marine reptiles (42 entries; Figure 4.3). Of the 313 studies of non-coral invertebrates, 90 entries related to molluscs, 84 to echinoderms, 69 to crustaceans, and 39 to sponges. Studies of marine mammals were primarily focused on seals and sea-lions (52 entries) and whales and dolphins (45 entries), with only 5 entries relating to dugongs. Of the 42 entries relating to marine reptiles 25 related to sea turtles and 17 related to sea snakes.

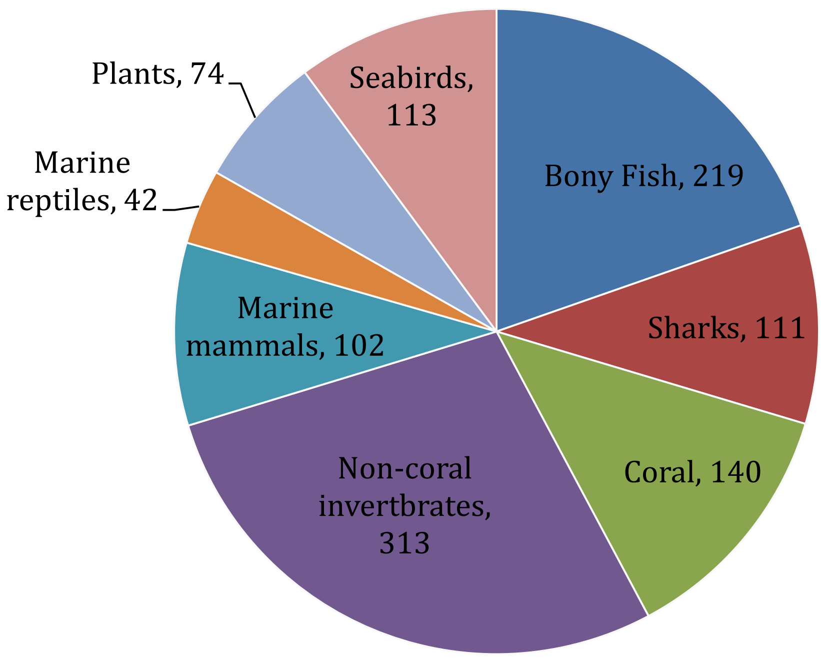

Figure 4.3 – The total number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of eight species groups. Non-coral invertebrates includes crustaceans, echinoderms, molluscs, sponges; marine

mammals includes cetaceans, pinnipeds, and dugongs; marine reptiles includes turtles and sea snakes.

4.3. ACTIVITIES AND PRESSURES

Of the entries that reported on, or related to activities and pressures in the marine environment the majority focused on fisheries (230 entries) and climate change (117 entries), with relatively few entries relating to native and introduced pests (39 entries), dredging and coastal development (21 entries), and oil and gas (13 entries; Figure 4.4). There were also a range of other activities including marine debris, recreational and commercial shipping, underwater structures, whale watching, recreational diving that collectively accounted for 38 entries (Figure 4.4)

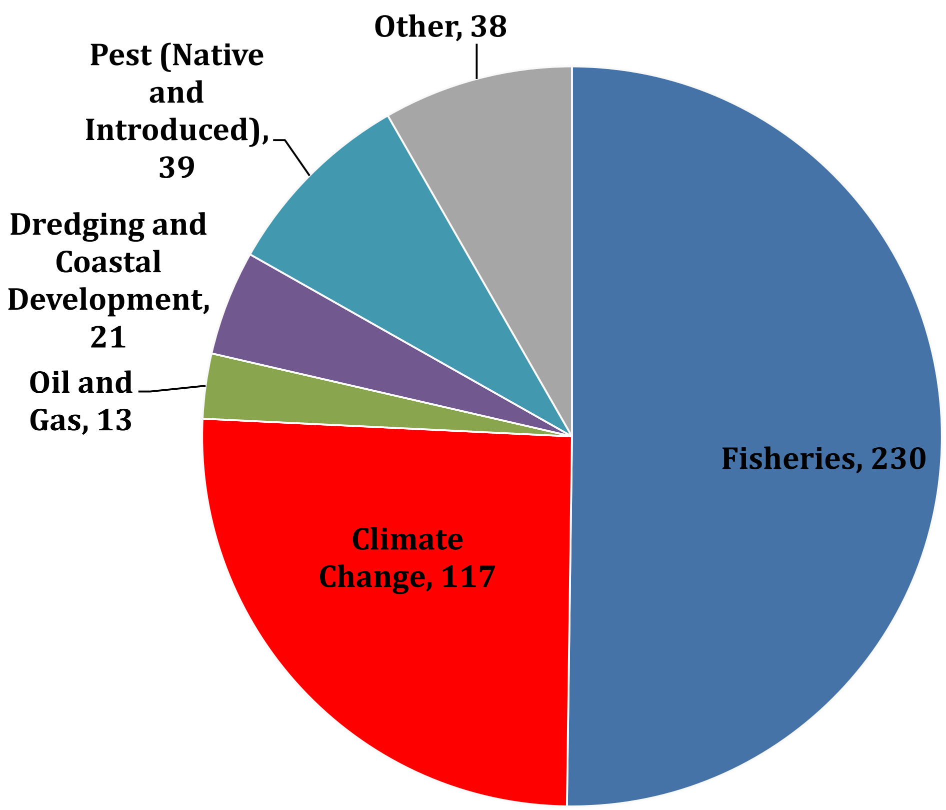

Figure 4.4 – Number of publications and reports *2016 CMR Literature Review Database* that relate (directly or indirectly) to anthropogenic activities and pressures within Australia's Commonwealth Marine Reserves Network.

4.4 KNOWLEDGE GAPS, FUTURE RESEARCH, AND INDICATORS

The review of literature related to Australia's Commonwealth Marine Reserves Networks highlighted several knowledge gaps which form the basis for future research priorities. These are listed below taking into consideration the nine research priority themes suggested to facilitate "robust, evidence-based decision-making for the management of [Commonwealth] marine reserves" as identified by Beeton (2016).

Key Knowledge Gaps:

- There was considerable variation in the number of records among the six regions (i.e. five CMR Networks and the Coral Sea CMR) ranging from 55 to 302 records, and this variation broadly translates to the relative published knowledge of biodiversity in each of these regions. The Networks with the least amount of published knowledge were the North CMR Network (55 records) and the Coral Sea CMR (116 records).
- Although there is comprehensive baseline data for some habitats/depths and locations within a limited number of CMRs (including Ashmore Reef, Lihou Reef, Elizabeth and Middleton Reefs, Solitary Islands, rocky reef features in Flinders and Freycinet, seamounts in Huon), comprehensive baseline biological data is lacking for the majority of the CMRs. This is largely attributable to the remoteness and deep waters in which many of the CMRs are located, thereby limiting access and increasing survey and sampling costs.
- No systematic research and monitoring program exists for Australia's CMR estate, and long-term monitoring data is lacking for the vast majority of individual CMRs. Exceptions include Ashmore Reef, Elizabeth and Middleton Reefs, and Lihou Reef in the Coral Sea, Flinders and Freycinet in the South-east and some monitoring of populations of significant marine species (e.g. Grey Nurse Shark)
- Existing published monitoring is generally too infrequent to detect change or attribute change to pressures, which can inform and initiate appropriate management actions.
- Major differences in sampling methodology (e.g., transects vs BRUVs), habitats (shallow vs deep), and study locations make it near impossible to analyse any temporal trends within individual CMRs, let alone comparisons across CMRs.

Future Research:

- Critical need for comprehensive baseline data on the natural values of all CMRs in the national estate. Ideally, this would include quantitative surveys of the abundance and taxonomic composition of marine fauna and flora and environmental variables (e.g. temperature, nutrients) in both pelagic and demersal environments, and spanning the spatial extent of each CMR. However, given the size, remoteness, and water depth of many CMRs the spatial coverage of baseline surveys could be reduced to focus on representative habitats. This baseline data on the natural values, together with information on key and emerging threats should be used to identify and prioritise key/important areas for systematic and ongoing monitoring.

- Continued monitoring of those locations for which a long-term temporal series exists (e.g. Ashmore Reef, Ashmore Reef, Elizabeth and Middleton Reefs, Coral Sea, Flinders, Freycinet). This will not only allow the continued assessment of condition of these areas, but also inform the likely status and trends for comparable habitats exposed to similar pressures.
- Shift toward including process-based monitoring, as well as current state-based monitoring, to understand potential vulnerabilities and resilience of habitats and communities.
- The development and adoption of standardized methodologies for process-based monitoring, together with use of baseline and monitoring data to identify appropriate indicator species, will **decrease costs** and **increase efficiency**, directly **inform** management by allowing comparisons both within and across CMRs, and the identify those areas, habitats, and species that are most vulnerable.

Potential indicators:

Potential indicators and associated performance indicators should be developed that are cost-effective and specific to a particular species and/or habitat type and the pressure/s to which they are exposed. These are discussed in greater detail for each of the regional CMR networks.

- For any species of conservation or commercial concern (threatened or endangered, endemic, or exploited species) potential indicators would include changes in the abundance and age / size structure of populations. Monitoring of these species would greatly benefit from the inclusion of population demographic rates (e.g., births or recruitment, mortality rates, etc). In some instances these could be extended to include monitoring of environmental variables (ocean temperatures, currents, and productivity) to predict availability of prey (especially for species that aggregate).
- For biological communities potential indicators should include the abundance and composition of habitat-forming (e.g., corals, kelps,

seagrass, deep water corals and sponges) or habitat-modifying species (e.g. urchins, herbivorous fishes, lobsters).

5. North-west Commonwealth Marine Reserves Network

5.1. OVERVIEW

The North-west Commonwealth Marine Reserves (CMR) Network extends from Kalbarri in Western Australia north to the Western Australian - Northern Territory border (Figure 5.1), encompassing extensive areas of tropical shallow-water habitat along the margins of the continental shelf, as well numerous offshore banks and shoals (Ceccarelli 2010).

The North-west CMR Network comprises 13 Commonwealth Marine Reserves (Argo-Rowley Terrace, Ashmore Reef, Cartier Island, Carnarvon Canyon, Dampier, Eighty Mile Beach, Gascoyne, Kimberley, Mermaid Reef, Ningaloo, Roebuck, Shark Bay and Montebello) that collectively encompass 335,437 km² (Table 5.1). The majority of the protected areas within the North-west CMR Network are IUCN categories VI (59.6%) and II (30.7%). The largest CMR in the North-west CMR Network is the Argo-Rowley Terrace (146,099km²) and the smallest is Cartier Island Marine Reserve (172km²).

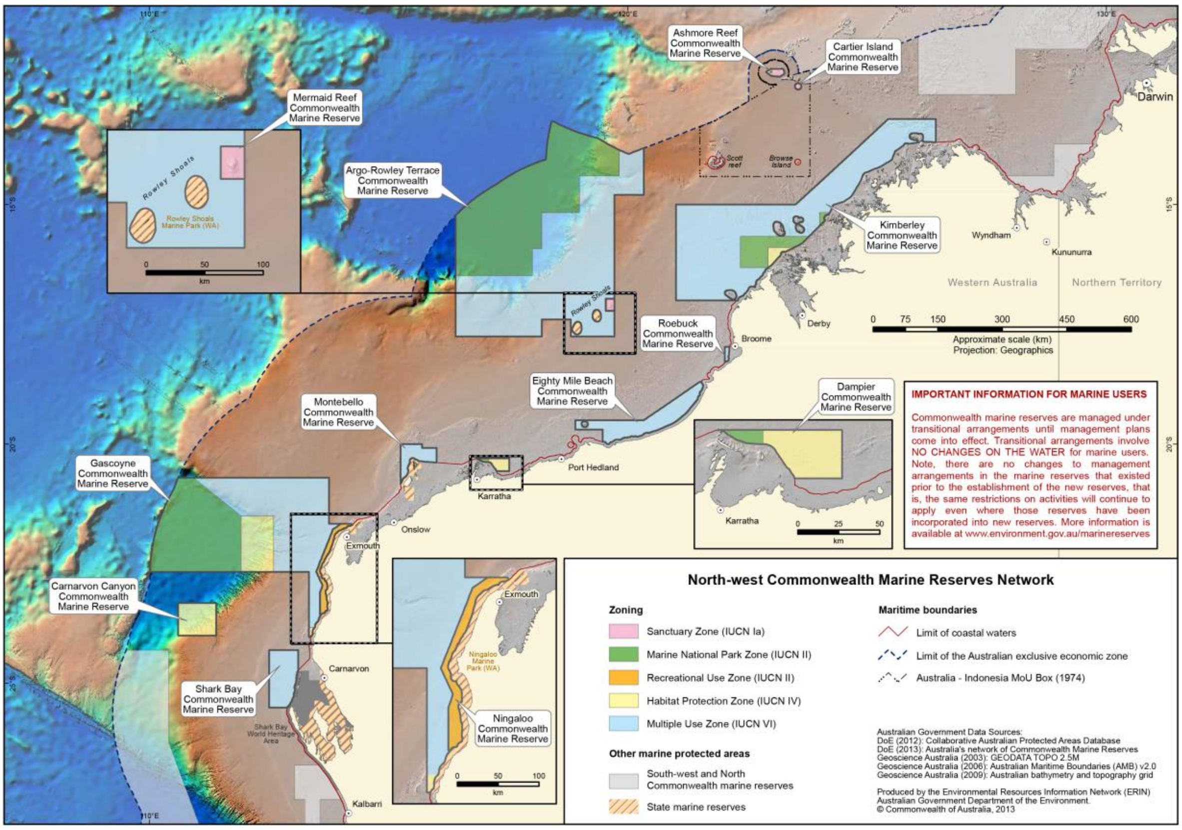

Figure 5.1 – Map of North-west Australia showing the location, size and zoning of the thirteen CMRs within the North-west CMR Network.

The seafloor across the North-west Marine Region is dominated by extensive continental slope habitat with a range of topographic features such as canyons, plateaus, terraces, ridges, reefs, and banks and shoals, which have important influences on biogeography and productivity (Commonwealth of Australia 2007). The oceanography of the North-west Marine Region is dominated by the predominantly pole-ward flow of the main surface currents. The dominant currents in the Region include the South Equatorial Current and the Indonesian Throughflow, which generate strong westerly flow across the Indo-Australian basin, producing eddies and some southerly tails in the North West Shelf and Exmouth Plateau. Further south, the Eastern Gyral Current hits the Western Australia coastline between North West Cape and Shark Bay, producing strong southerly flow (the Leeuwin Current) along the southern coast of Western Australia (Commonwealth of Australia 2007).

Table 5.1 – Commonwealth Marine Reserves within the North-west Marine Reserves Network. The spatial coverage and level of protection afforded each CMR is shown.

CMR	Area (km^2)	Level of protection – IUCN Category			
		I	II	IV	VI
North-west CMR Network	**335,437**	**3,697**	**103,117**	**17,680**	**200,095**
Argo-Rowley Terrace	146,099		62,720		83,379
Ashmore Reef National Nature Reserve	583	550	33		
Cartier Island Marine Reserve	172	172			
Carnarvon Canyon	6,177			6,177	
Dampier	1,252		150	1,102	
Eighty Mile Beach	10,785				10,785
Gascoyne	81,766		33,437	9,272	39,057
Kimberley	74,469		6,777	1,129	66,563
Mermaid Reef	540	540			
Montebello	3,413				3,413
Ningaloo	2,435	2,435			
Roebuck	304				304
Shark Bay	7,443				7,443

A total of 232 publications and reports relevant to the North-west CMR Network were entered in to the *2016 CMR Literature Review Database*, with the majority of entries (131 out of 232) being peer-reviewed journal articles, and, to a lesser extent, reports (86 out of 232; Figure 5.2). The total number of publications relevant to the North-west CMR Network increased steadily from 2000 to 2010, followed by a marked increase from 2010 to 2016 (Figure 5.2). Of the 232 publications relevant to the North-west CMR Network, 76 were broadly relevant to the region, but not directly related to any of the thirteen CMRs. Most of the publications and reports relevant to specific reserves referred to Ashmore Reef and/ or Cartier Island Commonwealth Marine Reserves (65 out of 232). There were a further 36 publications and reports that related specifically to Ningaloo, but rarely was any specific distinction made between the Ningaloo Marine Park and the adjacent Ningaloo Commonwealth Marine Reserve. There has been significant recent activity in the Kimberley Commonwealth Marine Reserve, with majority of publications and reports referring to this region (14 out of 18) published in just the last 5 years, but there has been relatively limited research activity (or at least limited publications and reports arising) in the other CMRs within the North-west marine region.

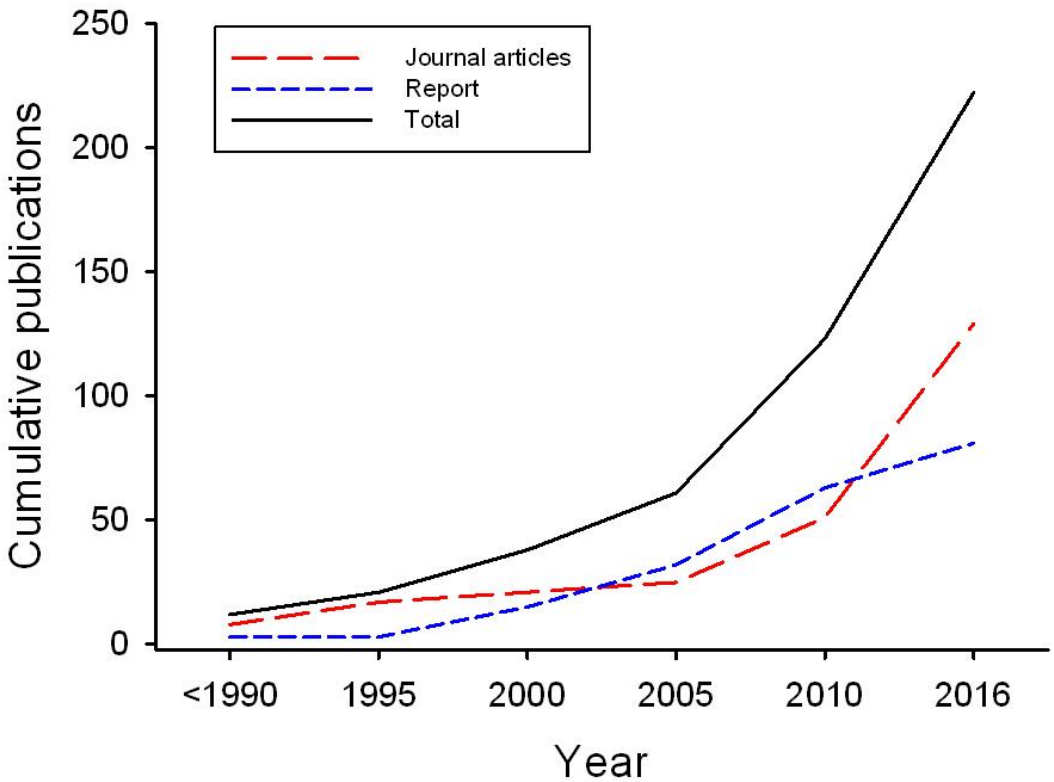

Figure 5.2 – The number of publications relevant to the North-west CMR Network. Lines show the increase in the number of journal articles (red), reports (blue), and total publications (black) from 1990 to 2016

5.2. BIODIVERSITY VALUES

5.2.1 Key Ecological Features (KEFs)

The KEFs within the North-west Marine Region include deep-water canyons and plateaus (Wallaby Saddle and Canyons linking the Argo Abyssal Plain and Scott Plateau), shoals (Glomar shoals), pinnacles (Pinnacles of the Bonaparte Basin) and coral reef habitats (e.g., Mermaid Reef and Commonwealth waters surrounding Rowley Shoals). The shoals, pinnacles and coral reef habitats within the North-west Marine Region are critically important in that they sustain very high biodiversity, as well as supporting high abundance of several ecologically and/ or economically important species. The Glomar Shoals, for example, are an important area for several fisheries species, such as rankin cod (*Epinephelus multinotatus*), whereas the Pinnacles of the Bonaparte Basin are an important biodiversity hotspot for sponges (Porifera). The deep-water canyons and plateaus meanwhile, are important geomorphic features that interact with major oceanographic features to produce areas of elevated productivity, which are important in attracting and sustain aggregations of marine species; the canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula interact with the Leeuwin Current to facilitate upwelling of nutrient-rich waters, that support aggregations of whale sharks, manta rays, humpback whales, sharks, large predatory fish and seabirds at Ningaloo (Sleeman et al. 2007).

Table 5.2 – Key Ecological Features identified for the North-west Marine Region, their location within individual Commonwealth Marine Reserves, and current pressures as identified by the marine bioregional plan (Commonwealth of Australia, 2012).

Key Ecological Feature	Relevant CMR	Main pressures
1. Wallaby Saddle	Carnarvon Canyon	Climate change (acidification)
2. Commonwealth waters adjacent to Ningaloo Reef	Ningaloo	Climate change (increasing SST, acidification), oil pollution, invasive species
3. Canyons linking the Cuvier Abyssal Plain and the Cape Range Peninsula	Ningaloo , Gascoyne	Climate change (acidification)
4. Exmouth Plateau	Gascoyne	Climate change (acidification)
5. Mermaid Reef and Commonwealth waters surrounding Rowley Shoals	Mermaid Reef, Agro-Rowley Terrace	Climate change (sea level rise, increasing SST, acidification), physical habitat modification (storm events), oil pollution, invasive species
6. Glomar Shoals	-	Climate change (increasing SST, acidification), commercial fishing, invasive species

7. Seringapatam Reef and Commonwealth waters in the Scott Reef complex	-	Non-domestic commercial fishing, marine debris, climate change (sea level rise, increasing SST, acidification), physical habitat modification (shipping anchorage, offshore construction, fishing practices), oil pollution, invasive species
8. Canyons linking the Argo Abyssal Plain and Scott Plateau	Argo-Rowley Terrace	Climate change (acidification)
9. Ancient coastline at 125 m depth contour	Kimberley, Montebello	Climate change (acidification)
10. Ashmore Reef and Cartier Island and surrounding Commonwealth waters	Ashmore Reef, Cartier Island Marine Reserve	IUU fishing, marine debris, climate change (sea level rise, increasing SST, acidification), physical habitat modification (storm events), oil pollution, invasive species
11. Pinnacles of the Bonaparte Basin	Oceanic Shoals	IUU fishing, climate change (increasing SST, acidification)
12. Continental slope demersal fish communities	Kimberley, Gascoyne	Climate change (increasing SST, acidification), physical habitat modification (fishing gear), commercial fishing (bycatch)
13. Carbonate bank and terrace system of the Sahul Shelf	Oceanic Shoals	IUU fishing, climate change (increasing SST, acidification)

5.2.2 Significant Marine Species

The North-west Marine Region encompasses critical marine and terrestrial habitats that support many significant, threatened or endangered species. Much of the North-west Marine Region is important for humpback wales, which migrate northwards through Shark Bay, Exmouth Gulf and the Montebellos, to breed and calve in the warm waters off the Kimberley Coast. Nutrient rich upwellings at many locations also represent important aggregation and feeding areas for many different cetaceans, as well as whale sharks (Ningaloo). Many of the offshore islands and emergent reefs in the North-west Region are important nesting habitats for marine turtles and sea birds (Commonwealth of Australia 2008 - *The North-west Marine Bioregional Plan*).

The Department of Environment and Energy, National Conservation Values Atlas (http://www.environment.gov.au/topics/marine/marine-bioregional-plans/conservation-values-atlas) identifies Biologically Important Areas (BIAs) for 21 species within the North-west CMRN (Table 5.3). *Biologically important areas* (BIAs) are spatially defined areas where aggregations of individuals of a species are known to display biologically important behaviour such as breeding, foraging, resting or migration The BIAs in the North-west CMRN include breeding and foraging areas for 10 species of seabirds, migration and breeding areas for 2 species of whale (including a calving area for the humpback whale in the Kimberley CMR), interesting areas for 4 species of turtle, foraging and nursing areas for 3 species of sawfish, and foraging areas for whale sharks (Table 5.3). Several other BIA's are situated immediately adjacent to the CMRs, such as foraging, breeding and calving areas for 3 species of inshore dolphin in the inshore waters adjacent to the Kimberley CMR.

5.2.3. Biological Communities

The most commonly investigated species groups within the North-west CMRN were non-coral invertebrates (69 entries), coral (46 entries), bony fish (33 entries), seabirds (27 entries), sharks (25 entries), and marine reptiles (25 entries) (Figure 5.3).

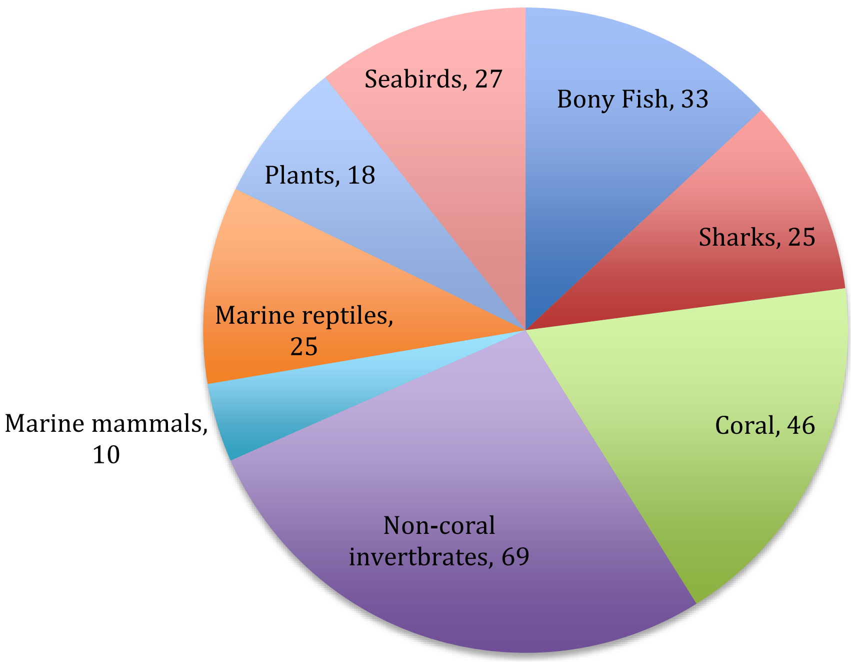

Figure 5.3 – The number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of eight species groups in the North-west CMR Network. Non-coral invertebrates includes crustaceans, echinoderms, molluscs, sponges; marine mammals includes cetaceans, pinnipeds, and dugongs; marine reptiles includes turtles and sea snakes

Benthic communities

Approximately 115 studies have focused on benthic communities (predominantly coral assemblages) within the North-west CMR Network, with most studies conducted at Ashmore Reef and Cartier Island, Ningaloo reef, or within the Kimberley region. Research conducted on benthic communities in these regions is largely focused on documenting the unique communities associated with different habitat types, especially in remote and deep-water environments (e.g., Alderslade et al. 2014, Richard et al. 2015)), though long-term sampling at some locations (e.g., Scott Reef, Gilmour et al. 2013) provides data in temporal dynamics in benthic communities (see resilience section below).

Fish communities

There are a total of 58 publications and reports that focus explicitly on fishes (sharks and bony fishes) in the North-west CMRs. Several of these studies report on spatial patterns in abundance or composition of fish communities, using baited underwater video (Meekan and Cappo 2004), and/ or visual transects (Holmes et al. 2013). Much of this research is concentrated in a few well-studied locations (e.g., Ashmore Reef and Ningaloo), and there are still significant knowledge gaps around the abundance and diversity of fishes across the broader CMR estate, which is necessary for exploring spatial variation fish assemblages among major biogeographical provinces relevant for effective management.

Table 5.3 – Biologically Important Areas identified for species listed under the EPBC Act for the North-west Commonwealth Marine Reserves Network (source Department of Environment and Energy, National Conservation Values Atlas). Letters refer to biological activities relevant to each of the eight reserves. *b – breeding, c – calving, d – distribution, f – foraging, m – migration, n – nursing, r - resting*

	Argo-Rowley Terrace	Ashmore Reef	Cartier Island	Carnarvon Canyon	Dampier	Eighty Mile Beach	Gascoyne	Kimberley	Mermaid Reef	Montebello	Ningaloo	Roebuck	Shark Bay
Seabirds													
Brown booby		bf				bf		bf					
Fairy tern													b
Greater frigatebird		bf	bf					bf					
Lesser crested tern		b				b		b					
Lesser frigatebird		bf	bf			bf		bf					
Little tern	r	r				b		r	r				
Red-footed booby		bf	bf					bf					
Roseate tern		b			b	b	b				b		b
Wedge-tailed shearwater		bf	bf		bf		bf			bf	bf		
White-tailed tropicbird	b	b	b						b				
Marine mammals													
Humpback whale					m	m	m	bc		m	m	m	m
Pygmy blue whale	m	m	m		d	d	m	d	m	d	m	d	m
Dugong								f				f	
Turtles													
Flatback turtle					i		i	i		i	i	fi	

Green turtle	i	i		i			i	i		i		
Hawksbill turtle	i			i					i	i		
Loggerhead turtle				i					i	i		i
Sharks												
Whale shark	f	f					f		f	f		
Dwarf sawfish					fn							
Freshwater sawfish					fn							
Green sawfish					fn							

Biologically important areas (BIAs) are spatially defined areas where aggregations of individuals of a species are known to display biologically important behaviour such as breeding, foraging, resting or migration.

5.2.4. Ecological Processes

Connectivity

Large-scale oceanographic patterns in north-west Australia have been studied, which has been used to predict hydrological connectivity across the North-west CMR networks (Kool and Nichol 2015). This model suggests that there is relatively limited large-scale connectivity across the National CMR Network, but significant regional-scale connectivity (Kool and Nichol 2015). Explicit studies of biological connectivity (e.g., Underwood et al. 2007, 2009) confirm that there are major genetic discontinuities among reefs and regions in north-west Australia.

Productivity

Many of the KEFs identified within the North-west CMR network (e.g., Canyons linking the Argo Abyssal Plain and Scott Plateau) are recognized as important areas of enhanced or high biological productivity (Commonwealth of Australia 2008 - *The North-west Marine Bioregional Plan*). However, biological productivity is inferred (often based on presence of high abundance or biomass of key indicator species) and there were no studies explicitly quantifying ocean productivity in the North-west CMR network.

Resilience

Despite the isolation and limited connectivity among shallow-water environments in North-west Australia (or perhaps because of the isolation from coastal processes and limited anthropogenic disturbances), Gilmour et al. (2013) demonstrated significant reliance among coral reef communities at Scott Reef. Coral reef communities (including benthic assemblages and associated fish assemblages) effectively recovered within 12 years after major bleaching and extensive coral loss in 1998 (Gilmour et al. 2013). Previously, it was suggested that isolated habitats would have very low capacity to recover from severe disturbances, owing to their limited connectivity to external sources of larvae, necessary for replenishment of decimated populations. However, the benefits of isolation from chronic anthropogenic pressures may outweigh the costs of limited connectivity, thereby conferring high levels of resilience to isolated environments.

The resilience of marine environments is being increasingly tested and challenged throughout the world, owing to increasing frequency, severity and diversity of disturbances (Wilson et al. 2006). Environments that are subject to very high frequency, or chronic, disturbances (e.g., prolonged or continuous exposure to high levels of sedimentation) often exhibit lowest levels of resilience, given limited capacity for population recovery between successive disturbance events (e.g., Berumen and Pratchett 2006). Accordingly, we might expect the lowest levels of resilience to occur in nearshore environments and areas closest to urban centers (e.g., Montebello and Barrow Islands). Pollock et al. (2014) suggested that coral assemblages in close proximity to areas of intensive dredging exhibit higher incidence of disease, which is one possible indicator of reduced resilience, but much research is required to establish spatial variation in resilience across North-west CMR network.

5.2.5. Benthic habitats

Broad-scale knowledge of the provincial bioregions and geomorphic/ seafloor features in the North-west Marine Region (Commonwealth of Australia 2008 - *The North-west Marine Bioregional Plan*) is being complemented by specific localized studies of benthic habitats. These studies are conducted in areas of specific conservation value (e.g., deepwater benthic habitats adjacent to Ningaloo Reef; Colquhoun et al. 2007), but there still remains considerable scope for more detailed habitat mapping throughout the North-west CMR Network.

5.3. ACTIVITIES AND PRESSURES

The North-west CMR Network supports a range of anthropogenic activities (including petroleum exploration and production, ports and shipping, commercial and recreational fisheries, aquaculture, and tourism) that may threaten biodiversity and natural values.

Fisheries

Extensive recreational fishing occurs throughout the North-west CMR Network, though mostly in State (rather than commonwealth) waters (Commonwealth of Australia 2008 – *The North-west Marine Bioregional Plan*), mostly targeting larger reef fishes (e.g., coral trout, *Plectropomus* spp.) and pelagic fishes, including tuna, mackeral and marlin. Recreational fishing is concentrated in waters adjacent to regional population centres (Broome, Karratha, Dampier, and Exmouth), as well as at Ningaloo.

Commercial fisheries operating in the North-west Marine Region target prawns (trawl-fishery), finfish and sharks (net and line fisheries), as well as pearl oysters and beche-de-mer (collection fisheries).

The presence and status of the contribution of Commonwealth CMRs to fisheries stocks is uncertain. There is definite concern regarding sustainability of the Western Australian tropical Shark Fishery, targeting sandbar sharks (*Carcharhinus plumbeus*), which are long-lived and highly vulnerable to overfishing. The sandbar shark is a wide-ranging coastal species in tropical and temperate regions and is found along most of the Western Australian coastline (McAuley et al 2005). Illegal, unreported and unregulated (IUU) fishing is also a significant issue in Australia's northern waters, mostly due to increasing incidence of foreign fishers operating within northern Australia. Historically, foreign fishers targeted mainly trochus, beche-de-mer and fin fishes, through hand collections and line fisheries in shallow reef environments. However, foreign fishers are increasingly targeting sharks, using nets (Commonwealth of Australia 2008 – *The North Marine Bioregional Plan;* Edyvane and Penny 2017).

Of the 232 publications and reports directly relevant to the North-west Marine Regions, 76 relate (directly or indirectly) to anthropogenic activities and pressures. Much of this research is focussed on fisheries-related pressures (Figure 5.4), including as subsistence fishing by Indonesian fishers at Ashmore Reef (e.g., Stacy 2007), or recreational fishing within the broader Ningaloo Marine Park (e.g., Sumner et al. 2001).

