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Research and Monitoring in Australia's Commonwealth Marine Protected Areas: A Review



Final Report to the Department of the Environment, Water,
Heritage and the Arts

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Draft Report: Research and Monitoring in Australia's Commonwealth Marine Protected Areas: A Review

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DRAFT



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EXECUTIVE SUMMARY

In recognition of the widespread success of marine protected areas (MPAs), the Australian Government is in the process of establishing a nation-wide network of Commonwealth MPAs (CMPAs) through a process of Marine Bioregional Planning. This process involves the gathering of information for the preparation of profiles that describe each Marine Region, and the implementation of Australia's National Representative System of Marine Protected Areas (NRSMPA) through the establishment of CMPA networks in each Region. Over the last four decades, a large amount of research has been undertaken by a large variety of institutes and organizations. This review provides an overview of research conducted in the existing CMPA estate, to highlight gaps in research and monitoring, and to make recommendations for filling those gaps.

This review identified 363 research papers and reports that were directly relevant to CMPAs and, where relevant, adjacent State MPAs. The earliest research paper dated as far back as 1960, but the bulk of the research has taken place in the last ten years. No systematic research and monitoring program exists for the CMPA estate as a whole, and the management of most CMPAs does not draw on monitoring programs designed for the long-term tracking of changes. The amount of research conducted in each CMPA is likely to be influenced by the remoteness of the CMPA from a land-based station, features of interest, proximity to research institutions, and the shifting research interests of the scientific community. The Great Australian Bight Marine Park (Commonwealth waters) (GABMP) and Lord Howe Island Marine Park (Commonwealth waters) (Lord Howe) have attracted the largest body of research. While ecological research has dominated the research effort in all CMPAs, recent years have seen a rise in molecular research and in studies that require more sophisticated technology. Literature reviews have provided a useful means of understanding specific threats to CMPAs, such as fishing, shipping and petroleum exploration and mining, but have also been an important tool in defining the characteristics of broad Marine Regions prior to the establishment of CMPA Networks.

Research in each CMPA has tended to focus on the features of the area considered most important, interesting or vulnerable. Ashmore Reef National Nature Reserve (Ashmore) was the only CMPA where successive ecological surveys could easily be tracked and related to previous and successive surveys. A relatively rich body of ecological work exists for Mermaid Reef Marine National Nature Reserve (Mermaid) and Ningaloo Marine Park (Commonwealth waters) (Ningaloo) in the North-west Marine Region. The South-east Commonwealth Marine Reserve Network has the largest body of literature reviews compiled to aid the establishment of the Network in 2002. The types of research projects available for each CMPA allow the identification of specific gaps. There is little CMPA-specific understanding of underlying environmental parameters such as oceanography, geology and geomorphology for a number of the CMPAs, and some still lack species lists. Patterns of productivity and fisheries activities relevant to each CMPA are also largely unknown.



A major gap for most research and monitoring programs in most CMPAs is the lack of consistent and reliable temporal data series, and the lack of research that incorporates reference or ‘control’ locations outside the CMPAs. CMPAs that have the closest thing to a useful time-series are Ashmore (reef ecology surveys) and Coringa-Herald National Nature Reserve (terrestrial and marine surveys). The CMPAs that have benefited from data collection inside and outside their boundaries are Ashmore, Cartier Island Marine Reserve (Cartier), Mermaid, the Cod Grounds Commonwealth Marine Reserve (Cod Grounds), the GABMP and Coringa-Herald’ terrestrial environments. The design of future research and monitoring surveys should take this into consideration.

Perhaps the greatest challenge in designing successful research and monitoring programs for individual CMPAs and Reserve Networks is one of administration. A centralised organisation or group responsible for the design, implementation and reporting of research is the simplest format that may ensure continuity and consistency. Staff turnover is often a critical factor in ensuring continuity and consistency, regardless of the model chosen. A centralised group that maintains responsibility for research and monitoring in CMPAs or Reserve Networks may rely on a dedicated field team, or may choose personnel to build field teams depending on expertise and availability. At present, the quality, quantity and type of information available therefore differs substantially between CMPAs. As the CMPA estate expands into large-scale Reserve Networks in the future, monitoring the effectiveness of protection and tracking changes over time will offer a challenge to managers. However, it will also offer an opportunity to design comprehensive, practical and cost-effective research and monitoring programs that fit into an adaptive management framework.

Key recommendations for research and monitoring in a system of new CMPA Networks arising from this review include:

- Locate, collate, analyse and report on known existing datasets and databases. In some cases these existing data may suffice to fill existing knowledge gaps, precluding the need for further research.
- Carry out baseline studies to ensure that there is knowledge for key areas of each proposed CMPA in new Networks and existing CMPAs. This will greatly assist in the establishment on management systems that can direct activities to the correct places – for instance: indicators for monitoring, specific areas of value or concern to be more highly protected, areas for active management such as pest eradication or control, and genetic connectivity between areas.
- Decide whether to protect the “strong” or the “weak”, or both. This means identifying and scoring areas that may be classified as “strong” (e.g. high resistance or resilience to disturbance, intact trophic structure, stable environmental parameters, good recovery potential, high abundance and diversity of key organisms, high connectivity to larval sources) or “weak” (e.g. low resistance or resilience to disturbance, elements of the trophic structure low or missing – e.g. through historic overfishing of predators or invertebrates, poor recovery potential, low abundance and diversity of key organisms, low



-
- connectivity to larval sources). These considerations are most usefully set into a risk assessment-type decision-making framework.
- Establish a system of environmental / ecological monitoring and compliance monitoring. The relative importance of types of monitoring will be dependent on the reserve type and usage patterns. If funds are short, compliance monitoring may be more important in some cases than environmental monitoring.
 - Collect environmental data as well as ecological, and facilitate the linking between the two types of data.
 - Regularly update this review with new information, to provide a central document that can act as a repository of current knowledge about CMPAs and CMPA Networks. Update the EndNote library with linked original electronic documents. The higher the frequency of these updates (e.g. annually), the lower the cost and time expenditure each time.



TABLE OF CONTENTS

Executive Summary	3
Introduction.....	10
Objectives and Scope	12
Methods.....	12
South-west Marine Region	14
Great Australian Bight Marine Park (Commonwealth Waters)	14
Uses and Threats	15
Climate and Oceanography	16
Geology and Geomorphology	16
Ecology	17
Fisheries Research	21
Gaps and Recommendations.....	22
North-west Marine Region	24
Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve	25
Uses and Threats	25
Climate and Oceanography	26
Geomorphology	26
Ecology	26
Fisheries Research	36
Gaps and recommendations	36
Mermaid Reef Marine National Nature Reserve.....	37
Uses and Threats	39
Climate and Oceanography.....	40
Geomorphology	40
Ecology	40
Gaps and recommendations	42
Ningaloo Marine Park (Commonwealth Waters).....	43
Uses and Threats	44
Climate and Oceanography.....	45
Geology and geomorphology.....	46
Ecology	46
Fisheries Research	49



Gaps and recommendations	50
North Marine Region	51
East Marine Region.....	52
Coringa-Herald National Nature Reserve	53
Uses and Threats	53
Climate and Oceanography.....	54
Geology and Geomorphology.....	55
Ecology	56
Gaps and Recommendations.....	60
Lihou Reef National Nature Reserve	61
Uses and Threats	61
Climate and Oceanography.....	61
Geology and Geomorphology.....	62
Ecology	62
Gaps and Recommendations.....	65
Solitary Islands Marine Reserve (Commonwealth Waters).....	66
Uses and Threats	66
Climate and Oceanography.....	67
Geology and geomorphology.....	67
Ecology	68
Fisheries Research	71
Gaps and recommendations	72
Cod Grounds Commonwealth Marine Reserve	73
Uses and Threats	73
Climate and Oceanography.....	73
Geology and Geomorphology.....	74
Ecology	74
Fisheries Research	75
Gaps and Recommendations.....	75
Elizabeth and Middleton Reefs Marine National Nature Reserve	76
Uses and Threats	77
Climate and Oceanography.....	77
Geology and Geomorphology.....	77



Ecology	78
Marine Megafauna	80
Gaps and Recommendations	80
Lord Howe Island Marine Park (Commonwealth Waters)	81
Uses and Threats	81
Climate and Oceanography	82
Geology and Geomorphology	82
Ecology	83
Fisheries Research	87
Gaps and Recommendations	88
South-east Marine Region	89
South-east Commonwealth Marine Reserve Network	89
Uses and Threats	91
Climate and Oceanography	93
Geology and Geomorphology	93
Ecology	95
Fisheries Research	98
Gaps and Recommendations	98
External Island Territories	100
Heard Island and McDonald Islands Marine Reserve	100
Uses and Threats	101
Terrestrial Research	101
Marine Research	106
Gaps and Recommendations	106
Macquarie Island Commonwealth Marine Reserve	107
Uses and Threats	107
Climate and Oceanography	108
Geology and Geomorphology	108
Ecology	109
Fisheries Research	111
Gaps and Recommendations	111
Summary and Discussion: Research and Monitoring Gaps	112
Recommendations	123



Acknowledgements.....	131
References.....	132
Appendix 1 – Databases, Collections and Metadata.....	166
Appendix 2 – Unavailable Literature.....	167

LIST OF FIGURES

Figure 1. Existing CMPAs within each Marine Bioregion.....	11
Figure 2. Habitat map of Ashmore Reef.....	28
Figure 3. Habitat map of Hibernia and Cartier Reefs.....	29
Figure 4. Broad-scale currents affecting the Coral Sea.....	55
Figure 5. Linkages between the terrestrial and marine environments of Lihou Reef.....	64
Figure 6. Location and names of individual Reserves within the South-east.....	89
Figure 7. Relationship between the number of years and the volume of research.....	113
Figure 8. Number of research papers and reports produced during each decade.....	115

LIST OF TABLES

Table 1. Summary of major ecological research reports from Ashmore and Cartier.....	33
Table 2. List of known datasets available for the Rowley Shoals.....	37
Table 3. Research and monitoring plan for the Ningaloo Marine Park.....	43
Table 4. Studies conducted during the bioregional planning process for the SEMR.....	90
Table 5. Classification of types of research undertaken in the HIMI.....	101
Table 6. Number of studies conducted in each CMPA.....	112
Table 7. Numbers of papers and reports of research of each type by decade.....	115
Table 8. Number of research papers and reports on each broad type of research.....	118
Table 9. List of recommendations for each CMPA.....	124



INTRODUCTION

Marine Protected Areas (MPAs) are widely used to offer protection from exploitation and other direct human impacts to marine species and ecosystems (McCook et al. 2010). The goals of establishing MPAs vary, and can include fisheries management (Russ et al. 2008), conservation of species and genetic diversity through the protection of habitat structure (Fernandes et al. 2005) and the protection of specific threatened species and communities (Embling et al. 2010).

In accordance with its policy of establishing a National Representative System of Marine Protected Areas (NRSMPA), the Australian Government is in the process of establishing a nation-wide network of Commonwealth MPAs (CMPAs) through a process of Marine Bioregional Planning (DEWHA 2010). This process focuses on Commonwealth waters (Australian waters between the outer edge of State / Northern Territory waters, 3 nautical miles from shore, to the outer limits of the Exclusive Economic Zone (EEZ), 200 nautical miles from shore). This process involves the gathering of background information, the preparation of profiles that describe each Marine Region, the establishment of CMPA networks in each Region and the production of management plans (DEWHA 2010).

The following Regions have been defined through the Marine Bioregional Planning process, and most Regions have existing CMPAs (Figure 1):

- The South-west Marine Region,
- The North-west Marine Region,
- The North Marine Region,
- The East Marine Region, and
- The South-east Marine Region.

Most research and monitoring in each Region has been conducted in existing CMPAs. Some of this research was commissioned by the Australian Government, often in order to identify each area's conservation values and to assess the effectiveness of management. In addition, a large amount of research has been undertaken by a wide variety of institutes and organizations. The South-east Marine Region was the first to have a network of CMPAs. With the future establishment of CMPA networks in all the Regions, focused and effective research and monitoring programs will be necessary to document the characteristics, dynamics and health of the CMPAs, and to inform their ongoing management.

This report brings together this disparate body of work as it relates to each Region, and provides a comprehensive review of available information regarding research and monitoring activities undertaken within the CMPA estate. Besides offering a useful overview of current knowledge, this report also identifies knowledge gaps to assist in development of future research and monitoring priorities. Ultimately, this report seeks to inform the best possible establishment and management of future larger networks of CMPAs.

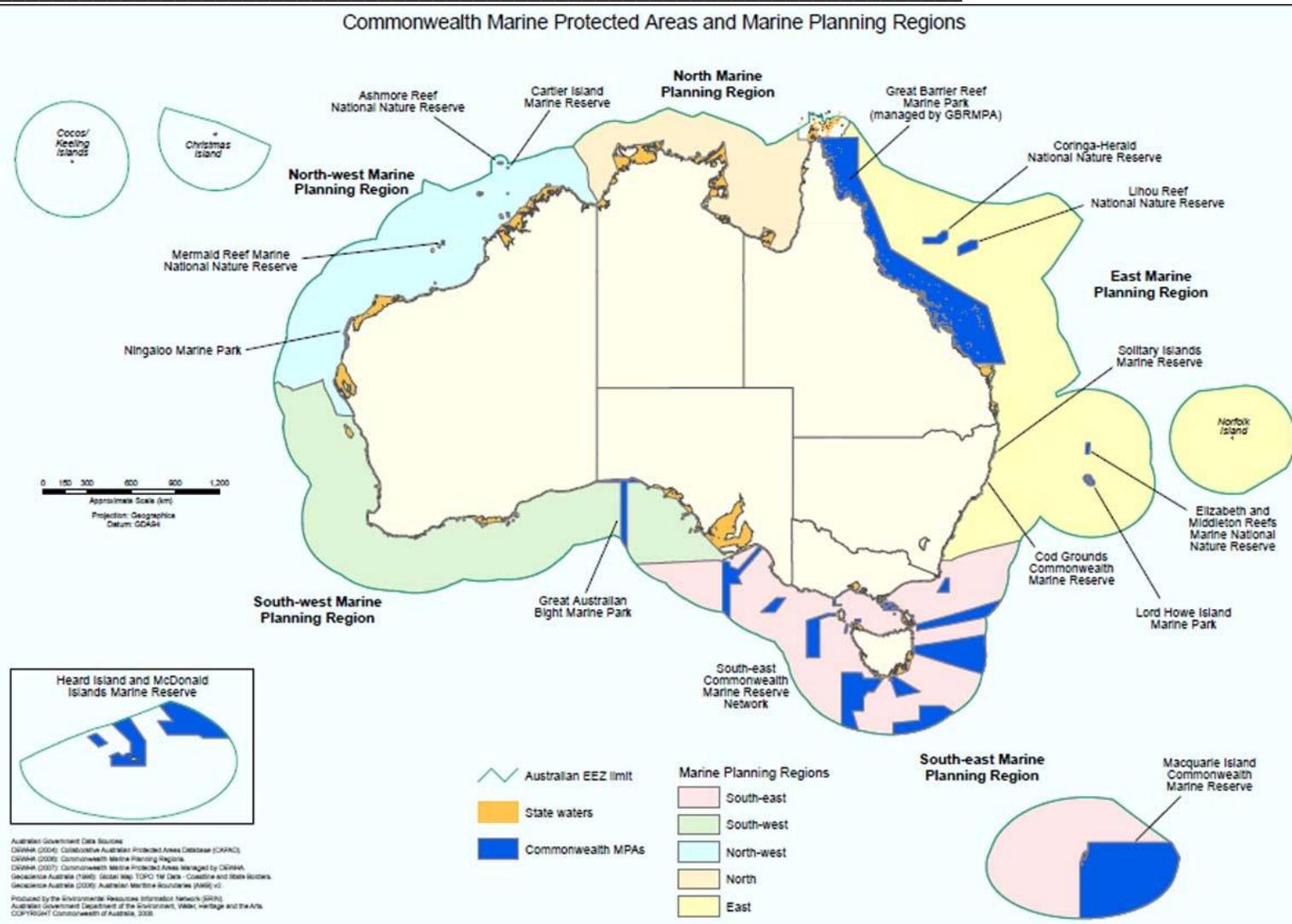


Figure 1. Existing CMPAs within each Marine Region, including the South-east Commonwealth Marine Reserve Network. Source: DEWHA.