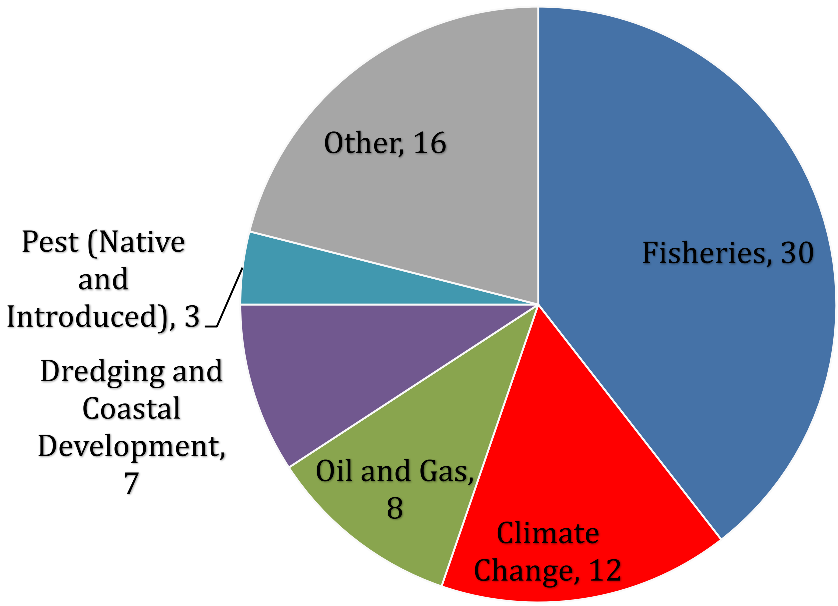

Figure 5.4 – Number of publications and reports that relate (directly or indirectly) to anthropogenic activities and pressures within the North-west CMR Network

Climate change

The important influence of global climate change on coral reefs and other tropical marine ecosystems is readily apparent given the moderate number of entries (12 out of 76) that explore changes in environmental conditions (mostly increasing temperature) and effects on marine species (e.g., Depczynski et al. 2013; Fulton et al. 2014) within the North-west Marine Region. Depczynski et al. (2013) documented effects of the 2010/11 heatwave within the Ningaloo Marine Park, where coral cover declined by 79-92% due to extensive and severe coral bleaching. Similarly, Gilmour et al. (2013) documented 80-90% coral loss at Scott Reef due to extreme temperatures and localised coral bleaching in 1998. These two studies are important in demonstrating the significant influence of temperature anomalies in the North-West Marine Region, but other effects of climate change (in other Commonwealth marine reserves, as well as effects of ocean acidification and other climate-induced environmental changes) are not apparent, requiring more intensive and comprehensive monitoring of environmental conditions (mainly, temperature, pH, aragonite saturation and dissolved oxygen concentrations) in different habitats and with increasing depth across the entire network of CMRs.

Other pressures and activities

The threat posed by oil and gas industries to CMRs was brought to the fore within the North-west Marine Region following the Montara oil and gas spill in the Timor Sea in 2009. In responding to this oil and gas spill, the Australian Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) commissioned extensive scientific research and monitoring to assess the effects of the oil and gas on marine and coastal habitats, as well as key and threatened wildlife (such as seabirds and megafauna). Results of ongoing research and monitoring are apparent within a range of publicly-available reports to DSEWPaC, but it is clear that not all of the reports arising from this work, nor the full set of findings, have been effectively captured within the *2016 CMR Literature Review Database*. The select (publicly-available) reports that are included suggest that the Montara oil and gas spill had relatively moderate environmental impacts, but also highlight the importance of effective baseline information with which to assess the ecological impacts of such disturbances on marine species and habitats.

5.4. KNOWLEDGE GAPS, FUTURE RESEARCH, AND INDICATORS

The review of the literature relevant to the North-west CMR network highlighted several knowledge gaps, future research priorities and to a lesser extent, potential indicators. These are listed below taking into consideration the nine research priority themes set to facilitate "robust, evidence-based decision-making for the management of [Commonwealth] marine reserves" as identified by Beeton (2016).

Key Knowledge Gaps:

- Fishery-independent data to assess the stock status and vulnerability to overfishing for key fisheries species, such as the sandbar shark (*Carcharhinus plumbeus*) - Much of the existing and ongoing research undertaken across northern Australia has been focused on assessing effects of long-term fisheries (including IUU fisheries) for trochus and beche-de-mer, but shifts in fisheries effort towards sharks, requires a renewed focus to better understand the extent to which the distribution of harvested species, such as the sandbar shark, overlaps with the CMR's and understand fisheries impacts and vulnerabilities of shark populations and species.

- Identify and assess the importance and vulnerability of key nesting, mating, and foraging sites for marine turtles and seabirds to climate change. Climate change (especially increasing temperatures and sea level rise) poses one of the greatest threat to the viability of coastal habitats as suitable nesting habitats (Fuentes et al. 2009), placing increasing importance on offshore nesting sites. Little is currently known about how changes in local environmental conditions will impact the many and diverse nesting locations across northern Australia.

- Local and regional predictions for changes in environmental conditions and hydrodynamic features with global climate change – sustained changes in environmental conditions, including ocean warming, acidification, reduced productivity and oxygenation, as well as changes in hydrodynamic regimes, will potentially undermine natural and biodiversity values of CMRs, but little is known about when or where impacts will occur, or the extent of those impacts.

Future Research:

- Ongoing monitoring of key habitats and species within Commonwealth CMRs (every 2-5 years), as well as appropriate reference locations, is required. Long-term, systematic monitoring has been undertaken at Scott Reef, Barrow Island, and to a lesser extent at

Ashmore Reef. However, these well-studied locations represent distinct and unique locations, and there is a definite need for more comprehensive research and monitoring across a broader range of locations, within the North-west Marine Reserve Network.

- Comprehensive monitoring of environmental conditions (e.g., currents, temperature, nutrients) across marine and coastal ecosystems is needed. This information will facilitate improved modeling and forecasting of environmental conditions and allow relationships between changes in populations and communities and changes in local environmental conditions to be investigated.
- Fine-scale studies of hydrological connectivity, as well as further studies of biological connectivity are needed across a much broader range of taxa.

Potential indicators*:*

Marine ecosystems with the North-west CMR Network are facing a range of pressures and threats from climate change and direct anthropogenic activities (see Activities and Pressures above). Potential indicators may be developed, and some are suggested here, but it must be remembered that an indicator species or community will be specific to a particular habitat type and the pressure/s it is facing.

Significant marine species

Indicators for any species of conservation concern (threatened or endangered, endemic, or exploited species) would include changes in the abundance and age/size structure of populations. Where possible, they would greatly benefit from the inclusion of population demographic rates (e.g., births or recruitment, mortality rates, etc.) to allow predictions of the vulnerable and resilience of the species to various pressures.

Given the majority of BIA’s in the North-west CMR Network relate to foraging, and hence productivity of the area, some metric of oceanographic productivity (either directly quantified or through remote sensing) may be a useful indicator for the viability of these species.

Biological communities

Many biological communities and even entire ecosystems are shaped by the abundance and composition of foundation (or habitat-forming) species.

For biological communities, the following are suggested as potential indicators for some habitats within the North-west CMR Network:

- Shallow reef environments: the abundance (or cover) and composition of scleractinian (hard or reef-building corals), and other major space-occupying taxa (macroalgae). Scleractinian corals should be identified to genus and growth form as a minimum. The size structure of coral colonies and the abundance of juvenile corals will also allow the longevity of coral species, and the input of new corals to be estimated. As growth, mortality, and longevity varies markedly among coral species, information on size structure and juvenile corals should be recorded for individual species or 'morphospecies' (combination of genus and growth form).

- The size and abundance of deep-water habitat forming corals and sponges. The logistics of sampling these areas would make demographic rates (replenishment, survivorship) difficult, if not impossible, to quantify.

6. North Commonwealth Marine Reserves Network

6.1. OVERVIEW

The North Marine Reserves Network encompasses Commonwealth waters from the Gulf of Carpentaria, Arafura Sea and the Timor Sea as far west as the Northern Territory – Western Australia Border (Figure 6.1). The North Marine Region is characterised by shallow-water tropical marine ecosystems (Commonwealth of Australia 2008a - *The North Marine Bioregional Plan*).

The North CMR Network comprises 8 Commonwealth Marine Reserves (Arafura, Arnhem, Gulf of Carpenteria, Joseph Bonaparte Gulf, Limmen, Oceanic Shoals, Wessel, and West Cape York) that collectively encompass 157,484 km^2 (Table 4.1). The majority of the protected areas within the North CMR Network are IUCN category VI (89.2%), with the remainder in category II (10.8%). The largest CMR in the North CMR Network is the Oceanic Shoals (71,744km^2), which accounts for 45.5% of the marine reserve area within the North Marine Region (Table 6.1)

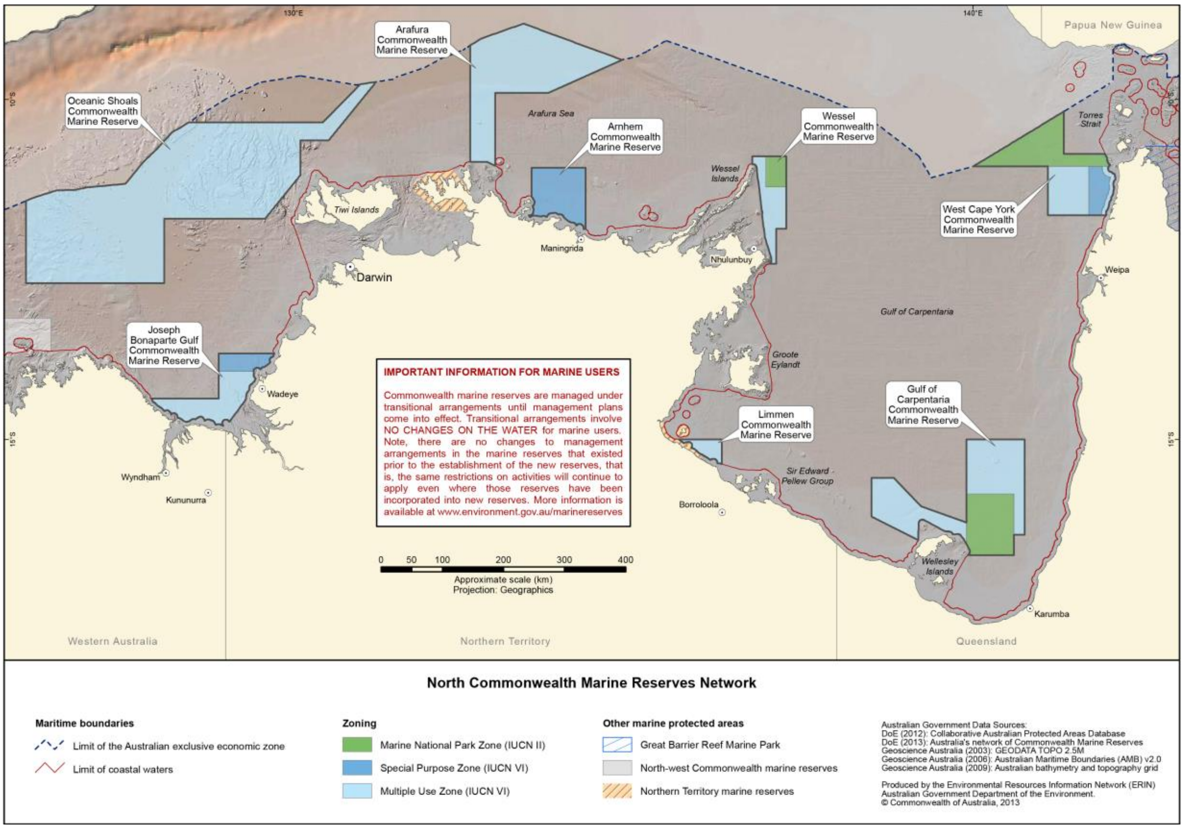

Figure 6.1 – Map of Northern Australia showing the location, size and zoning of the eight CMRs within the North CMR Network.

The North CMR Network comprises an extensive area shallow marine continental shelf (Commonwealth of Australia 2008 - *The North Marine Bioregional Plan*), dominated by soft sediment habitats. Oceanography in this region is influenced primarily by tidal flows, rather than ocean currents, creating complex patterns of water movement.

Table 6.1 – Commonwealth Marine Reserves within the North Marine Regions. The spatial coverage and level of protection afforded each CMR and the North-west and North Marine Region as a whole are given.

CMR	Area (km^2)	Level of protection – IUCN Category			
		I	II	IV	VI
North CMR Network	**157,484**	**0**	**16,977**	**0**	**140,507**
Arafura	22,924				22,924
Arnhem	7,125				7,125
Gulf of Carpenteria	23,775		7,388		16,387
Joseph Bonaparte Gulf	8,597				8,597
Limmen	1,399				1,399
Oceanic Shoals	71,744				71,744
Wessel	5,908		1,632		4,276
West Cape York	16,012		7,957		8,055

A total of 55 publications and reports relevant to the North CMR Network were entered in to the *2016 CMR Literature Review Database*. Prior to 2010, there were steady increases in the number of reports relevant to the North Marine Region, with a marked increase in the number of journal articles in the period 2011-2016 (Figure 6.2). Nonetheless, the total number of publications and reports relevant to the North Marine Region is well below that of the marine Regions (Figure 4.1). Moreover, most (35 out of 55) of the publications and reports that are relevant to the North CMR Network are large-scale studies relevant to two or more different CMR Networks.

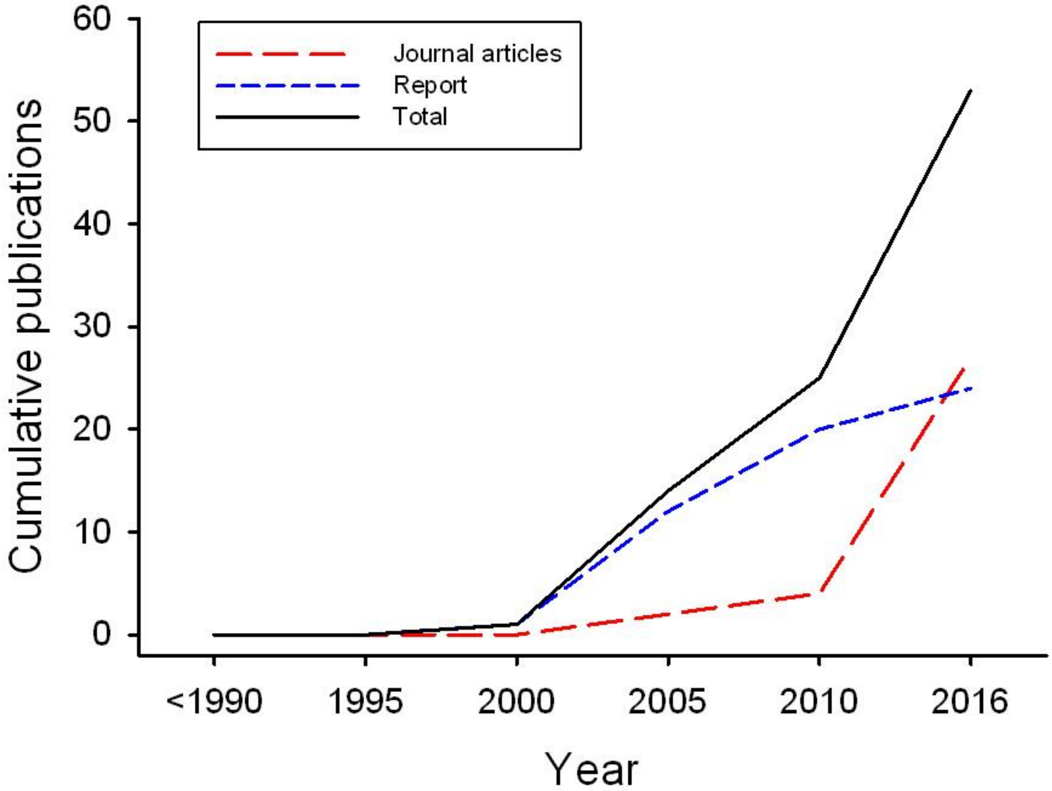

Figure 6.2 – The number of publications relevant to the North CMR Network. Lines show the increase in the number of journal articles (red), reports (blue), and total publications (black) from 1990 to 2016

6.2. BIODIVERSITY VALUES

6.2.1 Key Ecological Features (KEFs)

The KEFs within the North Marine Region (Table 6.2) include deep-water carbonate banks and shelf slopes and plateaus (Carbonate bank and terrace system of the Van Diemen Rise, Shelf break and slope of the Arafura Shelf), and extensive areas of soft-sediment habitat (Gulf of Carpentaria basin), with some submerged reefs (Submerged coral reefs of the Gulf of Carpentaria). Areas of high abundance and diversity of sponges and octocorals have been identified on the eastern Joseph Bonaparte Gulf along the banks, ridges and some terraces (Przeslawski et al. 2014). Similarly, Pinnacles of the Bonaparte basin provide areas of hard substrate in an area otherwise dominated by soft sediment, and support rich communities of hard and soft corals, sponges, sea whips, and sea fans (Nichol et al. 2013), which in turn, attract aggregations of demersal fish species such as snappers, emperors and groupers. The extensive soft-sediment habitats within the Gulf of Carpenteria are considered to be the most pristine habitat of its type anywhere in the world (Burford et al. 2009), characterised by abundant and diverse communities of polychaetes, crustaceans, molluscs and echinoderms.

Table 6.2 – Key Ecological Features identified for the North Marine Regions, their location within individual Commonwealth Marine Reserves, and current pressures as identified by the marine bioregional plan (Commonwealth of Australia, 2012). Together with the specific regional pressures identified, extraction of living resources (illegal, unreported and unregulated fishing) is a concern for all KEFs in the North and Marine Regions

Key Ecological Feature	Relevant CMR	Main pressures
1. Carbonate bank and terrace system of the Van Diemen Rise	Joseph Bonaparte Gulf	Climate change (increasing SST, acidification)
2. Pinnacles of the Bonaparte Basin	Joseph Bonaparte Gulf	Climate change (increasing SST, acidification)
3. Shelf break and slope of the Arafura Shelf	Arafura	Climate change (increasing SST, acidification), oil pollution
4. Gulf of Carpentaria basin	Gulf of Carpenteria	Marine debris, climate change (increasing SST, acidification)
5. Gulf of Carpentaria coastal zone	Gulf of Carpenteria	Marine debris, climate change (sea level rise increasing SST, acidification), physical habitat modification (offshore construction, storm events), changes in hydrological regimes
6. Plateaux and saddle north-west of the Wellesley Islands	Gulf of Carpenteria	Marine debris, climate change (increasing SST, acidification)
7. Tributary canyons of the Arafura Depression	Arafura	Climate change (increasing SST, acidification), physical habitat modification (offshore construction), oil pollution
8. Submerged coral reefs of the Gulf of Carpentaria	Gulf of Carpenteria	Marine debris, climate change (increasing SST, acidification)

6.2.2 Significant Marine Species

The North Marine Region encompasses critical marine and terrestrial habitats that support many significant, threatened or endangered species. Many of the offshore islands and emergent reefs in the North Marine Region are important nesting habitats for marine turtles (including green, loggerhead, flatback, hawksbill and olive ridley turtles) and sea birds (Commonwealth of Australia 2008a - *The North Marine Bioregional Plan*).

The Department of Environment and Energy, National Conservation Values Atlas (http://www.environment.gov.au/topics/marine/marine-bioregional-plans/conservation-values-atlas) identifies Biologically Important Areas (BIAs) for 10 species within the North CMRN (Table 6.3). These include BIA's for breeding and foraging for 5 species of seabirds, and foraging and interesting areas for 5 species of turtle (Table 6.3).

Table 6.3 – Biologically Important Areas identified for species listed under the EPBC Act for the North Commonwealth Marine Reserves Network (source Department of Environment and Energy, National Conservation Values Atlas). Letters refer to biological activities. *b – breeding, d – distribution, i – interesting, f – foraging, m migration*

	Arafura	Arnhem	Gulf of Carpenteria	Joseph Bonaprte Gulf	Limmen	Oceanic Shoals	Wessel	West Cape York
Seabirds								
Brown booby			bf					
Common noddy							bf	
Crested tern		bf					bf	
Lesser frigatebird			bf					bf
Roseate tern		bf					bf	
Turtles								
Flatback turtle	i		i	i	i		i	i
Green turtle			i	f			i	
Hawksbill turtle	i						i	i
Loggerhead turtle						f		
Olive ridley turtle				f		f	i	i

6.2.3. Biological Communities

The most commonly investigated species groups within the North CMRN were marine reptiles, mainly turtles (10 entries), seabirds (6 entries), non-coral invertebrates (6 entries), bony fish (5 entries), sharks (5 entries), and marine mammals (1 entry) (Figure 6.3).

Benthic communities

There has been very limited specific research on benthic communities within the North CMR Network in recent years. Benthic biological surveys were conducted opportunistically in the Arafura Sea in 2005 (Wilson 2005), which sampled a relatively small area, but a large depth gradient (69-234 m). Previously, benthic ecological surveys were conducted mainly in the Gulf of Carpentaria, focusing on extensive areas of seagrass (Commonwealth of Australia 2008a - *The North Marine Bioregional Plan*). There is however, a recognized need for benthic biological sampling, especially within the Joseph Bonaparte Gulf (Commonwealth of Australia 2008a - *The North Marine Bioregional Plan*).

Fish communities

Fish communities are poorly studied throughout the North CMR Network, though there have been some important studies focused on the biology, ecology and/ or vulnerable of individual species across the region (e.g., Field et al. 2012). Field et al. (2012) documented significant temporal trends in the size of sharks (*Carcharhinus tilstoni* and *C. sorrah*) reflective of changes in fishing pressure.

Marine Turtles

Given the national and international importance of the North Marine Regions as foraging and nesting habitats for marine turtles, it is not surprising that there have been several (10) recent studies exploring management of marine turtle population in these regions (e.g., Fuentes et al. 2009). Fuentes et al. (2009) explored the threat that global warming pose to nesting success of marine turtles at several locations across northern Australia, forecasting marked and imminent shifts in the sex ratio of hatchlings. Other major threats to marine turtles in these regions are nest depredation (Whytlaw et al. 2013) and ghost nets (Wilcox et la. 2013), highlighting the need for systematic and comprehensive monitoring of marine turtle populations across northern Australia (Jackson et al. 2015).

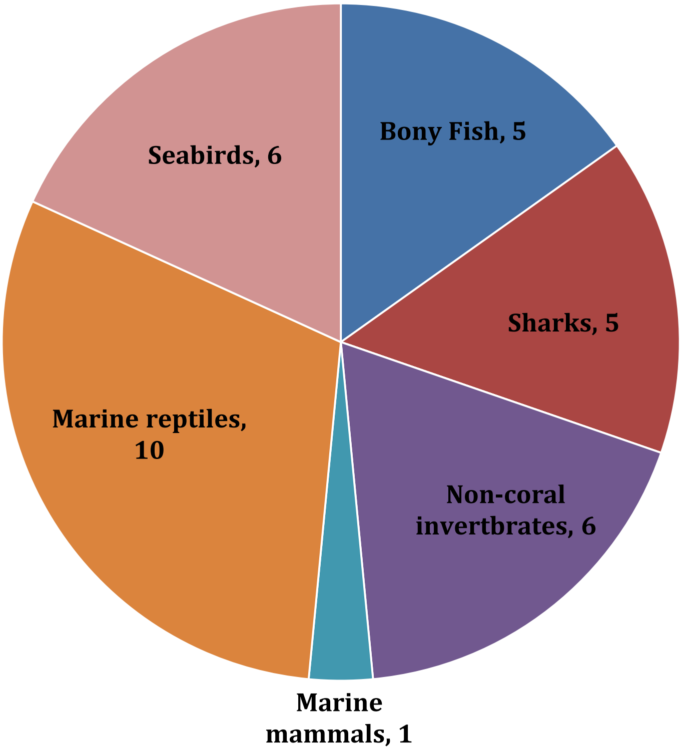

Figure 6.3 – The number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of eight species groups in the North CMR Network. Non-coral invertebrates includes crustaceans, echinoderms, molluscs, sponges; marine mammals includes cetaceans, pinnipeds, and dugongs; marine reptiles includes turtles and sea snakes

6.2.4. Ecological Processes

Connectivity

Large-scale oceanographic patterns in the North CMR Network were considered as part of a national study of hydrological connectivity across the CMR networks (Kool and Nichol 2015). This model suggests relatively limited large-scale connectivity, but strong regional connectivity among CMRs within the north-west shelf and Joseph Bonaparte Gulf (including Mermaid Reef, Ashmore Reef, and Oceanic Shoals) and within the Gulf of Carpentaria (Kool and Nichol 2015). Explicit studies of biological connectivity are yet to be conducted within the North CMR Network.

Productivity

Oceanographic productivity to support pelagic fish stocks across the North CMR Network is generally thought to be provided by the Indonesian Flowthrough (Commonwealth of Australia 2008a - *The North Marine*

Bioregional Plan). Biological productivity is also enhanced by important ecological features on the Arafura Shelf Break and Arafura depression, but there has not been any explicit research into these features or ecosystem processes in the North CMR Network (Commonwealth of Australia 2008a - *The North Marine Bioregional Plan*).

Resilience

There has been limited temporal sampling of biological communities and habitats in the North CMR Network, thereby preventing any informed assessment of ecosystem resilience.

6.2.5. Benthic habitats

The most extensive and characteristic habitats within the North Marine Region are relatively flat soft sediments (Commonwealth of Australia 2008a - *The North Marine Bioregional Plan*). Accordingly, there has been some recent research (e.g., Alongi et al. 2013) to explicitly consider the deposition and translocation on benthic sediments. There are some other ecologically important habitats (carbonate banks and seagrass meadows) within the North Marine Region, but there has been limited recent explicit research on these habitats.

6.3. ACTIVITIES AND PRESSURES

The North Marine Regions supports a range of anthropogenic activities (including petroleum exploration and production, ports and shipping, commercial and recreational fisheries, aquaculture, and tourism) that may threaten biodiversity and natural values.

Fisheries

Recreational fishing (including Charter fishing) is highly prevalent within the North Marine Region, concentrated near urban centers (mainly Darwin).

The predominant commercial fishery in the North Marine Region is the Northern Prawn Fishery, which accounts for >60% of fisheries production from this region. There is also an important offshore net fishery, which targets finfish and sharks, was well as line fisheries targeting both benthic and pelagic finfishes (Commonwealth of Australia 2008 – *The North Marine Bioregional Plan*).

Illegal, unreported and unregulated (IUU) fishing is a significant issue in Australia's northern waters, mostly due to increasing incidence of foreign fishers operating within northern Australia. Historically, foreign fishers targeted mainly trochus, beche-de-mer and fin fishes, through hand collections and line fisheries in shallow reef environments. However, foreign fishers are increasingly targeting sharks, using nets (Commonwealth of Australia 2008 – *The North Marine Bioregional Plan*).

Of the 55 publications and reports directly relevant to the North-west and North Marine Regions, 23 relate (directly or indirectly) to anthropogenic activities and pressures. Much of this research is focussed on fisheries-related pressures (Figure 6.4).

Climate change

While there is broad recognition of threat posed by climate change to tropical marine and coastal environments (Poloczanska et al. 2013), the only effects of climate change that have been explicitly considered within the North CMR Network are impacts of increased atmospheric temperature on nesting success of marine turtles (Fuentes et al. 2009) and climate-drive shifts in food availability and foraging success of seabirds (Chambers et al. 2011).

Other pressures and activities

There has been very limited research on any other anthropogenic activities and pressures in the North CMR Network.

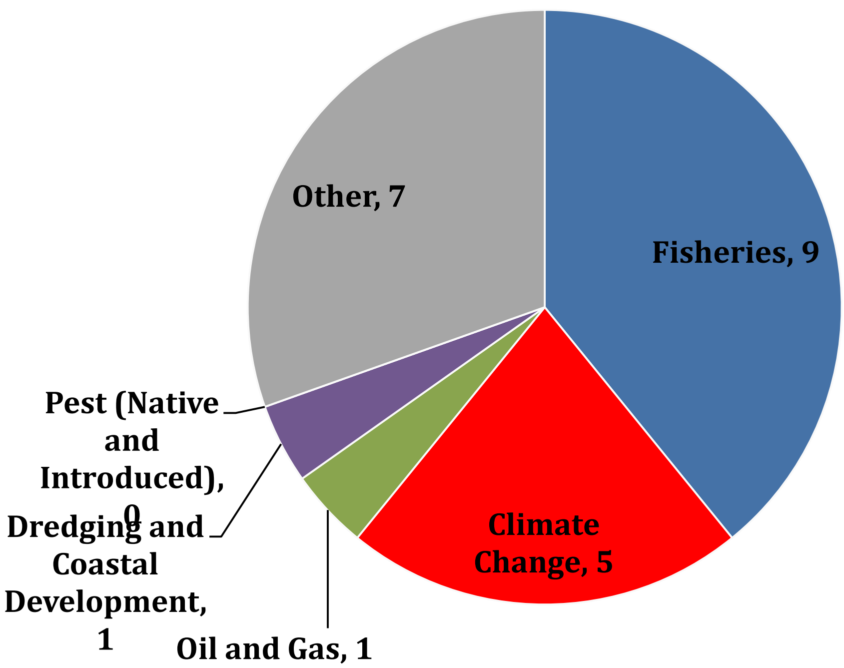

Figure 6.4 Number of publications and reports that relate (directly or indirectly) to anthropogenic activities and pressures within the North Marine Region.

6.4 KNOWLEDGE GAPS, FUTURE RESEARCH, AND INDICATORS

The review of the literature relevant to the North CMR network highlighted major knowledge gaps, future research priorities, and to a lesser extent, potential indicators. These are listed below taking into consideration the nine research priority themes set to facilitate "robust, evidence-based decision-making for the management of [Commonwealth] marine reserves" as identified by Beeton (2016).

Key Knowledge Gaps:

- While a persistent issue, IUU fishing was reported to decline from 2005 to 2007, however it has increased again across northern Australia (including the North CMR network) since 2007 (Edyvane and Penny 2017). Limited fisheries-independent data is constraining effective assessments of the current status and trends for most major fisheries stocks, and the extent to which they use habitats within the CMR's.

- Identify and assess the importance and vulnerability of key nesting, mating, and foraging sites for marine turtles and seabirds to climate change. Climate change (especially increasing temperatures and sea level rise) poses one of the greatest threat to the viability of coastal habitats as suitable nesting habitats (Fuentes et al. 2009), placing increasing importance on offshore nesting sites. Little is currently known about how changes in local environmental conditions will impact the many and diverse nesting locations across northern Australia.

- Local and regional predictions for changes in environmental conditions and hydrodynamic features with global climate change – sustained changes in environmental conditions, including ocean warming, acidification, reduced productivity and oxygenation, as well as changes in hydrodynamic regimes, will potentially undermine natural and biodiversity values of CMRs, but little is known about when or where impacts will occur.

Future Research:

- For the North CMR Network, the priority is to document the distribution and condition of ecologically important habitats, such as seagrass meadows and carbonate banks, that support a high diversity of species and/or provide food or shelter for key marine species. Ecological monitoring of extensive soft-sediment habitat is complicated by the inherent dynamics of such environments.

- Comprehensive monitoring of environmental conditions (e.g., currents, temperature, nutrients) across marine and coastal ecosystems is needed. This information will facilitate improved modeling and forecasting of environmental conditions and allow relationships between changes in populations and communities and changes in local environmental conditions to be investigated

Potential indicators*:*

Monitoring of marine species and habitats across much of the North CMR Network is extremely limited, though there are some important threats facing significant marine species, such as marine turtles and seabirds. Potential indicators may be developed, and some are suggested here, but it must be remembered that an indicator species will be specific to a particular habitat type and the pressure/s it is facing.

Significant marine species

Indicators for species of conservation concern (threatened or endangered, endemic, or exploited species) would include changes in the abundance and age/size structure of populations. Where possible, they would greatly benefit from the inclusion of population demographic rates (e.g., births or recruitment, mortality rates, etc.) to allow predictions of the vulnerable and resilience of the species to various pressures.

Biological communities

For biological communities the following are suggested as potential indicators for some habitats within the North CMR Network:

- Carbonate platforms: the abundance (or cover) and taxonomic composition of scleractinian corals, and other habitat-forming taxa (sponges and octocorals).

- Seagrass Meadows: the density, biomass and taxonomic composition of seagrasses, as well as measures of growth and condition (e.g., epiphyte loads) and organisms reliant on these habitats.

- Extensive soft-sediment habitats: Abundance and composition of epifaunal organisms, while accounting for sediment structure in sample areas.

7. CORAL SEA COMMONWEALTH MARINE RESERVE

7.1. OVERVIEW

The Coral Sea Commonwealth Marine Reserve is a single, large (989,842km^2) and continuous marine reserve directly adjoining the Great Barrier Reef Marine Park and extending north-east into the Coral Sea to the outer extent of Australia's Exclusive Economic Zone. The Coral Sea Commonwealth Marine Reserve encompasses the former Coral Sea Conservation Zone, Coringa-Herald National Nature Reserve and Lihou Reef National Nature Reserve.

The Coral Sea is considered environmentally significant owing to i) relatively undisturbed nature of its natural systems, ii) its unique marine habitats and fauna, iii) the provision of habitat for species of conservation significance and iv) connectivity with the Australia's Great Barrier Reef and other western Pacific provinces (Ceccarelli 2011). Large-scale oceanographic, bathymetric, and geological features of the Coral Sea are relatively well known, but considerable work is still required to resolve finer-scale processes and individual topographic features (Ceccarelli 2011).

The Coral Sea CMR is intended to provide additional protection for many endangered or vulnerable species, including loggerhead and leatherback turtles and the Herald petrel (www.environment.gov.au/topics/marine/marine-reserves). The Coral Sea CMR also encompasses areas of high productivity, such as seamounts, which support aggregations of lantern fish, albacore tuna, billfish, sharks, and the world's only known spawning aggregation of black marlin.

The major oceanographic feature affecting the Coral Sea CMR is the East Australian Current (EAC), which forms in Coral Sea, due to local influneces of the South Equatorial Current. The EAC flows is strongest during summer months, and crosses the continental shelf before being diverted both north and south adjacent to the Queensland coastline.

Table 7.1 – The spatial coverage and level of protection afforded the Coral Sea Commonwealth Marine Reserve

CMR	Area (km^2)	Level of protection – IUCN Category			
		I	II	IV	VI
Coral Sea Commonwealth Marine Reserve	**989,842**		**502,654**	**288,655**	**198,533**

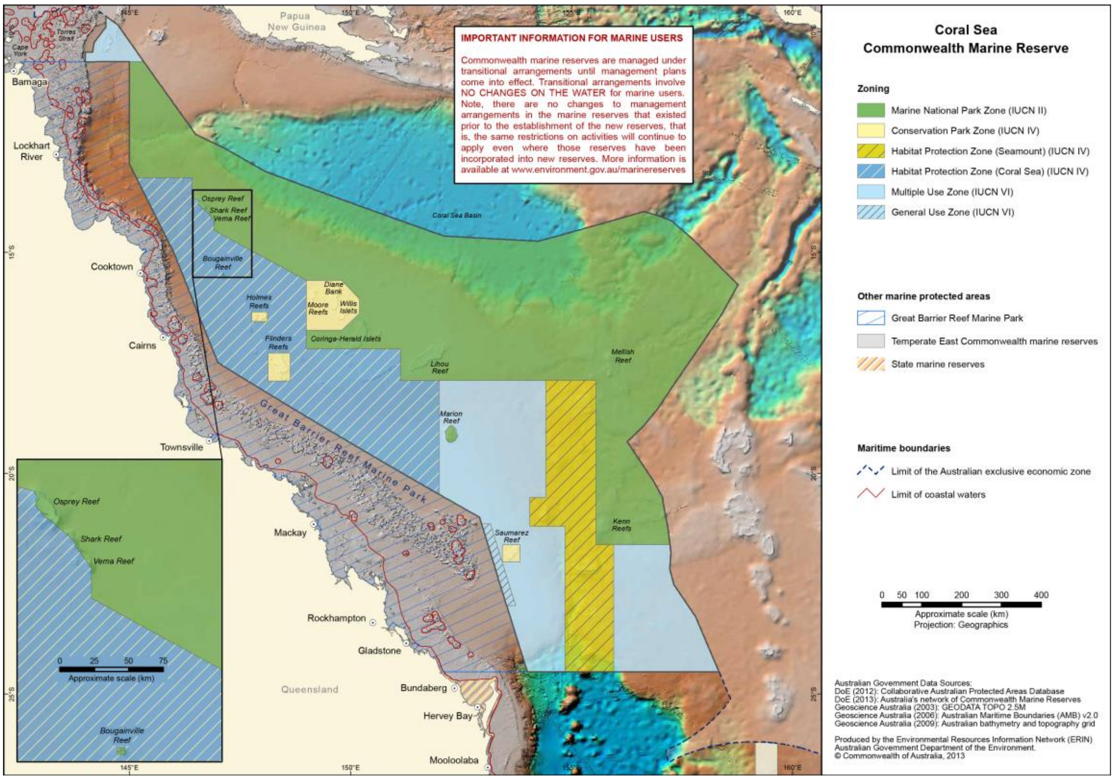

Figure 7.1 – Map of the Coral Sea showing location, size and zoning of Commonwealth Marine Reserve.