OBJECTIVES AND SCOPE

This review aims to provide an overview of research conducted in the existing CMPA estate within the context of each Marine Region. The report considers research conducted in all CMPAs, including those in external territories (the Heard Island and McDonald Islands Marine Reserve, and the Macquarie Island Marine Reserve). The scope of this review excludes the Great Barrier Reef Marine Park, which, although it is also a CMPA, is administered by the Great Barrier Reef Marine Park Authority. Where appropriate, findings of research in State MPAs adjoining CMPAs are included. Additionally, this review identifies gaps in knowledge for each CMPA, and recommends research to address missing information.

METHODS

This study consisted of a review of available publications and reports on the findings of research and monitoring activities in CMPAs and relevant adjoining State MPA within each Region. Additionally, research in the broader Region or from studies conducted elsewhere were sometimes included if this was deemed to add value to information gathered inside the CMPAs.

The information used to compile this study included:

- Peer-reviewed publications
- Management plans and Bioregional profiles
- Reports to DEWHA
- Museum reports and publications
- Direct liaison with authors and researchers
- Online sources and databases (e.g. CSIRO MarLIN)

This report is organized by Region, with a brief introduction and overview of the Region's values, followed by a more detailed review of each CMPA within the Region. Unless otherwise indicated, the information for each CMPA was organized into the following sections:

- Uses and Threats
- Climate and Oceanography
- Geology and Geomorphology
- Ecology
- Fisheries Research
- Gaps and Recommendations

Literature was organized according to each CMPA and systematically reviewed. Where reports or reviews provided information on the larger CMPA estate, such as a broad review of the impacts of climate change on protected areas (Lawrence et al. 2007), these



were assigned to a separate category. These broad works were useful for presenting a brief overview of uses and threats affecting each CMPA.

Where appropriate, information was sorted into broad disciplines such as ‘climate and oceanography, geology and geomorphology, ecology, etc. Available material did not always fall easily into these categories. Where a category was not easily assigned, the study was classified according to its primary objective. In some cases, research was already organized by a number of criteria or programs (e.g. Heard Island, Macquarie Island) set by the responsible research organization. Databases were identified and listed, but analysis of these databases fell outside the scope of this review (Appendix 1). Where literature was not available, Region-specific lists were compiled for future reference (Appendix 2). All reviewed work was entered into an Endnote database and linked to available electronic copies of literature or the appropriate web addresses of online sources.



SOUTH-WEST MARINE REGION

The South-west Marine Region comprises Commonwealth waters from the eastern end of Kangaroo Island, South Australia, to 70 km offshore from Shark Bay, Western Australia, and covers an area of some 1.3 million km². The marine ecosystem of the Region is characterized by relatively low-nutrient waters due to a lack of significant upwellings and river runoff. There are a number of features of conservation value, including species listed as threatened or migratory, endemic species, unique ecological communities and unusual geological features (McClatchie et al. 2006).

The South-west Marine Region profile identifies the south-western continental slope as one of Australia's most complex networks of submarine canyons. The oceanography in the Region is dominated by the Leeuwin Current. Additional currents include the subsurface Leeuwin Undercurrent on the west coast, the Flinders Current on the south coast, and the seasonal and coastal Capes and Cresswell Currents. The Region's currents generate a series of eddies that are thought to be important to variations in nutrient availability. Research in this Region has not yet fully explained observations in the variability and complexity of these eddy systems (Commonwealth of Australia 2007).

Waters of the Region are remarkably low in turbidity, due primarily to the combination of low nutrient availability and few rivers discharging sediment from the land. Light-dependent organisms are therefore able to exist in relatively deep environments, with seagrasses and macroalgae found as deep as 120m. The Great Australian Bight is thought to sustain one of the world's most diverse soft sediment ecosystems, and its waters host one of the world's main calving areas for southern right whales (Commonwealth of Australia 2007). The Great Australian Bight Marine Park (Commonwealth Waters) (GABMP¹) is the only CMPA that currently exists in the South-west Marine Region. The GABMP has benefited from a range of extensive literature reviews that synthesized research up to 2003.

GREAT AUSTRALIAN BIGHT MARINE PARK (COMMONWEALTH WATERS)

The GABMP was established in 1998 and covers 19,769 km², and its current management plan is designed to be in effect from 2005 to 2012 (Commonwealth of Australia 2005a). It extends along the coast from 200 km west of Ceduna in South Australia to the Western Australian border (Figure 1). It also includes a 20 nautical mile wide strip extending from 3 nautical miles offshore to the EEZ boundary 200nm offshore (Commonwealth of Australia 2005a). Landward, the Commonwealth waters of the GABMP adjoin the State waters, and management of the two Marine Park areas is undertaken jointly by State and Commonwealth authorities. The T-shaped Commonwealth waters include a Marine Mammal Protection Zone (MMPZ) and a Benthic Protection Zone (BPZ).

¹ The abbreviation 'GABMP' will refer to the Commonwealth waters of this Park in this document. When the State waters are mentioned, this will be specified.



The MMPZ and BPZ are specifically designed to protect the conservation values of the GABMP, namely:

- habitat for the southern right whale (*Eubalaena australis*),
- habitat for the Australian sea lion (*Neophoca cinerea*),
- habitat for other species of conservation significance, and
- a transect representative of the seabed on the continental shelf and slope of the Great Australian Bight (Commonwealth of Australia 2003).

In 2003, the South Australian Research and Development Institute (SARDI) and the Australian Government Department of the Environment and Heritage (as it was then known) compiled a series of literature reviews of the natural and economic values of the GABMP (Commonwealth of Australia 2003; McLeay et al. 2003; Ward et al. 2003a), and conducted ecological surveys to assess the GABMP's representativeness (Ward et al. 2006b). They acknowledged that relatively few data were available on the biology of non-commercial species in the GAB generally, and the GABMP in particular, to guide the implementation and positioning of the GABMP (Ward et al. 2006b). The following sections summarise the findings of previous literature reviews and, where possible, update these findings with more recent research.

Uses and Threats

The primary uses of the area inside and surrounding the GABMP are fishing, shipping, tourism and mineral exploration. Activities not permitted in the GABMP include mining and exploration in the MMPZ and demersal trawling throughout. Further restrictions include seasonal closures of the MMPZ to boating and commercial fishing, to coincide with activities of protected marine mammals (McLeay et al. 2003). Commercial and recreational fishing occurs throughout the GABMP. In 1996, combined commercial fisheries in the Commonwealth waters of the GABMP for rock lobster, tuna, shark and abalone were valued at between 4.3 and 4.5 million dollars (Morison 1996). The proportion of the catch was variable in the Commonwealth waters, amounting to 5-10% of the rock lobster catch, 65-75% of the shark catch, 90-95% of the abalone catch and almost 100% of the tuna catch (Morison 1996). While the Australian Fisheries Management Authority (AFMA) and SARDI maintain more recent estimates of catch and effort, no recent assessment exists of catch and effort specifically from the GABMP.

Threats from human activities in the GABMP include overfishing, interactions between fisheries and protected fauna and the impacts of mineral exploration and mining (McLeay et al. 2003). Illegal trawling also has the potential to damage the benthic communities in the BPZ (Kloser et al. 2001b). Southern bluefin tuna are thought to have reached dangerously low levels through overfishing (McLeay et al. 2003), potentially altering ecosystem properties through the removal of these predators. A number of potential impacts arise from mineral exploration and mining, including acoustic and habitat disturbances and the potential for oil and other pollution; these impacts were explored in detail by Pidcock et al. (2003) for the MMPZ. The impacts remain unexplored for the BPZ. Interactions between tourism and protected cetaceans are subject to guidelines



regarding the distance between vessels, people and aircraft from individual animals. A long-term study on the coastline of the GAB documented accumulation rates of marine debris, suggesting that ship-based marine litter is a problem even in remote areas (Edyvane et al. 2004). Predicted threats from climate change include changes in ocean currents and water temperature, decreases in mixed layer depth and increasing stratification, resulting in reduced nutrient transport to surface waters. Changes in water temperatures may have repercussions for phytoplankton production and can result in range extensions of marine organisms, increasing the threat of invasive species (Lawrence et al. 2007).

Climate and Oceanography

Seasonal variations in weather patterns over the GAB are driven by the changing position of the subtropical high pressure ridge. Cold fronts can occur when the southern low pressure systems interact with this high pressure ridge, and winds are predominantly from the east (Commonwealth of Australia 2005a). Ocean circulation in the region of the GABMP is dominated by a combination of the Leeuwin Current and the West Wind Drift, with seasonal influence of the Flinders Current.

A number of scientists have provided information about the GABMP's climate and oceanography. Recent modeling studies of the area's oceanography show a continuous 5,500km coastal current system from WA to SA, which forms eddies and varies seasonally (Batteen and Miller 2009). Edyvane (1998) described the area's climate as semi-arid, with most rainfall occurring in winter. Water temperatures are also linked to the prevailing currents; the Leeuwin current carries warm (17- 19°C), low-salinity water into the GABMP in the winter (Rochford 1986; Middleton and Bye 2007) while the Flinders Current carries colder water westward along the continental slope throughout the year (Bye 1983; Middleton and Cirano 2002). An anti-clockwise surface gyre occurs over the continental shelf during summer and autumn. Small-scale, seasonal upwellings occur primarily in summer and autumn during southeasterly winds, although they have more recently been found to occur in winter as well (Batteen and Miller 2009). Patches of cool, high-nutrient surface waters associated with these upwellings enhance primary productivity (Willis and Hobday 2007). Downwellings tend to occur in winter (Middleton and Bye 2007).

A recent review of the GAB's current systems suggests that El Niño events, occurring at 4-7 year intervals, can have a major impact on circulation, causing a rise in the thermocline by up to 150m (Middleton and Bye 2007). There is a hypothesis that El Niño events substantially reduce wintertime shelf-edge currents, therefore affecting downwelling events, but have no influence on summertime currents; this remains to be tested (Middleton et al. 2007).

Geology and Geomorphology

Previous literature reviews (Commonwealth of Australia 2003; McLeay et al. 2003) identify important studies on the bathymetric and geological characteristics of the GAB continental shelf, including (among others) James and Von der Borch (1991), James et al. (2000) and James et al. (2001). Swath mapping, seismic surveys for oil exploration and



exploratory drilling have provided much of the geological information for the GAB (Geoscience Australia 2010). The most comprehensive set of studies on bathymetry, geology and geomorphology were completed during expeditions on board the Rig Seismic vessel (e.g. James et al. 1994) and, later, by the CSIRO specifically within the BPZ (Kloser et al. 2001a).

The general GAB area is characterized by a wide continental shelf, mostly less than 200m deep, which was formed during the Cretaceous by the separation of Australia and Antarctica (James et al. 2001). At the Head of Bight, the shelf spans 260km and is the widest point of the Australian continental margin (Edyvane 1998). Within the boundaries of the GABMP, the edge of the shelf is a gentle slope down to 2,500m, with two small pinnacles (approximately 100m high and 700m across) near the 1,750m isobath. The slope becomes steep below 2,500m, with canyons and large holes (Commonwealth of Australia 2003). The term ‘shaved shelf’ was proposed for this part of the continental shelf, referring to the style of carbonate platform formed by alternating periods of accretion, cementation and erosion (James et al. 1994). Foraminiferans were sampled in the vicinity of the GABMP to investigate ancient fluctuations in salinity, and have revealed the occurrence of a hypersaline environment in the Pleistocene (Rivers et al. 2009). More recent work in the vicinity of the GABMP was able to discern a relationship between the dynamics of sediment accumulation, bottom currents and sea-level fluctuations (Puga-Bernabéu and Betzler 2008).

The lack of terrestrial input from rivers into shelf sediments has made the GAB one of the world’s largest expanses of temperate carbonate sediments (James et al. 1994; James et al. 2000; James et al. 2001), explaining the wealth of sedimentological research in the area. Shelf sediments in the region of the GABMP are dominated by bryozoans and minor amounts of quartz sand, and were described in detail by James et al. (2001). Slope sediments were studied by James et al. (2000). The carbonate nature of the sediments has also resulted in the preservation of relict calcareous Pleistocene sands and sediment-producing bryozoa, coralline algae, sponges, molluscs, asteroids and foraminiferans, as well as evidence of ancient lagoon environments and bryozoans reef mounds (James and Bone 1994; James et al. 2000; Kloser et al. 2001a; Holbourn et al. 2002). The ancient macro-invertebrate fauna in the sediments was described in the early 1990s (James and Bone 1994). Sediment type is one of the most important drivers of benthic ecology in the GAB (Ward et al. 2006b).

Ecology

The GABMP is located in the Eucla meso-scale bioregion, with marine biota typical of the transition between warm and temperate waters. An additional feature of the region’s ecology is a suite of tropical species transported south by the Leeuwin Current. McLeay et al. (2003) summarised biological and ecological research for the region. They also recommended additional research required to assess the status of benthic communities within the GABMP; subsequent work that addressed this was described by Currie et al. (2006; 2007; 2009) and Ward et al. (2003c; 2003b; 2006b).



Marine plants

South Australian marine plants were studied and described by Womersley (1984), and a list of algal surveys relevant to the GABMP is reviewed in Edyvane (1998). Macroalgal diversity is generally low, and there are relatively few seagrass meadows compared to other areas of the GAB. The coastal marine flora of South Australia has been found to be one of the richest in the world, but it is likely that algal abundance and diversity in the Commonwealth waters are limited by light and the low availability of hard substrate, as (Womersley 1984). Some information exists for estimates of standing stock of phytoplankton via measurements of chlorophyll-a, which are typical of nutrient-poor environments but respond to seasonal upwellings with temporary “blooms” (Motoda et al. 1978; Currie et al. 2007).

Marine invertebrates

Recent benthic fauna surveys recorded 797 species belonging to 10 phyla, collected in 65 5-minute tows of an epibenthic sled. The results corroborated the high diversity of the GAB’s benthic ecosystem, defining it as one of the most diverse on earth (O’Hara and Poore 2000; Kloser et al. 2001a; Ward et al. 2006b). Researchers found a clear relationship between sediment structure and the taxonomic composition of benthic communities (Ward et al. 2003c, 2003b). Investigations on the suitability of the location of the BPZ indicated that it was reasonably well-placed to represent this biodiversity, with 54% of all species collected in the GAB found there (Ward et al. 2006b). The benthic assemblage was dominated by sessile, colonial poriferans, ascidians and bryozoans, which made up 74% of the species richness and 96% of the biomass (Ward et al. 2003b; Ward et al. 2006b). Sponges were assessed in detail, and 139 species were described (Sorokin et al. 2005). The most abundant free-living organisms were echinoderms and molluscs. The relatively coarse sediments and high plankton concentrations were thought to account for the prevalence of suspension feeders in the GAB compared with soft-bottom habitats elsewhere (Ward et al. 2003a). There was evidence that past trawling activities had led to localized declines in density and species richness of invertebrates (Kloser et al. 2001a).

The epifauna survey was followed up with a survey of the GAB’s infauna, which differed from the epifauna in being relatively low in diversity (Currie et al. 2009). The inner shelf was found to be dominated by sessile filter feeders and the shelf break hosted predominantly motile, deposit-feeding species. In both surveys, the highest taxonomic richness was recorded near the Head of the Bight and in inner-shelf waters off the western Eyre Peninsula, where productivity is enhanced by seasonal upwelling (Currie et al. 2009). The infauna survey found that all three communities and 72% of taxa collected were represented within the BPZ, confirming findings from the epifaunal survey that this protected area is well placed to represent the benthic biodiversity of the eastern GAB (Currie et al. 2009).

Fish

The GAB’s fish fauna is also highly diverse, with very high levels of endemism. A number of factors have been hypothesized to act as barriers to dispersal and genetic



mixing between the GAB and regions to the east and west, including sharp temperature gradients, the lack of shallow reef habitat, a reef-free “dead zone” of sand and mud substratum at the Murray River and soft-bottom substratum in south-eastern Victoria (McLeay et al. 2003). A survey of offshore fish in the GAB, at depths of 400-1,200 m (Newton and Klaer 1991), recorded 166 species of from 125 genera and 77 families, effectively doubling the number of previously recorded species and extending some species distributions. Fish density and diversity was found to be positively correlated with the complexity of the surrounding habitat, and negatively correlated with the intensity of past fishing effort (Kloser et al. 2001a).

Sharks are a reasonably well-studied component of the region’s fish fauna. Although naturally uncommon, the great white shark (*Carcharodon carcharias*) is relatively abundant here due to the high availability of pinniped prey (Bruce 1992). A number of tagging studies that have resulted in considerable information on great white shark movements in Australian waters were initiated in the GAB (Bruce et al. 2006). The biology of the ornate angel shark, *Squatina tergocellata*, was studied from trawl catches, with the distribution of this species showing some overlap with the current BPZ (Bridge et al. 1998). This species is one of the South Australian endemics, found at depths of 130-400m on the continental slope of the GAB (Bridge et al. 1998). A recent tagging study of shortfin mako (*Isurus oxyrinchus*) and blue sharks (*Prionace glauca*) revealed that these oceanic sharks regularly migrate through the GABMP, often in offshore waters (Rogers et al. 2009) (See also Fisheries Research section below).

Pelagic ecology

A comprehensive study on the pelagic ecology of the eastern GAB did not include the GABMP, but can provide insight into pelagic drivers that may affect GABMP waters (Ward et al. 2006a). In fact, further research into this system suggests that the described patterns overlap with both the MMPZ and the BPZ (Willis and Hobday 2007). These studies provide insight into the ecological consequences of upwellings arising from the Flinders Current. The summer and autumn upwellings drive a temporary increase in chlorophyll density that acts as a resource for seasonally abundant zooplankton. Zooplankton was studied primarily in the western GAB, and it was found that the biomass of zooplankton in the GAB was only 2% of that in the Gulf of Carpentaria (Motoda et al. 1978). The zooplankton assemblage in the GAB is thought to be composed primarily of small copepods, meroplanktonic larvae and cladocerans (Van Ruth 2009). However, high concentrations of sardine and anchovy eggs and larvae were also detected during the upwelling season. The spawning biomass of these species was estimated to be an order of magnitude higher than elsewhere in southern Australia. Furthermore, juvenile southern bluefin tuna prey on these species, suggesting that this seasonal upwelling may drive the summer and autumn migration of juvenile southern bluefin tuna (Ward et al. 2006a; Willis and Hobday 2007).

Marine mammals

One of the main reasons for establishing the GABMP (especially its MMPZ) was the significance of this area as habitat for species of rare and endangered marine mammals,



especially pinnipeds and the southern right whale (Edyvane 1998). The endemic Australian sea lion (*Neophoca cinerea*) and New Zealand fur seal (*Arctocephalus forsteri*) breed in the GABMP. The Australian sea lion has been studied along South and Western Australian coasts (Gales et al. 1994; Dennis and Shaughnessy 1999; Goldsworthy et al. 2010). The world population of Australian sea lions is estimated at 10,000-12,000 individuals, with approximately 7,500 occurring in South Australia and 3,100 in Western Australia (Gales et al. 1994). Almost 10% of the South Australian population occurs in the GAB. The distribution of pinnipeds using the South Australian portion of the GAB was recently reviewed, with updated descriptions of breeding and haul-out sites (Goldsworthy and Page 2009). Recent research has found significant impacts of the SESSF shark fishery on Australian sea lion within the GABMP, while a broader-range study (Goldsworthy et al. 2010) has found similar significant impacts from demersal gillnets on the Australian sea lion across the range of its South Australian habitat.

A literature review of the sensitivities of marine mammals occurring in the GABMP to oil exploration activities (Pidcock et al. 2003) summarized the most relevant research on the GAB's marine mammals. The GAB is home to at least 28 species of cetaceans from six families, 17 of which have been recorded in offshore waters of the GABMP (Bannister et al. 1996). The life histories of most species are not well known (Pidcock et al. 2003). The most common species is the southern right whale *Eubalaena australis*. The southern right whale has been subject to a number of studies at the Head of Bight (Burnell and Bryden 1997; Bannister 2001) and along the southern coasts of South and Western Australia (Bannister et al. 1996). Aerial surveys and photo-identification studies have been underway since the 1990s (Bannister et al. 1997). More recently, tagging studies have documented migration routes of individual southern right whales between Australian and New Zealand waters (Pirzl et al. 2009). Few dedicated marine mammal surveys have been conducted in the GABMP.

Seabirds

Seabirds are also well-represented in the region, with approximately 75% of the breeding seabirds in South Australia found in the eastern GAB. Petrels, shearwaters and albatross are the most common species, including the great winged petrel (*Pterodroma macroptera*), shy albatross (*Thalassarche cauta*), wandering albatross (*Diomedea exulans*), royal albatross (*Diomedea epomophora*), fleshy-footed shearwater (*Puffinus carneipes*), crested tern (*Sterna bergii*), fairy tern (*Sterna nereis*), Caspian tern (*Sterna caspia*), Australasian gannet (*Morus serrator*), silver gull (*Larus novaehollandiae*), Pacific gull (*Larus pacificus*), pied cormorant (*Phalacrocorax varius*), black-faced cormorant (*Phalacrocorax fuscescens*), white-bellied sea-eagle (*Haliaeetus leucogaster*) and osprey (*Pandion haliaetus*). The little penguin (*Eudyptula minor*), endemic to southern Australia and New Zealand, has several breeding sites in the GAB (McLeay et al. 2003). Seabird studies have yet to be conducted specifically in the GABMP.



Fisheries Research

A large amount of the information on the GABMP's fish fauna comes from fisheries research in the area. The first large-scale, dedicated trawl survey to assess fisheries values and obtain biological information on key species was conducted in 1988 (Newton and Klaer 1991). This survey was instrumental in identifying trawlable ground and potentially valuable fish species, defining the depth ranges of commercial fish species, reporting fish species richness and community composition and making preliminary comments on biogeography.

Most fisheries in the GAB operate in its eastern portion, which was determined to be the most productive sector (Newton and Klaer 1991), and have little or no interaction with the GABMP – this is especially true for the State managed fisheries, few of which extend into Commonwealth waters. However, many of the species targeted are likely to have distributions that cross into GABMP waters, suggesting that the GABMP may have an important role in protecting fishery stock. The fisheries of most potential concern appear to be the Commonwealth Great Australian Bight Trawl Fishery (GABTF) and the Southern Bluefin Tuna Fishery (SBTF). These fisheries have historically operated within what is now the GABMP, and were found to still have the potential to impact the BPZ (Ward et al. 2003a).

Under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*, demersal trawling is prohibited within the BPZ, and there are seasonal closures of the MMPZ from May to October. Commercial fishing is prohibited inside the MMPZ from May 1 until October 31, but is permitted in the BPZ where it does not overlap with the MMPZ. Exclusion of the Great Australian Bight Trawl Fishery from these zones was intended to protect benthic communities and minimise interactions with cetaceans and pinnipeds.

SARDI undertook a three-part series of reports to synthesise information on fisheries in the GAB, and on interactions between these fisheries and the values of the GABMP (McLeay et al. 2003; Ward et al. 2003a). The reports described the spatial and temporal activity patterns of activity the fisheries, the potential or actual interactions between the fisheries and the values of the GABMP, and the need for further information to effectively manage fisheries within and around the GABMP. It was calculated from logbooks that in 1992, 14% of the GABTF trawling effort occurred in the area that has become the BPZ. There is concern that some trawling continues in the BPZ, however, and trawling tracks observed during deep-water benthic surveys James et al. (2001) suggest that the effects of trawling on benthos is likely to persist for a long time, and may affect habitats used by rare or valuable mobile species.

The main fish species targeted by commercial fishers in the GAB are southern bluefin tuna (*Thunnus maccoyii*), sardine (*Sardinops sagax*), school shark (*Galeorhinus galeus*), gummy shark (*Mustelus antarcticus*), bronze whaler shark (*Carcharhinus brachyurus*), snapper (*Pagrus auratus*), King George whiting (*Sillaginodes punctata*), deepwater flathead (*Neoplatycephalus conatus*), Bight redfish (*Centroberyx gerrardi*), deep sea



trevalla (*Hyperoglyphe antarctica*) and orange roughy (*Hoplostethus atlanticus*) (Burnell and Newton 1989). However, catch and Catch per Unit Effort (CPUE) information does not exist specifically for the GABMP.

Limited information on bycatch and on the fate of non-target catch and discards was available. Knuckey and Brown (2002) collected spatial and temporal information on the quantity and species composition of retained and discarded catch. They found that different species dominated the bycatch of different fishing methods. Of particular concern were the bronze whalers and great white sharks caught during Southern Bluefin Tuna Fishery purse-seine operations and long-line bycatch of seabirds such as short-tailed shearwaters and albatrosses (Thalman et al. 2009).

Much recent research is directed toward species of commercial interest, including the diving behavior of southern bluefin tuna (Willis et al. 2009). Tagging programs and mapping surveys are used to ascertain the extent of potential habitat for valuable species, and for species of conservation significance such as the gulper shark (Williams 2008). It is difficult to ascertain how much of these data were collected from within the GABMP, as opposed to the general GAB area, but species distributions often overlap with the GBAMP (Willis et al. 2009).

Gaps and Recommendations

Research in this region of Australian waters has historically focused on the GAB in general, making it difficult to derive information specifically for the GABMP. Modern mapping technology has made it possible to determine some of the characteristics relevant to the GABMP, such as sedimentological information. The SARDI surveys have shown that the GABMP is in the right place and is representative of bioregions and habitat types occurring in the GAB, especially the eastern and central areas (Ward et al. 2006b). Mapping and sedimentological information has also linked with studies of benthic communities (McLeay et al. 2003; Ward et al. 2003a), making it possible to initiate baseline surveys for future monitoring of the GABMP. In the absence of data from before the implementation of the GABMP, data must be collected inside and outside the Reserve to provide a measure of the Reserve's performance (Ward et al. 2006b). However, regular and consistent sampling over time will be required to detect divergent trajectories that would indicate an effect of protection. Further gaps in this area include GABMP-specific studies on marine mammals, pelagic communities and recent fisheries catches. Recommendations include:

- Regular (preferably annual) sampling of benthic and pelagic communities inside the GABMP and outside reference or 'control' sites, repeating methods used in the baseline study,
- A monitoring program for marine mammals and seabirds specifically from within the GABMP,
- A risk assessment for exploration and mining or petroleum and minerals in the BPZ,
- Regular collation and reporting of information on all bycatch from all fisheries, including sessile epibenthos, and especially from the vicinity of the GABMP,



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- Ongoing regular collation and reporting of interactions between fisheries and protected species, including capture and mortality of cetaceans, seabirds and pinnipeds, in the GABMP and surrounding waters,
 - An assessment to the extent to which the GABMP may protect important GAB fisheries stock, of both State- and Commonwealth-managed fisheries,
 - Regular collation and reporting of interactions between pinnipeds and rock lobster pots, active and derelict,
 - Regular reporting of logbook data, especially location information for all fisheries, to be regularly collated and information to be shared between Fisheries managers and GABMP managers,
 - Collection of quantitative data on the catches of recreational, indigenous and charter fishers, to be regularly collated and information to be shared between Fisheries managers and GABMP managers,
 - Monitoring of environmental parameters such as water quality, CO₂, temperature, etc., to assist in the interpretation of temporal dynamics and
 - Coupling of ecological data in the GABMP with data on potential impacts from anthropogenic sources, e.g. fishing, mining and marine debris.



NORTH-WEST MARINE REGION

The North-west Marine Region extends from the Western Australian - Northern Territory border to Kalbarri, south of Shark Bay. The marine environment of the Region's Commonwealth waters is characteristically shallow and tropical, and is home to globally significant populations of threatened species (Commonwealth of Australia 2008a). Its unique features include a wide continental shelf with a large number of banks and shoals, a highly variable tidal regime, a high incidence of tropical cyclones and a complex system of ocean currents. The bathymetry, geomorphology and sedimentology of the Region is described in detail by Baker et al. (2008b).

The primary oceanographic drivers of ecological processes in the Region are the Leeuwin Current and the Indonesian Throughflow (see below). The Indonesian Throughflow brings warm, low-nutrient (oligotrophic) water from the Pacific into the Indian Ocean through the Indonesian island group, and the Leeuwin Current carries this water mass further south. Subsurface currents of major significance are the Leeuwin Undercurrent and the West Australian Current. A large tidal range affects the movements of sediments and turbidity plumes. The interaction between ocean floor geology and the prevailing oceanographic patterns in the Region form internal waves, which are a further source of mixing (Commonwealth of Australia 2008a).

Despite its high species richness, the Region has relatively low endemism when compared with other Regions, and shares most species with either the Indian Ocean or the Indo-Pacific. The southern part of the Region represents a transition between tropical and temperate ecosystems. The Region's high species richness is thought to be a product of the intersecting tropical and temperate species pool, a wide variety of available habitats, including hard limestone seafloor, submerged cliffs and coral reefs – both in the Kimberley area and on the outer edge of the shelf – sandy and muddy areas, and the deep waters of the Cuvier and the Argo Abyssal Plains (Falkner et al. 2009).