A total of 116 publications and reports relevant to the Coral Sea Commonwealth Marine Reserve were entered in to the *2016 CMR Literature Review Database*, building on the 303 separate documents identified and reviewed by Ceccarelli (2011). Most of the recent research and monitoring relevant to the Coral Sea Commonwealth Marine Reserve encompasses very large areas of the CMR estate; include comparisons with the Temperate East and/ or North and North-west Marine Regions. Specific localised studies conducted within the Coral Sea CMR are largely conducted at Coringa-Herald (12/ 54 studies) and Osprey Reef (8/ 54 studies). The number of reports relevant to the Coral Sea CMR has increased steadily since 2000, with a marked increase in the number of journal articles in the period 2011-2016 (Figure 7.2).

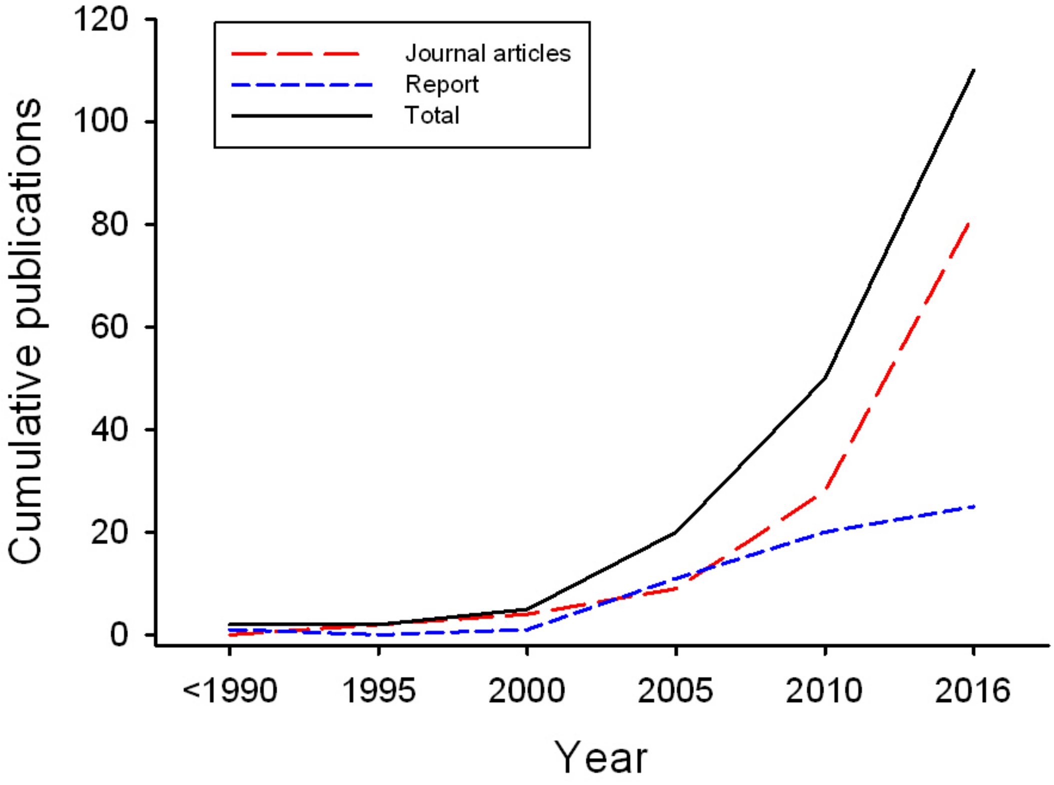

Figure 7.2 – The number of publications relevant to the Coral Sea CMR. Lines show the increase in the number of journal articles (red), reports (blue), and total publications (black) from 1990 to 2016

7.2. BIODIVERSITY VALUES

7.2.1 Key Ecological Features

The Coral Sea CMR encompasses extensive coral reef habitat, as well as sandy cays, deep sea plains and canyons. The islands and cays represent critical nesting sites for the green turtle and a range of seabirds (Ceccarelli, 2011). There are three KEFs contained within the Coral Sea CMR: i) Tasmantid seamount chain, ii) Reefs, cays and herbivorous fish of the Queensland Plateau, and iii) Reefs, cays and herbivorous fish of the Marion Plateau.

7.2.2 Significant Marine Species

A total of 341 species of conservation significance (IUCN Red List and EPBC) occur in the Coral Sea, including 26 species of cetaceans, 219 species of corals, 21 species of fish, 46 species of sharks and rays, 5 species of marine turtles, and 24 species of birds (Young et al. 2012). Most (51%) of these species are exhibiting declines in abundance within the Coral Sea.

7.2.3 Biological Communities

Extensive surveys of shallow reef environments (surveying benthic communities, fish assemblages and sharks) were conducted at 160 sites across the Coral Sea CMR in 2012-2013 (Stuart-Smith et al. 2013). This represents the first comprehensive survey across 17 distinct reefs, thereby limiting any assessment of temporal trends. Recent surveys of deeper (mesophotic) habitats have also revealed a vast expanse of coral-dominated reef habitat along the shelf edge (Bridge et al. 2011), which extends for >900km through the Coral Sea.

Benthic communities

In 2012-13, coral cover was relatively high (40%) on shallow reefs in the southern Coral Sea (e.g., Cato and Wreck Reefs) and dominated by fragile branching corals (Stuart-Smith et al. 2013). Coral cover was much lower (7-30%) at reefs in the central and northern reefs, which was attributed to recent effects of major cyclones. Moreover, the coral assemblages in these locations, were generally dominated by encrusting corals and had high cover of Halimeda and other calcifying algae (Stuart-Smith et al. 2013). In areas (e.g., Coringa-Herald reefs) where there has been recurrent sampling of benthic communities over several decades, it is apparent that low coral cover is a persistent feature of these reefs (see section 11.3), possibly due to recurrent disturbances or low resilience.

Fish communities

Fishes (including bony fishes and sharks) represent the primary focus of most recent research conducted in the Coral Sea, providing greater understanding of the biology and ecology of fishes in this region (e.g., Zischke et al. 2013, Werry et al. 2014). The Coral Sea supports one of the richest faunas of reef fishes anywhere in the world (Ceccarelli et al. 2013), representing a mix of Pacific oceanic and GBR fish faunas. Stuart-Smith et al. (2013) showed that reef fish diversity was highest in the northern Coral Sea, though coral-dependent fishes (e.g., butterflyfishes) were most abundant on reefs in the southern Coral Sea, where coral cover was highest. The Coral Sea also supports relatively high abundance of reef sharks (mainly *Carcharhinus amblyrhynchos* and *C. albimarginatus*) compared to other Indo-Pacific localities (Stuart-Smith et al. 2013, Ceccarelli et al. 2013).

7.2.4 Ecological Processes

Connectivity

Based on models of oceanographic circulation, larval transport is expected to occur westward across the Coral Sea and to the GBR (Stuart-Smith et al. 2013). The South Equatorial Current (SEC) is also expected to generate an effective barrier to connectivity between the northern and southern Coral Sea. However, connectivity between the Coral Sea and GBR, as well as patterns of retention versus dispersal within the Coral Sea are expected to vary with changes in the strength of the SEC (Young et al. 2012). Limited studies of animal migration and population genetics do show varying degrees of connectivity with western Pacific and GBR (Ceccarelli et al. 2013). For example, Werry et al. (2014) demonstrated movement tiger sharks across the Coral Sea from New Caledonia to Australia. Overall, much research is required to document patterns of connectivity at all spatial scales within the Coral Sea, as well as between the Coral Sea and adjacent biogeographical provinces.

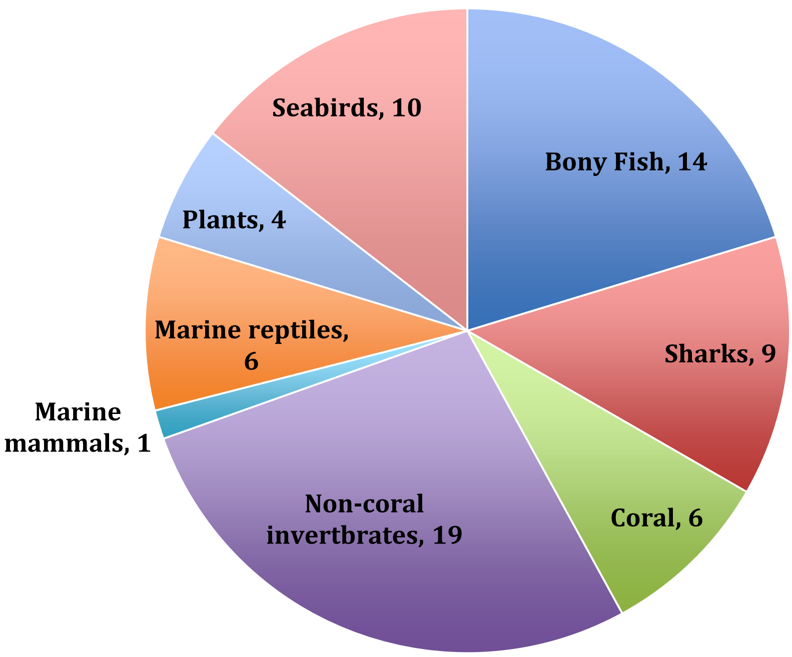

Figure 7.3 – The number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of eight species groups in the Coral Sea CMR. Non-coral invertebrates includes crustaceans, echinoderms, molluscs, sponges; marine mammals includes cetaceans, pinnipeds, and dugongs; marine reptiles includes turtles and sea snakes

Productivity

Oceanographic productivity in the Coral Sea is very low, especially compared to the southern nutrient rich waters off eastern Australia (Baird et al. 2008). This low productivity is attributed to the general lack of upwellings (Ceccarelli et al. 2008). However, there is a lack of information on the overall distribution of pelagic productivity and trophic dynamics specific to the Coral Sea.

Resilience

The resilience of marine species and communities in the Coral Sea is all but unknown. Ceccarelli et al. (2009) documented increases in coral cover in the aftermath of the 2004 bleaching at Lihou Reef, but it is unknown how coral reef communities in the Coral Sea would fare following severe and widespread disturbances (see Gilmour et al. 2013). Persistent low cover of scleractinain corals in some areas of the Coral Sea CMR (e.g., Coringa-Herald reefs) over more than a decade suggests there are significant constraints on recovery and resilience (potentially due to limited connectivity among reefs) in the Coral Sea CMR.

7.2.5. Benthic habitats

The large-scale bathymetric features of the Coral Sea CMR have been described, though there is a recognized need for more detailed habitat mapping (Ceccarelli et al. 2011). While there have been recent advances in documenting the biological communities across a broad range of shallow and deep-water habitats in the Coral Sea CMR (described above), there is yet to be any concomitant habitat surveys of these areas.

7.3. ACTIVITIES AND PRESSURES

Fisheries

Commercial and recreational fishing are currently permitted throughout much of the Coral Sea CMR, though extractive uses are prohibited within the former Coringa-Herald and Lihou Reef National Nature Reserves. The bêche-de-mer fishery has been experiencing declining catches since 1999, suggestive of over-exploitation (Oxley et al. 2004). In 2013-14, a total of 8.21 tonnes of bêche-de-mer was harvested from the Coral Sea, representing <20% of the total allowable catch. Other fisheries include reef line, trap and trawl fisheries, targeting finfish, sharks, and lobster, as well as harvesting of fishes for the ornamental (aquarium) market. Fishing effort is considered to be very low owing to isolation and limited access. However, there is no historical data on former (pre-fishery) densities or ongoing monitoring of target species, with which to assess localised effects of fishing.

Climate change

Average sea surface temperatures in the Coral Sea have risen by just under 0.5^{o}C in the last 5 years and are projected to increase a further 1-3 degrees by 2100 (Ceccarelli et al. 2013). However, there has been very limited empirical research into emergent and projected effects of global climate change within the Coral Sea CMR. Extensive coral bleaching (affecting 65% of coral colonies) was recorded in March 2004 at Lihou Reef (Oxley et al. 2004). Moreover, coral cover was already very low in 2004, which is attributed to significant coral mortality associated with severe coral bleaching in 2002 (Oxley et al. 2004), though there is no empirical data to confirm the occurrence or extent of the 2002 bleaching event. The spatial and temporal occurrence of coral bleaching within the Coral sea CMR, as well as effects of ocean acidification and other climate-induced environmental changes are poorly known, and require more intensive and comprehensive monitoring of environmental conditions (mainly, temperature, pH, aragonite saturation and dissolved oxygen concentrations), as well as effects of climate change on marine habitats and species, across a broad range of environments.

Other pressures and activities

Other recognised threats to the Coral Sea CMR include shipping, with at least 4 major shipping lanes dissecting the Coral Sea from major ports in Gladstone and Brisbane, as well as Townsville and Mackay, northwards to Papua New Guinea on onwards to Asia and Europe. Increasing shipping is associated with increased marine debris and pollution, collisions with marine species (e.g., turtles, dugongs and cetaceans), and increased risk of invasive species.

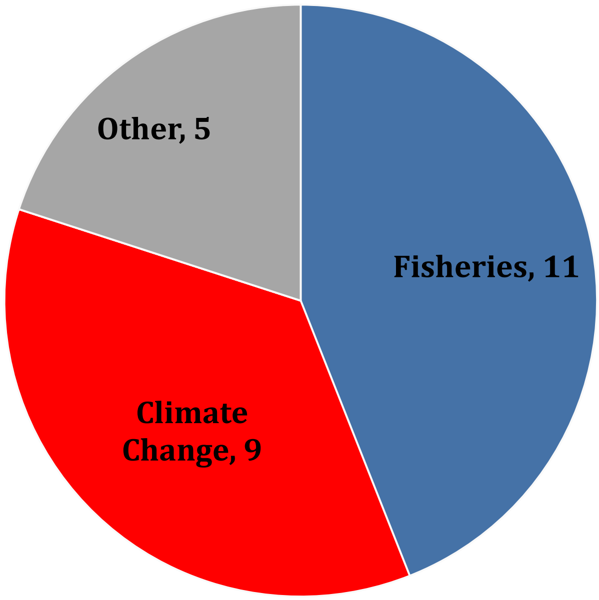

Figure 7.4. Number of publications and reports that relate (directly or indirectly) to anthropogenic activities and pressures within the Coral Sea CMR.

7.4. KNOWLEDGE GAPS, FUTURE RESEARCH, AND INDICATORS

Several recent and major reviews of research and monitoring within the Coral Sea (e.g., Ceccarelli et al. 2011, 2013; Young et al. 2012; Stuart-Smith et al. 2013) have highlighted several knowledge gaps and future research priorities. These are listed below taking into consideration the nine research priority themes set to facilitate "robust, evidence-based decision-making for the management of [Commonwealth] marine reserves" as identified by Beeton (2016).

Key Knowledge Gaps:

- The biodiversity contained within the Coral Sea CMR is largely unknown (Young et al. 2012, Ceccarelli et al. 2013), with large expanses of the CMR yet to be effectively surveyed. Benthic communities within deep water habitats, as well as demersal fish assemblages in the northern Coral Sea and associated with many of the seamounts are particularly under studied.

- Potentially limited resilience of reefs in the Coral Sea CMR (as indicated by depauperate fish and coral assemblages in some regions) warrants further investigation, as this will have critical management ramifications. Specific research is needed to explain persistent low cover of corals in particular areas of the Coral Sea, and associated impacts on other biological communities.

- While the South Equatorial Current (SEC) is known to have a major influence within the Coral Sea, major uncertainties exist around seasonal, inter-annual and decadal variability in the strength of the SEC and corresponding effects on regional hydrodynamics (Young et al. 2012).

- Distribution and abundance of sea snakes across the Coral Sea CMR – Alarming and unexplained declines in sea snake populations have occurred throughout much of northern Australia and throughout world (Lukoschek et al. 2013). Stuart-Smith et al. (2013) revealed very high densities at some reefs in the Coral Sea, which may represent an important refuge for these species. Ongoing research and monitoring should be prioritized to better understand population dynamics and limitations to their abundance across the Coral Sea.

- Local and regional predictions for changes in environmental conditions and hydrodynamic features with global climate change – sustained changes in environmental conditions, including ocean warming, acidification, reduced productivity and oxygenation, as well as changes in hydrodynamic regimes, will potentially undermine natural and biodiversity values of CMRs, but little is known about when or where impacts will occur.

Future Research:

- Recurrent monitoring of key habitats and species within Coral Sea CMR is recommended at least every 5 years, following on from baseline surveys of shallow reef environments across a large number of distinct reefs conducted by Stuart-Smith et al. (2013).

- Comprehensive monitoring of environmental conditions (e.g., currents, temperature, nutrients) across marine and coastal ecosystems is needed. This information will facilitate improved modeling and forecasting of environmental conditions and allow relationships between changes in populations and communities and changes in local environmental conditions to be investigated

- Ecological connectivity at all scales remains poorly known for the Coral Sea (Ceccarelli et al. 2013) and should be a prioritized. This requires increased understanding of hydrological connectivity as well as empirical data (from movement of individual recognized or tagged individuals or measures of populations genetics) on biological connectivity. Connectivity is critical to restore populations and communities in the aftermath of major disturbances, as well as establishing the importance of the Coral Sea as a source of replenishment for the Great Barrier Reef.

Potential indicators*:*

Marine ecosystems within the Coral Sea Commonwealth Marine Reserve are facing a range of pressures and threats from climate change and direct anthropogenic activities (see Activities and Pressures above). Potential indicators may be developed, and some are suggested here, but it must be remembered that an indicator species will be specific to a particular habitat type and the pressure/s it is facing.

Significant marine species

Indicators for any species of conservation concern (threatened or endangered, endemic, or exploited species) would include changes in the abundance and age/size structure of populations (e.g., sea snakes, sharks). Where possible, they would greatly benefit from the inclusion of population demographic rates (e.g., births or recruitment, mortality rates, etc.) to allow predictions of the vulnerability and resilience of the species to various pressures.

As for other Commonwealth Marine Reserves improved understanding of key ecological processes (e.g., connectivity and resilience) would greatly inform the vulnerability of significant marine species. For the Coral Sea, estimates of the strength and directionality of connectivity to adjacent reef systems (e.g., Great Barrier Reef) would be extremely valuable.

Biological communities

Many biological communities and even entire ecosystems are shaped by the abundance and composition of foundation (or habitat-forming) species.

For biological communities, the following are suggested as potential indicators for some habitats within the Coral Sea CMR:

- Shallow reef environments: the abundance (or cover) and composition of scleractinian (hard or reef-building corals), and other major space-occupying taxa (macroalgae). Scleractinian corals should be identified to genus and growth form as a minimum. The size structure of coral colonies and the abundance of juvenile corals will also allow the longevity of coral species, and the input of new corals to be estimated. As growth, mortality, and longevity varies markedly among coral species, information on size structure and juvenile corals should be recorded for individual species or 'morphospecies' (combination of genus and growth form).

- The cover and composition of deep-water corals and other habitat-forming organisms. The logistics of sampling these areas would make demographic rates (replenishment, survivorship) difficult to quantify.

8. TEMPERATE EAST COMMONWEALTH MARINE RESERVES NETWORK

8.1. OVERVIEW

The Temperate East Commonwealth Marine Reserves Network extends from the Victoria – New South Wales border north to Bundaberg, and east to Norfolk Island and its associated EEZ. It is bounded by the Great Barrier Reef Marine Park and Coral Sea CMR to the north, and the South-East CMR Network to the south (Figure 1.1). The Temperate East CMR Network includes both subtropical and temperate waters, and encompasses a range of habitats from shelf rocky reefs, deep-water canyons, and extensive seamount chains, namely the Lord Howe and Tasmantid seamount chains, and the Norfolk Ridge.

The East Australian Current (EAC) and Tasman Front are key oceanographic features of the Temperate East Region, and are key ecological drivers of both pelagic and demersal ecosystems. For example, schools of tuna aggregate on predictable water temperature and current features, and these aggregations are targeted by the Eastern Tuna and Billfish Fishery (Brewer et al. 2007). The EAC originates between 17-19°S and tracks largely southward along the coast until 30-32°S where it bifurcates, with one part remaining connected to the coast and continuing past the east coast of Tasmania (Ridgway and Dunn 2003). The other part (the Tasman Front) leaves the coast and flows eastwards across the Tasman Sea delivering warm waters to the Lord Howe Rise, then the deep waters of the New Caledonia Basin, and intermittently the Norfolk Ridge.

The Temperate East CMR Network comprises eight Commonwealth Marine Reserves (Central Eastern, Cod Grounds, Gifford, Hunter, Jervis, Lord Howe, Norfolk, Solitary Islands) that collectively encompass 383,352 km^2 of marine estate (Figure 8.1, Table 8.1). The majority of the protected areas within the Temperate East CMR Network are IUCN categories IV (36.5%) and VI (47.7%), and the remaining 15.7% under IUCN category II (Table 5.1). There is considerable variation in the size of the individual CMRs, ranging from 4 km^2 (Cod Grounds CMR) to 188,443 km^2 (Norfolk CMR).

Table 8.1 – Commonwealth Marine Reserves within the Temperate East Marine Region. The spatial coverage and level of protection afforded each CMR and the Temperate East CMR Network as a whole are given.

CMR	Area (km^2)	Level of protection – IUCN Category			
		I	II	IV	VI
Temperate East CMR Network	**383,352**		**60,264**	**140,083**	**183,004**
Central Eastern	70,054		8,110	52,066	9,878
Cod Grounds	4		4		
Gifford	5,829			5,829	
Hunter	6,257				6,257
Jervis	2,473				2,473
Lord Howe	110,139		10,488	61,204	38,446
Norfolk	188,443		41,661	20,984	125,799
Solitary Islands	152		1		151

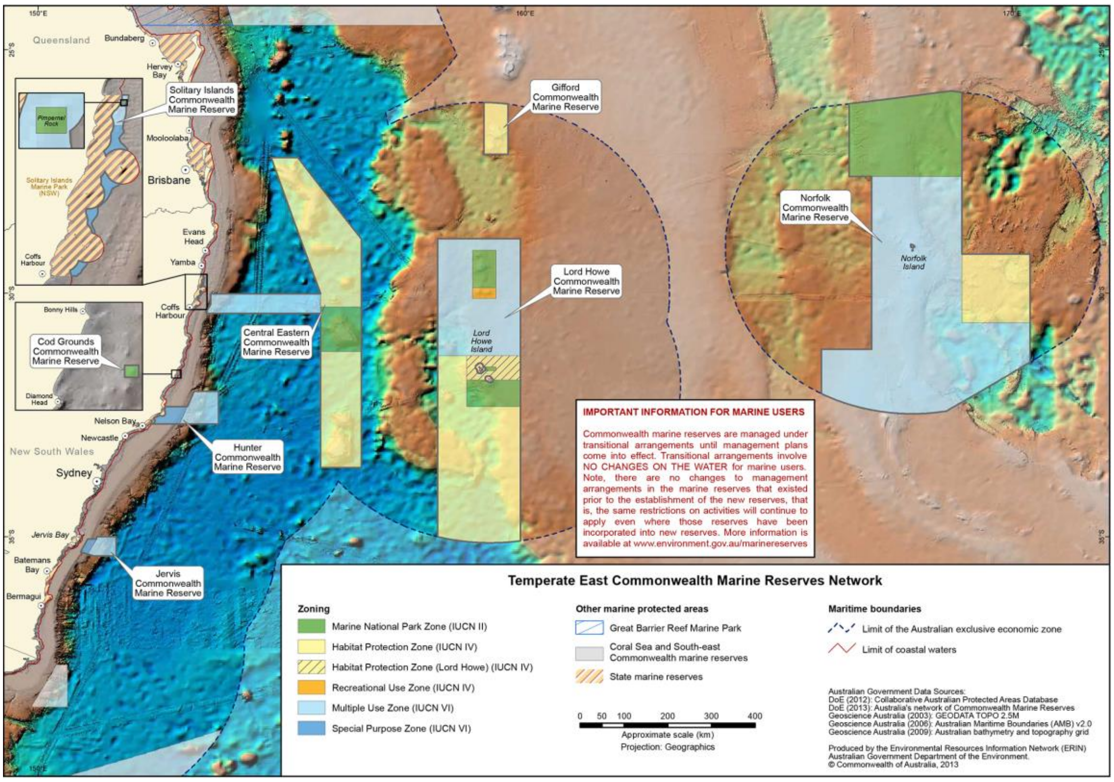

Figure 8.1 – Map of eastern Australia showing the location, size and zoning of the eight reserves with the Temperate East Marine CMR Network

A total of 230 publications and reports relevant to the Temperate East CMR Network were entered in to the *2016 CMR Literature Review Database*, with the majority of entries (169 out of 230) being peer-reviewed journal articles, and, to a lesser extent, reports (52 out of 230; Figure 8.2). The number of reports relevant to the Temperate East CMR Network has increased steadily since 2000, while the number of journal articles has increased exponentially over the same time period, with 86 new journal articles published in the period 2011-2016 (Figure 8.2). In terms of individual reserves, much of the recent research and monitoring, both reports and journal articles, focuses on Lord Howe (109 entries), Solitary Islands (60 entries) and/ or Norfolk (16 entries). It should be noted that many of the entries for the Lord Howe and Solitary Island CMRs relate to the adjacent State (NSW) Marine Protected Areas, but are included here as they are likely to be informative of the status and trends of adjacent communities in Commonwealth waters.

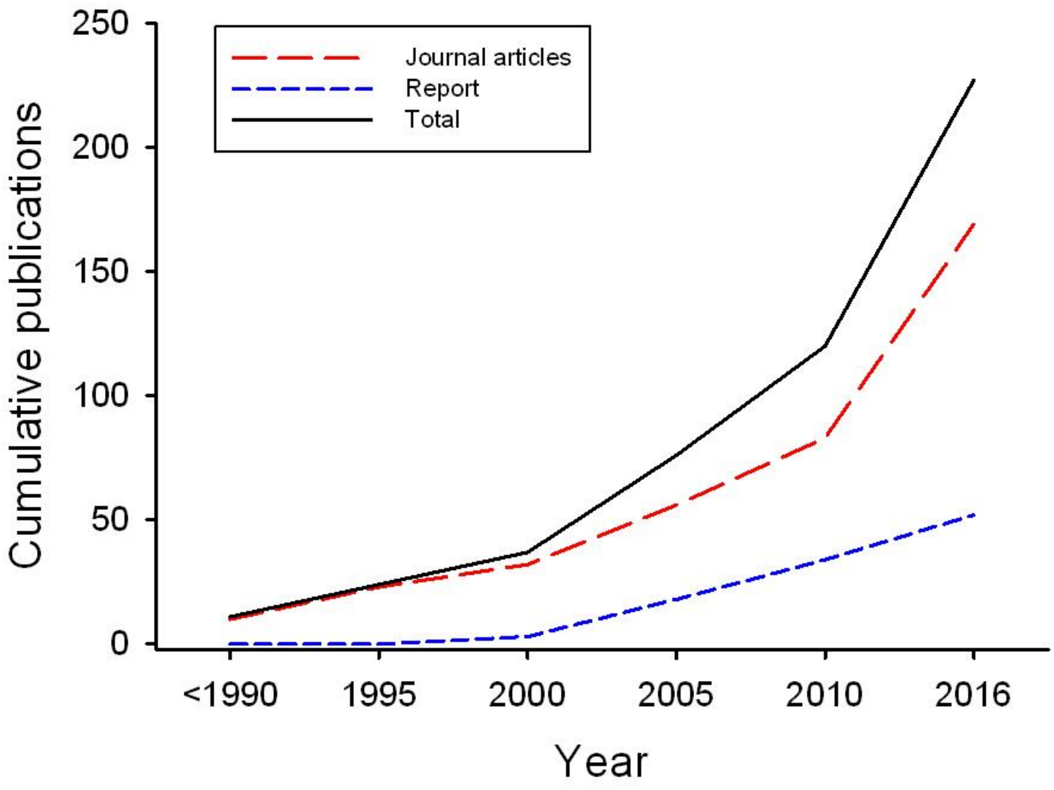

Figure 8.2 – The number of publications relevant to the Temperate East CMR Network. Lines show the increase in the number of journal articles (red), reports (blue), and total publications (black) from 1990 to 2016.

8.2. BIODIVERSITY VALUES

The Temperate East Marine Region contains eight Key Ecological Features (KEFs; Table 8.2) and biologically important areas for numerous endemic and threatened/endangered species.

8.2.1. Key Ecological Features

The KEFs within the Temperate East Marine Region are composed of three seamount chains (Lord Howe and Tasmantid seamount chains, and the Norfolk Ridge). These seamount chains provide unique habitats that are home to biological communities with high levels of diversity and endemism. The topography of these seamount chains also interacts with oceanographic features creating sites of enhanced productivity and aggregations of marine species. Elizabeth and Middleton Reefs are the southernmost platform reefs in the world, and support a diverse mix of tropical and temperate fishes, including several endemic species (e.g., Pratchett et al. 2011, Hoey et al. 2014). They also support high densities of the Black Cod and Galapagos shark.

The Tasman Front and Eddy Field is an oceanographic system that provides temporally variable patches of enhanced productivity that, in turn, attract aggregations of species supporting multiple trophic levels. The Tasman Front also provides biological connectivity between and among seamount habitats, and a link between the EAC and the East Auckland Current (Sutton and Bowen 2014). The first direct measurements of the flow in the Tasman Front were taken to the south of Norfolk Island and indicate flow to be eastward only in the upper 800m (6 Sv), with a weak westward flow (1.5 Sv) below 800m (Sutton and Bowen 2014). Similarly the Upwelling off Fraser Island brings nutrient rich and productive waters to the coast where they support food chains and fisheries.

Canyon systems, such as those on the Eastern Continental Shelf enhance the productivity and biodiversity of an area through their effects on local topography, geology and currents that concentrate nutrients and sediments into the canyon (Kloser and Keith 2010).

Shelf Rocky Reefs within the Temperate East Marine Region shift from algae- and kelp-dominated communities in shallow waters to sponge- and soft coral-dominated communities below 45m (Jordan et al. 2005; Dambacher et al. 2011). These complex habitat support diverse invertebrate and demersal fish assemblages and provide spatial refuges for numerous juvenile fishes.

Table 8.2 – Key Ecological Features identified for the Temperate East Marine Region, their location within individual Commonwealth Marine Reserves, and current pressures as identified by Dambacher et al. (2012). Together with the main pressures identified, pressures of potential concern for all KEFs include bycatch, destructive fishing gears, shipping, marine debris, oil and chemical pollution

Key Ecological Feature	Relevant CMR	Main pressures
1. Lord Howe Seamount Chain	Lord Howe, Gifford	Climate change (increasing SST, acidification), trawl fishing
2. Tasmantid Seamount Chain	Central Eastern	Climate change (increasing SST, acidification), trawl fishing
3. Norfolk Ridge	Norfolk	Climate change (increasing SST, acidification), trawl fishing
4. Elizabeth and Middleton Reefs	Lord Howe	Climate change (increasing SST, acidification, strength of the EAC), fishing (Elizabeth Reef), illegal fishing
5. Tasman Front and Eddy Field	Central Eastern, Lord Howe, Gifford	Climate change (strengthening of the EAC), marine debris
6. Canyons on the Eastern Continental Shelf	Central Eastern, Hunter, Jervis	Climate change ((increasing SST, changing oceanography), fishing, habitat modifying fishing gears
7. Shelf Rocky Reefs	Central Eastern, Cod Grounds, Hunter, Jervis, Solitary Islands	Climate change (increasing SST), fishing
8. Upwelling off Fraser Island	-	Climate change (strengthening of the EAC)

8.2.2. Significant Marine Species

The Temperate East Marine Region encompasses key habitats and supports populations of several threatened, and/or conservation dependent species. Notably, the *Temperate East Bioregional Plan* (Commonwealth of Australia 2012) identified 83 species of conservation value within the Temperate East Marine Region. These include 10 species of bony fish (e.g., Eastern Gemfish, Orange Roughy, Black Cod), six sharks (e.g., Grey Nurse Shark, White Shark), 9 Cetaceans (e.g., Humpback Whale, Southern Right Whale, Indo-Pacific

Bottlenose Dolphin), 34 species of seabirds, 20 species of seasnake, and four turtles (see Commonwealth of Australia 2012 for complete list).

The Department of Environment and Energy, National Conservation Values Atlas (http://www.environment.gov.au/topics/marine/marine-bioregional-plans/conservation-values-atlas) identifies Biologically Important Areas (BIAs) for 35 species within the Temperate East CMRN (Table 8.3). These include BIA's for 31 species of seabirds, two species of marine mammal, and two species of shark (Table 8.3). Importantly, the Lord Howe CMR and Norfolk CMR include breeding and foraging grounds for 14 and 13 species of EPBC listed seabird species, respectively (Table 8.3).

Table 8.3 – Biologically Important Areas identified for species listed under the EPBC Act for the Temperate East Commonwealth Marine Reserves Network (source Department of Environment and Energy, National Conservation Values Atlas). Letters refer to biological activities relevant to each of the eight reserves. *b – breeding, d – distribution, f – foraging, m migration*

	Central Eastern	Cod Grounds	Gifford	Hunter	Jervis	Lord Howe	Norfolk	Solitary Islands
Seabirds								
Antipodean albatross					f	f		
Black noddy						bf	bf	
Black petrel	f	f	f	f	f	f	f	f
Black-browed albatross	f			f	f			
Black-winged petrel						bf	bf	
Campbell albatross	f			f	f			
Common noddy						bf	bf	
Crested tern								bf
Flesh-footed shearwater	f	f	f	f	f	f		f
Flesh-footed shearwater						b		
Great-winged petrel	f	f	f	f	f	f		f
Grey ternlet						bf	bf	
Indian yellow-nosed albatross	f			f	f			
Kermadec petrel						bf	bf	
Little shearwater						bf	bf	
Masked booby						bf	bf	
Northern petrel	f			f	f			

Providence petrel						bf	bf	
Red-tailed tropicbird						bf	bf	
Short-tailed shearwater				f	f			
Sooty shearwater				bf	bf			
Sooty tern						bf	bf	
Southern giant petrel	f			f	f			
Wandering albatross	f			f	f			
Wedge-tailed shearwater		bf		bf	bf	bf	bf	
White tern						bf	bf	
White-bellied storm petrel						bf		
White-capped albatross					f			
White-faced storm-petrel					f			
White-necked petrel							bf	
Wilson's storm petrel	m			m	m			
Marine Mammals								
Humpback whale	m	m		m	m			m
Indo-Pacific Bottlenose Dolphin		b		b				b
Sharks								
Grey nurse shark		d		d				d
White shark	d	d		d	d			d

Notably, Cod Grounds CMR and Pimpernel Rock within the Solitary Islands CMR are important aggregation sites for the Grey Nurse Shark, and Elizabeth and Middleton Reefs within the Lord Howe CMR appear to be a stronghold for populations of the Black Cod (e.g., Hoey et al. 2014; Francis et al. 2015).