Some research and monitoring in the Region has focused on its complex oceanography and on a number of iconic species, such as the whale shark (*Rhincodon typus*) and the highly diverse seasnake community. The bulk of research activities has taken place on the Region's coral reefs, including those within the four existing CMPAs: Ashmore Reef National Nature Reserve, Cartier Island Marine Reserve, Mermaid Reef Marine National Nature Reserve and Ningaloo Marine Park (Commonwealth Waters). Recently, collaborations between Woodside and State museums (e.g. the Western Australian Museum, Northern Territory Museum and Art Galleries) have produced a variety of research on the marine biodiversity of the inshore Kimberley and associated continental shelf reefs, including Ashmore, Cartier and Mermaid reefs (WA Museum 2010).



ASHMORE REEF NATIONAL NATURE RESERVE AND CARTIER ISLAND MARINE RESERVE

Ashmore Reef National Nature Reserve (Ashmore) is located on Australia's north-west shelf in the Timor Sea (Figure 1). The Reserve covers 583 km² and encompasses a coral reef with wide reef flats, gently sloping outer reef slopes, two extensive lagoons, shifting sand flats and cays (including three permanent islands known as East, Middle and West Islands) and seagrass meadows (Berry 1993). Cartier Island Marine Reserve (Cartier) is located 25 nautical miles south-east of Ashmore and includes a coral reef, an unvegetated sand island and encompasses the area within a 4 nautical mile radius of the centre of the island (Commonwealth of Australia 2002a).

Ashmore and Cartier provide habitat for a high biodiversity of marine organisms, including sea snakes (Guinea 2008), dugongs (Whiting 1999), reef-building corals (Veron 1993), other sessile invertebrates (Marsh 1993), mobile invertebrates (Marsh et al. 1993), fish (Allen 1993), seabirds, shorebirds and marine turtles (Commonwealth of Australia 2002a). Terrestrial and marine environments at Ashmore are highly valued; its islands were designated as Ramsar Wetlands of International Importance in 2003 for their role as a staging point for migratory shorebirds and breeding habitat for large seabird colonies.

Ashmore was found to support the highest diversity of corals in the NW Region (Veron 1993). Ashmore and Cartier provide important dispersal stepping stones for coral reef species in the Region (Commonwealth of Australia 2002a). The main southward flowing current in the region, the Leeuwin Current, originates in these waters, playing a major role in larval transport from tropical to subtropical and even temperate waters (Simpson et al. 1991). Management and research issues at Ashmore have been extensively reviewed by Whiting (2000). Subsequently, Russell et al. (2003) provided a historic overview of scientific research previously conducted at Ashmore and Cartier, and described the results of a survey designed specifically for the detection of pest species.

Uses and Threats

The main legitimate uses of Ashmore and Cartier are subsistence fishing by Indonesian fishers at Ashmore and tourism, recreation and research (Commonwealth of Australia 2002a). An area of Ashmore is designated as open to anchorage for passing vessels, and limited access to West Island is permitted for the visiting of Indonesian grave sites and the collection of freshwater from an established well. Research activities are usually associated with management requirements of the Reserves, and despite their limited impact, have the potential to introduce foreign organisms and cause localised damage (Commonwealth of Australia 2002a).

Illegal fishing, primarily by Indonesian fishers, has been the greatest threat to the Reserves in recent years. Evidence of continued harvesting has been found through the lack of recovery of commercially valuable invertebrates (Ceccarelli et al. 2007; Richards et al. 2009). Illegal boat arrivals from Indonesia often land on Ashmore Reef, placing pressure on terrestrial and marine habitats through direct use and pollution



(Commonwealth of Australia 2002a). The Australian Customs Service provided a vessel to be stationed at Ashmore in the past; more recently, a dedicated vessel is stationed there permanently. Introduced plants and animals have been an issue primarily for terrestrial habitats, with records of introduced grasses and populations of small introduced mammals (*Rattus rattus* and *Mus musculus*) (Ferguson 2002). Pollution is also possible from passing commercial ships (e.g. sewerage, oil, marine debris) and nearby petroleum mining operations, and climate change is expected to add pressures such as increases in sea levels and temperatures, and greater incidences of extreme weather events (Lawrence et al. 2007). A recent oil spill from a petroleum well in the Timor Sea has posed a threat to Ashmore, and monitoring programs are underway to determine the extent of the damage to the Reserve and surrounding waters (DEWHA 2009b).

Climate and Oceanography

Ashmore and Cartier are located in the tropical monsoon belt, with seasonally high sea surface temperatures (SST) of up to 31°C and frequent cyclones (Commonwealth of Australia 2002a). The dominant winds are south-easterly, and the major current influencing Ashmore is the Indonesian Throughflow, which varies seasonally in strength and is complemented by the Indian Ocean Upwelling (Glenn and Chaproniere 2001). The Indonesian Throughflow carries warm, low-salinity and low-nutrient water from the western Pacific into cooler, high nutrient, highly saline up-welling water of the Indian Ocean. Much of the research into the Indonesian Throughflow current has been based in part at Ashmore, where current meters are stationed (Molcard et al. 1996; Sprintall et al. 2003). The southward flowing Leeuwin Current originates in the waters around Ashmore. As these currents flow southward past the reefs, they transport propagules that maintain coral reef and algal communities further to the south. The large tidal range (approximately 5m) creates strong tidal streams between the shallower reefs and shoals (Skewes et al. 1999b).

Geomorphology

Ashmore is a large carbonate reef with two extensive lagoons, shifting sand cays and sand flats, and three vegetated islands: East, Middle and West Islands (Commonwealth of Australia 2002a). Ashmore reef is different from more southern reefs in that it has greater extents of sandy areas, and lacks extensive shallow reef crest habitat and deep lagoons with steep lagoon edges (Skewes et al. 1999b). Cartier is a much smaller reef with a single unvegetated sand cay. It has a reef flat composed of sand, bare coral pavement, hard corals and a small lagoon approximately eight metres deep (Smith et al. 2002). The exposed fronts of both reefs are characterised by spur and groove formations, and the reef crests are dominated by coralline algae. The sediment is affected by tidal movements and is composed to a large proportion of *Halimeda* and foraminiferans (Glenn and Chaproniere 2001). Substantial hydrocarbon seeps are thought to introduce nutrients into the area and enhance productivity.

Ecology

A number of marine ecological surveys have taken place to fulfil the requirements of ecological monitoring set out within Ashmore and Cartier's management plans (Table 1). Detailed habitat maps for both reefs were produced (Skewes et al. 1999b) and have



guided the location of sampling sites of later surveys (Figure 2, Figure 3)(Smith et al. 2001b). These surveys have generally taken into account most major ecological components of the coral reef systems and associated cays and islands. However, a primary focus has been on capturing the spatial distribution, stock condition and to some extent temporal dynamics of the macroinvertebrates of commercial importance, such as holothurians, trochus and tridacnid clams. The studies have sometimes focused on Ashmore alone (Smith et al. 2001b) or Cartier alone (Smith et al. 2002), but more often surveys have combined Ashmore, Cartier and Mermaid (Rees et al. 2003; Kospartov et al. 2006). More rarely, unprotected reefs and shoals of the NW Region were included in the surveys, allowing for a comparison between protected and unprotected areas (Veron and Marsh 1988; Skewes et al. 1999a; Skewes et al. 1999b).

Benthic communities

Benthic and habitat mapping surveys have characterised Ashmore as having relatively high cover of seagrass (2%) when compared to reefs in the region, as well as low cover of algae (14.5%), soft coral (1.4%) and low overall cover of hard coral (3%) (Skewes et al. 1999b). In comparison, Cartier had 0.1% seagrass, 29.7% algae, 1.6% soft coral and 9.7% hard coral (Skewes et al. 1999b). Collections and cataloguing of scleractinian corals at Ashmore and Cartier were carried out in 1986 (Veron and Marsh 1988) and 1997 (Griffith 1997). The collections recorded 256 species from 56 genera. More recent surveys have recorded 275 species of hard coral, placing Ashmore at the high end of coral diversity in the region (Richards et al. 2009).

Substantial coral mortality occurred as a result of the abnormally high SST in the summer months of 1998. This caused widespread bleaching of corals throughout the Indo-Pacific, with high subsequent mortality in some areas (Skewes et al. 1999b). However, while the large southern reefs (Scott and Seringapatam in particular) experienced up to 76% mortality, Ashmore and Cartier had between 0 and 5% mortality associated with this event (Skewes et al. 1999b). However, later coral surveys estimated that coral cover at Ashmore and Cartier was very low, at ~5% and 10%, respectively, and it was suggested that some bleaching mortality may have occurred (Rees et al. 2003). Subsequent studies found that coral cover had increased to 10% at Ashmore and 16% at Cartier in 2005, and 25.6% and 29.4% respectively at Ashmore and Cartier in 2009, with little evidence of further bleaching (Kospartov et al. 2006; Richards et al. 2009). However, large stands of recently dead coral were noted both at Ashmore and Cartier (Kospartov et al. 2006). To truly ascertain the temporal changes in the overall coral cover at these reefs, it would be necessary to compare surveys carried out at exactly the same sites over a number of years.

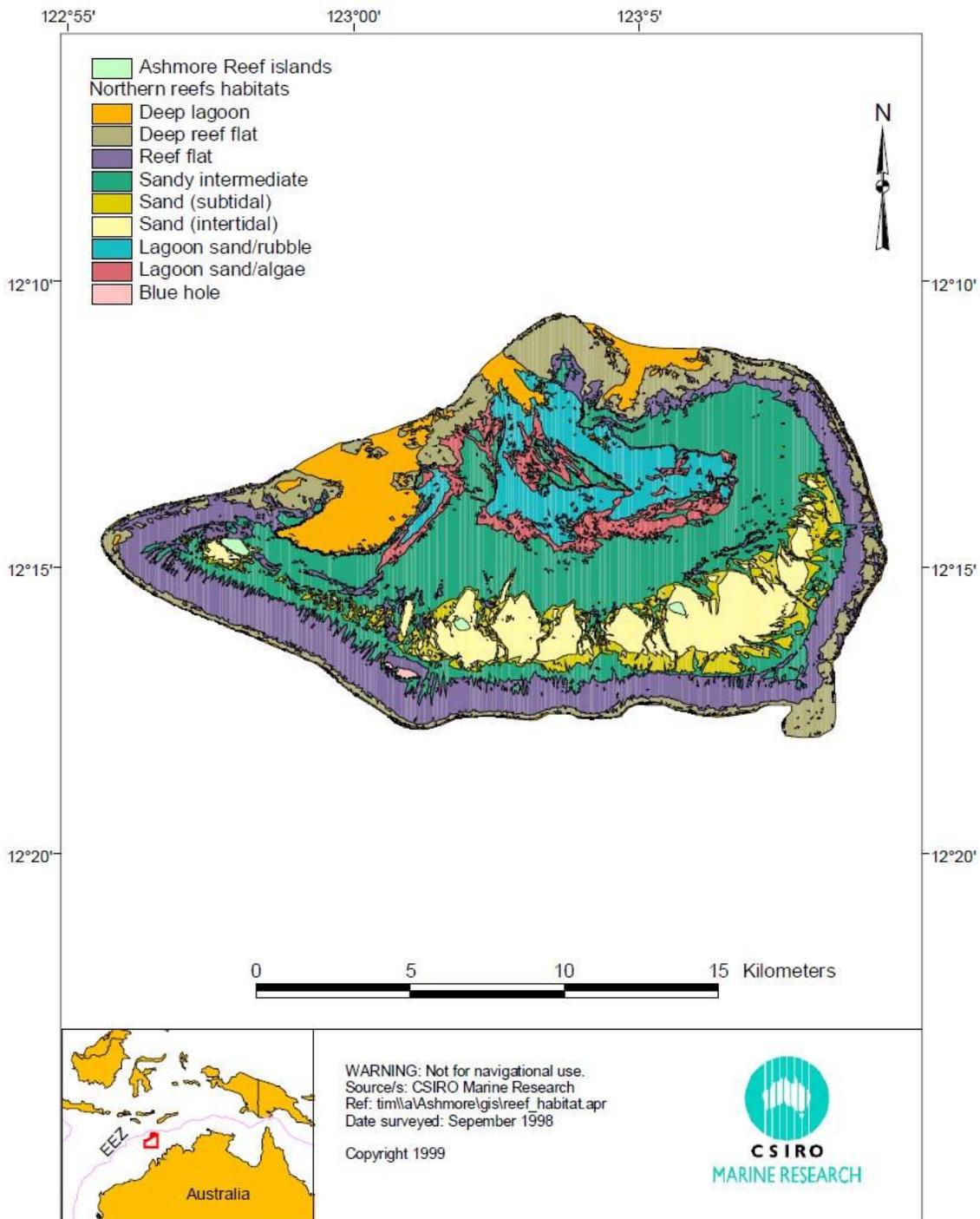


Figure 2. Habitat map of Ashmore Reef produced after extensive surveys by Skewes et al. (1999b).

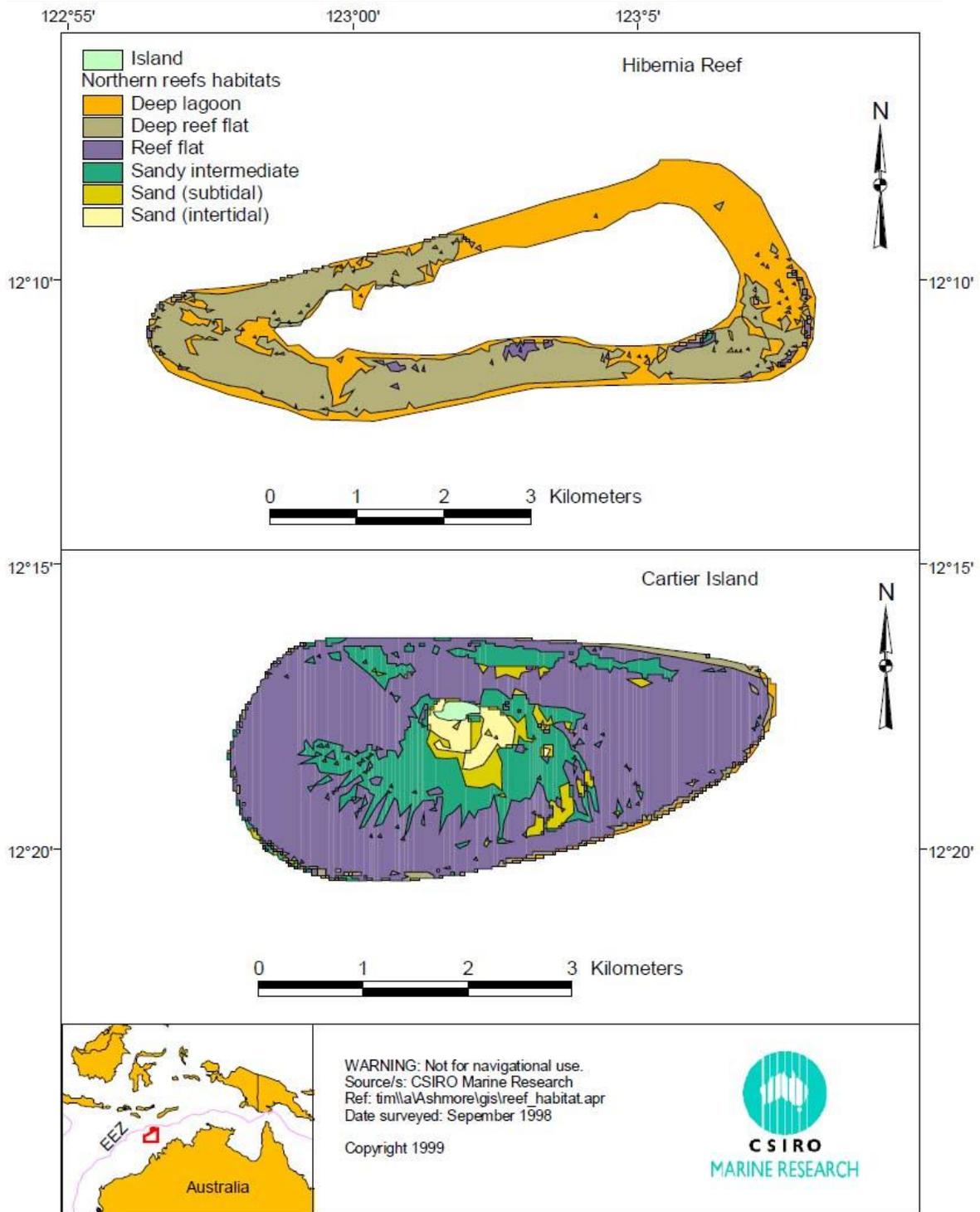


Figure 3. Habitat map of Hibernia and Cartier Reefs produced after extensive surveys by Skewes et al. (1999b).