The offshore subtropical reefs of the Temperate East Marine Region (Norfolk Island, Lord Howe Island, Elizabeth and Middleton Reefs) are also critical habitats for several endemic fishes, such as the Double-header wrasse (*Coris bulbifrons*), the three-band butterflyfish (*Chaetodon tricinctus*), the Elegant wrasse (*C. elegans*), the Lord Howe Butterflyfish (*Amphichaetodon lordhowensis*), McCulloch's Anemonefish (*Amphiprion mccullochi*) and the Wide-Band Anemonefish (*A. latezonatus*).

Grey Nurse Shark (Carcharias taurus).

Recent research on the critically endangered eastern population of the Grey Nurse Shark has focused primarily on changes in the abundance at individual sites and the overall population size. These studies have shown that population estimates for the grey nurse shark remain low (1131-2142 individuals), although are higher than previous estimates (Department of the Environment 2014). There are some promising signs of increase at individual sites with the re-establishment of an aggregation of juvenile and sub-adult sharks at site within NSW state waters of the Jervis Bay Marine Park which was historically known to be occupied by *C. taurus* but had since been abandoned (Lynch et al. 2013).

The recovery of the Grey Nurse Shark populations is likely attributed to their life history (low fecundity, slow growth and late age-at-maturity), and may be further hampered by their movement patterns. Ottway and Ellis (2011) showed that the distances travelled by tagged Grey Nurse Sharks ranged from 5 to 1550 km and varied according to sex and season. Although one individual was recorded to move to a depth of 232 m off South West Rocks on the New South Wales mid-north coast, both males and females spent >70% of their time in waters <40 m and 95% of their time in waters 17–24°C. By mainly occupying inshore waters, the Grey Nurse Shark is exposed to potentially adverse fishing-related interactions and shark control programs that may be difficult to mitigate.

Black Cod (Epinephelus daemelii).

Despite ~ 30 years of protection Black Cod remain rare or absent at all but a few sites along the NSW coast (Malcolm 2011, Harasti and Malcolm 2013). The population of Black Cod on Elizabeth and Middleton Reefs, appears to be the last stronghold for the species in the Temperate East Marine Region. Populations on Elizabeth and Middleton have remained relatively stable at approximately 2.0 – 2.5 individuals/ha from 2011 to 2014 (Pratchett et al. 2011, Hoey et al. 2014). Given these density estimates were broadly comparable among habitats, equates to a local population in excess of 4,000 individuals.

Endemic species

Species with restricted geographic ranges (i.e., endemic) are often highly specialised and present in low densities, and thus assumed to be at a high risk of extinction. Interestingly, the butterflyfish *Chaetodon tricinctus,* endemic to Lord Howe, Elizabeth and Middleton Reefs and Norfolk Island, is the single most abundant species of butterflyfish on Lord Howe Island (Pratchett et al. 2014) and Elizabeth and Middleton Reefs (e.g., Hoey et al. 2014). Although, the available data suggests that there have been no significant changes in the abundances of endemic fishes (Elizabeth and Middleton Reefs: Choat et al. 2006, Hobbs et al. 2007, Pratchett et al. 2011, Hoey et al. 2014), their restricted ranges and high levels of self-replenishment (see Section 5.4 below) make these species highly susceptible to future disturbances and/or habitat loss.

8.2.3. Biological Communities

Corals (55 entries), bony fish (52 entries), non-coral invertebrates (41 entries), and sharks (30 entries) were the most commonly investigated species groups within the Temperate East CMRN (Figure 8.3). There were relatively few entries that related to seabirds (15 entries), marine plants (13 entries), or marine mammals (3 entries).

Benthic communities

Over the 2010-2016 period several studies have documented spatial differences in benthic communities, predominantly shallow coral reef ecosystems, both within (e.g., Solitary Islands: Malcolm et al. 2010, 2011, Smith and Simpson 2010; Lord Howe Island: Hoey et al. 2011) and across regions (Dalton and Roff 2013, Beger et al. 2014, Sommer et al. 2014, Keith et al. 2015, Mizerek et al. 2016). These later studies have shown that coral communities on the subtropical reefs within the Temperate East Marine Region are dominated by species with larger depth ranges, more robust morphologies, and greater tolerance of turbid waters, compared to those on lower latitude reefs. In deeper waters, the submerged mid-shelf reefs of Balls Pyramid were found to be similar to the fossil coral reef system discovered on the Lord Howe Island shelf; with scleractinian corals extending down to 94m depth and greatest cover (13.3%) between 30-40m (Linklater et al. 2015, 2016).

There have been relatively few studies that have investigated temporal variation in benthic communities in the Temperate East Marine Region over the past 6 years, and of these most have been conducted with NSW MPA’s (Lord Howe Island: Aquanel 2010, Solitary Islands: Verges et al. 2016). The only temporal studies identified in Commonwealth waters were the ecological surveys of Elizabeth and Middleton Reefs commissioned by the Department of the Environment (i.e., Oxley et al. 2003, Choat et al. 2006, Hobbs et al. 2007, Pratchett et al. 2011, Hoey et al. 2014). Collectively, these surveys have highlighted the slow and protracted recovery of coral cover on these reefs following an outbreak of the coral-feeding Crown-of-Thorns Starfish in the 1980’s (from 10% cover in 1994 to 20-30% in 2014). This recovery of coral populations is substantively slower than low latitude reefs (e.g., Gilmour et al. 2013), and appears to be related to the limited replenishment of corals through larval settlement and low growth rates of corals.

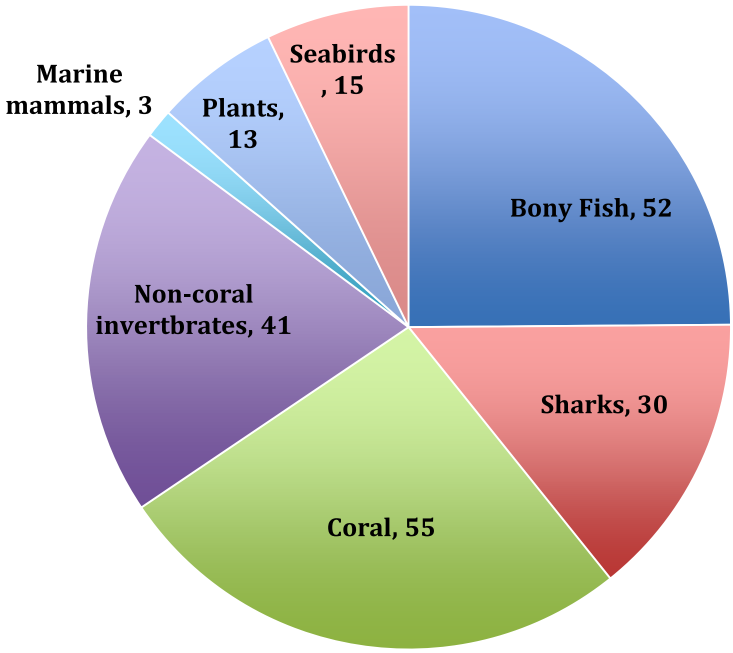

Figure 8.3 – The number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of eight species groups in the Temperate East CMR Network. Non-coral invertebrates includes crustaceans, echinoderms, molluscs, sponges; marine mammals includes cetaceans, pinnipeds, and dugongs; marine reptiles includes turtles and sea snakes

Fish Communities

Similar to the research on coral communities, the majority of studies on fish communities have focused on spatial variation in the abundance of particular taxa (e.g., Harasti and Malcolm 2013, Ferguson et al. 2015, Malcolm et al. 2015), functional or taxonomic groups (e.g., Hoey et al 2011), or the entire community (e.g., Schultz et al. 2012, 2014; Coleman et al. 2015). For example, Schultz et al. (2012, 2014) found that depth, distance from shore, and distance from the nearest reef were important determinants of fish assemblages in the Solitary Islands. Comparisons of areas open and closed to fishing suggest that responses are species specific, with some species such as the Pink Snapper being more abundant and of larger body size in Sanctuary Zones than adjacent fished areas 3 years after protection (Malcolm et al. 2015), while many other species show no difference between fished and protected areas (Edgar and Barrett 2002). Additionally comparisons of sampling methods for monitoring deep-water fish assemblages (baited longlines versus baited remote underwater videos, BRUVs) revealed these two techniques capture largely different components of the fish assemblage, with only 30 out of 94 species being common to both methods (McLean et al 2015).

Studies of temporal change in fish communities with the Temperate East Marine Region were limited, with most restricted to state waters (Malcolm et al. 2007, Aquanel 2010, Figuiera and Booth 2010, Edgar and Barrett 2012, Verges et al. 2016). Collectively, these studies have shown that most fish populations are relatively slow to respond to protection from fishing, and there are increasing numbers of tropical species entering subtropical and temperate areas (Figuera and Booth 2010, Verges et al. 2016). The ecological surveys of Elizabeth and Middleton Reefs, a 20-year study of changes in the catch of the South-east trawl (slope) fishery (Foster et al. 2015), and the Grey Nurse Shark (see below) are the only temporal studies we identified in Commonwealth waters. Foster et al. (2015) found that shelf fish assemblages had variable responses to cumulative (temporal) fishing pressure, and some but not all of the variation was driven by the life history traits of the component species. Fish assemblages on Elizabeth and Middleton Reefs have been relatively stable over the past decade, the only exception being the density of juvenile and subadult Galapagos reef shark (*Carcharhinus galapagensis*) that increased 18-fold from 2006 to 2011, and a further 2-fold from 2011 to 2014 (Hoey et al. 2014). The high and increasing densities indicate that these reefs are important nursery areas for this species.

Seabirds

Despite the number of BIA's identified for seabirds within the Temperate East CMRN, relatively few studies (10 entries) were identified in the *2016 CMR Literature Review Database* that related to this group for this region. The eastern population of flesh-footed shearwaters breed at a single site, Lord Howe Island. While it is not threatened on the island, they are vulnerable to impacts of fishing and debris on their oceanic foraging grounds that occur both within the Temperate East CMRs and adjacent waters in this region (Table 8.3). It has been estimated that 1800-4500 birds per year die as a result of bycatch in the East Coast Tuna and Billfish Fishery (Baker and Wise 2005). Further, a high proportion of birds have been shown to ingest plastic debris (Lavers and Bond 2016), resulting in reduced body condition and/or death (Lavers et al 2014).

Sommerfield et al. (2013, 2015) investigated the utility of depth-acceleration and GPS loggers for detecting foraging behaviours of masked boobies from Norfolk Island and found birds appeared to trade-off between foraging locally on predictable but not abundant resources, or foraging at distant locations on patchily distributed dense patches of prey.

8.2.4. Ecological Processes

Connectivity

There have been considerable advances in our understanding of the biological connectivity among subtropical reefs within the Temperate East Marine Region. Comparisons of endemic reef fishes (*A. latezonatus, A. mccullochi, C. bulbifrons,* and *C. tricinctus*) from Lord Howe Island, Norfolk Island, Elizabeth Reef, Middleton Reef, and the Solitary Islands reveal limited contemporary gene flow among locations with high levels of self-replenishment (c. 70-95%; van der Meer 2012, 2013, 2015, Steinberg et al. 2016). Such high levels of self-replenishment make these populations extremely vulnerable to local disturbances. Similarly, populations of three species of scleractinian corals were genetically differentiated Lord Howe Island, Elizabeth and Middleton Reefs and Solitary Island, although genetic exchange may be supplemented by occasional long-distance dispersal (Noreen 2010, Noreen et al. 2013).

Large and/or more mobile species appear to have greater connectivity among locations. The Black Cod from Elizabeth and Middleton Reefs appear to form a single population (Appleyard and Ward 2007), and comparisons with four individuals from the NSW coast suggest they may not be distinct from the mainland population (van Herwerden et al. 2009). Similarly, Galapagos sharks from Elizabeth and Middleton Reefs form one population that is distinct from the Lord Howe Island population (van Herwerden et al. 2008).

Productivity

Several of the KEF’s (e.g., Tasman Front and Eddy Field, Lord Howe seamount chain; Table 8.2) and BIA’s (foraging areas for seabirds) within the Temperate East CMR are associated with areas of elevated productivity, however there were no studies were identified in the database that have directly quantified productivity in these areas over the past six years.

Resilience – Coral Replenishment

The capacity of a population to recover from a disturbance is critical to its long-term persistence. Within coral reef ecosystems the replenishment of corals, and their subsequent growth and survival are fundamental to their resilience of these systems, while a considerable body of research has been conducted on the resilience of low latitude reefs, less is known of the resilience of subtropical reefs.

Although rates of coral settlement at Lord Howe Island are broadly comparable to those from the GBR (Harriott 1992) and have changed little from 1990/1 to 2011/12 (Cameron and Harrison 2016), the densities of juvenile corals are 5-200 times lower than low latitude reefs (Hoey et al. 2011). This coupled with the low rates of coral growth (Anderson et al. 2012, 2015) suggest that the reefs of Lord Howe, and other isolated high latitude reefs may be slow to recover from disturbances such as coral bleaching or outbreaks of Crown-of-Thorns starfish. This may be further compounded by the negative impact of increasing water temperatures on the dispersal potential of coral larvae (Figuierdo et al. 2014).

8.2.5. Benthic habitats

In addition to those studies that have examined benthic (biological) communities (see above), relatively few studies were identified (6 entries) that investigated benthic habitats within the Temperate East CMRN and adjacent areas in the past six years. Of these, the majority investigated the composition of deep water benthic habitats surrounding Lord Howe Island and Balls Pyramid using multibeam sonar (e.g., Linklater et al. 2015) or sediment cores (Kennedy et al. 2011), and a single study that examined the deep water habitats around Jervis CMR (Huang et al. 2012). These studies complement several earlier studies in the region (e.g., the eastern marine region: Keene et al 2008, Cod Grounds: Davies et al. 2008).

8.3. ACTIVITIES AND PRESSURES

Fisheries

Numerous Commonwealth and State commercial fisheries targeting both pelagic and demersal fishes and invertebrates, and using a range of gears operate within the commonwealth waters of the Temperate East Marine Region. These include the Eastern Tuna and Billfish Fishery, South and Eastern Scalefish and Shark Fishery (Commonwealth Trawl Sector, East Coast Deepwater Trawl, Gillnet, Hook and Trap Sector), High Seas Fisheries, Small Pelagic Fishery, NSW Ocean Trawl Fishery (Fish and Prawn Trawl Sectors), and the NSW Ocean Trap and Line Fishery (ABARES 2012). These together with the recreational and charter fishing operations in areas closer to the coast place considerable pressure on targeted species. Indeed, this has led to the listing of the Black Cod (*Epinephelus daemelii*) as threatened and the Grey Nurse Shark (*Carcharias taurus)* as critically endangered.

Of the 227 publications and reports directly relevant to the Temperate East CMR Network, 81 relate (directly or indirectly) to anthropogenic activities and pressures. Over half of this research is focussed on a broad variety of fisheries-related pressures (Figure 8.4), such as the bycatch of seabirds by the longline fishery (e.g., Baker and Wise 2005, Thalman et al. 2009), the influence of protection on demersal fish communities (e.g., Malcolm et al. 2010; Edgar and Barrett 2012), the likely social impacts of the implementation of a marine reserve (e.g., Schirmer et al. 2004), or the potential for the asexual propagation of sea anemones to reduce take by the ornamental aquarium trade (Scott et al.

2014). The vast majority of this research has focused on the effects of fishing on shallow water (< 30m) populations and communities.

Climate change

Similar to the tropical regions of the North and North-west CMR Networks, the importance of global climate change on subtropical marine ecosystems is evident by the high number of entries (32 out of 81) that explore changes in environmental conditions (mostly increasing temperature) and effects on marine species (e.g., Figueira and Booth 2010, Verges et al. 2016) within the Temperate East Marine Region. For example, Harrison et al. (2011) reported thermal bleaching of corals at isolated sites on Lord Howe Island, and while reefs around Lord Howe Island were not affected by the 2016 bleaching event, there was considerable bleaching within the Solitary Islands Marine Park.

The most apparent impact of increasing water temperatures within the Temperate East Marine Region is the poleward shifts in the distributions of marine organisms. Warming of global sea surface temperatures and the strengthening of the EAC is leading to range expansions of both corals (e.g. Baird et al. 2012) and fish (e.g., Figueira and Booth 2010, Feary et al. 2014) down Australia's east coast. Such tropicalisation of marine organisms is leading to novel interactions as tropical species are exposed to temperate and subtropical species for the first time, and can have a dramatic and lasting impact of marine ecosystems. For example, Verges et al. (2016) documented the loss of the habitat-forming kelp, *Ecklonia radiata*, over a 10-year period in the Solitary Islands and were able to attribute the kelp loss to increased consumption by range-shifting tropical herbivorous fishes.

Collectively, these studies demonstrate the marked influence of both acute and chronic increases in temperature in the Temperate East Marine Region, however, there is a general lack of studies investigating other likely effects of climate change, such as ocean acidification, hypoxia, and habitat fragmentation. The potential effect of ocean acidification on reef building corals is particular relevant for the Temperate East Marine Region due to the lower aragonite saturation of subtropical waters. Indeed, Anderson et al. (2015) reported a 70% decline in the growth rates of two of three coral species from 1994/5 to 2010/11 at Lord Howe Island. Although they could not directly attribute the reduction in growth to declines in aragonite saturation or increases in seawater temperatures above optimum, it highlights the negative effect climate change is having subtropical coral reefs.

Other pressures and activities

The remaining pressures and activities identified in the *2016 CMR Literature Review Database* are varied, ranging from the impact of commercial whale watching (Bruce et al. 2014), dredge spoil on soft sediment communities

(Smith and Rule 2001), and the ingestion of plastic debris by seabirds (Lavers et al. 2014, Lavers and Bond 2016).

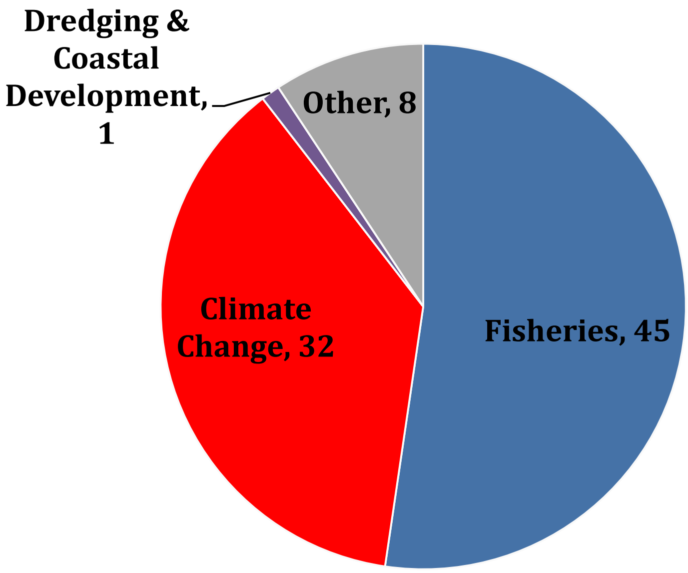

Figure 8.4 – Number of publications and reports that relate (directly or indirectly) to anthropogenic activities and pressures within the Temperate East CMR Network

8.4. KNOWLEDGE GAPS AND FUTURE RESEARCH

The review of literature relevant to the Temperate East CMR Network highlighted several knowledge gaps, future research priorities and to a lesser extent, potential indicators. These are listed below taking into consideration the nine research priority themes set to facilitate "robust, evidence-based decision-making for the management of [Commonwealth] marine reserves" as identified by Beeton (2016).

<u>Key Knowledge Gaps</u>:

- The vast majority of research and monitoring within the Temperate East CMRN was concentrated on two CMRs; Lord Howe and Solitary Islands, with little, if any, research conducted within the remaining six CMRs. In particular, no studies of the Gifford or Hunter CMR, and only two entries relating to the Central Eastern CMR were identified. As such basic geomorphological and biological information for these areas are lacking.
- Oceanographic features (EAC, Tasman Front and Eddy Fields)

characterize the Temperate East region, and are temporally variable sources of productivity and connectivity among offshore areas. While there have been substantial advances in our understanding of ecological connectivity among some of the offshore CMRs (e.g. van der Meer 2012, 2013, 2015, Steinberg et al. 2016), there is limited detail on the short- or long-term variability in the strength, connectivity, and productivity of these oceanographic features.

- With the exception of shallow benthic and fish communities on Elizabeth and Middleton Reefs, the Grey Nurse Shark, and some ongoing fish and benthic monitoring in NSW state waters, monitoring of temporal trends of populations and communities in the Temperate East CMR Network was extremely limited.

- Climate change is one of the greatest threats facing marine ecosystems, with Australia's east coast a 'hotspot' for warming. Models have predicted a strengthening of the EAC leading to the incursion of warmer waters further down Australia's east coast (Suthers et al. 2011), but little is known how this will affect other environmental conditions (ocean acidification, productivity, and oxygenation), or how this will influence individuals, populations, species, and communities, or how range-extending species may impact ecological processes. For example, in the shallow state waters of the Solitary Islands Marine Park, the tropicalisation of herbivorous fish communities has been related to the loss of kelp forests (Verges et al. 2016).

Future Research:

- Baseline data (bathymetric mapping, biological surveys) are needed for key habitats and species within Gifford, Hunter, and Central Eastern CMRs

- Ongoing monitoring of key habitats and species within Commonwealth CMRs (every 2-5 years), as well as appropriate reference locations, is required. Long-term, systematic monitoring has been undertaken at Elizabeth and Middleton Reefs in the Lord Howe CMR and represents the most valuable and comprehensive monitoring of shallow water biological communities in the Temperate East CMRN, and one of the most valuable in the Australia's Commonwealth Marine Estate. While inferences may be drawn from this well studied location to adjacent areas (i.e., other shallow habitats within the Lord Howe CMR, and to a lesser extent the Norfolk CMR), its isolation and unique fauna makes it distinct from most other CMRs within this CMR Network. There is a definite need for more comprehensive research and monitoring across a broader range of CMRs including Central

Eastern, Gifford, Hunter, Jervis, and Norfolk.

- The proximity of several NSW Marine Parks and CMRs (e.g. Jervis, Lord Howe, Solitary Islands) within the Temperate East region made it difficult to separate data collected from state and commonwealth waters. There are several dedicated monitoring programs for the NSW Marine Parks, but these do not generally extend to the adjacent commonwealth waters. Developing an integrated monitoring program for these areas that combines both state and commonwealth waters would be both efficient and cost-effective.

- Comprehensive environmental monitoring across inshore and offshore environments (from either data loggers or remote sensing), to facilitate improved environmental forecasting and establish links between biological and ecological changes and local environmental change.

- Fine-scale studies of hydrological connectivity both within and among CMRs, and studies of biological connectivity that extend beyond those identified for Elizabeth and Middleton Reefs, Lord Howe, and Norfolk Islands.

- Subtropical reefs, such as those in the Lord Howe, Norfolk Island and Solitary Islands CMRs represent transitional zones between tropical and temperate marine environments, and as such are those most likely to show early responses to climate change. In addition to recording environmental data and state- or condition-based ecological data, there is a need to move toward process-based monitoring. While state-based monitoring allows the current condition and past trends to be evaluated, process-based monitoring will allow predictions of future trajectories and resilience.

<u>Potential indicators</u>*:*

Marine ecosystems with the Temperate East CMR Network are facing a range of pressures and threats from climate change and direct anthropogenic activities (see Activities and Pressures above), and these pressures are likely to increase into the future. Potential indicators may be developed, and some are suggested here, but it must be remembered that an indicator species will be specific to a particular habitat type and the pressure/s it is facing.

Significant marine species

For any species of conservation concern (threatened or endangered, endemic, or exploited species) baseline indicators would include changes in the abundance and structure of populations and would greatly benefit from the inclusion of population demographic rates (e.g., births or recruitment, mortality rates, etc). Quantifying the abundance of a particular species would provide an indicator of the current population status (relative to previous estimates), and the ability to respond to any declines would be dependent on the frequency of monitoring. Quantifying demographic rates would allow future trajectories of populations to be predicted and facilitate early management intervention. This may be particularly relevant for long-lived species such as the Black Cod, and Grey Nurse Shark.

Biological communities

Many biological communities and even entire ecosystems are shaped by the abundance and composition of foundation (or habitat-forming) species, such as corals on tropical reefs or kelps on tropical reefs. These foundation species provide habitat and food for a range of organisms and can facilitate entire communities and ecosystems. Consequently, changes in the abundance of these species can have dramatic flow-on effects to populations of a diversity of species.

For biological communities we suggest the following as potential indicators for the shallow subtropical reefs in the Temperate East CMR Network:

- Shallow reef environments: the abundance (or cover) and composition of scleractinian (hard or reef-building corals), and other major space-occupying taxa (macroalgae). Scleractinian corals should be identified to genus and growth form as a minimum.

- The size structure of coral colonies and the abundance of juvenile corals will also allow the longevity of coral species, and the input of new corals to be estimated. As growth, mortality, and longevity varies markedly among coral species, information on size structure and juvenile corals should be recorded for individual species or 'morphospecies' (combination of genus and growth form).

9. South-east Commonwealth Marine Reserves Network

9.1. OVERVIEW

The South-east Commonwealth Marine Reserves Network extends from the Victoria – New South Wales border south to the southern limit of Tasmania's EEZ, and west to Kangaroo Island. The South-east CMR Network also includes the World Heritage Listed Macquarie Island and its associated EEZ (Figure 1.1). The South-east CMR Network includes warm and cool temperate waters, and the subantarctic waters surrounding Macquarie Island.

The South-east Marine Region encompasses a range of habitats in depths from 40 to over 5,000m, including rocky reefs in Bass Strait to deep-water canyons, abyssal plains and seamounts south and east of Tasmania. This diversity of seafloor features, together with the various oceanographic features, contribute to the high species diversity and productivity of the region (Commonwealth of Australia 2015). The oceanography of the region is complex and seasonally variable (Hosack and Dambacher 2012; Oliver et al. 2016). The eastern parts of the region are strongly influenced by the EAC and the western parts by the Zeehan current. The influence of the EAC is strongest during summer, and increases northwards and in an offshore direction. During winter the EAC weakens and the Zeehan current dominates the oceanography of eastern Tasmania (Oliver et al. 2016).

The South-east CMR Network comprises fourteen Commonwealth Marine Reserves (Apollo, Beagle, Boags, East Gippsland, Flinders, Franklin, Freycinet, Huon, Macquarie Island, Murray, Nelson, South Tasman Rise, Tasman Fracture, and Zeehan) that collectively encompass 388,464 km^2 of marine estate (Figure 9.1, Table 9.1). The protected areas within the South-east CMR Network are relatively evenly spread across IUCN categories II (24.7%), IV (26.8%) and VI (33.4%), with the remaining 14.9% under IUCN category I (Table 5.1). There is considerable variation in the size of the individual CMRs, ranging from 537 km^2 (Boags) to 162,000 km^2 (Macquarie Island).

Table 9.1 – Commonwealth Marine Reserves within the South-east Marine Region. The spatial coverage and level of protection afforded each CMR and the South-east CMR Network as a whole are given.

CMR	Area (km^2)	Level of protection – IUCN Category			
		I	II	IV	VI
South-East CMR Network	**388,464**	**58,000**	**96,046**	**104,712**	**129,703**
Apollo	1,184				1,184
Beagle	2,928				2,928
Boags	537				537
East Gippsland	4,137				4,137
Flinders	27,043		25,812		1,231
Franklin	671				671
Freycinet	57,942		56,793	323	826
Huon	9,991			389	9,602
Macquarie Island	162,000	58,000		104,000	
Murray	25,803		12,749		13,054
Nelson	6,123				6,123
South Tasman Rise	27,704				27,704
Tasman Fracture	42,501		692		41,809
Zeehan	19,897				19,897

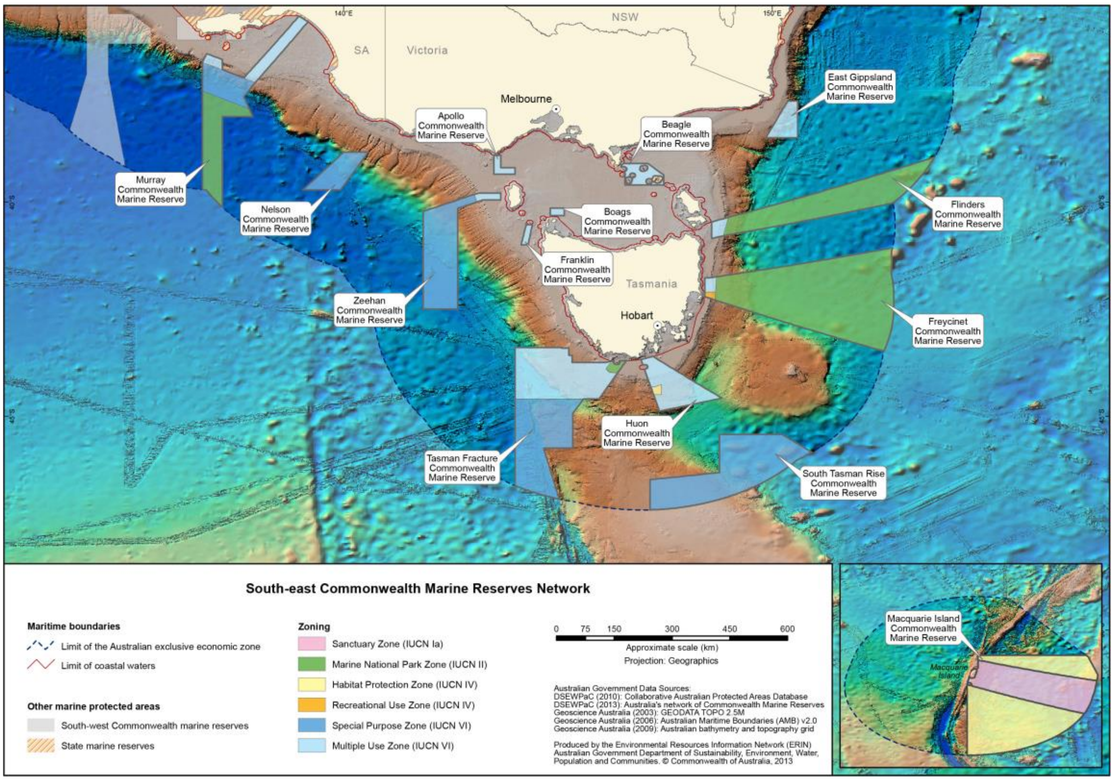

Figure 9.1 – Map of south-eastern Australia showing the location, size and zoning of the fourteen reserves with the South-east CMR Network

A total of 277 publications and reports relevant to the South-east Marine Region were entered in to the *2016 CMR Literature Review Database*, with the majority of entries (204 out of 277) being peer-reviewed journal articles, and, to a lesser extent, reports (61 out of 277; Figure 9.2). The total number of publications relevant to the South-east CMR Network increased steadily from 2000 to 2010, followed by a marked increase from 2010 to 2016 in which the number of reports doubled and the number of journal articles tripled (Figure 5.2). Of the 277 publications relevant to the South-east, over half (148 of 277 entries) were broadly relevant to the region, but not directly related to any of the fourteen reserves. Many of these were conducted in shallow coastal waters (i.e. state waters), or outside the boundaries of the reserves in deeper Commonwealth waters. Of the 126 entries found to be directly relevant to individual reserves, over half were conducted within or adjacent to Macquarie Island CMR (67 entries). The remaining entries were relatively evenly spread among the remaining thirteen CMRs (1-14 entries per reserve).

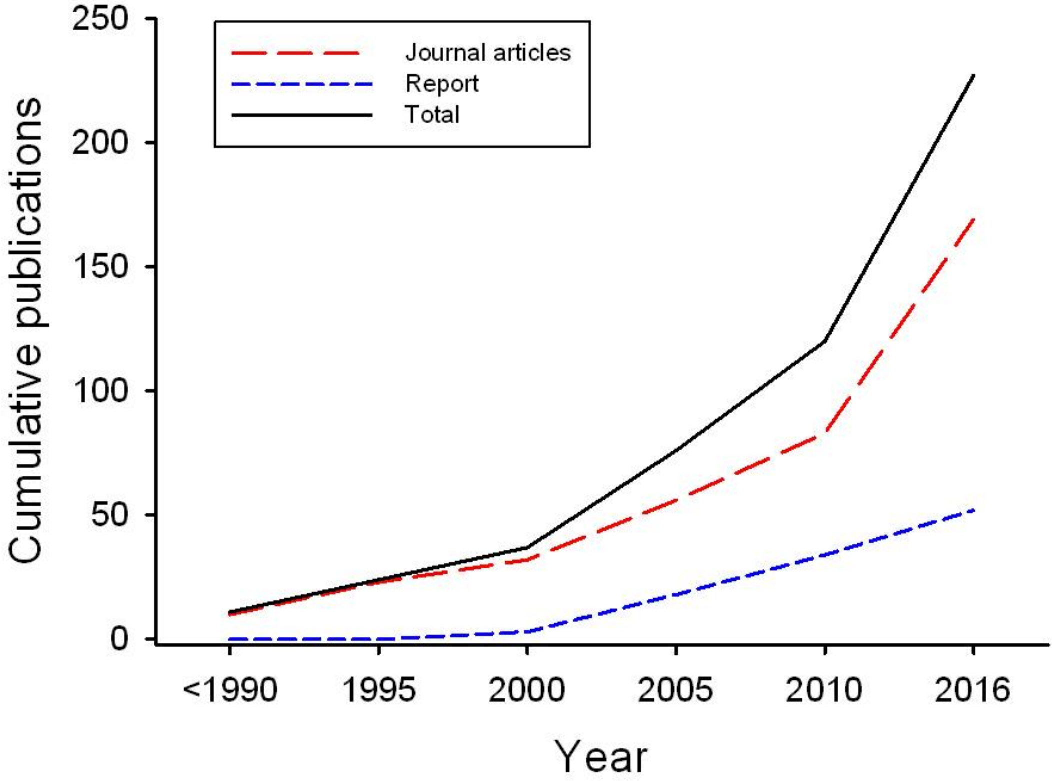

Figure 9.2 – The number of publications relevant to the South-east CMR Network. Lines show the increase in the number of journal articles (red), reports (blue), and total publications (black) from 1990 to 2016.

9.2. BIODIVERSITY VALUES

The South-east Marine Region contains eight Key Ecological Features (KEFs; Table 9.2) and provides habitat for numerous endemic and threatened/endangered species.

9.2.1. Key Ecological Features

The KEFs within the South-east Marine Region are composed of four highly productive oceanographic features (Bonney Coast upwelling, East Tasmania subtropical convergence zone, Bass Cascade, Upwelling east of Eden). The Bonney Coast upwelling is a large and predictable seasonal upwelling that brings cold nutrient rich waters to the surface (Nieblas et al 2009), and is one of only twelve areas worldwide where blue whales feed in high numbers. The East Tasmania subtropical convergence zone results from eddies of the EAC interacting with subantarctic waters and is characterized by spring and autumn plankton blooms. The Bass Cascade occurs during winter where the northward flow of warmer Bass Strait waters form an undercurrent and push cooler nutrient rich waters to the surface.

Table 9.2 – Key Ecological Features identified for the South-east Marine Region, their location within individual Commonwealth Marine Reserves, and current anthropogenic pressures (Hosack and Dambacher 2012). Together with the main pressures identified, pressures of potential concern for all KEFs include bycatch, destructive fishing gears, shipping, marine debris, oil and chemical pollution

Key Ecological Feature	Relevant CMR	Main pressures
1. Bass cascade	East Gippsland	Climate change (increasing SST, oceanography), small pelagic fishery, fur seal recovery, oil and gas, shipping
2. Big horseshoe canyon	-	Climate change (increasing SST, oceanography), demersal trawl and/or longline
3. Bonney coast upwelling	Murray	Climate change (effects on upwelling), fur seal recovery, fishing, oil and gas
4. East Tasmania subtropical convergence zone	Flinders, Freycinet	Climate change (strength EAC, increasing SST), small pelagic fishery, fur seal recovery, shipping
5. Seamounts south and east of Tasmania	Huon, South Tasman Rise, Tasman Fracture	Climate change (increasing SST, acidification, changing oceanography), demersal trawl
6. Shelf rocky reefs and hard substrates	Murray, Franklin, Boags	Climate change (increasing SST, changing oceanography), demersal trawl, oil and gas, shipping, fishing
7. Upwelling east of Eden	East Gippsland	Climate change (increasing SST, oceanography), small pelagic fishery, fur seal recovery, oil and gas, shipping
8. West Tasmania canyons	Tasman Fracture, Zeehan	Climate change (increasing SST, oceanography), demersal trawl and/or longline

The Big Horseshoe Canyon and the West Tasmanian can alter currents creating upwellings and trap rich organic sediments, thereby enhancing local productivity (Kloser and Keith 2010), and supporting higher abundance and/or biomass of benthic organism (Conlan et al. 2015). The steep rocky slopes of the canyons also provide habitat for sponges and other habitat forming invertebrates. Seamounts, like those to the south and east of Tasmania, also influence water flow and productivity, and provide unique habitats for attached invertebrate communities. Shelf rocky reefs and hard substrates occur at depths from 50-220m in Commonwealth waters, and provide important habitat for macroalgae and sessile invertebrates, which in provide habitat for a diversity of organisms.

9.2.2. Significant Marine Species

The South-east Marine Region encompasses key habitats and supports populations of several threatened, and/or conservation dependent species. Notably, 46 species protected under the EPBC Act are *known* or *likely* to occur, and a further 94 species that *may* occur, in the South-east Marine Region (Commonwealth of Australia 2015). These include seven bony fish (e.g., Gemfish, Orange Roughy, Southern Bluefin Tuna, Spotted Handfish), eight sharks (e.g., White Shark, Shortfin Mako, Southern Dogfish, School Shark), 36 Cetaceans (e.g., Blue Whale, Southern Right Whale, Fin Whale), six Pinnipeds (e.g., Subantarctic Fur-seal, Southern Elephant Seal), 53 birds, and four turtles (see Commonwealth of Australia 2015 – Appendix A for complete list).

The Department of Environment and Energy, National Conservation Values Atlas (http://www.environment.gov.au/topics/marine/marine-bioregional-plans/conservation-values-atlas) identifies Biologically Important Areas (BIAs) for 20 species within the South-east CMRN (Table 9.3). These include 16 species of seabirds, two species of whale (Pygmy blue whale and Sperm whale), the Australian sea lion, and White shark (Table 9.3). Most of the BIA's in the South-east CMRN are widespread (occurring in 10 or more individual CMRs), with the vast majority are identified as important foraging grounds for seabirds and marine mammals (Table 8.3). The prevalence of BIA's relating to foraging areas reflect the highly productive environment of the South-east region.

Table 9.3 – Biologically Important Areas identified for species listed under the EPBC Act for the South-east Commonwealth Marine Reserves Network (source Department of Environment and Energy, National Conservation Values Atlas). Letters refer to biological activities relevant to each of the eight reserves. *b – breeding, d – distribution, f – foraging, m migration*

	Apollo	Beagle	Boags	East Gippsland	Flinders	Franklin	Freycinet	Huon	Macquarie Island	Murray	Nelson	South Tasman Rise	Tasman Fracture	Zeehan
Seabirds														
Antipodean albatross				f	f	f	f	f	f	f	f	f	f	f
Australian gannet						f		f						
Black-browed albatross	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Black-faced cormorant													f	
Buller's albatross	f	f	f	f	f	f	f	f			f		f	f
Campbell albatross	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Common diving-petrel	f	f	f		f	f	f	f					f	f
Indian yellow-nosed albatross	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Little penguin		f				f								
Short-tailed shearwater	f	f	f		f	f	f	f						f
Shy albatross	f	f	f	f	f	f	f	f		f	f	f	f	f
Soft-plumaged petrel								f					f	
Sooty shearwater								bf					bf	
Wandering albatross	f	f	f	f	f	f	f	f		f	f	f	f	f
Wedge-tailed shearwater	bf			bf										
White-faced storm-petrel		f	f	f	f	f	f							
Marine mammals														

Australian sea lion										f				
Pygmy Blue Whale	f	f	f	f	f	f	f	f		f*			f	f
Sperm whale										f				
Sharks														
White shark	d	d	d	d	d	d	d	d		d			d	d

9.2.3. Biological Communities

Non-coral invertebrates (92 entries) were the most commonly investigated species group within the South-east CMRN (Figure 9.3). There was also a substantial number of entries relating to bony fish (53 entries), marine mammals (35 entries), seabrids (35 entries), and relatively few entries that related to sharks, corals, or marine plants (15-17 entries).

Benthic communities

Research on benthic communities has covered a wide range of habitats, from state coastal waters (e.g., Marzinelli et al 2015, Ford and Hamer 2016), shelf habitats (e.g., Monk et al. 2015), canyons (e.g., Currie et al. 2012), and seamounts (e.g., Thresher et al. 2014). Of the research directly relevant to the commonwealth waters most has focused on the seamounts and, to a lesser extent, canyons.

Both seamounts and canyons have been identified as hotspots of biodiversity and productivity, but are vulnerable to the effects of fishing. Although there is some evidence supporting these ideas, the limited number of comparative studies has led some to question the ubiquity of these findings (e.g., Rowden et al 2010). Recent research in the South-east Marine Region has attempted to address some of these gaps. Within two canyons along the Bonney coast Currie and Sorokin (2014) demonstrate that benthic communities within canyons are dominated by suspension-feeding organisms (sponges, molluscs, cnidarians), and that biomass and species richness declined with depth. Importantly, a comparison of canyon interiors with adjacent areas outside the canyon revealed there was no difference in species composition, however canyon interiors had higher abundance and/or biomass, increased species dominance (Conlan et al. 2015).

Similarly, studies on seamounts within the South-east Marine region have shown the biomass of epibenthic megafauna and the habitat-forming coral *Solenosmilia variabilis* to be ca. 4x and 29x greater, respectively on seamounts than on the adjacent habitat at similar depth (Rowden et al 2010); epibenthic megafauna assemblages on seamounts vary with depth, with highest biomass and diversity at intermediate depths (Thresher et al. 2014), and among seamounts (Dunstan et al. 2012).

The effect of fishing, especially demersal trawls, on seamount communities is unequivocal. Trawling has been shown to reduce the cover of *S. variabilis* by 2 orders of magnitude, and reduce the diversity and biomass of other epibenthic[1] megafauna by 3-fold (e.g., Althaus et al. 2009, Clark et al. 2015). Importantly, these impacts are persistent over scales of at least 10 years (Williams et al. 2010, Clark et al. 2015).

Fish communities

There have been relative few studies that have quantified spatial and/or temporal variation in fish assemblages in the South-east Marine Region. Spatial comparisons of fish assemblages have shown that the taxonomic composition of fish assemblages vary with depth within the Bonney Canyon (Currie et al. 2012), and with depth and cover of hard substrata within the Flinders CMR (Hill et al. 2014b).

Temporal comparisons (20 yr) have confirmed that differences in the species richness and functional traits of fish assemblages differ between coastal MPA’s and fished areas is temporally variable (e.g., Bates et al. 2014), and that fish assemblages on the continental shelf have variable responses to cumulative (temporal) fishing pressure (Foster et al. 2015). There has also been an increase in the biomass of Orange Roughy at spawning sites, however given the age-at-maturity for this species (30 years) it is likely that these changes represent pre-fishing recruitment entering the fishery (Kloser et al. 2015).

[1] epibenthic meaning living on the surface of the seafloor

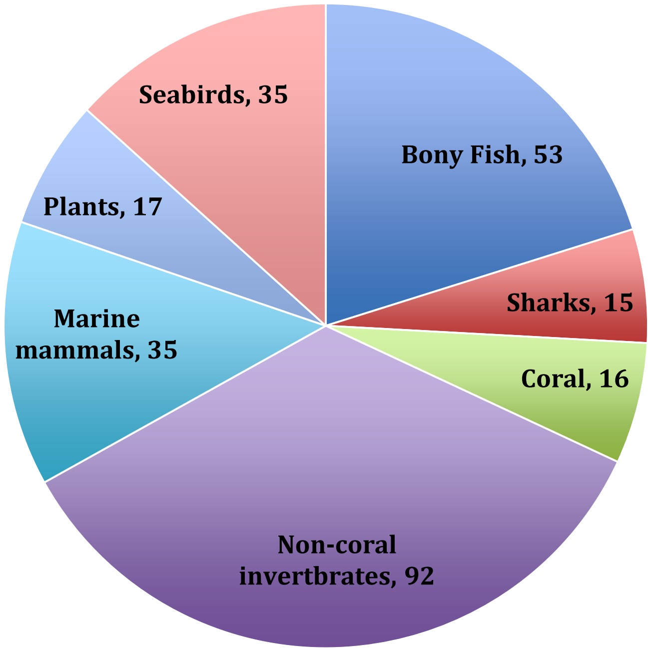

Figure 9.3 – The number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of eight species groups in the South-east CMR Network. Non-coral invertebrates includes crustaceans, echinoderms, molluscs, sponges; marine mammals includes cetaceans, pinnipeds, and dugongs; marine reptiles includes turtles and sea snakes

Sharks

Few studies were identified that related to sharks in the South-east Marine Region. Of those two described the movement patterns of shortfin Makos studies, and identified the continental shelf and slope and associated submarine canyons of the Great Australian Bight as important habitats for juveniles of this species (Rogers and Bailleul 2015, Rogers et al. 2015), and another study used satellite tracking data to show that white sharks change their search/foraging patterns depending on prey availability (Sims et al. 2012).

Cetaceans

The majority of studies of cetaceans have focused on various aspects of the ecology of the Blue Whale along the Bonney Coast, and have shown that Australian and Antarctic Blue Whales aggregate at different times along the coast (Tripovich et al. 2015), the areas occupied related to areas of greatest prey abundance (Morris 2014), and the potential use of acoustic methods to increase detectability of whales in this region (Miller et al. 2012). Other studies have investigated the genetic structure of the Burranan dolphin (Charlton-

Robb et al. 2015) and Gray's beaked whale populations (Thompson et al. 2016).

Pinnipeds

There have been numerous studies on pinnpeds with many investigating how environmental conditions influence foraging patterns and survival, and have shown that SST is an important determinant of both foraging patterns and survival of seals, presumably through its influence of prey availability (Baylis et al. 2012, McIntosh et al. 2013, Hoskins and Arnould 2014). Interestingly, the foraging of Australian fur seals was related to time lagged SST, suggesting that the survival and recruitment of prey was critical to future prey availability (Hoskins and Arnould 2014).

There have also been several recent studies investigating the ecology of the southern elephant seal on Macquarie Island. These studies have described various aspects of the diets of juveniles (Field et al. 2011) and adults (Banks et al. 2014), reproduction (Deprez et al. 2014), and foraging patterns (Bestley et al. 2013, Thums et al. 2011) in a bid to understand the causes of the declines in the Macquarie Island population over the past 50 years. There is some evidence that the decline in southern elephant seals on Macquarie Island was related to sea ice duration with their foraging ranges, and hence the population may respond positively to a reduced sea ice field under climate change (van den Hoff et al. 2014).

Seabirds

Studies on seabirds have generally focussed on either population trends (e.g., Weh et al. 2010) or foraging ecology (e.g., Belincourt and Arnould 2015a). Some populations, such as the king penguin on Macquarie Island have been increasing (Heupink et al. 2012) while others, such as the shy albatross have been decreasing (Alderman et al. 2011), with the latter linked to competition with the increasing population of Australian gannets. Like pinnipeds, the foraging behaviour and breeding success of penguins was related to environmental conditions, primarily SST (Belincourt and Arnould 2015b). Together with the pressures of climate change and the direct effects of fishing on seabirds, marine plastic debris has been increasing, with discarded or lost fishing gear accounting for approx. 25% of all debris (Eriksson et al. 2013).

9.2.4 Ecological Processes

Connectivity

Although numerous studies have investigated the ecological connectivity of marine organisms in the South-east Marine Region the majority have used shallow water or intertidal organisms as their focal species (e.g., seagrass:

Sinclair et al. 2016; molluscs: Li et al. 2013, Teske et al. 2014; seadragons: Wilson et al. 2016), and have shown that population connectivity is largely dependent on the dispersive abilities of the organisms and regional oceanography. The few studies that have investigated population connectivity for organisms from deeper habitats have found varying levels of connectivity, with some deep water coral species showing high genetic differentiation and hence low connectivity (Miller et al. 2010), while other deep water corals (Miller et al. 2010), bathyal (200-3500m) brittle-stars (O'Hara et al. 2014), and Grays beaked whale (Thompson et al. 2016) showed little to no genetic differentiation among habitats (i.e., high connectivity).

Together with population connectivity, there has also been some investigation in ecosystem connectivity. For example, Bulman and Fulton (2015) investigated potential connections between the small pelagic fishes of the shelf ecosystem of the Huon CMR with the deepwater benthic community. While they found no connection with the small pelagic fishes, their model indicated significant allochthonus[2] input of particulate organic matter (POM) from adjacent oceanic areas.

Productivity

The South-east CMRN is situated within a highly productive region that provides important foraging area for many species of seabirds and cetaceans (Table 9.3), and supports numerous fisheries (see below). Many of the KEF's (e.g., Bonney Coast upwelling, Upwelling east of Eden; Table 9.2) and BIA's (foraging areas for seabirds) within the South-east CMRN are associated with areas of elevated productivity. Despite the importance of productivity to the region, relatively few studies were identified that attempted to quantify oceanic productivity. Four studies were identified that used ocean colours derived from satellite imagery as a proxy for productivity and/or current patterns (e.g., Condie et al. 2011). While three of these studies were largely descriptive, Hoskins and Arnould (2014) related temporal patterns in productivity to the foraging patterns of female Australian fur seals and found that diving time and foraging trip duration were related to surface chlorophyll, but typically with a 1-2 year time lag. The authors suggested environmental factors were influencing the settlement and post-settlement processes of prey, and this affecting foraging of the seals when the prey were 1-2 years old.

[2] allochthonus meaning a deposit or formation that originated at a distance from its present position.

Resilience

The South-east Marine Region is a global hotspot for marine warming, with increasing SST, ocean acidification and changing oceanography already having a dramatic impact on many organisms and communities. In some shallow waters the tropicalisation of communities is having cascading effects on entire ecosystems. While state MPA's have been shown to be able to slow or reduce these impacts (e.g., Ling et al. 2009, Bates et al. 2014), it is unclear what the longer-term implications will be. Attempts to rehabilitate areas through the re-introduction of urchin predators (i.e., lobsters), or manual removal of urchins (Sanderson et al. 2016) have been largely unsuccessful, and it seems unlikely that any range-extending predators (e.g. eastern blue grouper; Casper et al. 2011) will have a substantive effect on urchin populations.

Deep sea fishes and invertebrates are typically long-lived, slow growing and often mature late, limiting their capacity to recover from population declines. Benthic taxa, especially the dominant mega-faunal components of deep-sea systems such as corals and sponges, are also highly vulnerable to bottom trawls. While some taxa have natural resilience due to their small size and/or robust growth form, and some can survive in natural refuges inaccessible to trawls, most habitat forming species are extremely susceptible to trawls (Clark et al. 2015). Indeed, studies have shown dramatic reductions in the cover and biomass of habitat-forming corals and sponges between seamounts that have been fished versus those that have never been fished, with little signs of recovery 10 years after fishing has ceased (Althaus et al. 2009, Williams et al. 2010). Recovery is likely to take decades to centuries, if at all, after fishing has ceased (Clark et al. 2015).

Similarly, deep-sea fishes have life histories that render them far less resilient to exploitation than shallow-water fishes. While increases in biomass of Orange Roughy at spawning sites has been reported in recent years, this increase is likely related to pre-fishery recruitment entering the fishery, and as such we are yet to see the true effects of the fishery on their population.

9.2.5. Benthic habitats

Thirteen studies were identified that have mapped marine habitats and/or benthic communities within the South-east Marine Region using a variety of techniques over the 2010-2016 period, complementing those of earlier mapping studies in the region (e.g., Bax et al. 2001, Kloser et al. 2001). These studies used multibeam sonar (9 out of 13 entries, and/or Autonomous Underwater Vehicles (AUV) (5 out of 13 studies) to map areas of the seafloor including the coastal waters off Tasmainia's east coast (Seiler et al. 2012, Hill et al. 2014a, Marzinelli et al. 2015), coastal Victoria (Young et al. 2015), the shelf and slope areas of the Flinders CMR (Lucier et al. 2013, Lawrence et al. 2015, Monk et al. 2016a), and the northern section of the Tasman Fracture CMR (Monk et al. 2015, 2016b).

9.3. ACTIVITIES AND PRESSURES

Fisheries

The South-east Marine Region is highly productive with numerous Commonwealth and State commercial fisheries operating within these waters that collectively account for ca. 50% of Australia's fisheries production. These include Commonwealth: Bass Strait Central Zone Scallop Fishery, Small Pelagic Fishery, Southern and Eastern Scalefish and Shark Fishery (Commonwealth Trawl Sector, Scalefish Hook Sector, Shark Gillnet and Shark Hook Sectors), Southern Bluefin Tuna Fishery (line fishing), Southern Squid Jig Fishery, Macquarie Island Toothfish Fishery, Eastern Tuna and Billfish Fishery; Victorian: Giant Crab Fishery, Rock Lobster Fishery, Scallop Fishery; Tasmanian: Giant Crab Fishery, Rock Lobster Fishery, Scallop Fishery; Scalefish Fishery; New South Wales: Ocean Trap and Line Fishery, Lobster Fishery; South Australian: Rocklobster Fishery, Scalefish Fishery, Giant Crab Fishery, and Sardine Fishery (Commonwealth of Australia 2015) These together with the recreational and charter fishing operations in areas closer to the coast place considerable pressure on targeted species.

Of the 277 publications and reports directly relevant to the South-east CMR Network, 123 relate (directly or indirectly) to anthropogenic activities and pressures. Approximately 2/3 of this research (90 out of 123 entries) is focussed on a broad variety of fisheries-related pressures (Figure 6.3). This body of research has covered topics such as the impacts of trawl (e.g., Althaus et al. 2009) and pelagic fisheries (e.g., Bulman and Fulton 2015) on seamount benthic communities, the influence of protection on demersal fish communities (e.g., Cameron 2013, Bates et al. 2014), temporal patterns in landings (e.g., Andre and Hartman 2014, Emery et al. 2015), bycatch (e.g., Anderson and Clarke 2003, Monk et al. 2015), behaviour of fishers in response to catch rates and market prices (Emery et al. 2014), and the depredation of lobsters within lobster pots (Briceno et al. 2015, 2016).

Climate change

Potential effects of climate change marine populations and communities were again a common theme in recent research in the South-east Marine Region, accounting for 32 of the 123 entries (Figure 6.3). This is not a surprising result given temperate coastal waters in south-eastern Australia are warming at approximately four times the global average due to both the increasing SST and the strengthening of the EAC leading to greater southward penetration of warm waters (e.g., Ridgeway 2007). Moreover, model projections suggest a further strengthening of the EAC, decreased flow along the Tasman front resulting in a Tasman Sea-wide warming of up to 3°C (Oliver and Holbrook 2014). Studies on climate change within the South-east Marine Region ranged from those investigating the likely effects of ocean acidification on the habitat-forming deep-water coral *Solenosmilia variabilis* (Thresher et al 2012, 2013), to the responses of organisms and ecosystems to increasing SST (Johnson et al. 2011), the changing phenology of penguins (Hindell et al. 2012), and fishers' perception of climate change (Nursey-Bray et al. 2012).

One of the most apparent impacts of increasing water temperatures within the South-east Marine Region is the poleward shift in the distributions of marine organisms. Warming of global sea surface temperatures and the strengthening of the EAC is leading to range expansions and distributional shifts in many ecologically and commercially important fish (e.g., Casper et al. 2011) and invertebrate species (Ling et al. 2008; Harmon et al. 2014). These shifts are leading to novel interactions, and is having major implications for pelagic and benthic systems. Importantly, populations of the range extending sea urchin (*Centrostephanus rodgersii*) has led to conversion of biodiverse and productive kelp beds to depauperate and less productive barren habitats (Johnson et al. 2009). While ocean warming has been a prime driver of change in the South-east Marine Region and the focus of much research, there have been several calls to complement this with targeted research on the impacts of ocean acidification (e.g., McDonald et al. 2013).

Other pressures and activities

The remaining pressures and activities identified in the *2016 CMR Literature Review Database* are varied, ranging from the identification of suitable sites for wave energy farms (Flocard et al. 2016), non-native species (Garside et al. 2015), and the ecological impacts of submarine cables (Sherwood et al. 2016).

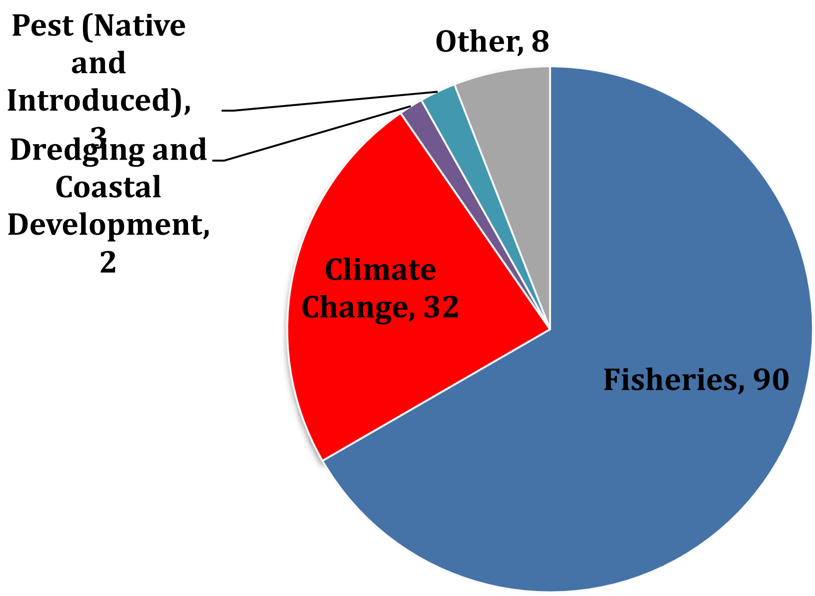

Figure 9.4 – Number of publications and reports that relate (directly or indirectly) to anthropogenic activities and pressures within the South-east CMR Network

9.4. KNOWLEDGE GAPS, FUTURE RESEARCH, AND INDICATORS

The review of the South-east Commonwealth Marine Reserve literature highlighted several knowledge gaps, future research priorities and to a lesser extent potential indicators. These are listed below taking into consideration the nine research priority themes set to facilitate "robust, evidence-based decision-making for the management of [Commonwealth] marine reserves" as identified by Beeton (2016).

<u>Key Knowledge Gaps</u>:

- There was a substantial body of work that related to the Macquarie Island area, while only one to fourteen entries were identified that related to each of the remaining thirteen CMRs. Although major seafloor features of the South-east Marine Region have been mapped (Commonwealth of Australia 2015 – *South-east marine regional profile*) comprehensive surveys of the benthos are still lacking for many areas. The capacity to obtain such information will be constrained by the depth, area, and isolation of many of the CMRs.

- The south-east marine region is characterized by the convergence of several major ocean currents (EAC, Leeuwin Current, Zeehan Current, and Antarctic Circumpolar Current). While large scale spatial and temporal patterns in these ocean currents have been examined (e.g., Hosack and Dambacher 2012; Oliver et al. 2016), there is limited information on the short-term variability or local variation in the strength, connectivity, and productivity of these oceanographic features.

- Seamounts and Canyons have been identified as hotspots of biodiversity and productivity, however, there have been few studies that have examined spatial and/or temporal variability in these deep sea communities, and as such comprehensive surveys of the flora and fauna associated with these features are limited. Spatial and temporal comparisons have also been hindered by the use of different sampling methods (e.g. towed video vs benthic grabs), and for temporal data the lack of repeated sampling at fixed sites. While some sampling methodologies may use randomly assigned sites, such approaches require a substantially larger number of sites to differentiate spatial variation between sites from temporal variation.

- Relatively few studies have quantified the population connectivity of deep water organisms, or their basic biological information (dispersal capabilities, recruitment, and movement (for mobile species)). Consequently our understanding of biological connectivity within and between CMRs is limited.

- There are still gaps relate to the ecology and biology of many species, including some significant marine species (e.g., fisheries species).

<u>Future Research:</u>

- Comprehensive surveys of fish and benthic assemblages associated with KEFs (e.g., seamounts and canyons, rocky reefs on continental shelf), and adjacent areas, both among and within CMRs. These surveys should use a 'standard' or consistent methodology to facilitate meaningful comparisons among locations. These will allow detailed species lists and populations estimates to be developed for each feature and CMR.

- Regular temporal monitoring (every 2-5 years) of key habitats and species within South-east CMRs, as well as appropriate reference locations, is required. A standard methodology should be developed for shallow and deepwater habitats and fixed (representative) sampling sites selected for temporal surveys. Further, the monitoring of exploited species should be extended to include fisheries-independent data

- Comprehensive environmental monitoring across inshore and offshore environments (from either data loggers or remote sensing), to facilitate improved environmental forecasting and establish links between biological and ecological changes and local environmental change.
- Fine-scale studies of hydrological and biological connectivity both within and among CMRs, and studies of ecosystem connectivity between shallow and deep water ecosystems
- Empirical data to populate models of productivity, and the links between productivity and significant marine species

Potential indicators*:*

Marine ecosystems with the South-east CMR Network are facing a range of pressures and threats from climate change and direct anthropogenic activities (see Activities and Pressures above). Importantly, the South-east is climate change hotspot and supports numerous commercial and recreational fisheries, as well as oil and gas industries. Potential indicators may be developed, and some are suggested here, but it must be remembered that an indicator species will be specific to a particular habitat type and the pressure/s it is facing.

Significant marine species

As stated previously, baseline indicators for any species of conservation concern (threatened or endangered, endemic, or exploited species) would include changes in the abundance and age/size structure of populations. Where possible, they would greatly benefit from the inclusion of population demographic rates (e.g., births or recruitment, mortality rates, etc) to allow predictions of the vulnerable and resilience of the species to various pressures.

Given the majority of BIA's in the South-east CMR Network relate to foraging, and hence productivity of the area, some metric of oceanographic productivity (either directly quantified or through remote sensing) may be a useful indicator for the viability of these species.

Biological communities

Many biological communities and even entire ecosystems are shaped by the abundance and composition of foundation (or habitat-forming) species.

For biological communities the following are suggested as potential indicators for some habitats within the South-east CMR Network:

- The size and abundance of deep-water habitat forming corals and sponges. The logistics of sampling these areas would make demographic rates (replenishment, survivorship) difficult, if not impossible, to quantify

10. South-west Commonwealth Marine Reserves Network

10.1. OVERVIEW

The South-west Commonwealth Marine Reserves Network extends from the eastern tip of Kangaroo Island, west along the South Australian and Western Australian coasts of the Great Australian Bight, and north to Shark Bay. The South-west Marine Region is extensive, covering ca. 1,300,000 km^2 marine estate, and is adjacent to the longest coastline facing the Southern Ocean in the world. The South-west CMR Network includes both temperate and subtropical waters, and encompasses a diverse range of habitats.

The South-west Marine Region is renowned for some of the most diverse temperate marine ecosystems. Examples include the unique mix of temperate and tropical marine species that inhabit the waters off the Houtman-Abrolhos Islands; the deep mountains of the Diamantina Fracture; and the world's richest known temperate soft-sediment communities in the Great Australian Bight. Hotspots of endemism include the Houtman-Abrolhos Islands, the overlap between tropical and temperate fauna along the west coast, the Recherché Archipelago and the soft sediment ecosystems in the Great Australian Bight. The Region provides important calving regions for the endangered southern right whale and colonies of Australia's only endemic pinniped – the Australian sea lion. The south-west corner of the Region is an important area for beaked whales. Other protected species known to occur in the Region include white shark, humpback whale and several species of albatross (Director of National Parks 2013 – *South-west Commonwealth Marine Reserves Management Plan 2014-2024*).

The South-west CMR Network comprises 14 Commonwealth Marine Reserves (Abrolhos, Jurien, Two Rocks, Perth Canyon, Geographe, South-west Corner, Eastern Recherché, Twilight, Bremer, Great Australian Bight, Murat, Western Eyre, Western Kangaroo Island, Southern Kangaroo Island) that collectively encompass 508, 605 km^2 of marine estate (Figure 10.1, Table 10.1). Individual reserves vary in size from 630km^2 (Southern Kangaroo Island CMR) to 271,898 km^2 (South-west corner CMR; Table 10.1). The majority of the protected areas within the South-west CMR Network are IUCN categories II (35.3%), IV (18.5%), and VI (46.1% which includes 1.9% within an oil and gas exclusion area (Table 10.1).

Table 10.1 – Commonwealth Marine Reserves within the South-west Marine Region. The spatial coverage and level of protection afforded each CMR and the South-west CMR Network as a whole are given.

CMR	Area (km^2)	Level of protection – IUCN Category			
		I	II	IV	VI
South-West CMR Network	**508,605**		**179,627**	**94,473**	**234,505**
Abrolhos	88,126		2,548		85,578
Bremer	4,472		284		4,188
Eastern Recherche	20,574		16,072		4,502
Geographe	977		36		941
Great Australian Bight	45,926		7,728		38,198
Jurien	1,851		31		1,820
Murat	938		938		
Perth Canyon	7,409		1,107	2,569	3,733
Southern Kangaroo Island	630				630
South-west Corner	271,898		128,676	91,904	51,318
Twilight	4,641		4,641		
Two Rocks	882		7		875
Western Eyre	57,946		17,439		40,507
Western Kangaroo Island	2,335		120		2,215

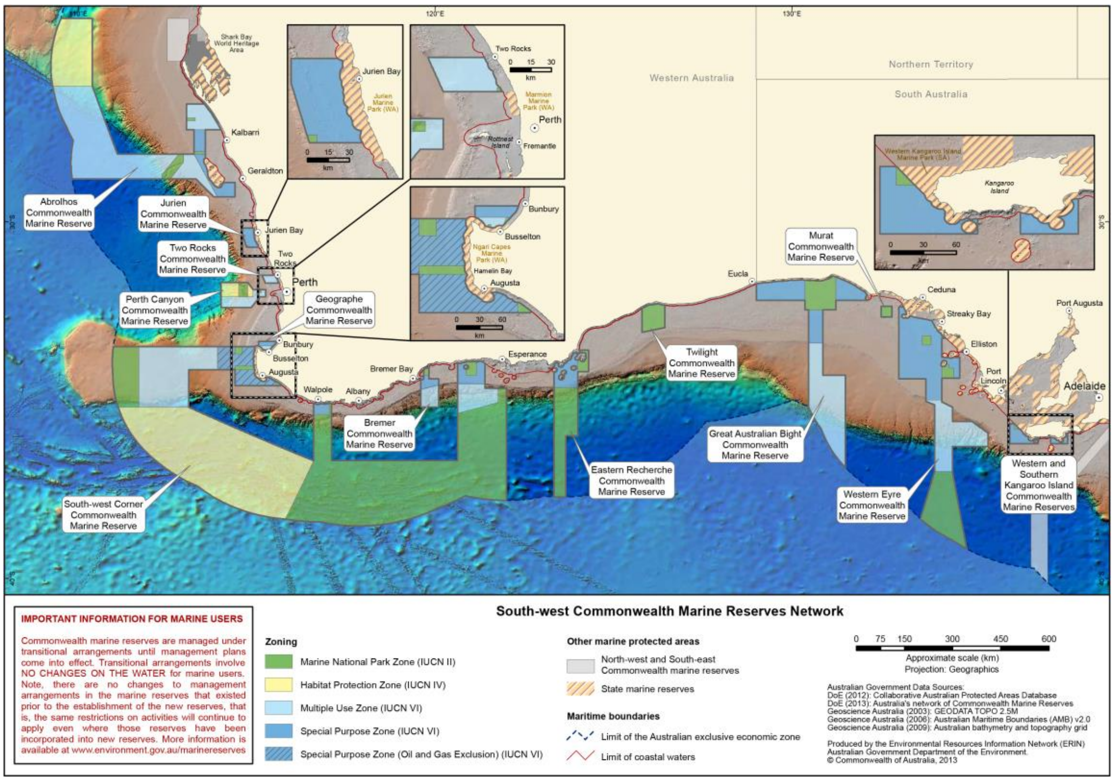

Figure 10.1 – Map of South-west Australia showing the location, size and zoning of the fourteen reserves with the South-west CMR Network

A total of 302 publications and reports relevant to the South-west CMR Network were entered in to the *2016 CMR Literature Review Database*, with the majority of entries (211 out of 302) being peer-reviewed journal articles, and, to a lesser extent, reports (75 out of 302; Figure 10.2). The number of reports relevant to the South-west Marine Region has increased steadily since 2000, with approximately equal numbers of reports (n=41) and journal articles (n=43) being published prior to 2010. There was, however, an exponential increase in the number of publications relevant to the South-west Marine Region in the 6 years since 2010, with 168 new journal articles published during that period (Figure 10.2). Of the 302 entries, approximately half (146 out of 302 entries) were found to be relevant to individual reserves. There is considerable variation in the number of entries relevant to each CMR, ranging from Twilight (2 entries) and Murat (3 entries) to Abrolhos (34 entries) and Great Australian Bight (53 entries).

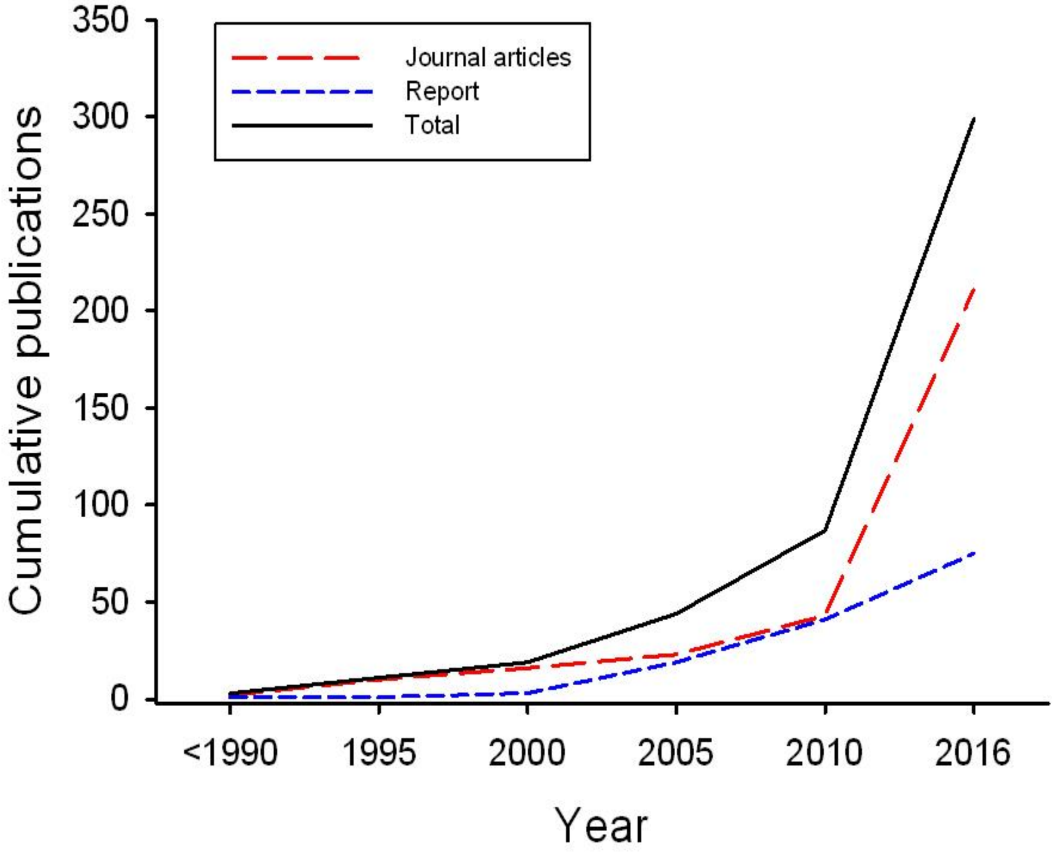

Figure 10.2 – The number of publications relevant to the South-west CMR Network. Lines show the increase in the number of journal articles (red), reports (blue), and total publications (black) from 1990 to 2016.