Macroinvertebrates

Ashmore has been highlighted as having the highest species richness in the region of molluscs (Wells 1993) and decapod crustaceans (Morgan and Berry 1993), and very high holothurian diversity, with 45 species recorded originally (Marsh et al. 1993). Successive surveyors have agreed that high-value holothurian species such as *Holothuria nobilis* and *H. fuscogilva* were fished in large volumes in the 1980s and have now largely disappeared, with the highest remaining densities of *H. nobilis* in the region occurring at Mermaid Reef. Species richness of holothurians has remained high during recent surveys, with 16 species recorded in 2005 (Kospartov et al. 2006) and 18 in 2006 (Ceccarelli et al. 2007). A high-density aggregation of *Holothuria leucospilota* was visited on successive survey trips and appears to have remained stable, both spatially and numerically (Rees et al. 2003; Kospartov et al. 2006; Ceccarelli et al. 2007). Holothurians play an important role as bioturbators, sorting and cleaning lagoonal sediments, together with other echinoderms, annelids, bivalves, Callianassa shrimps, dugongs, stingrays and turtles (Glenn and Chaproniere 2001). AIMS Bioresources have a substantial collection from both Ashmore and Cartier reefs, and the database records from this (linked to taxonomic voucher collection and frozen material) could be used to investigate the diversity of a wide range of invertebrate groups (Dr. L. Evans-Illidge, AIMS, pers. comm.).

Fish

The reef fishes of Ashmore and Cartier are highly diverse, with a total of 932 species from 91 families recorded from the Sahul Shelf reefs, whereby 756 species (81.1% of total) came from Ashmore and 411 species (44.3% of total) from Cartier (Russell et al. 2001). In comparison, Hibernia Reef yielded 351 species (37.9% of total). The abundance of reef fishes was assessed in monitoring surveys starting in 2005 (Kospartov et al. 2006), with a follow-up in 2009 (Richards et al. 2009). Baited Remote Underwater Video Stations (BRUVS) also recorded a greater diversity of finfish at Ashmore than on the Rowley Shoals (Meekan et al. 2005). Sampling effort played a part in causing some of these differences, but Ashmore's proximity to the Indonesian archipelago – which has the world's most diverse fish fauna – is thought to contribute to Ashmore's high fish diversity. Other atolls and reefs of the region (Seringapatam Reef, Scott Reef, and Rowley Shoals) have progressively fewer species with increasing latitude (Russell et al. 2001).

The shallow and deep reef habitats of Ashmore and Cartier support at least 11 species of shark, detected by BRUVS (Meekan et al. 2005). Shallow areas were dominated by the grey reef shark *Carcharhinus amblyrhinchos* and the whitetip reef shark *Triaenodon obesus*, while deeper sites hosted primarily *C. amblyrhinchos* and the silvertip shark *C. albimarginatus*. This survey suggested that Ashmore and Cartier had experienced recovery of some species and habitats from previous overfishing of shark populations (Meekan et al. 2005). The most recent survey that included sharks (Richards et al. 2009) reported very low densities, but these surveys were likely unsuitable for shark population assessments as they were only conducted on the surface on snorkel, missing all sharks occurring below 5 to 10m depth.



Seasnakes

Ashmore has historically been known as a centre of seasnake species richness and abundance, with records of between 9 and 13 species (Commonwealth of Australia 2002a; Guinea 2008). A further four species are thought to exist in the area, but these have not been found inside the marine reserve (Guinea 2008). Three endemic species of *Aipysurus* are reported as inhabiting Ashmore: *Aipysurus foliosquama*, *A. apraefrontalis* and *A. fuscus* (Guinea 2008). Recently two of these species, *A. foliosquama* and *A. apraefrontalis*, appear to have become locally extinct at Ashmore (Lukoschek 2007). A number of surveys and research programs have focused on Ashmore's seasnakes (reviewed in Guinea 2008). In recent years, an alarming decline in both abundance and species richness has been documented. Guinea (2008) examined the declines both with a review of the literature and a field survey in 2008, where he recorded 12 seasnakes in 2 hours at Cartier, but only six at Ashmore in 20 survey days. Further areas monitored include Scott Reef (13 to 35 snakes per hour), Browse Island (no evidence of sea snakes), Seringapatam Reef (17 snakes per hour), and Hibernia Reef (no details given). It appears that the dramatic population decline is restricted to Ashmore (Guinea 2008).

Possible reasons for the decline are still largely speculative, and include climate change, direct human impacts such as fishing, and observed geomorphological changes (Guinea 2008). Silting of the West Island Channel and associated coral heads could be an issue, but this is quite localised and unlikely to cause such large population changes. Movement between reefs has not been demonstrated for the species present at Ashmore, and it is thought not to occur (Guinea 2008). However, recent genetic studies on seasnakes suggest that connectivity may have existed in the past (Lukoschek et al. 2007; Lukoschek et al. 2008), despite the findings that Ashmore, Cartier and Hibernia Reef populations are distinct from those found at Scott Reef.

Turtles

Ashmore Reef, and to a lesser extent Cartier, support an internationally significant population of marine turtles, with up to 11,000 individuals feeding at Ashmore in any given year (Whiting and Guinea 2001b). They are primarily green turtles, with smaller populations of loggerhead and hawksbill turtles. Green turtles are the dominant nesting species at Ashmore and Scott Reefs and Cartier and Browse Islands (Whiting and Guinea 2001b), and the foraging population at Ashmore appears to be genetically distinct from those further north or south (Moritz et al. 2002). Research on marine turtles at Ashmore has been somewhat sporadic, and has involved groups such as the Bureau of Meteorology, the Department of Territories, the Australian National Parks and Wildlife Service and the Sea Turtle Research Group from the Northern Territory University. These studies rely on a minimum of five consecutive years of research to estimate parameters such as population size. Unfortunately, lack of funds in 2000 is reported to have prevented the program from reaching its fifth year. Sea turtle populations at Ashmore are thought to be at high risk from predicted increases in SST, with a heating of the sand on West Island expected to result in a skewing towards female hatchlings by as early as 2030 (Fuentes et al. 2009).



Marine mammals

Ashmore Reef also hosts a small but genetically important population of resident dugongs, supported by extensive seagrass beds in the lagoons (Whiting and Guinea 2001a). Dugongs were first recorded in 1986, and a first dedicated aerial survey was conducted in 1996 (Whiting 1999). A wider area of habitat utilization is probable, with dugongs traveling between reefs of the Sahul Shelf (Whiting and Guinea 2001a). The isolation of this population may afford them protection against threats such as mesh nets and boat-strike, but may make them more vulnerable to illegal hunting by Indonesian fishers, habitat loss due to increased oil and gas exploration and retrieval, and the hazards associated with increased boating (Whiting and Guinea 2001a).

Terrestrial ecology

Terrestrial research has included work on Ashmore's vegetated cays, especially West Island, and has included nesting turtles, seabirds, vegetation and terrestrial reptiles. Ashmore's West Island supports a small range of plant species that are adapted to long-range dispersal and can withstand cyclones, long dry seasons and beach erosion (Ferguson 2002). West Island has herb land interior, fringed with shrubland made up of *Argusia argentea*, with isolated patches of *Guettarda speciosa*, *Scaevola sericea* and *Cordia subcordata*. The other islands have vestigial remains of shrubland (particularly Middle Island), but are primarily composed of herb land. Middle Island shrubs provide the nesting habitat for great frigatebirds (*Fregata minor*). Ashmore Reef is the only known location in Australia where the Asian beach spinifex *Spinifex littoreus* has been recorded (Ferguson 2002).

Ashmore's West Island is a recognized breeding and roosting ground of international significance, as well as an annual migratory stop-over for birds on their way between eastern Asia and Australia, resulting in its listing as a Ramsar site (Ferguson 2002). A study in 1998 found that Ashmore was supporting over 50,000 breeding pairs of various species (Milton 1999). Later work confirmed 93 species of birds, 40 of which are listed on JAMBA and CAMBA². Breeding colonies consisted primarily of common noddies, sooty terns, crested terns, intermediate egrets and reef egrets. *Pisonia* trees on West Island serve as valuable habitat for roosting and nesting birds. Thirteen species of shorebird were also identified, including internationally significant numbers of grey-tailed tattler (Milton 1999). Reptile survey results indicate that only the Asian house gecko *Hemidactylus frenatus* is present in abundance. This is likely due to the high abundance of diurnal avian predators, rather than a lack of opportunities for colonisation (Horner 2001).

² Japan-Australia Migratory Bird Agreement and China-Australia Migratory Bird Agreement



Table 1. Summary of major ecological research reports from Ashmore and Cartier, with available information on sampling effort and major target organisms and findings.

Year	Survey led by	Elements surveyed	Number of sites	Major findings
1993	Western Australian Museum and Northern Territory Museum	Corals and other cnidarians, molluscs, decapods crustaceans, echinoderms, fish	Ashmore (20 sites) and Cartier (4 sites)	Catalogue of species, habitat types and physical environment
1999	CSIRO	Holothurians, trochus, finfish, sharks	Ashmore, Cartier, Seringapatam, Scott, Hibernia, Browse Island surrounds, Woodbine shoal, Johnson shoal, 3 unnamed shoals. 765 sites on shallow reefs, 176 sites on deeper shoals	High-value holothurians found in very low densities, some lower-value species (<i>Holothuria atra</i>) found in very high densities. Trochus severely depleted throughout, small remnant populations on Cartier and Hibernia, Ashmore has highest densities but also shows signs of depletion. Finfish stocks appear to be healthy throughout, with higher densities inside the CMPAs. Sharks have low density throughout. Detailed habitat maps produced. Comparative % cover of major benthic organisms, and % of coral mortality as a result of 1998 bleaching event.
1999	CSIRO	Habitat mapping, corals	Ashmore, Cartier, Seringapatam, Scott, Hibernia, Browse Island surrounds, Woodbine shoal, Johnson shoal, 3 unnamed shoals. 765 sites on shallow reefs, 176 sites on deeper shoals	
1999	CSIRO	Seabirds	Two days on Ashmore	10,000 seabirds of 9 species at Ashmore
2000	AIMS	Holothurians, trochus	Manta tows (59), reef walks (10), spot checks, SCUBA dives, snorkel swims, timed swims	High-value holothurians and trochus depleted at Ashmore. <i>Holothuria fuscogilva</i> reasonably abundant due to depth refuge from fishing



Year	Survey led by	Elements surveyed	Number of sites	Major findings
2001	AIMS	Holothurians, trochus	Distance swim surveys, manta tows, timed swims	High-value holothurians and trochus depleted at Cartier, including <i>Holothuria fuscogilva</i>
2003	AIMS	Holothurians, trochus, tridacnid clams, corals	For macroinvertebrates: Ashmore: 53, Cartier:22, Mermaid: 31. Ashmore lagoon spot surveys for high-density aggregation of <i>H. leucospilota</i> Number of sites not given for corals	Holothurians lowest at Cartier; highest value species (<i>Holothuria nobilis</i> and <i>H. fuscogilva</i>) all but disappeared from Ashmore, <i>H. nobilis</i> found in reasonable densities at Mermaid, density and diversity of other species good at Ashmore; large trochus aggregation on Ashmore's southern crest, tridacnid clams found to be healthy in the region; corals at Ashmore and Cartier affected by large bleaching event, coral cover 30% at Ashmore, 10% at Cartier, unaffected by bleaching at Mermaid, 50% cover
2005	UniQuest	Holothurians, trochus, tridacnid clams, corals, reef fish	12 (4) sites for total reef assessment at Ashmore (Cartier), 33 sites targeting invertebrates and 20 lagoon spot surveys for high-density aggregation of <i>H. leucospilota</i> .	Trochus densities appeared stable since 2003. Holothurians were diverse but mostly low-density. Many species are highly habitat-specific. Tridacnid clam populations found to be healthy, but <i>T. gigas</i> is largely absent. Live coral cover is 10% at Ashmore and 16% at Cartier. Highly diverse benthos and fish community; diversity is highest on sheltered northern sites.
2005	AIMS	Finfish and sharks	BRUVS deployed at Ashmore (58), Cartier and Mermaid, also Scott, Clerke and Imperieuse Reefs	11 species of sharks, higher species richness at deep sites. Deep BRUVS find 2-4 times more sharks at unfished sites. Overfishing implicated at all reefs, some recovery surmised at Ashmore and Cartier. Ashmore has greater abundance and diversity of finfish



Year	Survey led by	Elements surveyed	Number of sites	Major findings
2006	C&R Consulting	Holothurians, trochus, tridacnid clams	49 sites at Ashmore Reef	than Rowley Shoals. A decline in trochus densities and size is reported as a consequence of possible illegal fishing. High-value holothurians are already so low in density that a change could not be detected. Clam densities were not affected.
2006-2008	James Cook University	Turtles	Nesting period over 2-3 years	Hatchling production predicted to skew towards all females by 2030 at Ashmore
2008	Charles Darwin University	Seasnakes	2 hours at Cartier, 20 days at Ashmore	Dramatic decline in seasnake abundance and diversity, especially at Ashmore (6 seasnakes recorded in 20 days)
2009	ARC CoE	Holothurians, trochus, tridacnid clams, corals, reef fish, sea stars	SCUBA sites (8), long snorkel and SCUBA swims, Ashmore and Cartier	Decline in mean abundance of reef fish and invertebrates and low numbers of reef sharks, high parasite load on small reef fish, coral cover recovery



Fisheries Research

Ashmore and Cartier belong to the MOU74 Box, an area of approximately 50,000 km² within the Australian Fishing Zone managed by the Australian Government through a Memorandum of Understanding with the Indonesian Government. This area has been fished by traditional Indonesian fishers for at least three centuries (Vail and Russell 1990; Beech 2001). Indonesian fishing boats (praus) have been surveyed periodically, with a first documented survey in 1987. The documented catch included trochus shell, pearl oysters, squid, octopus, helmet and baler shells, finfish and sharks, clam meat and shell, turtle meat and shell, bêche-de-mer (holothurians), seabirds and eggs and turtle eggs (the latter two mainly at Ashmore) (Vail and Russell 1990).