10.2. BIODIVERSITY VALUES

10.2.1. Key Ecological Features

The South-west Marine Region contains 16 Key Ecological Features (KEFs; Table 10.2). These KEFs are composed of three deep-water canyon systems (West Coast Canyons, Albany Canyons and the Kangaroo Island Canyons), numerous upwellings and unique seafloor features (Diamantina Fracture Zone), diverse benthic habitats (coral reefs, seagrass beds and rocky reefs) and the Western Rock Lobster. The canyon systems are important ecological features because they interact with the Leeuwin and Flinders currents to increase the biological productivity of the region. Interactions between the major current systems and the unique seafloor features (canyons, fractures and pools) creates eddies and upwellings, increasing pelagic production.

Table 10.2 – Key Ecological Features identified for the South-west Marine Region, their location within individual CMR, as identified by the then Department of the Environment, Water Heritage and the Arts (2007).

Key Ecological Feature	Relevant CMR	Main pressures
1. West Coast Canyons and adjacent Shelf Break	Perth Canyon	Climate change (increasing SST, acidification), bottom fishing
2. Diamantina Fracture Zone	South-west corner	Climate change (increasing SST, acidification), deep water trawl fishing
3. Albany Canyons Group and adjacent shelf break	South-west corner	Climate change (increasing SST, acidification), deep water trawl fishing
4. Kangaroo Island Canyons and adjacent shelf break	Western and Eastern Kangaroo Islands	Climate change, fishing,
5. Kangaroo Island Pool and Eyre Peninsula upwellings	Western Kangaroo Island, Western Eyre	Climate change, fishing, marine debris, aquaculture
6. Meso-scale eddies (several locations)	Abrolhos, Jurien, Perth Canyon, Eastern Recherche, SW corner, Eyre Peninsula	Climate change (increasing SST, changing oceanography), fishing
7. Naturalist Plateau	South-west corner	Climate change (increasing SST, changing oceanography), fishing
8. Commonwealth waters within and adjacent to the west coast inshore lagoons	Jurien and Two Rocks	Fishing, commercial and recreational vessel use, coastal development and runoff
9.Commonwealth waters surrounding Houtman-Abrolhos Islands	Abrolhos	Climate change (increasing SST, changing oceanography), fishing
10. Commonwealth waters within and adjacent to Geographe Bay	Geographe	Fishing, commercial and recreational vessel use, coastal development and runoff
11. Commonwealth waters surrounding the Recherche Archipelago	Eastern Recherche	Climate change (increasing SST, changing oceanography), fishing, aquaculture
12. Cape Mentelle upwelling	South-west corner	Climate change (increasing SST, changing oceanography), fishing
13. Western Rock Lobster	Abrolhos	Climate change (increasing SST, changing oceanography), fishing
14. Small pelagic fish of the south west marine region	Not currently defined but important in GAB	Fishing
15. Demersal slope fish communities of the Central Western Province	Two Rocks, Jurien and Abrolhos	Fishing

The Perth Canyon system is one of Australia's largest underwater canyons. It supports high productivity feeding aggregations (e.g. blue whale, whale shark) and highly diverse fish communities. A recent study using pelagic baited stereo-video cameras around the canyon system identified the distribution of mid-water fishes and sharks. For some species, video results indicated the preferred habitat range extended further than the Perth Canyon CMR boundaries (Bouchet and Meeuwig 2015). Limited information was available on the Albany Canyon and Diamantina Fracture Zone, with the former known to be an important aggregation site for Orange Roughy.

The Great Australian Bight (GAB) benthic communities, Kangaroo Island Pool and Eyre Peninsula Upwelling's support high productivity, biodiversity and endemism. Benthic communities of the GAB are one of the most studied areas in the South-west CMR. Benthic surveys of the GAB continental shelf identified 797 species (dominated by porifera, ascidians and bryozoans) suggesting it supports one of the world's most diverse soft sediment systems (Ward et al. 2006). Several studies confirmed the location of the Benthic Protection Zone within the GAB CMZ is effectively placed to protect a representation of these benthic communities (Ward et al. 2006; Currie et al. 2007). The unique northern boundary Flinders Current intersects these KEF's generating plumes and seasonal upwelling's, which support important fisheries (e.g. Southern Bluefin Tuna, Sardines, Shark) (Willis and Hobday 2007).

Waters adjacent to the Houtman-Abrolhos Islands contain the southern-most coral reef in the Indian Ocean. The reef system contains high biodiversity with ~184 species from 42 genera (Veron and Marsh 1988). The influence of the Leeuwin Current transports tropical species to this location resulting in a mix of temperate and tropical fauna and flora. Similar to the GAB, this KEF is potentially the most well studied location within the western margin of the South-west Marine Region.

Geographe Bay, Jurien and Two Rocks provide important inshore habitats for fisheries species and benthic communities. Seagrass meadows within Geographe Bay and Jurien support large seagrass meadows, which provide habitat for diverse macrobenthic communities and nursery habitats for fish (Parfitt and Whisson 2013). Almost all locational KEF's to some extent provide seasonal calving habitat for the threatened southern right whale (Bremer, Eastern Recherche, Twilight, Great Australian Bight and Western and Southern Kangaroo Island); foraging habitat for breeding colonies of the threatened Australian sea lion (Abrolhos, Jurien, Two Rocks, South-west Corner, Bremer, Twilight, Great Australian Bight, Western Eyre and Western and Southern Kangaroo Islands); foraging habitat for the broad-ranging threatened white shark, blue whale, Indian yellow-nosed albatross and soft-plumaged petrel, and for several species of migratory seabirds (Jurien, Two

Rocks, Geographe Bay, South-west Corner, Twilight, Murat and Western Eyre); and resting places for migrating humpback whales, feeding areas for sperm and killer whales, and a migration route for threatened blue whales (Abrolhos, Jurien, Two Rocks, South-west Corner, Perth Canyon, and Western Eyre) (adapted from Director of National Parks 2013 – *South-west Commonwealth Marine Reserves Management Plan 2014-2024*).

10.2.2. Significant Marine Species

The South-west Marine Region encompasses key habitats and supports populations of several threatened and/or conservation dependent species. These include at least 38 species of whales and dolphins (see Table 4.3.1 in McClatchie et al. 2006), over 832 demersal fish species (McClatchie et al. 2006), and 189 ascidians (South-West Marine Bioregional Plan 2007). Notably 105 species protected under the EPBC Act are known or likely to occur in the South-west Marine Region. Of these, 26 species are listed as threatened, including five endangered species, 20 vulnerable and one (Orange Roughy) listed as conservation dependent.

The Department of Environment and Energy, National Conservation Values Atlas (http://www.environment.gov.au/topics/marine/marine-bioregional-plans/conservation-values-atlas) identifies Biologically Important Areas (BIAs) for 23 species within the South-west CMRN (Table 10.3). These include 17 species of seabirds, four species of whale, the Australian sea lion, and White shark (Table 9.3). Most of the BIA's in the South-west CMRN are identified as important foraging grounds for seabirds and marine mammals, and many of the coastal areas as important breeding sites for the Australian sea lion, and calving areas for the Southern right whale (Table 10.3).

Australian Sea lion

The Australian Sea Lion is listed as threatened under the EPBC Act 1999. The South-west Marine Region contains all of the current extant breeding and feeding grounds for this species extending between the Abrolhos and the Pages Islands in South Australia (McClatchie et al. 2006). At least 50 islands, 27 in Western Australia and 23 in South Australia, are important breeding sites (Gales et al. 1994). Distinct colonies that may be only 10 km apart can display asynchrony in the timing of their breeding, in some case ~ six months apart (see Figure 4.17.3 in McClatchie et al. 2006). Within the GAB the Australian Sea Lion is exposed to entanglement and bycatch mortality within shark gill-nets that are set within foraging grounds (e.g. Bunda Cliffs) (Hamer et al. 2009) and lobster pots around the Abrolhos.

Table 10.3 – Biologically Important Areas identified for species listed under the EPBC Act for the South-west Commonwealth Marine Reserves Network (source Department of Environment and Energy, National Conservation Values Atlas). Letters refer to biological activities relevant to each of the eight reserves. *a* - aggregation, *b – breeding, c – calving, d – distribution, f – foraging, m migration*

	Abrolhos	Bremer	Eastern Recherche	Geographe	Great Australian Bight	Jurien	Murat	Perth Canyon	Southern Kangaroo Island	South-west corner	Twilight	Two Rocks	Western Eyre	Western Kangaroo Island
Seabirds														
Australian lesser noddy	f													
Black-faced cormorant			f							f			f	
Bridled tern	f	f		f		f				f		f		
Caspian tern	f	f	f			f				f		f	f	f
Common noddy	f					f						f		
Fairy tern	f	f	f			f			f			f	f	f
Flesh-footed shearwater		f	f	a						f				
Great-winged petrel		f	f							f	f			
Indian yellow-nosed albatross		f								f				
Little penguin		f	f							f			f	
Little shearwater	f	f	f	f		f		f		f	f	f		
Pacific gull	f	f	f	f	f		f		f	f	f	f	f	f
Roseate tern	f					f						f		
Short-tailed shearwater		f	f		f		f			f			f	f
Soft-plumaged petrel						f		f		f		f		
Sooty tern	f							f		f		f		

Wedge-tailed shearwater	f			f		f				f		f		
Marine mammals														
Australian sea lion	bf	bf	bf		bf	bf	f		bf	bf	f	f	bf	bf
Blue whale								f		f				
Humpback whale	m	m		m		m		m		m		m		
Pygmy blue whale	fm	d	d	d	d	fm		fm		fm		d	d	f
Sperm whale					f			f		f			f	
Southern right whale		c	c	c	c				c	c	c	c	c	c
Sharks														
White shark	f	f	f		f	f			f	f	f		f	f

Western Rock lobster

The Western Rock Lobster (WRL) is a KEF for the South-west Region due to its key role in the food web on the inner shelf of the west coast. Movement and settlement of WRL young is strongly linked to the Leeuwin current, with greater settlement when the current is at its strongest (outside ENSO years) (Feng et al., 2003). This species is the dominant large benthic invertebrate in this bioregion and forms the basis of one of Australia's most valuable commercial fisheries. Studies by Bellchambers et al. (2013) and Bellchambers and Pember (2014) identified a strong association between WRL abundance and the presence of *Eklonia* and sponges. This suggests these habitat indicators may provide cost effective indicators of WRL presence especially in deep water sites >40m.

Endemic species

Due to its long period of isolation from other continents and the influence of cold and warm water currents converging, the area between Jurien and the Recherché Archipelago forms on of the 18 major centers for endemism (Tuya et al. 2001). The marine flora of southern Australia is highly diverse with approximately 1000 species of benthic macroalgae. Over 50% of all genera were found to be endemic to the southern bioregion (Kerswell 2006). Surveys by Smale et al. (2011) identified one third of the total 1000 species of macroalgae within their study area between Kalbarri and the Eastern Recherché Archipelago. Species richness increased toward the cooler Recherché Archipelago.

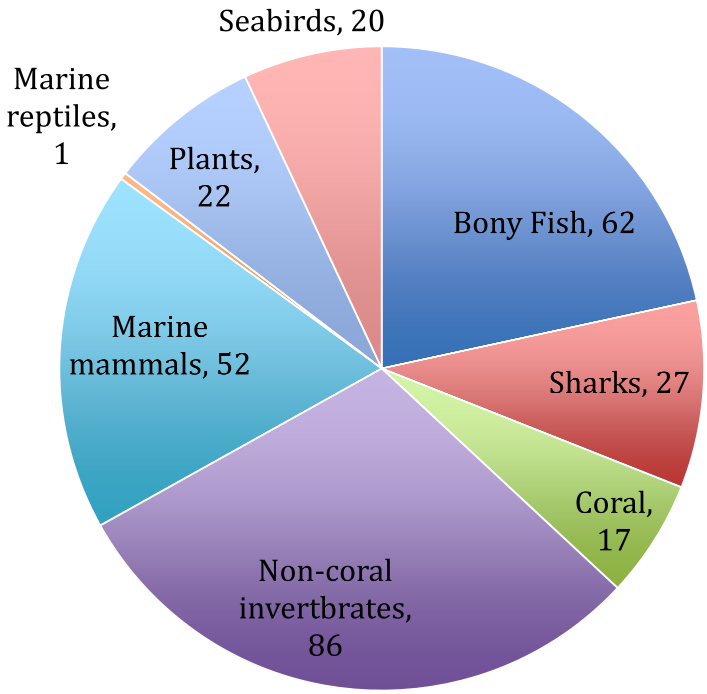

Figure 10.3 – The number of entries (publication and reports) in the *2016 CMR Literature Review Database* that are relevant to each of eight species groups in the South-west CMR Network. Non-coral invertebrates includes crustaceans, echinoderms, molluscs, sponges; marine mammals includes cetaceans, pinnipeds, and dugongs; marine reptiles includes turtles and sea snakes

10.2.3 Biological Communities

Within the South-west CMRN and adjacent waters non-coral invertebrates (86 entries), bony fish (62 entries), and marine mammals (52 entries) were the most commonly investigated species groups (Figure 10.3). There were relatively few entries that related to sharks (27 entries), marine plants (22 entries), seabirds (20 entries) or marine reptiles (1 entry).

Benthic communities

Thirty-nine studies were identified that documented aspects of benthic communities within the South-west Marine Reserve with 15 of these within the GAB. On the west coast the studies of consequence, which documented benthic communities in areas previously underrepresented include: Kendrick and Rule 2014 (Marmion, Two Rocks – publication includes a checklist of 71 species which include 12 endemics); Twomey and van Ruth 2006 (Extensive species lists for invertebrates and fish).

Fish Communities

The majority of articles on fish communities concentrated on species important to fisheries. The western blue groper (*Achoerodus gouldii*) is targeted recreationally and is the largest permanent-resident reef fish in southern Australian waters (Bryars et al. 2012). Bryars et al. 2012 found that even small no-take reserves effectively protected the western-blue groper due to its high site fidelity and small home range. Demersal fish species within the South-west Marine Reserve cover a range of depths and habitats. Some are habitat dependent, while others split their life between nursery habitats and completely different adult habitats (e.g. King George Whiting, Spangled Emperor, Pink Snapper and some leather jackets) (McClatchie et al. 2006). This transition highlights the need for well-connected marine reserves that protect a range of representative habitats.

An increasing number of fish monitoring programs (19 in total) use modified baited underwater video, pelagic floating video devices and ROV's to document the distribution and abundance of fish species (in shallow and deep habitats) (e.g. Bornt et al. 2015, Birt et al. 2012, Bouchet 2015, Langlois et al. 2012). BRUV's enable day and night surveys, highlighting important changes in fish assemblages at night. Nocturnal fish assemblage data is expected to improve management effectiveness assessments for open and closed fishery areas (Harvey et al. 2012).

Whales

The South-west marine region supports numerous cetaceans due to its proximity to the southern ocean, numerous upwellings and eddies. In the summer months blue whales congregate to feed at several of the KEF's (e.g. Kangaroo Island and the Perth Canyon (Gill et al. 2011). Surveys have also detected feeding of the blue, humpback and southern right whales in Geographe Bay (Burton 2003, 2004). Of all the whale tracking studies identified within this review the Perth Canyon, Albany Canyon, Recherché Archipelago and the Kangaroo Island upwellings appear to be important hotspots (see Connectivity section below).

Seabirds

Within the Houtman-Abrolhos (e.g. Rat Island), seabird populations appear to be recovering following a series of historical impacts (guano mining, introduced cats and rats), which decimated seabird populations. A 10-year monitoring program (2003-2013) documented the steady increase in seabirds (including Pacific/Silver Gulls, several species of Tern, and the White Faced Storm Petrel) with 2011-12 recording a significant increase in the number of breeding pairs (Dunlop et al. 2015). Alternatively, tagging studies of Little Penguins (ranging between Rottnest to Geographe Bay) found lower breeding success in 2015 compared with the long-term average (Cannell 2016). This was attributed to warmer than average sea temperatures (See Climate Change section below).

10.2.4 Ecological Processes

Connectivity

Connectivity among canyon systems and KEFs is strongly influenced by the Leeuwin current and the Flinders current. A study that used brittlestar larvae as a model species found exchange among canyons to be unidirectional around Cape Leeuwin, and extending into the GAB (Kool et al. 2015). Some self-retention did occur within canyon systems but if larvae made it to the canyon top they showed high dispersal ability (potential could be dispersal ~550km in 33 d, or 20 km in 5 d when weighted) (Kool et al. 2015).

Large and/or more mobile species appear to have greater connectivity among locations. The Leeuwin currents' influence in the southwestern region drives the distribution of juvenile Southern Bluefin Tuna (SBT) (Fujioka et al. 2012). When the intrusion of the current over the shelf is spread wide juvenile Tuna move quickly out of local foraging habitats suggesting an aversion to the cooler low productivity waters (Fujioka et al. 2012). Departure of adult SBT were also observed in a tagging study around upwellings in the GAB once water temperatures decreased (Willis and Hobday 2007).

Several studies documented the migration and movement of cetaceans (blue whale, Gill et al 2011; pygmy blue whale, Andrews-Goff et al. 2014, Double et al. 2012; sperm whales, Johnson et al. 2013) indicating connected migration routes along the coastline from Indonesia, the west coast canyons (in particular the Perth Canyon), the southern canyons upwellings and the Bass Strait. Conversely genetic studies suggest the southwestern Southern right whale stock to be a distinct stock from the south-east, however it appears recent reproductive interchange between these stocks may be occurring increasing their connectivity (Carroll et al 2011.)

Productivity

Despite the potential importance of productivity in shaping ecological communities in the South-west marine region we didn't identify any papers that directly quantified oceanic productivity in this region.

Resilience

Several species and habitats within the South-west Marine Region display traits that confer resilience. For example, the seagrass *Amphibolis griffithii* can modify its leaf shape mid-canopy and shunt reserves to the top canopy in response to low light levels (e.g. as a result of run-off, dredging etc) (McMahon and Lavery 2014). Manipulative shading experiments of the seagrass in Jurien Bay showed a strong recovery potential following 3 months of light stress (McMahon et al. 2011), however recovery decreased if the stress persisted for 6–9 months. Species with longer life spans and fewer young take longer to 'bounce back' following disturbance. The southern right whale is showing signs of population recovery following historical whaling pressure, which reduced the population by ~150,000 (Carroll et al. 2011). However the Australian Sea Lion is not recovering to the same extent with current pressures from fisheries bycatch (e.g. Shark gillnet fishery) affecting populations and pup outputs (Hamer et al. 2011, Shaughnessy et al. 2011).

In contrast, coral communities within the Houtman-Abrolhos appear to have limited scope for recovery following persistent disturbances such as increasing bleaching events. Houtman-Abrolhos coral reefs are largely self-seeding, with limited sourcing potential from northern reef systems (Babcock et al. 1994, Markey et al. 2016). Kelp, another important habitat forming species also showed signs of stress (extensive epibiosis) with limited recovery following the bleaching event in 2011 (Smale and Wernberg 2012).

10.2.5. Benthic habitats

Very few database entries were identified that specifically mapped benthic habitats (as opposed to biological communities) in the 2011-2016 period. Of few studies that have been conducted, two were aimed at mapping habitats for the Western Rock Lobster in 40-100m deep waters (Bellchambers et al. 2013, Bellchambers and Pember 2014), and compared the effectiveness of towed video versus multibeam acoustics (Bellchambers et al. 2013).

10.3. ACTIVITIES AND PRESSURES

Fisheries

Over 20 Commonwealth and State commercial fisheries targeting both pelagic and demersal fishes and invertebrates, and using a range of gears operate within the commonwealth waters of the South-west Marine Region. These include the western rock lobster, Southern Bluefin Tuna Fishery, Shark Fishery, deepwater Trawl (Kompas et al. 2012) and abalone. These together with the recreational and charter fishing operations in areas closer to the coast (with the highest density north of Perth) place considerable pressure on targeted species.

Of the 299 publications and reports directly relevant to the South-west CMR Network, 122 relate (directly or indirectly) to anthropogenic activities and pressures. Over half of this research is focussed on a broad variety of fisheries-related pressures (Figure 10.3), such as the bycatch of sea lions by the western rock lobster and shark gillnet fisheries (e.g., Goldsworthy et al. 2010), effectiveness of the GAB trawl fishery and its bycatch footprint (Knuckey and Brown 2002); entanglement of whales in long lines (Kemper et al. 2008), and remaining effects from historical fisheries (e.g., sea lions Berry et al. 2012).

The South Australian Sardine Fishery in the GAB is Australia's largest fishery by mass of catch (Goldsworthy et al. 2013). Given its proximity to the coast and sea lion foraging sites (Eyre Peninsula and Kangaroo Island) it has the potential to impact on high-level predators. Goldsworthy et al. (2013) developed the first trophic model of the eastern GAB which highlighted the importance of small pelagic fish to the higher trophic levels and, despite rapid growth of the sardine fishery since 1991, model results suggest negligible impacts on other trophic groups.

Climate change

Similar to the North-west CMR Network to the north and South-east CMR Network to the east, the importance of global climate change to Australia's marine ecosystems is evident by the high number of entries (29 out of 122) that explore changes in environmental conditions (mostly increasing temperature) and effects on marine species (e.g., earlier spawning of the WRL leading to a mismatch with key food sources de Lestang et al. 2016) within the South-west Marine Region.

The Western Australian coast experienced a marine heat wave in 2011 with the Houtman-Abrolhos corals bleaching for the first time in recorded history (Markey et al. 2016). An analysis of long-term trends (1900-2011) for the marine climate at this location found the 2011 event led to temperatures 4.2 degrees above normal thresholds (Abdo et al. 2012). This study predicts the potential for future marine heat waves. Given the Houtman-Abrolhos is largely depended on self-recruitment (with limited large-scale larval input from tropical climes) (Markey et al. 2016) this could pose serious threats to the stability and resilience of this high latitudinal coral reef system.

Seabird populations are also showing signs of stress from increasing sea temperatures. A model using 20 years of data predicts future increases in sea temperature will reduce the breeding success of little penguins on the west coast (between Perth and Geographe Bay), as was seen in 2015 when temperatures were above average (Cannell et al. 2012). Current climate forecasts predict stronger El Niño-Southern Oscillation and weaker Leeuwin currents – which will affect the strength of upwellings and important feeding aggregations for many threatened and endangered species. Flesh-footed Shearwater populations are declining and it is predicted competition for resources will increase under this forecast (Bond and Lavers 2014).

Increased sea surface temperatures will influence range extensions of species, similar to the Temperate East. The endemic fish species *Choerodon rubescens,* have been found in areas to the south of their range where they were previously absent. This range extension coincided with a 2 degrees increase in southern habitats (Cure et al. 2015). Cheung et al. (2012) predicted the rate of poleward shifts of 'tropical' species in the South-west to progress at a median rate of ~19 km decade–1 and 9 m deeper decade–1 by 2055. There are likely to be species gains and losses with significant changes in the functioning of marine systems and the social and economic values tied to them.

Collectively, these studies demonstrate the marked influence of both acute and chronic increases in temperature in the South-west Marine Region, however, there is a general lack of studies investigating other likely effects of climate change, such as ocean acidification, changes in foraging patterns, hypoxia, and habitat fragmentation.

Other pressures and activities

The remaining pressures and activities identified for the South-west Marine Region in the *2016 CMR Literature Review Database* are varied. These pressure included oil and gas (5 entries), dredging and coastal development (9 entries), pests (1 entry), and a range of other activities (23 entries) such as the impact of cage diving on Great White Sharks (Bruce and Bradford 2013; Techera and Klein 2013), the impact of commercial whale watching (Bruce et al. 2014), oil spills resulting from exploration in the GAB (Lebreton 2015), release of a virus from aquaculture stock into natural populations (Jones and Fletcher 2012), the longest running annual survey of ocean-based litter in Australia (Edyvane et al. 2004) and illegal fishing (McClean et al. 2011; McLaren et al. 2015).

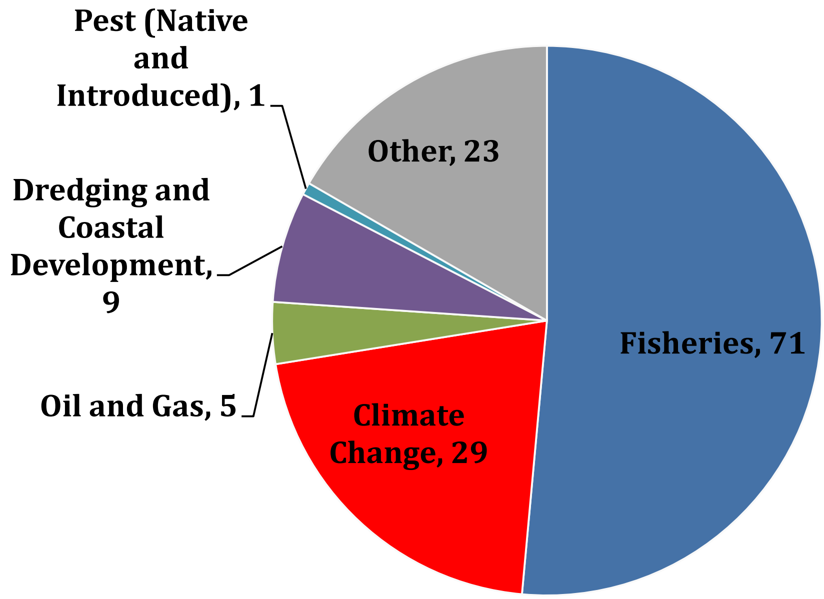

Figure 10.4 – Number of publications and reports that relate (directly or indirectly) to anthropogenic activities and pressures within the South-west CMR Network

10.4. KNOWLEDGE GAPS, FUTURE RESEARCH, AND POTENTIAL INDICATORS

The review of the South-west Marine Reserve literature highlighted several knowledge gaps, future research priorities and to a lesser extent potential indicators. These are listed below taking into consideration the nine research priority themes set to facilitate "robust, evidence-based decision-making for the management of [Commonwealth] marine reserves" as identified by Beeton (2016).

Key Knowledge Gaps:

- Long-term monitoring of key habitats and species (e.g. Australian Sea Lion, coral reef ecosystem at Houtman-Abrolhos). There were short-term (2-3 yr) studies on specific species however the methods between disparate studies reduced the ability to compare trends (Key research theme #6 Beeton 2016). Programs similar to the AIMS Long-term monitoring program for tropical reefs should be considered for key benthic habitats throughout the South-west CMR Network.

- Lack of species-specific data for sharks in fishery statistics and market sales make it difficult to estimate shark catches or landings (e.g. *Squatina tergocellata*).

- Surveys to identify and monitor invasive species to inform early detection and rapid response.

- Studies to better understand biological and hydrographical connectivity within and among CMRs (Key research theme #9 Beeton 2016).

Future Research (note also Key Knowledge Gaps):

- Fisheries gear modifications and improvements to reduce and compulsorily monitor bycatch of species of conservation concern, or ecologically important species within CMR boundaries.

- If deep-water benthic communities are to be protected they need to be adequately documented and their conservation values assessed (noting the GAB benthic population within the Benthic Protection Zone has been well studied).

- Connectivity studies to monitor and predict poleward shifts of species following increased sea surface temperature and changes to current systems.

Potential Indicators

Marine ecosystems with the South-west CMR Network are facing a range of pressures and threats from climate change and direct anthropogenic activities (see Activities and Pressures above). Potential indicators may be developed, and some are suggested here, but it must be remembered that an indicator species will be specific to a particular habitat type and the pressure/s it is facing.

Significant marine species

As stated previously, indicators for any species of conservation concern (threatened or endangered, endemic, or exploited species) would include changes in the abundance and age/size structure of populations. Where possible, they would greatly benefit from the inclusion of population demographic rates (e.g., births or recruitment, mortality rates, etc) to allow predictions of the vulnerability and resilience of the species to various pressures. Species that could be potential indicators in this category include: the Southern right Whale, pygmy blue whale, Little Penguin (numbers declining), the Australian Sea Lion, and Western Rock Lobster.

Biological communities

Many biological communities and even entire ecosystems are shaped by the abundance and composition of foundation (or habitat-forming) species, and many of these are sensitive to a range of climate and anthropogenic stressors.

For biological communities the following are suggested as potential indicators for some habitats within the South-west CMR Network: Australian anchovy and sardine (important prey species within marine foodwebs and important fisheries species), key functional groups (e.g. herbivores, top predators), Western Blue Groper (*Achoerodus gouldii*), Baldchin Groper (*Choerodon rubescens*) (studies suggest this endemic species is a valuable indicator of tropicalisation of temperate communities), habitat forming coral species, endemic macroalgae and kelp, seagrasses (Geographe Bay in particular).

11. Case Studies Of Individual Commonwealth Marine Reserves

11.1 NORTH-WEST CMR NETWORK: ASHMORE REEF

Ashmore Reef is an exposed open ocean platform reefs located on the North-western edge of the Sahul Shelf in North West Australia. Ashmore Reef (12° 17′S, 123° 02′E) is approximately 583 square kilometres and comprises three small vegetated islands, a number of sand cay, two lagoons and extensive reef

Ashmore Reef Commonwealth Marine Reserve supports extremely high biodiversity with regionally and internationally significant fauna including marine invertebrates (coral, sponge, mollusc, crustacean, echinoderm and others), reef and pelagic fish, dugongs, turtles, sea snakes, seabirds and shorebirds. Ashmore Reefs occurs in a unique isolated oceanic location meaning that these systems are relatively undisturbed compared with many other coral reefs around the world.

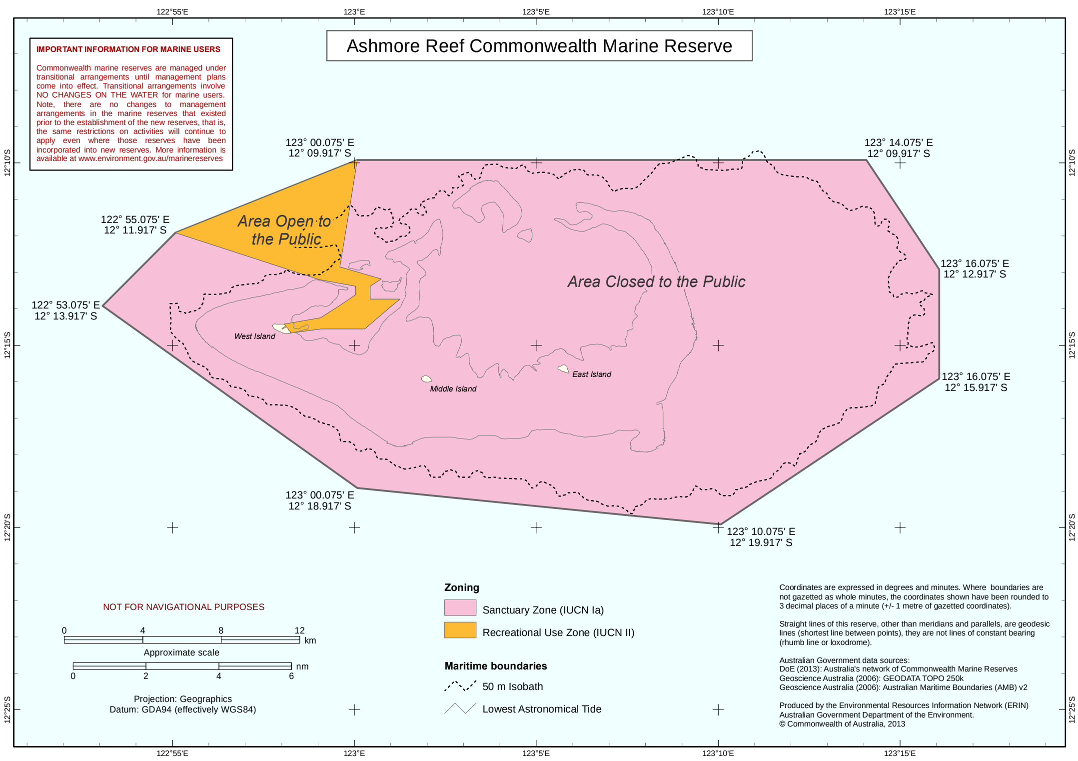

Figure 11.1.1: Ashmore Reef Commonwealth Marine Reserve, source: environment.gov.au

Ashmore Reef CMR is included on the Register of the National Estate and included on the World Conservation Union (IUCN) list of Coral Reefs of International Significance. Ashmore Reef is also a Ramsar site (Commonwealth of Australia

2008). The waters surrounding Ashmore Reef are a Marine National Park Zone (IUCN I and II).

A total of 62 entries (publications and reports) relevant to the Ashmore Reef CMR were entered in to the *2016 CMR Literature Review Database*.

11.1.1 BIODIVERSITY VALUES

Key Ecological Features

Ashmore Reef (and nearby Cartier Island) and surrounding Commonwealth waters are recognized as a KEF because of their "high productivity and aggregations of marine life". Ashmore Reef is the largest emergent oceanic reef in the north-eastern Indian Ocean and the only oceanic reef in this region with vegetated islands. Ashmore Reef is regionally important for foraging and breeding for seabirds and also supports the highest diversity of corals in Western Australia.

Significant Marine Species

Seabirds – Ashmore Reef is a Biologically Important Area (BIA) for nine species of seabirds (Table 5.3), many of which (including the brown booby, greater frigatebird, lesser frigatebird, red-footed booby and wedge-tailed shearwater) breed at Ashmore Reef.

Dugong – While dugong are generally restricted to coastal environments, a small (< 50 individuals), but genetically distinct population of dugongs is known to occur at Ashmore Reef (Commonwealth of Australia 2008). Despite the importance of these population, there has not been any recent research to assess the persistence or viability of this population.

Sea snakes – Sustained declines in the densities of sea-snakes have been recorded at Ashmore Reef (and across the North-west marine region) over recent decades. In 2009, only two species of Sea Snake were recorded in the current survey (Olive Sea Snake *Aipyurus laevis* and Turtle-headed Sea Snake *Emydocephalus annulatus*) despite 13 species of Sea Snake reported to occur in the Reserves (Wilson and Swan, 2004). The extent and cause(s) of these declines are still not known but generally attributed to environmental change.

Turtles – Ashmore Reef is critical nesting habitats for green turtles, supporting one of three genetically distinct populations in the North-west Marine Region. Loggerhead turtles have also been recorded nesting at Ashmore Reef, while hawksbill turtles forage in the area.

Biological communities

Since 1999, at least six field surveys have been undertaken at Ashmore Reef to quantify coral cover and composition (Skewes et al. 1999; Rees et al. 2003; Kospartov et al. 2006; Richards et al. 2009; Heyward et al. 2011). Despite the number of surveys, establishing specific trends is complicated by differences in sampling methods, especially the specific range of habitats considered. Nonetheless, there is evidence that coral cover has increased or remained stable (Table 11.1.1). Comparable surveys conducted in 2005 and 2009, revealed marked increases in coral cover; The percent cover of hard coral increased from 10.2% in 2005 to 29.4% in 2009, averaged across all habitats (Ceccarelli et al. 2011). This trend likely reflects recovery prolonged following severe bleaching in 1998, and again in 2003. Successive surveys (2010 and 2011) showed that coral cover was high, and there were high levels of coral recruitment, contributing to sustained increases in coral abundance and diversity. The subsequent trend and status of coral assemblages is largely unknown, but there was limited bleaching recorded in 2016.

Table 11.1.1. Benthic surveys undertaken at Ashmore Reef since 1999.

Year	Citation	Extent of surveys	Coral cover
1998	Skewes et al. 1999	Single belt transects at each of >100 sites, including sandy substrate and reef flat	3.16%
2003	Rees et al. 2003	Random swims in diverse habitat types	<5 to >30% depending on habitat type
2005	Kospartov et al. 2006	PIT at 3-5m and 8-10m at 6 sites	10.2% (1.46 SE)
2009	Richards et al. 2009	PIT at 3-5m and 8-10m at 6 sites	29.4% (1.83 SE)
2010	Heyward et al. 2011	Belt transects at 3m and 6m at 8 sites	24.35%
2011	Heyward et al. 2011	Belt transects at 3m and 6m at 8 sites	26.23%

Sustained declines in the abundance of several different taxa including reef fishes (Pomacentridae, Labridae, Scarinae and Siganidae), holothurians, trochus and clams have been recorded at Ashmore Reef, despite documented increases in coral cover. An obvious explanation for these declines would be an increase in mortality rates (e.g., due to fishing and harvesting) across all study sites, though there may also be other explanations.

11.1.2. ECOLOGICAL PROCESSES

Connectivity

Existing research into biological connectivity (e.g., Underwood et al. 2007, 2009) suggests that there is very limited connectivity between Ashmore Reef and other emergent oceanic reefs in the eastern Indian ocean (e.g., Scott Reef).

Resilience

Given limited connectivity, it is likely that biological communities at Ashmore Reef will have very low resilience to any disturbances that simultaneously impact the entire area of Ashmore Reef and Cartier Island CMRs. However, like Scott Reef (see Gilmour et al. 2013) isolation of Ashmore Reef from major anthropogenic disturbances may partially offset the disadvantages associated with limited connectivity to potential source populations following localised devastation of biological communities. Fortunately, these reef systems have been largely spared from major coral bleaching episodes that have occurred in 1998 and 2016, but these systems are nonetheless extremely vulnerable to increasing ocean temperature which will likely cause severe coral bleaching in coming years or decades.

11.1.3 ACTIVITES AND PRESSURES

The main pressures of concern for Ashmore Reef are climate change (in particular ocean warming and associated coral bleaching), as well as illegal, unregulated and unreported (IUU) fishing. Significant and extensive coral bleaching was reported at Ashmore Reef in 1998 and 2003, though the extent of coral mortality that occurred during these bleaching events is largely unknown (because there were no successive surveys to explicitly assess what proportion of bleached corals actually died). It is apparent however, that the severity of coral bleaching recorded at Ashmore Reef was much less than at Scott Reef.

Illegal harvesting and fishing of holothurians, trochus, clams, turtles, sharks and other resources remain a constant threat Ashmore Reef. As such, in April 2008, the Customs vessel, *Ashmore Guardian*, has since provided a near permanent presence at Ashmore, offering an unparalleled level of protection. Since the implementation of this protection, there is evidence of sustained recovery in abundance of key fishery species (e.g., Trochus and sea-cucumbers), but this recovery was largely undermined by declines in abundance of such species during an extended period of limited compliance and enforcement in 2006 (Ceccarelli et al. 2007).

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11.1.4. KEY FINDINGS

Despite its isolation, Ashmore Reef is among the best studied of the CMRs, especially in the North-west Marine Region. This is largely due to the series of ecological surveys commissioned by the Australian Government with the specific objective of assessing the status and trends of reef assemblages, especially corals, reef fishes, trochus and trepang (sea-cucumbers). Even so, there are difficulties in establishing long-term trends in biological communities due to inconsistencies in sampling protocols. Such difficulties, will been even more pronounced if reliant on independent research projects that will likely have very different objectives and sampling protocols.

Recurrent and consistent monitoring is critical to assess the impacts of both historical and emerging threats to reef assemblages at Ashmore Reef (and other offshore CMRs), and thereby inform and facilitate effective long-term management of these unique environments. The benefits of matching previous sampling methods and sites to facilitate rigorous temporal comparisons of biological communities should not be underestimated. Implementation of comparable sampling methods across all CMRs would also enable meaningful spatial and temporal comparisons.

11.2 NORTH CMR NETWORK: JOSEPH BONAPARTE COMMONWEALTH MARINE RESERVE

The Joseph Bonaparte Commonwealth Marine Reserve (CMR) is a 8,597 km^2 multiple use (IUCN Category VI) CMR adjacent to the complex of three estuaries (The Keep, Victoria and Fitzmaurice rivers) in the Joseph Bonaparte Gulf. The Joseph Bonaparte Gulf is comprised mostly of soft-sediment habitat, where epibenthos is sparse (Przeslawski et al. 2011), though there are localized areas of hard substrate with high densities of sessile organisms, including crinoids. Extensive palaeo-river channels up to 150 km long, 5 km wide and 240 m deep, connect the present-day Joseph Bonaparte Gulf ocean basin with the old shoreline at the edge of the shelf (Commonwealth of Australia 2008). The Joseph Bonaparte Gulf is subject to the tidal ranges of up to 7–8 m, creating strong tidal currents that generate high turbidity and considerable movement of sediments.

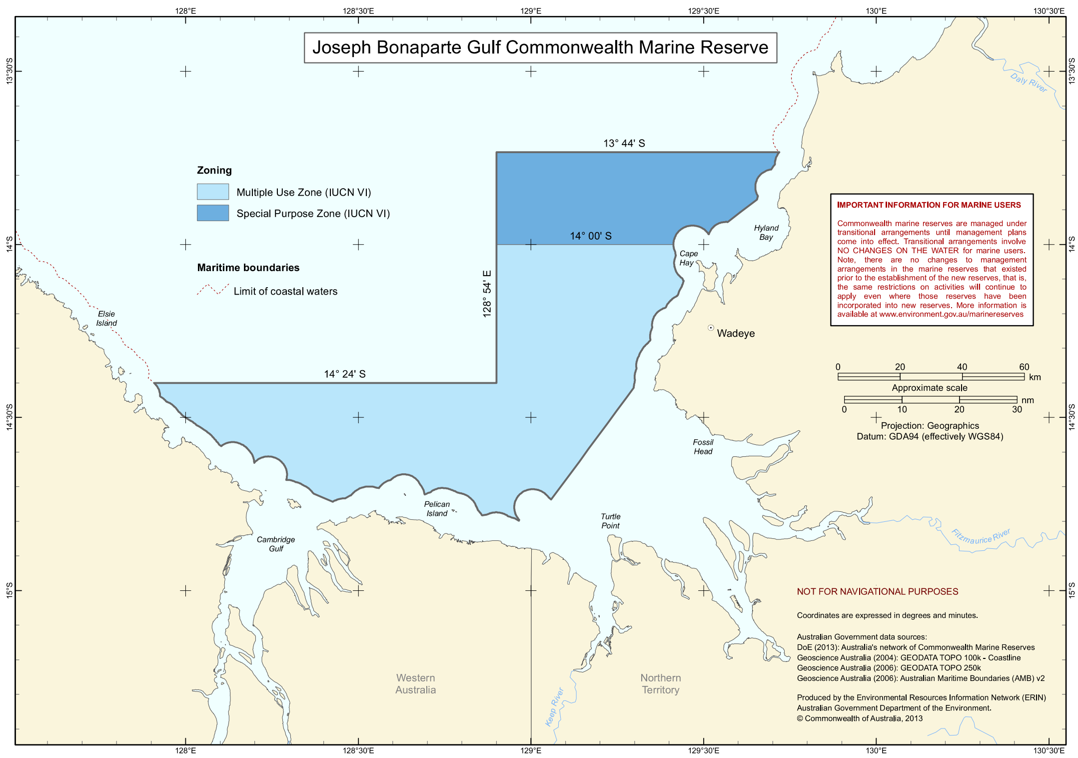

Figure 11.2.1: Joseph Bonaparte Commonwealth Marine Reserve, source: environment.gov.au

Although there have been only very moderate amounts of research undertaken (or at least published) explicitly relating to the Joseph Bonaparte CMR (just 6 entries in the *2016 CMR Literature Review Database*), this is more than has been conducted in any of the other CMRs within the North CMR Network. The predominant focus of this research has been on geomorphic structure (including the distribution of key habitat features and sediment dynamics) and hydrodynamics. The major habitat within the Joseph Bonaparte CMR is also very unique and presents considerable challenges to the conduct of effective monitoring to establish the status and trends of marine species and habitats within this region.

11.2.1 BIODIVERSITY VALUES

Key Ecological Features

One key ecological feature (KEF) is included in the Joseph Bonaparte CMR (carbonate banks of the Joseph Bonaparte Gulf) which is a unique seafloor feature recognized for its enhanced productivity and high biodiversity.

Significant Marine Species

Marine Turtles – the Joseph Bonaparte CMR is an important foraging area for both green and olive ridely turtles. Given the high turbidity and expansive areas of ephemeral habitat, effectively assessing the status and trends in these populations would be extremely challenging.

Australian snubfin dolphin – The Australian snubfin dolphin is endemic to northern Australia and occurs mainly in coastal environments. The major threat to this species is incidental capture in fishing nets and ghost nets. While known to occur in Joseph Bonaparte CMR, the status and trends of this population is unknown

Seabirds - Extensive areas of shorebird and waterbird feeding habitat are associated with the mangroves and mudflats in the Joseph Bonaparte Gulf (Commonwealth of Australia 2008). Significant bird feeding areas are located on the wetlands between the Keep and Victoria River estuaries and north of Fossil Head. Protected migratory species (e.g., terek sandpiper, greater and lesser sand plover, ruddy turnstone, sanderling, broad-billed sandpiper and white-winged tern) occur in large numbers in this area.

Biological communities

Reef-forming hard corals are rare in the Joseph Bonaparte Gulf, with the exception of isolated nearshore coral reefs and mixed coral and sponge gardens on carbonate banks of the Van Diemen Rise. The epibenthic communities across much of the Joseph Bonaparte CMR are extremely sparse owing to strong tidal currents, high turbidity and significant sediment movement.

11.2.2. ECOLOGICAL PROCESSES

Connectivity

The only study of biological connectivity conducted for marine species sampled within the Joseph Bonaparte CMR is for pig-eye sharks (Tillet et al. 2012). Tillet et al. (2012) showed that pig-eye sharks sampled in the Joseph Bonaparte CMR maintain reasonably high levels of genetic exchange with populations sampled through Western Australia, the Northern Territory and even into Queensland. These results may be due to the relatively conserved nature of the molecular markers used, or otherwise suggest that female pig-eye sharks may travel long-distances to interbreed with sharks from other regions.

Resilience

Given the significant environmental stress (strong tidal currents, high turbidity and low light) and highly ephemeral nature of the dominant habitats and associated epibenthic communities within the Joseph Bonaparte CMR, it is tempting to suggest that such communities and habitats would be extremely resilient. There is not however, sufficient information to assess the vulnerability of species or habitats to anthropogenic pressures and changes in environmental conditions within this region

11.2.3 ACTIVITES AND PRESSURES

None of the recent studies conducted within the Joseph Bonaparte CMR were directly relevant to anthropogenic activities and pressures. Studies into the benthic habitat features of the Joseph Bonaparte CMR do relate to climate change, but mostly consider the potential of these features (specifically, pockmarks) to capture carbon and mediate climate change (Nichols et al. 2014).

11.2.4. KEY FINDINGS

The Joseph Bonaparte CMR encompasses unique habitat types, for which effective monitoring protocols and potential indicator species are yet to be established. Current research being conducted within this area is largely focussed on documenting broad-scale habitat features and the types of organisms associated with such habitat features.

11.3 CORAL SEA COMMONWEALTH MARINE RESERVE: FORMER CORINGA-HERALD NATIONAL NATURE RESERVE

The Former Coringa-Herald Reef National Nature Reserve is located 400 km East of Cairns in the Coral Sea. The Former Coringa-Herald Reef National Nature Reserve is 8,852 km^2 encompassing six emergent sand cays with surrounding coral reefs. This area was a former sanctuary zone (IUCN Category 1a), which has now been incorporated into the Coral Sea Commonwealth Marine Reserve (see Chapter 6).

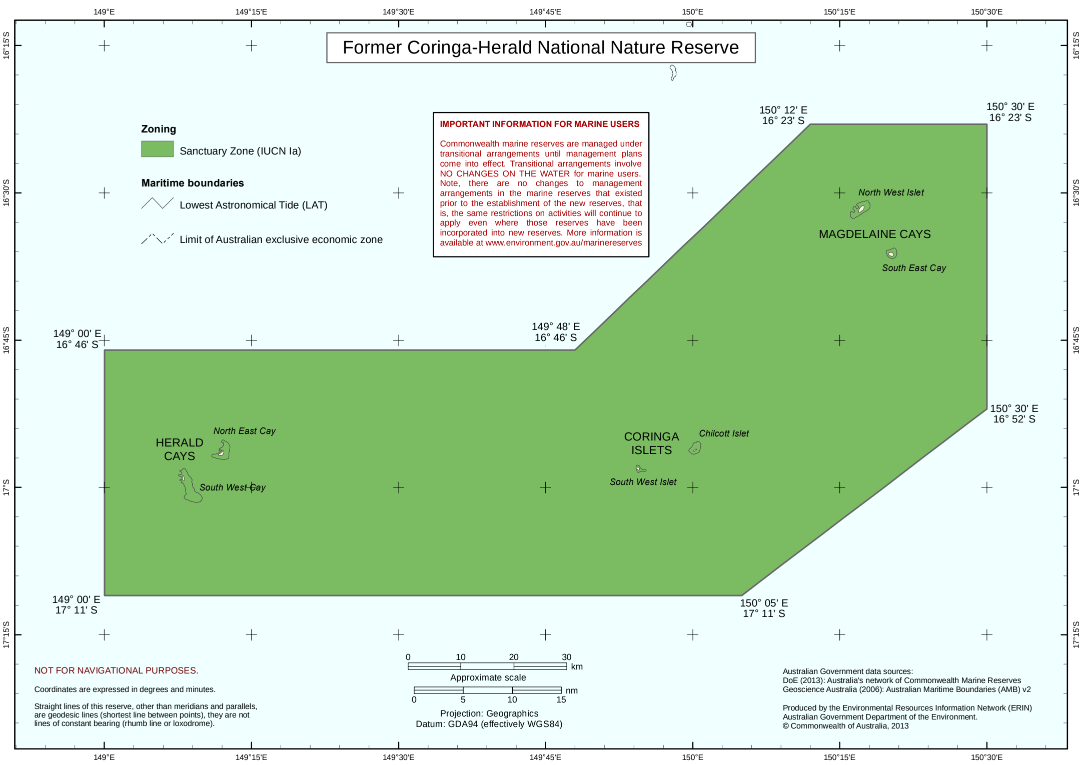

Figure 11.2.1: Former Coringa-Herald Reef National Nature Reserve, source: environment.gov.au

Most research conducted in the Coral Sea has been conducted within the Former Coringa-Herald Reef National Nature Reserve (Ceccarelli et al. 2010). Of the 54 studies entered *CMR Literature Review Database* that related to specific regions within the Coral Sea CMR, most (12/ 54 studies) referred to Former Coringa-Herald Reef National Nature Reserve.

11.3.1 BIODIVERSITY VALUES

Key Ecological Features

The Former Coringa-Herald Reef National Nature Reserve incorporates one of the three recognized KEFs (Reefs, cays and herbivorous fish of the Queensland Plateau) in the Cora Sea CMR.

Significant Marine Species

Sea Turtles – The Coringa-Herald Cays are important nesting habitat for green turtles. Annual monitoring of nesting green turtles since the 1990, have revealed high fidelity, with 75% of tagged nesting females returning within a 4–6-year period (Harvey et al. 2005).

Biological communities

Benthic surveys have been conducted in the Former Coringa-Herald Reef National Nature Reserve at semi-regular intervals since 2003 (Table 11.3.1), with historical estimates of coral cover available from surveys conducted in the 1990s (Ceccarelli et al. 2008). Coral cover declined significantly from 1997 to 2003, possibly due to bleaching in 1998 and 2002 (Oxley et al. 2003), but likely compounded by major cyclones. The persistent low coral cover at Coringa-Herald Cays is probably also reflective of low capacity for recovery, due to isolation and exposure (Ceccarelli et al. 2008).

Table 11.3.1. Benthic surveys undertaken at Ashmore Reef since 1999.

Year	Citation	Extent of surveys	Coral cover
2003	Oxley et al. 2003	50x0.3m belt transects (n=3) at 6 sites. Analysed using CPUE (200 points per transect).	1.9-5.2% depending on Cay
2007	Ceccarelli et al. 2008	20m line-intercept transects (n=8) at 14 sites.	7.3%
2012	Stuart-Smith et al. 2013	50m belt transects (n=) at 9 sites. Analysed using CPUE (100 points per transect).	9%

Densities of macroinvertebrates (e.g., holothurians, tridacnid clams, sea urchins and other molluscs) are comparable to those recorded on other isolated, oceanic reefs (Ceccarelli et al. 2008). However, fish assemblages at Coringa-Herald reefs are extremely depauperate, possibly linked to low cover, diversity and complexity of coral habitats.

11.3.2. ECOLOGICAL PROCESSES

Connectivity

There are yet to be any studies of biological connectivity within and among reefs and cays within the Coral Sea Marine Reserve. This research is critically important in understanding both i) links between the Coral Sea and the Great Barrier Reef, and ii) understanding resilience of biological communities in the Coral Sea (see below).

Resilience

Coral cover in the Former Coringa-Herald Reef National Nature Reserve was reported to be very low (<10%) in 2002 (Oxley et al. 2003) and has shown little change to 2012 (Stuart-Smith et al. 2013). This suggests that either the reefs at Former Coringa-Herald Reef National Nature Reserve are subject to continual pressures or frequent disturbances that continually depress coral cover, and/ or there are significant local constraints on recovery and resilience of coral assemblages. The limited capacity for coral recovery is reflected in the low levels of population replenishment (recruitment) recorded for hard corals in 2007 (Ceccarelli et al. 2008).

11.2.3 ACTIVITES AND PRESSURES

Extractive activities (e.g., fishing) are prohibited throughout the Former Coringa-Herald Reef National Nature Reserve. However, illegal foreign fishing does sometimes occur, and is especially damaging to Coringa-Herald reefs given that local populations are already small, vulnerable and easily depleted (Ceccarelli et al. 2008).

Climate changes (especially increasing ocean temperatures) poses a significant threat to shallow reef assemblages in the Coral Sea CMR, but there are yet to be any specific reports of climatic impacts (e.g., severe coral bleaching) at Coringa-Herald reefs. Oxley et al. (2003) attributed low coral cover to coral bleaching in 1998 and 2002, though there is no empirical data to confirm the occurrence or extent of bleaching at Coringa-Herald reefs. Extensive coral bleaching (affecting 65% of coral colonies) was documented in March 2004 at Lihou Reef (Oxley et al. 2004), but no comparable bleaching surveys were conducted within the Former Coringa-Herald Reef National Nature Reserve.

11.2.4. KEY FINDINGS

The Former Coringa-Herald Reef National Nature Reserve is the best studied system of reefs within the Coral Sea CMR. This is largely due to a series of ecological surveys commissioned by the Australian Government, since 2003, which have revealed persistent low cover and diversity of habitat-forming corals and depauperate fish assemblages. These results point to very limited resilience of biological communities at this location, possibly due to the isolation and very limited connectivity to other viable source populations that are necessary for recovery. Explicit studies of the reproductive viability, growth and survival of corals, as well as investigations into biological connectivity are needed to establish specific limitation on resilience and the prospect for reef assemblages at this location.

11.4 TEMPERATE EAST CMR NETWORK: ELIZABETH AND MIDDLETON REEFS

Elizabeth and Middleton Reefs lie approximately 600 km east of the Australian coast, and are the southernmost platform coral reefs in the world. The reefs are highly isolated, being situated on the peaks of volcanic seamounts surrounded by deep waters (>2000m), and the nearest major coral formations are Lord Howe Island approximately 260 km to the south, and the southern GBR approximately 900km to the north. These high latitude reef systems lie close to the boundary between the Coral Sea and the Tasman Sea, receiving warm tropical water from an extension of the EAC and Tasman Front.

Elizabeth and Middleton Reefs support a unique mix of tropical and subtropical species (ca. 120 species of coral, and 300 species of fish), which are often at their southernmost and northernmost limits, respectively (Choat et al. 2006, Hoey et al 2014). Notably these reefs also support a number endemic species, and because of their isolation support populations of species that are generally rare over most of their range (e.g. Black cod, Galapagos shark).

Elizabeth and Middleton Reefs are protected as a Ramsar site (Lee Long 2009) and form part of The Lord Howe Commonwealth Marine Reserve (covering an area of 110,139 km^2; Figure 8.1), that encompasses the former Lord Howe Island Marine Park (Commonwealth Waters) and the former Elizabeth and Middleton Reefs Marine National Nature Reserve. The waters surrounding Middleton Reef are a Marine National Park Zone (IUCN II), while those surrounding Elizabeth Reef are a Recreational Use Zone (IUCN IV).

A total of 109 entries (publications and reports) relevant to the Lord Howe CMR were entered in to the *2016 CMR Literature Review Database*, with 16 relating directly to Elizabeth and Middleton Reefs.

11.4.1 BIODIVERSITY VALUES

Key Ecological Features

Elizabeth and Middleton Reefs are recognized as a KEF because of their unique location and the diversity of marine life they support, including high levels of endemism. They have also been identified as strongholds for populations of the vulnerable Black Cod *Epinephelus daemelii*, and the Galapagos shark *Carcharinus galapagensis* (Choat et al. 2006, Hoey et al. 2014).

Significant Marine Species

As well as being one of the few remaining strongholds for populations of Black Cod and supporting high densities of Galapagos sharks (described above), Elizabeth and Middleton Reefs are home to numerous endemic species, including the Double-header wrasse (*Coris bulbifrons*), the three-band butterflyfish (*Chaetodon tricinctus*), the Elegant wrasse (*Coris elegans*), the Lord Howe Butterflyfish (*Amphichaetodon lordhowensis*), McCulloch's Anemonefish (*Amphiprion mccullochi*) and the Wide-Band Anemonefish (*A. latezonatus*), as well as many species that are rare elsewhere in Australian waters (e.g. South-Pacific wrasse *Anampses femininus*, and Pacific slopehead parrotfish *Chlorurus frontalis*) (Hoey et al. 2014). Further the Lord Howe CMR supports foraging and breeding BIA's for 18 species of seabird (Table 8.3).

Black Cod (Epinephelus daemelii).

Despite ~ 30 years of protection Black Cod remain rare or absent at all but a few sites along the NSW coast (Malcolm 2011, Harasti and Malcolm 2013). The population of Black Cod on Elizabeth and Middleton Reefs, appears to be the last stronghold for the species in the Temperate East Marine Region, and has remained relatively stable at approximately 2.0 – 2.5 individuals/ha from 2011 to 2014 (Pratchett et al. 2011, Hoey et al. 2014). Given these density estimates were broadly comparable among habitats, this equates to a local population in excess of 4,000 individuals on these two reefs.

Endemic species

Species with restricted geographic ranges (i.e., endemic) are often highly specialised and present in low densities, and thus assumed to be at a high risk of extinction. Interestingly, the butterflyfish *Chaetodon tricinctus,* endemic to Lord Howe, Elizabeth and Middleton Reefs and Norfolk Island, is the single most abundant species of butterflyfish on Elizabeth and Middleton Reefs (e.g., Hoey et al. 2014). Although, the available data suggests that there have been no significant changes in the abundances of endemic fishes (Elizabeth and Middleton Reefs: Choat et al. 2006, Hobbs et al. 2007, Pratchett et al. 2011, Hoey et al. 2014), their restricted ranges and reliance on self-replenishment make these species highly susceptible to disturbances and/or habitat loss.

Biological communities

Despite its isolation there has been ten ecological surveys conducted at Elizabeth and/or Middleton Reefs since 1979 (Table 11.4.1). Many of these studies were commissioned by the Australian Government as part of the mandated monitoring of these unique shallow water habitats. This body of work has been critical in providing comprehensive assessments of the shallow water biological communities (primarily fish and corals), the detection of any 'new' or range extending species, and perhaps most importantly the detection of temporal patterns in key fish and benthic groups. These temporal comparisons were facilitated by the use of consistent methodology and the repeated use of some survey sites during period 2006-2014 (Choat et al. 2006, Hobbs and Feary 2007, Pratchett et al. 2011, Hoey et al. 2014). The latter two studies used identical survey sites.

Table 11.4.1. Marine surveys undertaken at Elizabeth and/ or Middleton Reef since 1979. For a comprehensive overview of surveys conducted prior to 1979 see Australian Museum (1992).

No.	Year	Locations	Purpose	Reference
1	1979	Elizabeth & Middleton	Coral diversity	Australian Museum 1992
2	1981	Middleton	Assess impacts of COTS	Harriot 1998
3	1984	Elizabeth & Middleton	Coral diversity	Australian Museum 1992
4	1987	Elizabeth & Middleton	Biodiversity assessment	Australian Museum 1992
5	1994	Elizabeth & Middleton	Marine ecological survey	Choat et al. unpublished data
6	2003	Elizabeth	Marine ecological survey	Oxley et al. 2004
7	2006	Elizabeth & Middleton	Marine ecological survey	Choat et al. 2006
8	2007	Elizabeth & Middleton	Rapid assessment of reef health	Hobbs and Feary 2007
9	2011	Elizabeth & Middleton	Marine ecological survey	Pratchett et al. 2011
10	2014	Elizabeth & Middleton	Marine ecological survey	Hoey et al. 2014

A total of 356 species of reef fish have been recorded from Elizabeth and Middleton Reefs, including 10 new records during the most recent ecological survey (see Appendix 1 in Hoey et al. 2014). Several early studies estimated the number of coral species on Elizabeth and Middleton Reefs to be in the vicinity of 110-120 species (Australian Museum 1992, Oxley et al. 2004), however there have been no subsequent rigorous assessments of coral species diversity on these reefs.

Both benthic and fish communities on Elizabeth and Middleton Reefs show considerable differences between reefs, among habitats (back reef, lagoon, reef front; Fig. 11.4.1), and among sites within a habitat (e.g., Hoey et al. 2014). Such variation in characteristic of ecological systems and highlights the benefit of having fixed sites for examining temporal trends. Comparisons of coral cover across fixed sites (for which the data was available) reveal important insights into both the history and recovery of these communities. For example, coral cover on the exposed reef front on Middleton Reef has been gradually been increasing from a low of ca 3-12% cover in 1994 to 15 to 28% at the same sites in 2014 (Figure 11.4.2). While coral cover has been generally higher on Elizabeth than Middleton Reef it has shown similar temporal patterns (Hoey et al. 2014)

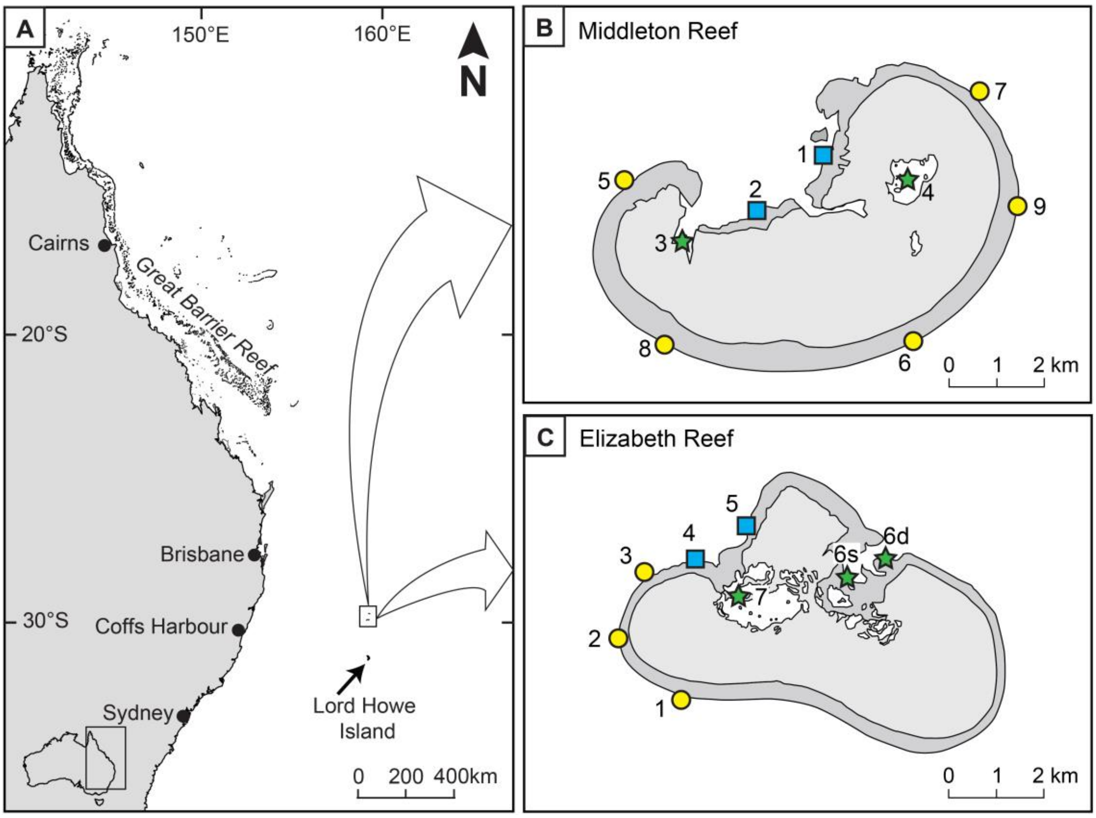

Figure 11.4.1: Map showing the location of the 16 georeferenced study sites used in the last four marine ecological surveys (2006-2014, Table 11.1) at (c) Elizabeth and (b) Middleton Reefs. Colours and symbols refer to reef habitats. *yellow circles* = reef front, *blue squares* = back reef, *green stars* = lagoon. NB. Due to unfavourable weather not all sites were surveyed during each expedition. (source Hoey et al. 2014).

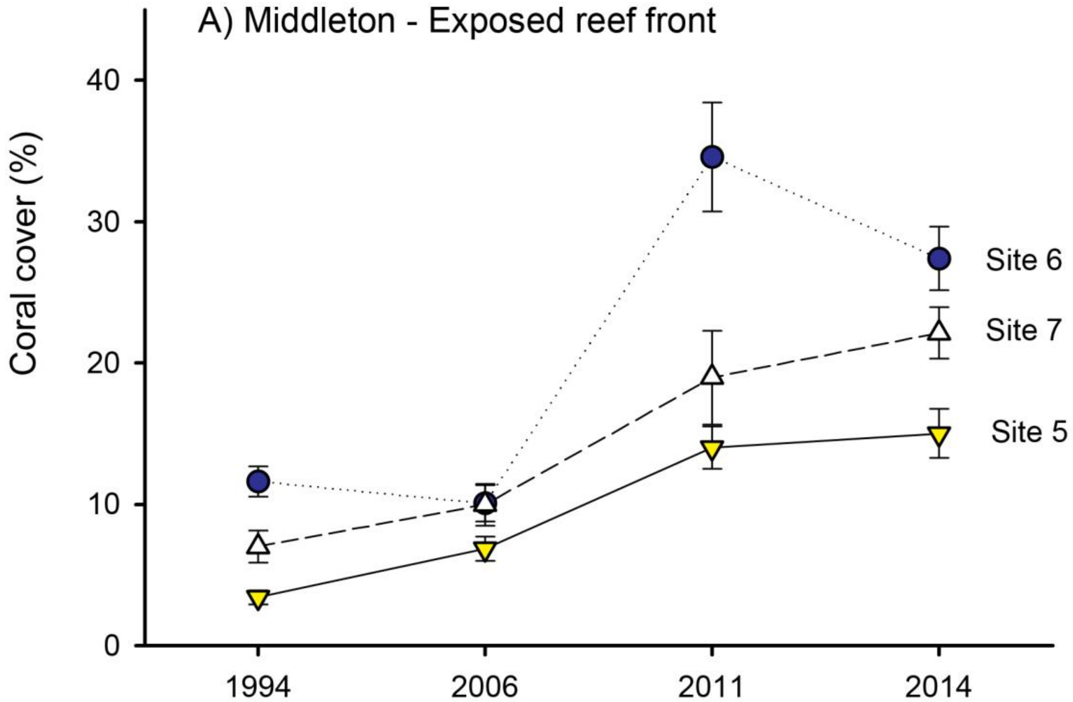

Figure 11.4.2: Temporal change in coral cover on the exposed reef crest of Middleton Reef (source Hoey et al. 2014).

Repeated surveys of fish assemblages have revealed that the majority of species surveyed (including the endemics *C. tricinctus, C. bulbifrons, A. mccullochi*, and ecological important herbivorous reef fishes) were stable or increasing in density (Pratchett et al 2011, Hoey et al. 2014). Importantly, the density of juveniles of each of these species (a proxy for population replenishment) was also stable or increasing (Hoey et al. 2014). Similarly, densities of the Black Cod have remained stable over the past two surveys for which data were available, while the densities of the Galapagos Shark have almost doubled between 2011 and 2014 (Figure 11.4.3), with the majority of individuals sited being less than 1.2m in length (Hoey et al. 2014). Given that Galapagos sharks can reach up to 3m in length, the prevalence of small individuals led to the suggestion that Elizabeth and Middleton Reefs were an important nursery area for this species.

11.4.2. ECOLOGICAL PROCESSES

Connectivity

As discussed in Section 8.2.4 there have been considerable advances in our understanding of the biological connectivity between Elizabeth and Middleton Reefs, and the reefs of Lord Howe Island and Norfolk Island. Much of this research has been generated as a result of the ecologically and evolutionary processes that maintain populations of endemic species. Comparisons of endemic reef fishes (*A.*

latezonatus, A. mccullochi, C. bulbifrons, and *C. tricinctus*) from Elizabeth and Middleton Reefs, with those of Lord Howe Island, Norfolk Island, and the Solitary Islands reveal limited contemporary gene flow among locations with high levels of self-replenishment (c. 70-95%; van der Meer 2012, 2013, 2015, Steinberg et al. 2016). Such high levels of self-replenishment make these populations extremely vulnerable to local disturbances.

Large and/or more mobile species appear to have greater connectivity among locations. The Black Cod from Elizabeth and Middleton Reefs appear to form a single population (Appleyard and Ward 2007), and comparisons with four individuals from the NSW coast suggest they may not be distinct from the mainland population (van Herwerden et al. 2009). Similarly, Galapagos sharks from Elizabeth and Middleton Reefs form one population that is distinct from the Lord Howe Island population (van Herwerden et al. 2008). Further, analyses of the microstructure of otoliths suggest the yellowtail kingfish population on Elizabeth and Middleton Reefs is also likely to be self-sustaining (Patterson and Swearer 2008).