Numbers of vessels recorded varied from approximately 200 in the early 1990s to 150 in 1998 (Skewes et al. 1999a). Ecological surveys that focused primarily on commercially valuable invertebrates found that stocks were largely depleted by historical overfishing, and have recovered slowly or not at all (Skewes et al. 1999a; Rees et al. 2003). Illegal fishing occurs (Beech 2001), and a survey was carried out specifically to assess the impacts of this on invertebrate stocks in 2006 (Ceccarelli et al. 2007). Anecdotal and empirical evidence suggests that fishing pressure in the region has increased dramatically in the last 20 years (Gilmour et al. 2007).

Gaps and recommendations

Despite its remote location, Ashmore has benefited from numerous ecological studies, including successive surveys on terrestrial and coral reef communities. The detailed comparison and analysis of surveys conducted inside and outside the Reserves is beyond the scope of this review, but would be a good first step in designing a comprehensive monitoring program for Ashmore and Cartier. The greatest gap lies perhaps in the lack of continuity in the monitoring surveys. Given the existing platform in the form of either Australian Customs Vessels or the currently stationed Ashmore Guardian at the site, Ashmore offers the possibility of a more cohesive monitoring program. A number of recommendations have been voiced by previous researchers for Ashmore and Cartier (Skewes et al. 1999a; Skewes et al. 1999b; Smith et al. 2001b; Whiting and Guinea 2001b, 2001a; Commonwealth of Australia 2002a; Rees et al. 2003; Guinea 2008; Richards et al. 2009), including:

- Collation and analysis of current knowledge from possible control locations outside the Reserves,
- A detailed analysis of existing surveys both inside the Reserves and in surrounding areas,
- A monitoring program for Ashmore, with standardisation of methods and repetition of surveys and monitoring activities for all species of concern, and for major ecological communities, within Ashmore and Cartier and at external, unprotected 'control' locations,
- Investigating the viability of using the vessel stationed at Ashmore for more regular research activities,



- Incorporating a program of more frequent snapshot surveys carried out by staff stationed on the vessel,
- Geology and geomorphology studies within the Reserves,
- Integrating physical data such as temperature, current speed, water quality and salinity regimes,
- Initiating or continuing genetic studies on species of concern and conservation significance, especially seasnakes, holothurians, trochus, dugongs and turtles
- Researching dugong movements, population size and preferred habitats
- Preparing a comprehensive risk assessment for the region’s turtle populations, and continuing turtle tagging and monitoring studies
- Further addressing the risk of oil spill/impacts on this CMPA, to be informed by the results of the assessment currently underway,
- Monitoring and reporting of all illegal fishing activity, and
- Centralised storing of all data collected in the Reserve.

MERMAID REEF MARINE NATIONAL NATURE RESERVE

The Mermaid Reef Marine National Nature Reserve (Mermaid) encompasses the northernmost of the three reefs of the Rowley Shoals in the Indian Ocean (Figure 1). The three reefs (Imperieuse, Clerke and Mermaid) are similar in size and shape, with significant lagoonal areas, small sand cays and steep outer reef edges. While Mermaid is fully closed to extractive uses, the other two reefs, Clerke and Imperieuse, experience some recreational and charter fishing (Commonwealth of Australia 2000). Mermaid is considered the most recently formed of the three reefs; it is 14.5 km long and 7.6 km wide at its widest point, with a lagoon 20m in depth. The most comprehensive report, which considers Mermaid within the context of the Rowley Shoals, was compiled by AIMS in 2007 (Gilmour et al. 2007). An additional survey was undertaken by AIMS and the Western Australian Department of Environment and Conservation (WA DEC) (Long et al. 2008). The resulting report contains detailed site and methodology information for all previous research conducted at Mermaid, and lists other datasets available for the Rowley Shoals (

Table 2). A program named ReserveWatch has been drafted that will involve tourism operators collecting information when they visit Mermaid Reef (Commonwealth of Australia 2010). Since 2007, annual reports about the ecological status of Mermaid Reef communities have been provided by at least one tourism operator (Lewis 2007, 2008b, 2009).

Table 2. List of known datasets available for the Rowley Shoals, including Mermaid Reef. Reproduced and modified from Long et al. (2008).

Agency	Dataset / collection / report	Listed contact
WA DEC	Bibliography of published research relevant to the Rowley Shoals. Draft Marine Science Program Report.	Suzanne Long
WA DEC	Database of current and	Suzanne Long



Agency	Dataset / collection / report	Listed contact
WAM, DEC	proposed research relevant to the Rowley Shoals. Draft Marine Science Program Report. Keyword-searchable database inventory of all marine specimens in the Western Australian Museum (WAM) collected from the oceanic atolls of Western Australia, including the Rowley Shoals.	Clay Bryce (WAM) or Suzanne Long (DEC)
AIMS	Octocorals of the Rowley Shoals: basic photo ID guide	Katharina Fabricius (AIMS), available through AIMS and DEC websites
WA Herbarium, DEC, Murdoch	Macroalgae of the Rowley Shoals: basic photo ID guide	Compiled by John Huisman, available through DEC website
DEC	Human use of the Rowley Shoals Marine Park. Draft DEC internal report.	Fiona Galloway (West Kimberley District, DEC)
Fugro, for DEWHA	Swath map and bathymetry data for Mermaid Reef	Nick Kuster
CSIRO	Deepwater biodiversity of NW Shelf, including numerous sampling locations at Imperieuse and Mermaid Reefs.	Alan Williams
WA Fisheries	Deepwater fish biodiversity of the Rowley Shoals	Steve Newman
JCU and WA Fisheries	Underwater visual census and other observations of selected fish species (including <i>Plectropomus</i> spp.) at the Rowley Shoals, 2007	Howard Choat (JCU) or Steve Newman (WA Fisheries)
AIMS	Installation of water temperature loggers and data collection throughout Australia, including the Rowley Shoals.	Ray Berkelmans
AIMS	Baited remote underwater video survey of shallow reef slope fish assemblages at the Rowley Shoals, plus BRUVS of	Mike Cappo



Agency	Dataset / collection / report	Listed contact
AIMS	lagoonal fish assemblages inside Mermaid lagoon. Underwater visual census of lagoonal and shallow reef slope fish assemblages at the Rowley Shoals.	Andrew Heyward
AIMS	Various oceanographic and current studies relevant to the Rowley Shoals.	Andrew Heyward
CSIRO for AFMA	Foreign fishing vessel effort in northern Australia, estimated from Coastwatch surveillance data. 2007 report to AFMA.	John Salini
CSIRO	Assessment of the utility of DIVE as an MPA management support tool: Rowley Shoals case study.	Gary Carroll
AIMS	Genetic connectivity of damselfish populations of WA's coral reefs, including the Rowley Shoals (study underway Jan 2008).	Jim Underwood
AIMS	Invertebrate sample database records linked to preserved taxonomic vouchers and frozen biomass, in the AIMS Bioresources library.	Libby Evans-Illidge

Uses and Threats

Tourism operations, research activities, nearby commercial and recreational fishing and petroleum exploration and mining are the primary uses of the area around Mermaid (Commonwealth of Australia 2000). While Mermaid itself is closed to fishing, surrounding waters support the Western Tuna and Billfish Fishery and the North West Slope Trawl Fishery, and the other two Rowley Shoals reefs are open to recreational fishing. Between 100 and 200 individual visitors (Lawrence et al. 2007), arriving on between two and five charter tourist vessels, are approved to visit Mermaid each year for recreational diving and snorkeling activities (K. O'Dowd, DEWHA, pers. comm.). Localised damage may result from these operations, but they may also provide a platform for monitoring of reef communities and provide a presence to deter poaching (Commonwealth of Australia 2010).

Compared to the fished Rowley Shoals reefs, Mermaid supports visibly higher densities of commercially valued species of invertebrates and fish (Meekan et al. 2005; Lewis



2009). Illegal fishing is possible, but no assessment of this can be made without dedicated monitoring of fish abundance and biomass. Pollution from tourism boats and nearby fisheries and petroleum operations is also a potential threat to the values of Mermaid (Commonwealth of Australia 2000). Threats from climate change to the Reserve include predicted increases in sea surface temperature and tropical storm activity (Lawrence et al. 2007).

Climate and Oceanography

The Rowley Shoals are located within the arid tropics and are affected by monsoonal weather patterns, with mild wet summers and dry winters. Cyclones can affect the region between January and April; Gilmour et al. (2007) identify eight cyclones that have affected the Rowley Shoals in the 22 years prior to 2007. The Leeuwin Current is the primary oceanographic influence on the Rowley Shoals area, particularly between February and June, bringing clear, warm, low-nutrient water from the north (McLoughlin et al. 1988). Mermaid is also to some extent influenced by the Indonesian Throughflow and prevailing south-easterly trade winds. The tidal range of approximately 4m creates strong currents at points of flow in and out of the lagoon (Berry and Marsh 1986). Direct research on the area's hydrodynamics and oceanography is scarce, and data from temperature loggers deployed in 2007 has not yet been analysed (Berkelmans 2009).

Geomorphology

The Rowley Shoals are located on a marginal plateau adjoining the continental shelf of north-western Australia, in the centre of the Roebuck Basin (Berry and Marsh 1986). An early assessment of sediment types around the emergent reefs found primarily mud with a high carbonate content, with patches of sand composed of both benthic and pelagic skeletal remains (McLoughlin et al. 1988). Sediment composition was found to have a strong relationship with the benthic community. A recent swath mapping project of the deep outer reef slopes of Imperieuse and Mermaid characterised the bathymetry, photographed the substratum and collected deep-water benthic organisms (Williams and Barker 2007).

Ecology

The most recent biodiversity survey of Mermaid occurred in 2006 (Bryce 2006). Compared with other reef systems in the region (Scott, Seringapatam, Ashmore, Cartier and Hibernia), the Rowley Shoals, and Mermaid in particular, are said to represent the 'pristine' state of WA's offshore reefs (Hutchings 1994; Gilmour et al. 2007). Anthropogenic impacts are reduced due to the remoteness of the reefs; there is little input of land-based sedimentation, nutrients, and other pollutants, negligible rates of illegal fishing and harvesting and low levels of recreational fishing (Gilmour et al. 2007). The only direct impacts of potential concern are the consistent removal of apex predators where fishing is permitted and the activities of tourism operations.



Benthic communities

A recent review of Mermaid reported 214 coral species from 56 genera (Gilmour et al. 2007). The coral communities at Mermaid were unique even when compared with Clerke and Imperieuse Reefs, with relatively high overall coral cover (34%), but proportionally higher cover of soft (5%), massive (24%), and encrusting (15%) corals. This contributed to the small shift in community structure at Mermaid after the area's most significant cyclone compared to the other two reefs, which changed more dramatically. Some mortality of corals was also recorded during temperature-induced bleaching events in 1998 and 2005. Recent increases in crown-of-thorns starfish have been recorded in the Rowley Shoals, but only at Clerke Reef (Lewis 2007, 2008b, 2009). Trajectories of reef recovery suggest that these reefs are relatively resilient to periodic disturbances at intervals of 10 to 20 years. The uniqueness of Mermaid compared to the other Rowley Shoals has also been reported by Dr. Jane Fromont in sponge surveys of all 3 reefs (Dr. Libby Evans-Illidge, AIMS, pers. comm.).

Reef communities vary between the lagoon, back reef, reef flat, channel and reef slope of Mermaid (Bryce 2006). In 2007 coral cover was estimated at between 60 and 100% on the reef flats and crests, and 30-60% on exposed reef slopes (Lewis 2009). There is concern that reef health will degrade with increasing average SST and increasing frequencies and intensity of cyclonic disturbances. This is especially true for isolated reef systems in oceanic environments, where communities are largely self-seeding and dispersal from outside sources is rare and sporadic (Ayre and Hughes 2004). Dispersal distances were inferred from DNA microsatellite data for a broadcast spawning coral and a brooding species (Underwood et al. 2009), showing that the Rowley Shoals were demographically independent, especially for the brooding species.

Invertebrates

Collections by various museums have recorded 28 species of holothurians, 260 species of macro-mollusc, 233 species of reef-building corals, 34 species of decapods crustacean, and eight species of non-reef-building cnidarians (Berry and Morgan 1986; Marsh 1986a, 1986b; Veron 1986; Wells and Slack-Smith 1986; Bryce 2006). Species richness appears to increase towards the north, with Scott Reef hosting more species than the Rowley Shoals, and Ashmore hosting the highest species richness in the region (see above). However, the Rowley Shoals is closed to traditional fishers, and its distance from both the Indonesian islands and the Australian mainland has afforded these reefs greater historical protection from exploitation (Rees et al. 2003). Therefore the Rowley Shoals are sometimes portrayed as a regional refuge for trochus, holothurians and giant clam which have been exploited on other reefs (Gilmour et al. 2007). Comparative ecological surveys have found relatively high densities of the high-value *Holothuria nobilis* and larger average shell sizes of trochus at Mermaid reef than at reefs further to the north (Rees et al. 2003).

Fish

A recent review reported 530 fish species from 74 families at Mermaid (Gilmour et al. 2007). A complete taxonomic survey at Mermaid Reef was conducted in 1986 in shallow



(0-12m depth) waters (Allen and Russell 1986); the fish species list was updated in 1993 (Hutchins et al. 1995). The structure of reef fish communities was found to be strongly associated with the structural integrity of the habitat, with Mermaid exhibiting the most stable fish community between 1995 and 2001 (Gilmour et al. 2007). More recently, Mermaid was found to host higher densities of otherwise exploited fish such as reef sharks, humpheaded Maori wrasse and large piscivorous reef fishes than Clerke and Imperieuse (Lewis 2008b, 2009). BRUVS deployed at Mermaid and surrounding fished reefs detected that reef sharks and other predatory fish were 2-4 times more abundant in unfished areas than in areas open to fishing (Meekan and Cappo 2004). Overall, striking differences between fished and unfished reefs included 12 sharks of 2 species in 46 deployments at Scott Reef (fished) and 153 sharks of 4 species in 72 deployments at Mermaid Reef (unfished). Mermaid was found to host the greatest numbers of grey reef sharks and whitetip reef sharks in shallow areas among all the reefs in the region, including other protected reefs such as Ashmore and Cartier (Meekan et al. 2005). BRUVS also recorded individuals of the rare thresher shark (*Alopias pelagicus*), sicklefin hound shark (*Hemitriakis* spA) and fossil shark (*Hemipristis elongata*). The flow-on effect of these differences on the rest of the fish community has not been investigated.

Megafauna

Seabirds, turtles and cetaceans are sighted only rarely at Mermaid Reef (Commonwealth of Australia 2000). Only one dedicated survey has examined the presence and abundance of megafauna in the Rowley Shoals. This survey found five species of seasnakes, one species of marine turtle and twelve species of seabirds using the area (Berry 1986).