Similarly, Lord Howe Island, Elizabeth and Middleton Reefs and Solitary Island populations of three species of scleractinian corals were found to be genetically differentiated, although may be supplemented by occasional long-distance dispersal (Noreen 2010, Noreen et al. 2013).

Resilience

The low but increasing coral cover on Elizabeth and Middleton Reefs compared to those of Lord Howe Island (Hoey et al. 2011) and the southern GBR (e.g., Trapon et al. 2013) suggest that these reefs are still recovering from previous disturbance/s. While quantitative estimates of baseline coral coral are rare for these reefs, photographs and qualitative estimates suggest it was much higher than present levels (T. Done pers. com.). The declines in coral cover since 1981 corresponded with high densities of Crown-of-Thorns Starfish in the 1980’s and early 1990’s with over 400 individuals being recorded at some sites (Australian Museum 1992; Harriot 1998).

These rates of recovery in coral cover are extremely slow, even compared to other isolated reef systems (e.g. Scott Reef: Gilmour et al. 2013) and likely reflect a combination of the low levels of larval input and reduced growth. Indeed densities of juvenile corals at Elizabeth and Middleton Reefs (mean = 11.26 juveniles per 10m^2) are 6x lower than estimates from low latitude reefs of the southern GBR (Trapon et al. 2013), but similar to those from Lord Howe Island (Hoey et al. 2011).

11.4.3 ACTIVITES AND PRESSURES

The main pressures of concern identified for Elizabeth and Middleton Reefs are climate change (in particular ocean warming and acidification), changes in oceanography, fishing, marine debris, and shipping (Commonwealth of Australia 2012 – *Marine Bioregional Plan for the Temperate East Marine Region*). There have been no studies on Elizabeth and Middleton that have directly assessed these pressures, however several inferences can be drawn from available data from these reefs and adjacent regions. For example, there is little evidence of illegal fishing and/or permitted fishing on Elizabeth Reef impacting fish populations. Large predators such as sharks and cods are usually the first to be taken by fishers. The stability of the Black Cod population and increase in Galapagos shark population between 2011 and 2014 suggest there have been minimal impacts of fishing on either reef.

Coral bleaching is one of the greatest threats to coral reefs globally and has been recorded on both Lord Howe (Harrison et al 2011), and the Solitary Islands (Hughes et al. 2017). To date, there have been no records of coral bleaching on Elizabeth and Middleton, although this may be related to infrequent nature of surveys/visitations to the area. The potential effect of ocean acidification on reef building corals is particular relevant for the Elizabeth and Middleton Reefs due to the lower aragonite saturation of subtropical waters. For example, Anderson et al. (2015) reported a 70% decline in the growth rates of two of three coral species from 1994/5 to 2010/11 at Lord Howe Island. Although they could not directly attribute the reduction in growth to declines in aragonite saturation or increases in seawater temperatures above optimum, it highlights the negative effect climate change is having subtropical coral reefs.

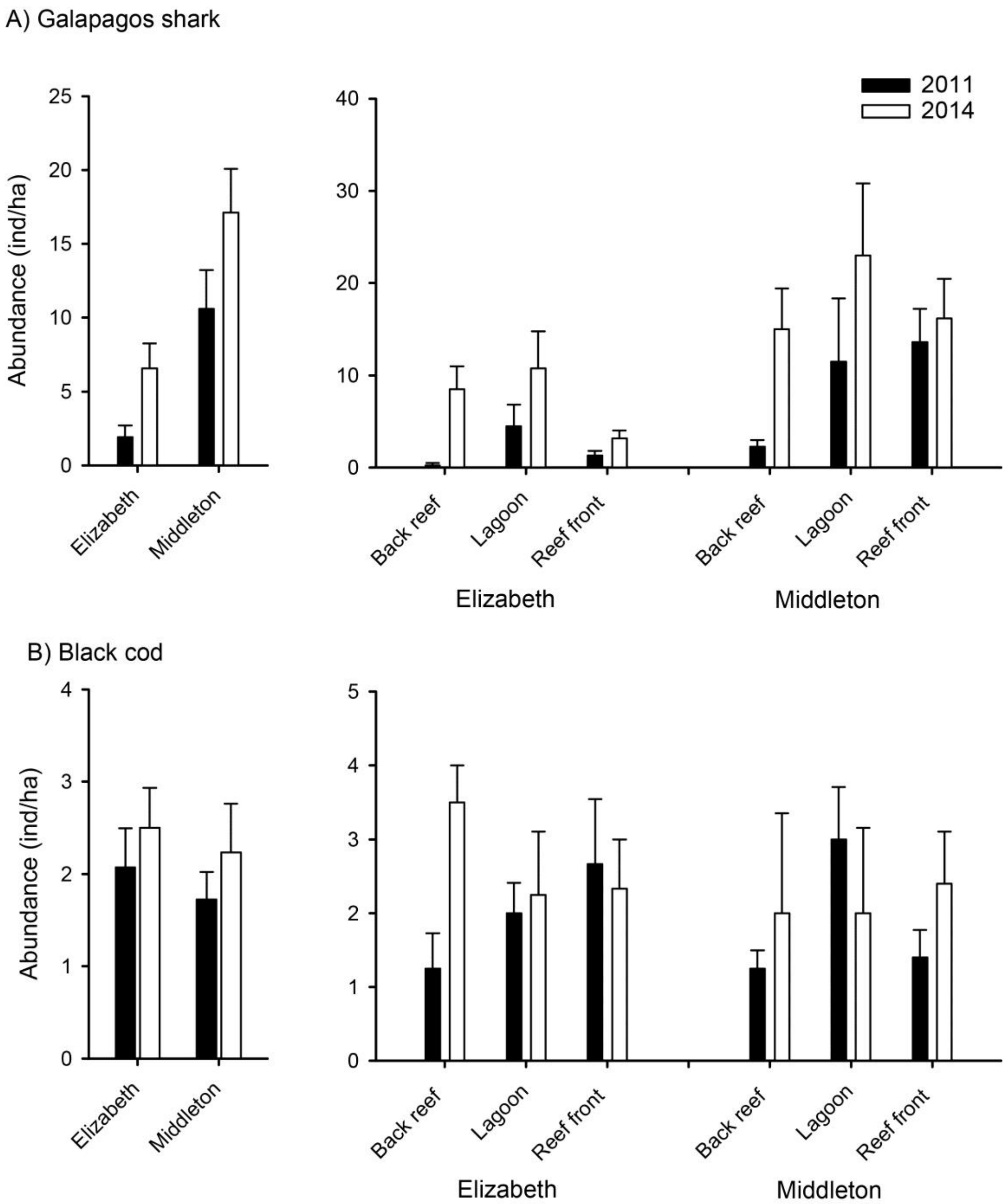

Figure 11.4.3. Temporal variation in the mean abundance of (a) the Galapagos Reef Shark and (b) the Black Cod at Elizabeth and Middleton Reefs (source Hoey et al. 2014).

The most apparent impact of increasing water temperatures within the Temperate East Marine Region is the poleward shifts in the distributions of marine organisms. Warming sea surface temperatures and the strengthening of the EAC is leading to range expansions of both corals (e.g. Baird et al. 2012) and fish (e.g., Figueira and Booth 2010, Feary et al. 2014) down Australia's east coast. Although several new records of fish have typically been recorded in subsequent surveys on Elizabeth and Middleton Reefs it is not clear if these are chance dispersal events related to isolation or a true indicator of warming seas.

11.4.4. KEY FINDINGS

Despite its isolation, the long-term monitoring of the shallow water habitats of Elizabeth and Middleton Reefs are perhaps one of the most informative and valuable of any of Australia's CMRs. This is perhaps not surprising given this series of ecological surveys were commissioned by the Australian Government with the specific objective of assessing the status and trends of fish and benthic assemblages. Collectively these surveys have documented the unique the biodiversity of the reefs, and although impacts of current pressures appear to be low, the isolation and limited connectivity means that local populations are likely to be slow to recover from any disturbance that reduces population abundances.

The continuation of regular monitoring is critical to assess the impacts of both historical and emerging threats to corals and key fish species, such as the Galapagos shark and Black cod, and thereby inform and facilitate effective long-term management of these unique assemblages. The benefits of matching previous sampling methods and sites to facilitate rigorous temporal comparisons of biological communities should not be underestimated. Implementation of comparable sampling methods across all CMRs would also enable meaningful spatial and temporal comparisons.

11.5 SOUTH-EAST CMR NETWORK: MACQUARIE ISLAND

Macquarie Island is an important biosphere reserve and World Heritage Area located 1,500 km south east of Tasmania. Its unique location and current influence supports high productivity and benthic species at the north and southern edge of their range to due to current divergence and underwater ridges. Sixty seven entries in the *2016 CMR Literature Review Database* were identified as directly relevant, with over half published in the last seven years. Seven studies related to established monitoring programs, with six of those related to the Patagonian Toothfish, and the seventh to precipitation patterns.

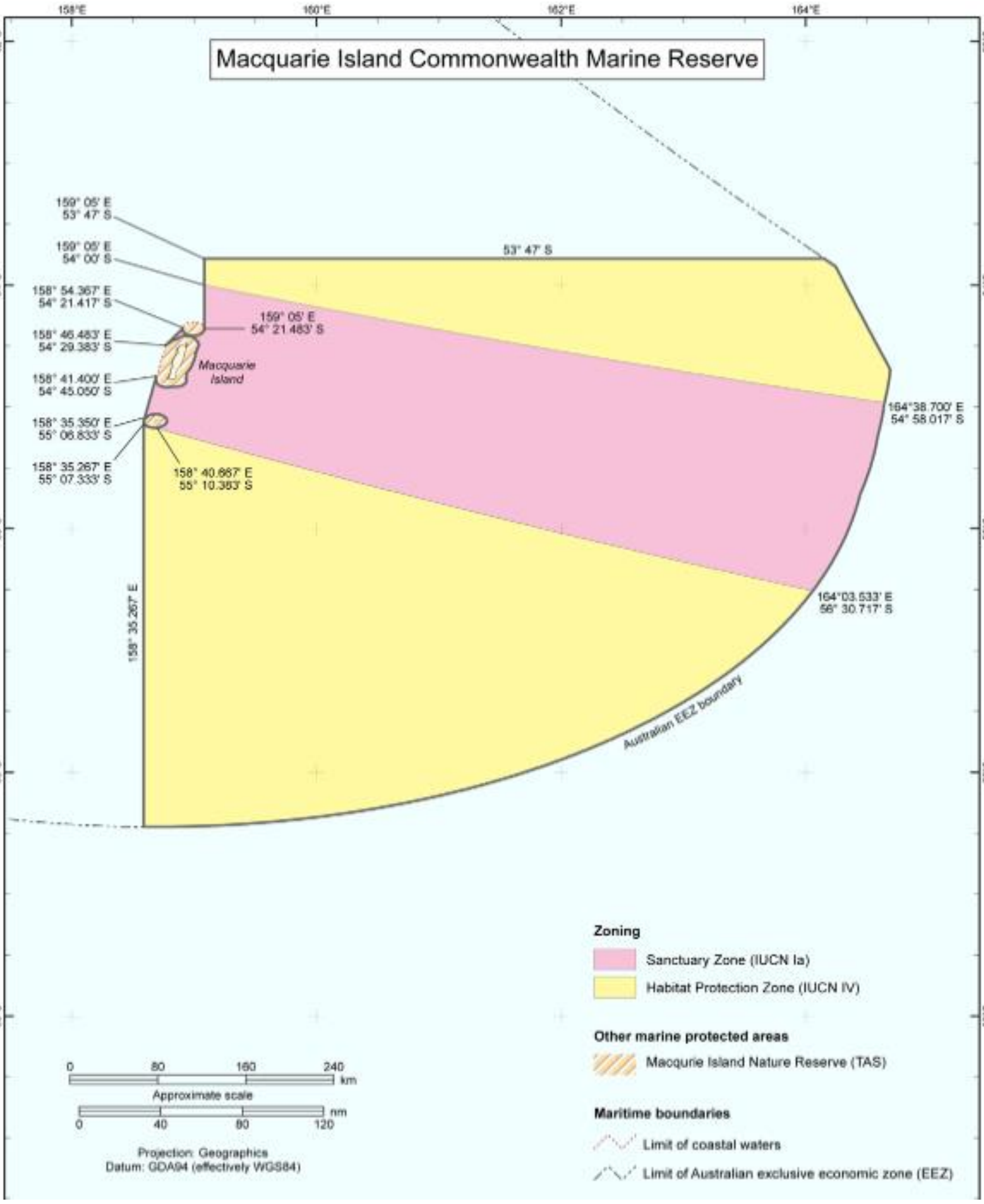

Figure 11.5.1: Macquarie Island Commonwealth Marine Reserve, source: environment.gov.au.

LEVEL OF PROTECTION

CMR	Area (km²)	Level of protection – IUCN Category			
		I	II	IV	VI
Macquarie Island	162,000	58,000		104,000	

11.5.1 BIODIVERSITY VALUES

Macquarie Island is a Biosphere Reserve and a World Heritage Area. Like the Perth Canyon (in the SW CMRN) Macquarie Island CMR is a unique location situated in a convergence transition zone, supporting numerous species at the limit of their range (Butler et al. 2000).

Significant Marine Species

Macquarie Island is an important foraging area for four listed vulnerable seabird species: Antipodean albatross, Black-browed albatross, Campbell albatross, and the Indian yellow-nosed albatross. There have also been several recent studies investigating the ecology of the southern elephant seal on Macquarie Island. These studies have described various aspects of the diets of juveniles (Field et al. 2011) and adults (Banks et al. 2014), reproduction (Deprez et al. 2014), and foraging patterns (Bestley et al. 2013, Thums et al. 2011) in a bid to understand the causes of the declines in the Macquarie Island population over the past 50 years. There is some evidence that the decline in southern elephant seals on Macquarie Island was related to sea ice duration with their foraging ranges, and hence the population may respond positively to a reduced sea ice field under climate change (van den Hoff et al. 2014). New technologies using satellite imagery to accurately count Elephant seals from space are yielding promising results (McMahon et al. 2014).

There have been several studies investigating temporal trends in Macquarie Island populations of several bird species. These studies have shown that some populations, such as the king penguin on Macquarie Island have been increasing (Heupink et al. 2012) while others, such as the shy albatross have been decreasing (Alderman et al. 2011), with the latter linked to competition with the increasing population of Australian gannets. Like pinnipeds, the foraging behaviour and breeding success of penguins around Macquarie Island was related to environmental conditions, primarily SST (Belincourt and Arnould 2015b).

Benthic and Fish Communities

There are relatively few studies on the bathyal seafloor across the Southern Ocean. The ophiuroid fauna on the Macquarie Ridge was found to be more closely related to south-eastern Australia and New Zealand (83 %) than neighbouring Antarctic regions (O'Hara et al. 2013). Macquarie Island has diverse benthic communities characterized by sponges, brachiopods, hydroids, hydrocorals, octocorals, anemones and holothurians). Benthic taxa, especially the dominant mega-faunal components of deep-sea systems such as corals and sponges, are also highly vulnerable to bottom trawls. While some taxa have natural resilience due to their small size and/or robust growth form, and some can survive in natural refuges inaccessible to trawls, Few benthic surveys have been conducted at Macquarie Island since 2010.

The Patagonian Toothfish (*Dissostichus eleginoides*) is the most well studied fish stock in the Macquarie Island Reserve. It is a valuable plate fish overseas but its life history traits make it vulnerable to overfishing (large, long-lived, bottom-dwelling species). An Integrated stock assessment of the fishery is conducted annually to determine total allowable catch and evaluation against stock synthesis software to determine stability of the population using tagging data. The 2016 results indicate the current female spawning biomass estimate is 67% of unfished at the start of 2016 (a slight decrease from 2015 – 69%) (Day et al. 2016). Lanternfishes are highly diverse in this area (23 species: Flynn and Williams 2012) and form an important food source for diving predators (several penguin species and fur seals)

11.5.2 ECOLOGICAL PROCESSES

Seamounts provide biodiversity hotspots and 'stepping stones' for dispersal (Ceccareli 2011), yet studies of connectivity among seamounts, especially those of the Macquarie Ridge are rare. The Macquarie Island Reserve has unique geological characteristics due to its orientation and underwater ridges, which form barriers to major currents creating upwellings, and eddies. These may also acts as biologically barriers limiting the dispersal of larvae to and from the area. Floating objects, such as kelp rafts, have been suggested to support dispersal from southern areas of Australia to Macquarie Island (Smith 2002), although this remains largely untested.

There has been limited research on ecological connectivity within the Macquarie CMR, with most relating to the population (or stock) structure of fisheries species. Comparisons of the genetic structure of populations of the three fish species have sown that while the mackerel icefish, Patagonian toothfish are genetically distinct (Kuhn and Gaffney 2006, Toomey et al. 2016), there appeared to be some connectivity between HIMI and Macquarie Island populations of the deep-sea cod.

11.5.3 ACTIVITIES AND PRESSURES

The primary uses include commercial fishing (primarily for Patagonian Toothfish) and scientific research. Benthic impacts from trawling and pelagic impacts associated with discarded ghost nets remain the greatest threats after climate change. A recent study of marine debris found the majority of plastics deposited on Macquarie Island (95% of 6389 items) consisted of ropes and plastics identified to originate from the Toothfish fishery (Eriksson et al. 2013).

The effects of climate change are likely to effect circulation patterns and the location of important food sources (krill, lantern fishes) for many top predators. Further the location and seasonality of eddies and upwellings may shift leading tp sublethal food chain effects on foraging species (e.g. whales, penguins, seals, seabirds) (Flynn and Williams 2012).

11.5.4 KEY FINDINGS

The Macquarie Island Reserve is very well studied considering its remote location. A wealth of data has been generated through ongoing monitoring programs (e.g. elephant seals, toothfish, penguins, benthic surveys) however some of the data sources and sampling designs remain disparate. There is little knowledge climate change effects will influence connectivity and circulation patterns. It is recommended that a process driven, temporally consistent monitoring program be carried out.

11.6 SOUTH-WEST CMR NETWORK: PERTH CANYON

The Perth Canyon system is one of Australia's largest underwater canyons (with circulating eddies 200-300m in diameter), and is larger in area than the Grand Canyon**.** Given its high productivity it is one of the four most important hotspots in the South-West Marine Reserve for whale migration and feeding (particularly humpback whales, sperm and killer whales and threatened blue whales). Eighteen entries in the *2016 CMR Literature Review Database* were identified as directly relevant to the Perth Canyon. The majority of research has occurred between 2005-2015. None of these are part of ongoing long-term studies and therefore temporal trends cannot be presented.

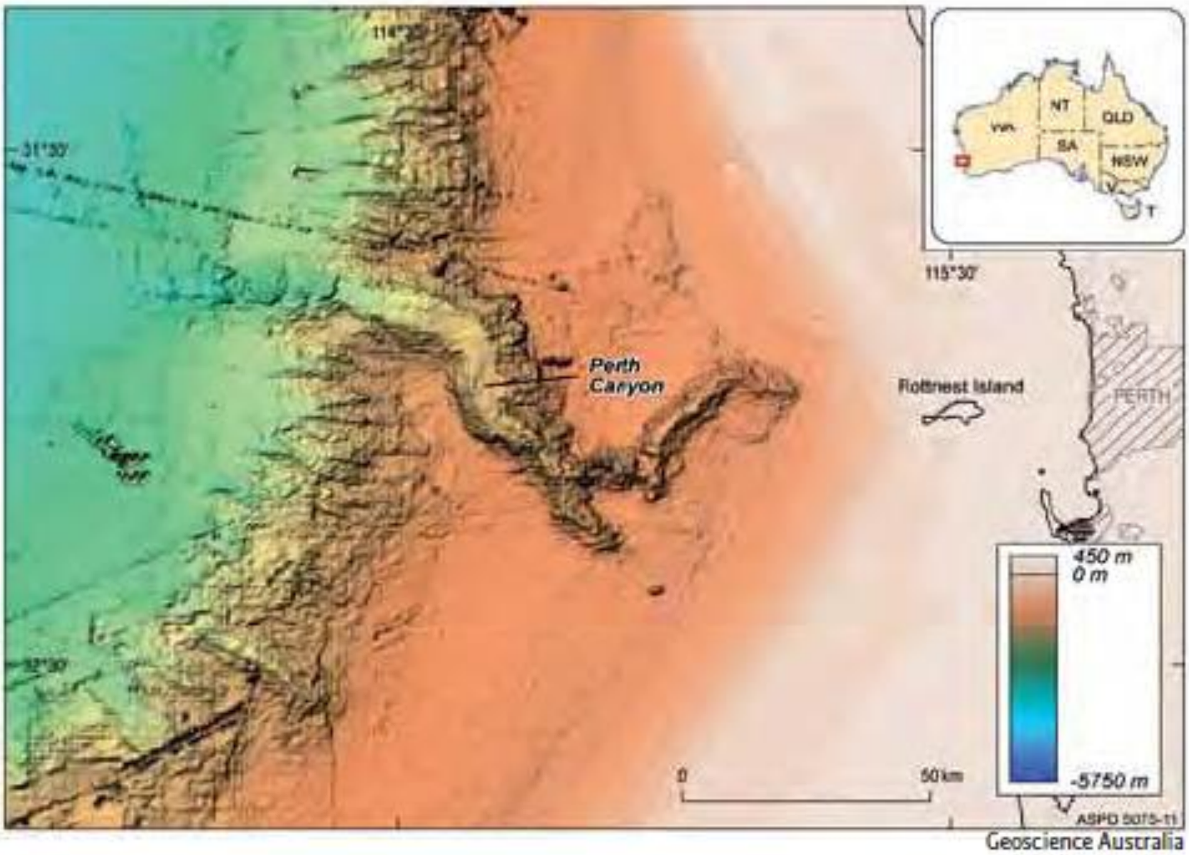

Figure 11.6.1 Bathymetry Map showing the geographic location and bathymetric profile of Perth Canyon (source: Geoscience Australia, SW Bioregional Profile)

LEVEL OF PROTECTION

CMR	Area (km²)	Level of protection – IUCN Category			
		I	II	IV	VI
Perth Canyon	7,409		1,107	2,569	3,733

Key Ecological Feature	Main pressures
1. West Coast Canyons and adjacent Shelf Break	Climate change (increasing SST, acidification), bottom fishing
2. Meso-scale eddies (several locations)	Climate change (increasing SST, changing oceanography), fishing

11.6.1. BIODIVERSITY VALUES

Key Ecological Features

The geomorphology of the Perth Canyon forces deep ocean currents carrying nutrient rich cold waters to the surface. These highly productive nutrient rich waters support aggregations of small fish, krill and squid, that in turn attract feeding aggregations of pygmy blue whales and large predatory fishes. The Perth Canyon has been identified as a regional priority on the basis of its important contribution to the region's biodiversity. (Commonwealth of Australia 2012 – *Marine Bioregional Plan for the South-west Marine Region*).

Significant marine species

As described above the Perth Canyon is an important ecological feature attracting feeding aggregations of several threatened and endangered species (including Blue whale, Pygmy blue whale, Sperm whale; Table 10.3) due to its proximity to the southern ocean, numerous upwellings and eddies (See Figure 11.6.2). The Perth Canyon also marks the southern boundary for numerous tropical organisms (Commonwealth of Australia – *South-west Marine Bioregional Plan, Bioregional Profile*). In the summer months blue whales congregate to feed at this location (Gill et al. 2011).

Biological Communities

Benthic and Fish Communities

The Perth Canyon supports a diverse array of pelagic communities. A 2015 study using pelagic baited stereo videos deployed at ~100m documented 15 species of fish from 11 families (including carangids and mackerels), the most abundant being dolphinfish (a targeted commercial and recreational species) (Bouchet and Meeuwig 2015). Shark records indicate the Perth canyon is an important refuge (and potential nursery area) for vulnerable and near threatened species (blue shark *Prionace glauca*, shortfin mako *Isurus oxyrinchus*, silky shark *Carcharhinus falciformis* (Bouchet and Meeuwig 2015). It is also been found to be a site for Whale Sharks, which were previously thought to only reside further North (Ningaloo). Studies of the benthos are extremely limited even though the South West Profile (2008) indicates the Canyon supports the southern extent of numerous tropical organisms (e.g. sponges, corals, decapods and xanthid crabs).

Whales

In the summer months blue whales congregate to feed (Gill et al. 2011) and pygmy whales may spend up to one month foraging at the Perth Canyon. Of all the whale tracking studies identified, Perth Canyon, Albany Canyon, Recherché Archipelago and the Kangaroo Island upwellings appear to be important hotspots. Upwellings support important foraging grounds for sperm whales, Fin Whales, Sei whales, Blue and Pygmy blue whales, killer whales and pelagic dolphins.

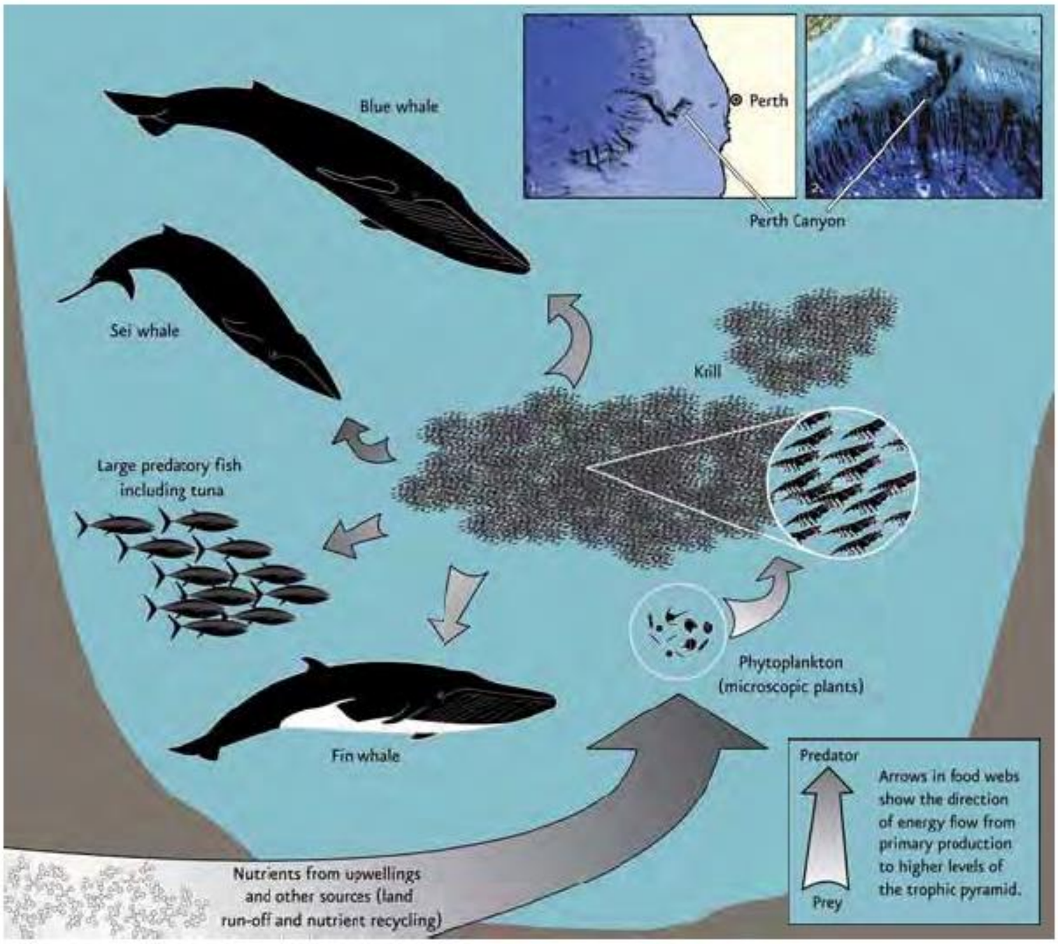

Figure 11.6.2 Food web dynamics supported by Perth Canyon geomorphology (Geoscience Australia, SW Marine Profile 2008)

Ecological Processes

Connectivity among canyon systems and KEFs is strongly influenced by the Leeuwin current. A study that used brittlestar larvae as a model species found exchange among canyons to be unidirectional around Cape Leeuwin, and extending into the GAB (Kool et al. 2015). Some self-retention did occur within the

Perth canyon as well as other systems but if larvae made it to the canyon top they showed high dispersal ability (Kool et al. 2015). This indicates the Perth Canyon may be an important dispersal stepping stone for larvae and species reliant on larval aggregations.

A 2016 study by McCauley et al. 2016 identified a unique acoustic chorus emitted from foraging lantern fishes within the Perth Canyon. The large spatial extent of the acoustic emissions indicate this phenomenon may be provide an acoustic beacon to other organisms, driving feeding aggregations and high biomass. This is exhibited in the high abundance of migrating cetaceans through the Perth Canyon (blue whale, Gill et al 2011; pygmy blue whale, Andrews-Goff et al. 2014, Double et al. 2012; sperm whales, Johnson et al. 2013) indicating connected migration routes along the coastline from Indonesia to the Perth Canyon in particular.

11.6.2. ACTIVITIES AND PRESSURES

The Perth Canyon is approximately 60 km from Perth/Rottnest Island and therefore receives use from commercial fishing, industrial shipping and military exercises. Underwater video surveys indicate the preferred habitat range for targeted fisheries species extended further than the Perth Canyon CMR boundaries (Bouchet and Meeuwig 2015). This has important ramifications for Commonwealth Marine Reserve Management Plans around the Perth Canyon as species which are the focus of protection in no take areas may be exposed to recreational and commercial fishing, vessel traffic and noise. This is particularly important for cetaceans who communicate acoustically and use the Perth Canyon as a stop-over (some for significant periods e.g. one month Pygmy Blue Whale: Jenner et al 2012) as they migrate. Acoustic surveys using data from established Integrated Marine Observing System moorings at the Perth Canyon show noise from shipping significantly contributes to sound scape throughout the entire day and year round (Erbe et al. 2015).

There are a general lack of studies investigating likely effects of climate change, such as ocean acidification, changes in foraging patterns, hypoxia, and habitat fragmentation.

11.6.3. KEY FINDINGS

Despite proximity to Perth and relative high use for an offshore location, the Perth Canyon has received limited research of its pelagic fish communities. Tagging research indicates the Perth Canyon is an important migration route for numerous whale species. If deep-water benthic communities are to be protected within this area they need to be adequately documented and their conservation values assessed.

12. RECOMMENDATIONS

This review summarises the foci of 1,115 publications and reports that were relevant to Australia's CMR estate and adjacent waters and entered into the *2016 CMR Literature Review Database*. Recommendations that relate to individual CMR Networks, or individual CMRs (where appropriate) have been provided in the preceding sections. Many of these transcend network boundaries, and/or may be condensed into broader recommendations that apply across the CMR estate. These recommendations include:

- Collection of comprehensive environmental and biological data for networks and reserves where baseline data is lacking (e.g. North CMR)
- Prioritize key/important areas for systematic and ongoing monitoring. This may include consideration of the key ecological features, significant species, pressures and threats, and the level of protection (i.e. zoning) afforded to an area. Collect baseline environmental and biological data on the biodiversity values of these key areas (as a minimum). The collection of both environmental and ecological data is critical to allow attribution of local versus regional or global pressures (e.g. climate change) to any shifts in ecological communities
- The development and adoption of standardized methodologies for process-based monitoring and the establishment of indicator species for a range of ecosystems (e.g. shallow reefs, seamounts). This will decrease costs and increase efficiency, directly inform management by allowing comparisons both within and across CMRs, and the identify those areas, habitats, and species that are most vulnerable
- Continued monitoring of those locations for which a long-term temporal series exists (e.g. Ashmore Reef, Elizabeth and Middleton Reefs, Coral Sea). This will not allow the continued long-term assessment of these areas, but also inform the likely status and trends for comparable habitats exposed to similar pressures
- Shift toward process-based monitoring, as opposed to current state-based monitoring, to understand potential vulnerabilities and resilience of habitats and communities
- Co-ordination and integration of monitoring with existing monitoring programs, especially those that are conducted in adjacent or nearby state waters
- Initiating and coordinating systematic monitoring of Australia's CMR estate will be logistically and financially challenging. Initiatives to foster greater support and collaboration between researchers/research institutions and the DNP will be critical in directing management relevant research. Some

options to achieve this include: partnering with researchers/research institutions and leveraging direct investment from DNP through funding opportunities such the ARC Linkage program; development of a Scientific Information Needs for Management Policy (updated every 3-5 years) that describes the priority information needs relating to each CMR, each CMR Network, and the estate as a whole.

- The database currently contains 1115 entries and is an invaluable tool. The database should be maintained and updated regularly (at least every 6-12 months), and the information used to update this review.
- One of the major obstacles in compiling data for this review was determining whether a particular study had been conducted within the bounds of a CMR. The DNP should encourage or mandate (through permissions to conduct research within CMRs) that researchers provide copies of all publications and reports relevant to CMRs, and at a minimum provide the citation and the exact location of the research. The remainder of the record to be populated by DNP to ensure consistency
- Establish and maintain a repository for electronic versions (PDFs) of papers and reports included within the database, and make these available to any person/s charged with updating the database.
- Redesign the interface for the database to allow future records to be directly imported from search engines, allow existing records to be edited on the 'data entry' page, and allow for standard queries to be run

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14. Appendix: Literature Search and Database

SOURCING LITERATURE

The literature sourced for this review was searched and obtained in several ways.

Initially, all reports and papers identified in the previous review of research and monitoring within the CMRs (Ceccarelli 2011) and those listed in attachment D of the contract were searched by title and/or author through Google Scholar and/or Google search engines. Resources from Ceccarelli (2011) were not provided, and those in appendix D were not initially provided by DNP which added considerable time to the review process.

Secondly, keyword searches in both Google Scholar and Google were used, focusing on the period since that previous review (2011-2016). These search engines were used as they are more effective at capturing grey literature and reports than scientific databases (e.g. Web of Science, ISI). We used a range of keywords for each CMR network that included: the geographic region (e.g., Coral Sea), individual reserves (e.g., Gifford, Cod Grounds) or locations (e.g. Middleton Reef), key ecological features (e.g., Bonney Coast Upwelling, Tasmanian Seamounts), biological communities or habitats (e.g. coral reef, seamounts, canyon), vulnerable or threatened species (e.g., Black Cod, Blue Whale), potential threats and pressures (e.g., demersal longline, climate change, fishing).

Finally, these were supplemented through references cited within these reports (i.e., 'snowball' search) and conversations with various scientists and managers.

OBSTACLES AND CONSTRAINTS

There were many obstacles to gathering and synthesizing the records of research and monitoring for the updated review and database:

Much of the relevant literature doesn't provide reference to individual CMRs or exact details of the study locations, making it difficult or impossible to determine if the research had been conducted within, or even in the vicinity of a CMR. In such instances studies were included in the database as they were likely to provide information relevant to the region, even if not specific to a particular CMR

Research relating to oil and gas was relatively scarce and while considerable monitoring is likely to have been conducted around these developments it is not readily accessible or available.

The database itself is cumbersome, making data entry unnecessarily time consuming and extraction of data and analyses difficult. A single entry takes 10-15 minutes to enter (without reading or critically evaluating the information), equating to over 180 hrs (>5 weeks) for the 1115 records to be entered. This could be simplified by facilitating some of the fields to be populated by importing data directly from search engines (e.g. Google Scholar or Web of Science). It was also not possible to re-open existing entries for editing on the data-entry page. Further, extensive knowledge of database systems, or instruction from someone with such knowledge, is required to run relatively basic queries.