Gaps and recommendations

Research and monitoring in the Rowley Shoals in general, and Mermaid in particular, has been sporadic, and detailed information on the area's oceanography is still largely lacking (Gilmour et al. 2007; Underwood et al. 2009). Although management of the three reefs is undertaken by different jurisdictions, it would be of benefit to integrate all three reefs into a joined monitoring program that includes physical, biological and ecological data. The use of the area by commercial tourist vessels offers an opportunity for collaboration with scientists, and a 'ReserveWatch' program is currently being implemented. However, ideally this should complement, rather than replace, a dedicated scientific monitoring program. Specific recommendations include:

- Establish a consistent monitoring program for the coral reef communities at all three reefs, with methods that allow comparisons with other CMPAS, with an additional reactive monitoring strategy to put in place after major disturbance events (cyclones, bleaching), and including density, size structure and health indicators for all important reef organisms and physical data,
- Collect demographic data for corals and fish,
- Update reef fish species lists, including nocturnal, cryptic and pelagic fish,
- Initiate mark-recapture studies of high-value invertebrates,
- Research connectivity within and among reefs of the Rowley Shoals, and between the Rowley Shoals and other reefs and shoals in the region, especially for reef fish and commercially targeted invertebrates,



- Investigate community-wide differences in reef fishes between fished and unfished reefs, including visual and BRUVS methods suited to deeper reef communities and shallower areas,
- Study movements and migratory patterns of reef sharks to ascertain their vulnerability to fisheries operating outside the protected zones,
- Develop a reporting mechanism for tourism operators that includes the nature and length of their visits and any observations of illegal fishing and harvesting, and
- Centralised storing of data from research on all three reefs, with regular reporting on results.

NINGALOO MARINE PARK (COMMONWEALTH WATERS)

The Commonwealth waters of Ningaloo Marine Park (Ningaloo) include primarily deep-water habitats adjoining the State waters that protect Ningaloo Reef itself. Ningaloo extends 300km along the west coast of the Cape Range Peninsula near Exmouth, Western Australia (Figure 1). The total area of Ningaloo is 2,435 km², and its depth ranges from 30m to 500m. Ningaloo hosts both tropical and temperate species, many at the limits of their geographic range. Ningaloo Reef, which is protected by the Park's State waters, is the largest fringing-barrier reef in Australia, one of the longest fringing coral reefs in the world, and is the only extensive coral reef in the world fringing the west coast of a continent (Taylor and Pearce 1999). The most iconic species to frequent the Park is the whale shark, which aggregates, numbering in the hundreds, in its waters between March and June each year.

There is considerable hydrodynamic and ecological overlap between the State and Commonwealth waters of Ningaloo. Tidal currents move between the two jurisdictions on a daily basis, allowing for a regular exchange of water. Pelagic and demersal organisms also move regularly between the two jurisdictions for feeding and reproduction. The main habitats of the Commonwealth waters are the waters and seabed of the continental shelf and slope; supporting key planktonic, benthic and demersal species (LeProvost Dames & Moore 2000). Due to its proximity to the WA coast, scientific research is regularly conducted on Ningaloo Reef, in the State waters. In the Commonwealth waters, research efforts have focused on oceanographic studies of the Leeuwin and Ningaloo currents (Taylor and Pearce 1999), and studies on the biology and migration patterns of marine megafauna such as whale sharks (Stewart et al. 2005) and humpback whales (Commonwealth of Australia 2002c). There has also been some tagging of game fish, geological studies and surveys of the deep water benthic communities (Colquhoun et al. 2007). Le Provost Dames & Moore (2000) listed research programs that were underway prior to 2000, and an updated list was provided by Ceccarelli and Kospartov (2006) (Table 3).

Table 3. Research and monitoring plan for the Ningaloo Marine Park set out in 2005 by the State Environment Department, taken and modified from Ceccarelli and Kospartov (2006).



Ecological values	Research and monitoring strategies	Relevance to management	Institutions
Geomorphology	Undertake research to map and classify the seabed geomorphology of the reserves, with a particular emphasis on the deeper (>20m) areas and reserve areas of Exmouth Gulf. (CALM). (H)	Will assist in broad scale mapping of deeper water biodiversity values and contribute to the identification of biodiversity surrogates.	AIMS (Australian Institute of Marine Science) Curtin University WAM (Western Australian Museum) UWA (University of Western Australia)
Water Quality (KPI)	Develop an appropriate understanding and predictive capacity of the circulation and mixing of the reserves' waters, particularly in relation to key ecological processes (eg nutrient supply and productivity, recruitment, connectivity) (CALM). (H)	Will assist in the interpretation of water and sediment quality studies; will support key ecological investigations (e.g. coral and fish recruitment); will assist decision-making in relation to emergency responses to oils spills; will assist in managing visitor risks.	DoIR (Department of Industry and Resources) AMSA (Australian Maritime Safety Authority) UWA Curtin Uni.
Coral Reef Communities (KPI)	Undertake research to characterise the distribution, abundance and key functional groups of coral populations within the reserves, with a particular emphasis on the seaward deeper water communities (CALM). (H)	Will provide a better understanding of coral reef community ecology and the role of key functional groups in maintaining healthy coral reef systems.	AIMS CSIRO (the Commonwealth Science and Industry Research Organization) Curtin Uni. DoF (Department of Fisheries) ECU (Edith Cowan University) Murdoch Uni.

Uses and Threats

The relatively remote nature of the Commonwealth waters of Ningaloo from the coast ensure that human use of the area is low, with most activities taking place in the State waters and on Ningaloo Reef itself (Commonwealth of Australia 2002c). Recreational and charter fishing are permitted (Hourston and Johnson 2008), and there is likely to be a low incidence of commercial shipping passing through Ningaloo (Ceccarelli and Kospartov 2006). Commercial fisheries also have a small overlap with the Commonwealth waters. Whale shark tourism probably makes up most of the human activity in this part of Ningaloo (Commonwealth of Australia 2002c).



Possible threats of greatest concern are those arising from direct and potentially inappropriate interactions with marine megafauna (Commonwealth of Australia 2002c). The whale shark population that aggregates in these waters is also at risk from exploitation and other human interactions outside Australian waters, affecting the local aggregation (Meekan et al. 2008). Fishing can cause damage to benthic communities and changes in the trophic structure of fish communities through the removal of predators (Rees et al. 2004). Nearby seismic operations during petroleum exploration, marine debris and pollution from vessels can also potentially affect populations of feeding and breeding organisms, as well as posing a threat to the high water quality typical of Ningaloo (Commonwealth of Australia 2002c). Climate change may pose a threat through changes in storm frequency and intensity, changes in current systems and altered food webs (Lawrence et al. 2007).

Climate and Oceanography

Ningaloo experiences strong prevailing southerly winds from September to March, and more easterly winds between April and August (Taylor and Pearce 1999). Wind and rainfall are significantly influenced by tropical cyclones, especially between January and March, when the region experiences an average of three cyclones per year (LeProvost Dames & Moore 2000).

Ningaloo is affected by two major current systems. Firstly, the southward flowing Leeuwin current brings warm, low salinity water southwards from the tropics at approximately the 200m depth contour near the continental shelf. The low-nutrient condition of the area is maintained by the oligotrophic waters brought in by the Leeuwin Current and the system of downwelling it supports (Woo and Pattiaratchi 2008). Secondly, from September to mid-April the northward-flowing Ningaloo current flows closer to Ningaloo Reef (Taylor and Pearce 1999) and can enhance nitrate concentrations on the continental shelf through localized upwelling (Hanson et al. 2007). Variations in these major surface currents have been linked to El Niño years (Woo and Pattiaratchi 2008).

The tidal range affecting Ningaloo is much smaller than the tides occurring in the Kimberley and Pilbara region, but the funneling of the ebb tide through openings in the reef produces locally strong currents (LeProvost Dames & Moore 2000). More recently, five separate water masses were distinguished in the region (Woo and Pattiaratchi 2008). However, LeProvost Dames & Moore (2000) succinctly summarized the primary hydrodynamic influences of Ningaloo: *“The Leeuwin and Ningaloo currents thus play a significant part in transporting tropical organisms into the Marine Park, modifying conditions (warming) such that they are suitable for their existence (Leeuwin Current) and recirculating nutrients within the system (Ningaloo Current), such that an essentially low nutrient system is able to sustain relatively high productivity”*.

The high water quality of Ningaloo is maintained by its distance from large human populations on a largely erosional shoreline with an absence of large river inputs, the



narrowness of the continental shelf, the proximity of the open ocean and the Leeuwin Current (Ceccarelli and Kospartov 2006). Detailed water quality information is available only for sporadic periods when research vessels have monitored water chemistry offshore (Brooke et al. 2009).

Geology and geomorphology

Ningaloo is located on the northern extremity of the Dirk Hartog Shelf of Western Australia (LeProvost Dames & Moore 2000). The reef edge coincides with a gently sloping submarine shelf, underlain by Pleistocene limestone and a layer of marine sediments. The northern part of Ningaloo features a steep drop-off, resulting in a narrow shelf with its landward edge unusually close to the shore. The shelf break is thought to occur at approximately 100m depth (LeProvost Dames & Moore 2000). The narrowness of the continental shelf is instrumental in bringing oceanic species relatively close to shore. The shelf broadens to the south, to more than 30 km near Amherst Point (LeProvost Dames & Moore 2000). The structure and geomorphology of the reef and slope interact closely with the oceanography within and surrounding the Park.

Recent comprehensive surveys of deeper waters of Ningaloo (Colquhoun et al. 2007; Brooke et al. 2009) found a clear zonation of habitat types across the shelf, with benthic habitats closely associated with the underlying geomorphology. An extensive system of large ridges was identified, resulting in a highly rugose slope, and the deepest parts of the Park were found to be dominated by soft sediments (Brooke et al. 2009).

Ecology

Key ecological values and characteristics of Ningaloo have been reviewed twice (LeProvost Dames & Moore 2000; Ceccarelli and Kospartov 2006), and more recently have been subject to direct surveys (Colquhoun et al. 2007). Research has focused most of all on the area's pelagic ecology, especially as a support system for the Park's iconic species, the whale shark. Deep-water benthic and demersal species have been surveyed periodically, but have only recently been accessible to dedicated and comprehensive research programs.

Key habitats include the open ocean and the seabed seaward of Ningaloo Reef, including parts of the continental slope and shelf. The particular patterns of water movement in and around Ningaloo have resulted in a regular mixing of tropical and temperate influences, supporting unique pelagic, demersal and benthic communities. Shallow areas to the west of North West Cape support both tropical and temperate biota, but the benthic assemblages found in Ningaloo differ substantially from those further north (Dampier Archipelago) and south (Abrolhos Islands) (Ceccarelli and Kospartov 2006).

Many of the invertebrate and fish species endemic to WA occur in the waters of Ningaloo. For example, two new species of volutid gastropod molluscs were described from depths of approximately 130m in the 1970s. The Park supports 464 species of fish, 5% of which are endemic to Ningaloo, approximately 600 species of molluscs, 10% of which are endemic, and 90 species of echinoderms with up to 20% endemism. A large



variety of ecological processes, including the migration of pelagic species (tuna, humpback and other whales, turtles), seasonal feeding aggregations (whale sharks, manta rays), and possible nursery grounds (sponge gardens and deepwater seabed communities) are supported by the open waters and deeper habitats of Ningaloo (Ceccarelli and Kospartov 2006).

Benthic communities

Surveys targeting the deep-water benthic communities of Ningaloo have been undertaken only recently (Rees et al. 2004; Colquhoun et al. 2007; Brooke et al. 2009), as research there has previously been limited by depth. Benthic organisms are strongly associated with the substrate composition, with higher density and diversity found on hard substrata. Corals disappear in the 30-40m zone, although they persist into the 40-50m zone towards the south. Benthic communities are dominated by sponges, crinoids, soft corals and macroalgae, which sometimes form medium to high density ‘sponge gardens’ (Colquhoun et al. 2007). There are areas of sandy seabed which support sand-dwelling organisms such as sea cucumbers. Reef-building corals (Order Scleractinia) have not been found in the Commonwealth waters except in the shallowest areas at the southern end. The recent survey of the seabed (Rees et al. 2004) concluded that they are potential biodiversity hotspots for filter-feeding communities. Ningaloo supports a number of unique tropical benthic assemblages not found in similar surveys elsewhere off the coast of WA (Rees et al. 2004). Recently, novel methods of collecting both benthic and planktobenthic (immediately above the benthos) samples have been tested in the vicinity of Ningaloo (Przeslawski and McArthur 2009). Due to the recent nature of benthic collections, much of the identification of species and taxonomic characterizations are currently underway (Brooke et al. 2009).

Fish

The sponge gardens provide food and habitat for a number of shark and fish species, including parrotfish, damselfish and surgeonfish. Common pelagic fish species include black, blue and striped marlin, sailfish, trevally, mackerel and tuna. Large demersal fish species include snappers, seaperches, emperors, lizardfish and goatfish (Commonwealth of Australia 2002c). The Commonwealth waters are significant for the migration of various species of tuna and potentially provide nursery habitat for juvenile southern bluefin tuna (Commonwealth of Australia 2002c). Some squid species are also found in the deeper waters, although research has focused primarily on shallow waters (Jackson et al. 2008).

A survey of the deeper waters of Ningaloo revealed 52 species from 25 fish and elasmobranch families, some of which are commercially and recreationally significant (Rees et al. 2004). This survey also found sandbar sharks (*Carcharhinus plumbeus*, listed as ‘near threatened’ by the IUCN), bull sharks (*C. leucas*), silvertip sharks (*C. albimarginatus*), gold-band snapper (*Pristipomoides multidens*), and high densities of red-throat emperor (*Lethrinus miniatus*). The presence of the grey gummy shark (*Mustelus* sp.) has possible implications for conservation, as its biology is poorly understood and its range appears to be restricted (Rees et al. 2004). Large sharks



including oceanic white-tip and tiger sharks are also known from these waters (Rees et al. 2004). More recently, BRUVS recorded 319 species of finfish from 54 families, but this was thought to be an underestimate of species richness for both commonly encountered and rare species (Colquhoun et al. 2007). This deep-water survey found distinct depth zonation and clear habitat partitioning in the fish community.

Megafauna

Ningaloo is noted internationally for its marine megafauna, including whale sharks, whales, dolphins, manta rays, dugongs and turtles, and a multitude of pelagic fish species. While some of these organisms have been well-documented in the past (e.g. Whale sharks), research on others has begun only recently (e.g. manta rays (Sleeman et al. 2007)). Only one record exists of a large-scale aerial survey encompassing all major megafauna groups (Sleeman et al. 2007). This study found that the relative biomass of krill feeders (i.e. minke whales, whale sharks, manta rays) were related to SST, chlorophyll-a (as an indicator for nutrient availability) and bathymetry; relative biomass of fish/cephalopod feeders (dolphins, sharks) were weakly correlated with changes in SST, other invertebrate/macroalgal feeders (turtles, dugong) were weakly responding to changes in steepness of the shelf (bathymetry gradient).

Four species of marine turtles have been recorded in Ningaloo, including the hawksbill, flatback, green and loggerhead turtles (Preen et al. 1997). Both the State and the Commonwealth waters of Ningaloo are important transit zones for females travelling to the coastline to lay eggs and for hatchlings returning to the ocean. Monitoring of marine turtles in both jurisdictions has been occurring since approximately 2002 (Ceccarelli and Kospartov 2006). Dugongs are occasionally seen in the Commonwealth waters, but primarily frequent the shallower State waters and Exmouth Gulf, where seagrass is plentiful (Commonwealth of Australia 2002c). Approximately 30 species of seabird have been recorded within the boundaries of the Park, where they either reside or seasonally migrate. Of these, 19 have been recorded in the Commonwealth waters, where they use the pelagic habitat for feeding (Ceccarelli and Kospartov 2006).

Many species of dolphin reside permanently in Ningaloo, including Indo-Pacific bottlenose dolphins, Indo-Pacific humpbacked dolphins, common dolphins, spinner dolphins, spotted dolphins, striped dolphins and Risso's dolphins (Commonwealth of Australia 2002c). Migratory whales passing through include the sei whale, orcas, the endangered blue whale and southern right whales, sperm whales, minke whales, Bryde's whale, pygmy sperm whale, pygmy killer whale, false killer whale, short-finned pilot whale and melon headed whale. The northern migration occurs more generally in offshore waters (often within the Commonwealth waters), while the southern migration route occurs closer to land (often inside State waters), with Exmouth Gulf being a major resting area for mothers and their calves (Roland Mau, DEC, pers comm in Ceccarelli and Kospartov 2006).



Whale shark

The filter-feeding whale shark is the world's largest fish, with adults measuring up to 20m in length. This species has attracted the largest volume of research in and around Ningaloo (Bradshaw et al. 2008), including the development of photo-identification methods for population studies (Meekan et al. 2006), satellite tagging (Norman 2005) and record-keeping by tourism operators (Meekan et al. 2008). They are believed to reach maturity at 30 years of age and possibly live to 100 years of age; their slow growth and low reproductive output are key factors to their classification both in the EPBC Act and on the IUCN Red List as a vulnerable species (Commonwealth of Australia 2005b).

Whale sharks inhabit waters between the latitudes 30°N and 35°S, in sea temperatures of 21-25°C. They appear to be highly migratory, and aggregations have been recorded in waters off Australia, India, Indonesia, Thailand, the Philippines, Taiwan, Seychelles, Kenya and Somalia. Genetic studies indicate that Indo-Pacific whale shark populations are not distinct, and that their highly migratory nature has led to genetic mixing (Meekan et al. 2008). Long-distance tagging studies have shown that the Ningaloo population of whale sharks is part of a wider stock that is likely to encompass waters of the south eastern Indian Ocean and South East Asia (Meekan et al. 2008).

Recent efforts by AIMS scientists to track individual whale sharks have indicated that Ningaloo is a critical habitat for this species, providing feeding grounds when zooplankton is abundant between March and June, and supporting the local tourism industry (Catlin and Jones 2010). Most of the individuals in this area have been identified as immature males, indicating that Ningaloo is probably not a breeding area (Norman 2005). The abundance of whale sharks in Ningaloo is estimated to vary between 200 and 400 individuals per year (Bradshaw et al. 2008). Population size and migration routes are currently being studied, and do not appear to be as longitudinally narrow as the migration routes of humpback whales.

Ongoing work includes the analysis of satellite tag tracks and dive records, and aims to quantify the extent of genetic interchange among three major whale shark aggregations: Ningaloo, Seychelles and Mozambique (Meekan et al. 2008). Recent research has highlighted concerns that over-exploitation in areas where the whale shark is not protected is affecting Ningaloo's population, resulting in fewer (by ~40%) and smaller (by ~ 2m) individuals (Bradshaw et al. 2008). In contrast, injury through boat strike, investigated by comparing boat strike scars, appeared lower in the Ningaloo region than in the Seychelles (Speed et al. 2008). Tagging and genetic studies of whale sharks have been completed or are currently underway, as well as the compilation of photoidentification libraries (Norman 2005; Stewart et al. 2005; Meekan et al. 2008).

Fisheries Research

Commercial fishing is not allowed inside Ningaloo's waters. Fishing effort in the Commonwealth waters is restricted to charter fishing boats, often targeting higher-order predators (Hourston and Johnson 2008). The most recent survey detected a decline in charter fishing activities over the preceding eight years, and a change in the compositions



of the catch. The change constitutes a shift from emperor species (e.g. spangled, red and blue-spotted) towards a more diverse selection of species, including those less commonly targeted such as chinaman cod (Hourston and Johnson 2008). The authors of this report state that the most complete dataset that is pertinent to fishing activities in the Park is the logbook data from the charter fishing boat operators based in the Gascoyne Bioregion, in which they are required to complete daily trip return sheets as a condition of their license (Sumner et al. 2002). While commercial fishing is not allowed, commercially valuable species do occur there and therefore Ningaloo is likely an important tool for management of commercial stocks for fisheries nearby.

Gaps and recommendations

Research in Ningaloo's Commonwealth waters is challenging due to its depth and offshore nature; to track the health of the ecosystem it may be more cost-effective to monitor physical characteristics support its ecology (e.g. water quality) and specific threats (e.g. fishing activities). There are still gaps in whale shark research; however, these are being addressed through successive studies by various agencies and institutions. No temporal data exists for Ningaloo's other important megafauna, and surveys of the benthic and demersal communities have only recently begun (LeProvost Dames & Moore 2000; Rees et al. 2004; Norman 2005; Bradshaw et al. 2008). Recommendations for Ningaloo include:

- Design a monitoring program for the Reserve's water and sediment quality, and a reporting mechanism for threats and pressures,
- Initiate regular boat-based and aerial surveys of marine megafauna,
- Conduct further research on the planktonic composition of the pelagic habitats of the reserve, with a view to designing a monitoring program,
- Continuing deep-water surveys using high-resolution acoustic methods backed with video validation and grab sampling, using the methods and sites of the baseline survey and including 'control' sites outside the Reserve,
- Linking data on the Reserve's specific hydrodynamics to its biological characteristics,
- Continue and expand whale shark tagging, mark-recapture, biopsy sampling and life history studies to identify migration pathways and life history,
- Maintain eco-tourism logbooks with annual analysis of data and reporting,
- Continue investigations into the reasons for whale shark decline,
- Expand, update and use the established photoidentification library; encourage international pooling of photo-ID libraries,
- Conduct risk assessments to assess the effects of the tourism industry and petroleum exploration activities on whale sharks, and the impacts of continued fishing on fish communities,
- Analyse exploitation levels of whale sharks internationally, and
- Forge international links and relationships to ensure better protection for whale sharks worldwide.



NORTH MARINE REGION

The North Marine Region contains the most extensive areas of Australia's shallow continental shelf, and lies entirely in tropical waters. It includes the Commonwealth waters of the Gulf of Carpentaria, Arafura Sea and the Timor Sea, and reaches west to the Northern Territory - Western Australian border. The Region's tropical climate is characterized by the cycle of wet and dry seasons, with the monsoonal wet season typically lasting from December to March. The monsoonal cycles also drive processes in the Region's marine ecosystems, especially the large influx of freshwater run-off that contributes to seasonally elevated nutrient levels and the prevalence of tropical cyclones during the wet season. No current CMPAs exist in the Region.

During the process of Bioregional Marine Planning in the North, a number of key ecological features, flagship species and species of international significance, including 11 species listed as threatened under the EPBC Act, were identified. Key ecological features include shelf areas that support aggregations of marine life, soft-sediment benthic communities and seagrass beds, corals and reefs, both emergent and submerged, and unique geological features of the seafloor. Flagship species that are uniquely associated with this Region are the flatback turtle, Australian snubfin dolphin, narrow sawfish, brown booby and heart urchin (Commonwealth of Australia 2008b).

Other features of the Region include extensive hydrocarbon seeps, *Halimeda* mounds and large shoals. The rich deposits in this area support a growing hydrocarbons industry that represents both an economic value and a potential environmental threat to the waters of the Region. The lack of current CMPAs means that this Region is outside the scope of this review. It is recommended, however, that a provision to regularly review the research and monitoring associated with a future CMPA Network be included in the resulting management plan.



EAST MARINE REGION

The East Marine Region includes the Commonwealth waters of the Coral Sea and the Tasman Sea, extending from the northern tip of Cape York to southern NSW and the Commonwealth waters around Lord Howe and Norfolk Islands. It lies adjacent to the Great Barrier Reef Marine Park. It includes both tropical and subtropical waters and encompasses Australia's most extensive areas of marginal plateau with extensive seamount chains and emergent reefs and islands (Keene et al. 2008). The Region's oceanography and marine ecology are dominated by the East Australian Current, which flows southwards from the Coral Sea to waters east of Tasmania. Its strength varies seasonally, and productivity is affected by its large eddies and associated upwellings. It flows up to 500m deep, 100km wide and transports up to 30 million cubic meters per second, carrying and supporting tropical and subtropical species in temperate waters. The East Australian Current meets the Tasman front at approximately 30 degrees latitude, and this delineates the tropical-temperate transition. This convergence zone is highly productive and geographically dynamic, in that it moves seasonally north or south.

The East Australian Current and Tasman Front are recognized as key ecological features of this Region. Other such features include the offshore chains of seamounts (especially the Tasmantid seamount chain, the Lord Howe seamount chain and the Norfolk Ridge), canyons and rocky outcrops and terraces of the shelf edge, emergent reefs and cays of the Coral Sea plateau, temperate reefs and large pelagic species. Seamounts and reefs may have provided a refuge for coral reef species during periods of much lower sea levels (up to 120m below today's levels), and may have served to replenish the Great Barrier Reef when it became inundated at the end of the last ice age (Planes et al. 2001). Seamounts in particular have attracted scientific research for their volcanic, geological, biological, ecological and biogeographic attributes (McDougall and Green 1988).

Six existing CMPAs occur in both tropical and temperate waters of the Region: the Coringa–Herald National Nature Reserve, the Lihou Reef National Nature Reserve (sometimes referred to collectively as the Coral Sea Reserves), Elizabeth and Middleton Reefs Marine National Nature Reserve, the Solitary Islands Marine Reserve, Lord Howe Island Marine Park (Commonwealth Waters) and the Cod Grounds Commonwealth Marine Reserve. Three of these CMPAs (Elizabeth and Middleton Reefs and the Coral Sea Reserves) are also protected as Ramsar sites (Lee Long 2009b, 2009a). Research in this Region extends beyond the CMPAs and includes a range of oceanographic, geological and geomorphological features and a wide variety of pelagic and benthic ecosystems and species. The location of the Great Barrier Reef Marine Park adjacent to the waters of the Region means that there is a concentration of scientific research institutions on the eastern seaboard, many with the capacity to conduct research further offshore.



CORINGA-HERALD NATIONAL NATURE RESERVE

The Coringa-Herald National Nature Reserve (Coringa-Herald) lies in the Coral Sea, covering 8,856 km² and including six emergent sand cays with surrounding coral reefs (Figure 1). Its western boundary lies approximately 400km east of Cairns, North Queensland. It is situated on the Queensland Plateau, which is separated from the Great Barrier Reef and the Australian continental shelf by the Queensland Trough. It is one of two protected reef systems on the Queensland Plateau in the Coral Sea, the other being Lihou Reef National Nature Reserve (see below). Some of the research and general information available for the area may include both CMPAs, but they are reviewed separately here due to the underlying structural differences between the two reef systems. Most research in the Coral Sea has focused on these two areas, with occasional studies including nearby unprotected reefs (Planes et al. 2001; Sinclair et al. 2007; Batianoff et al. 2008b). The most comprehensive body of research in this area was conducted on the Herald Cays, within the Coringa-Herald group, by the Royal Geographical Society of Queensland; the resulting monograph describes the cays' history, terrestrial and marine flora and fauna, climate and geomorphology (Comben 2001).

Uses and Threats

Human uses of Coringa-Herald and surrounding waters include research, tourism and recreation, nearby commercial and charter fishing, commercial shipping and mineral exploration (Commonwealth of Australia 2001a). Extractive uses within the Reserve are prohibited. Research includes both terrestrial and marine monitoring of ecological characteristics, especially on North-east Herald Cay (Comben 2001). This cay has been the subject of a number of in-depth vegetation, invertebrate and seabird surveys, with less focus on the marine environment. The cays on the eastern side of the Reserve have received less attention, with only a few recent studies (Batianoff et al. 2008a; Ceccarelli et al. 2008).

Research activities have the potential of introducing pests, especially to the terrestrial environment, and indeed the Coringa-Herald cays have been subject to pest invasions in the past (Greenslade 2008). Localised damage to marine and terrestrial environments may also occur from research and tourism (Commonwealth of Australia 2001a). Commercial and charter fisheries on reefs surrounding the Reserve may deplete sources of larvae to the Reserve's reefs, which could be critical sources of replenishment after damage from natural disturbances (Oxley et al. 2003). Pollution from passing ships (marine debris) is also a threat to terrestrial environments. Illegal fishing has the potential to occur, and is especially damaging to reefs such as Coringa-Herald because their isolation, small size and exposure to heavy seas mean that local populations are already small, vulnerable and easily depleted (Ceccarelli et al. 2008). Existing pressures may be further exacerbated by sea level rise and sea surface temperature increases predicted in the future (Lawrence et al. 2007).



Climate and Oceanography

Coringa-Herald is characterized by a 'dry' tropical climate, with little seasonal temperature variability, but highly seasonal rainfall and periodic tropical cyclones. Predominant south-easterly winds play a large role in shaping the terrestrial and marine ecosystems of Coringa-Herald (Commonwealth of Australia 2001a). Generally, this region has long term variable cycles of 'dry' or 'wet' periods lasting for 2–6 years; recent research highlights a +0.7°C increase in minimum temperatures and increased drought periods in recent years (Batianoff et al. 2008a). A manned weather station on Willis Island, to the north of Coringa-Herald, has allowed for the collection and interpretation of detailed climate data since 1921.

The Coral Sea is affected by the Interdecadal Pacific Oscillation (IPO) over decadal timescales, and by the El Niño-Southern Oscillation (ENSO) Index on an interannual basis, as measured in cores from a *Porites* coral on Flinders Reef (Calvo et al. 2007). SST data show that the Coral Sea is especially vulnerable to prolonged periods of calm, hot conditions, making the reefs of Coringa-Herald vulnerable to bleaching events (Oxley et al. 2003). Additionally, the exposure to cyclones and the prevailing south-easterly trade winds suggests a high frequency of disturbance for these reefs (Brewer et al. 2007).

Regional ocean currents are dominated by the South Equatorial Current (SEC) that travels westward through the Coral Sea (Figure 4)(Brewer et al. 2007). In the central Coral Sea, the SEC bifurcates to generate the East Australia Current that flows south along the eastern margin of Australia, and the Coral Sea Coastal Current that flows north toward Papua New Guinea. The strength of the three currents are also dependent upon the strength of the Southern Oscillation Index (SOI) (Kingsford and Wolanski 2008). The Australian Bureau of Meteorology provide an online SOI database with data reaching as far back as 1876, and CSIRO Marine and Atmospheric Research provide current and SST data for the last 15 years. Additionally, deployment and analysis of data loggers within Coringa-Herald is underway (Berkelmans 2009).

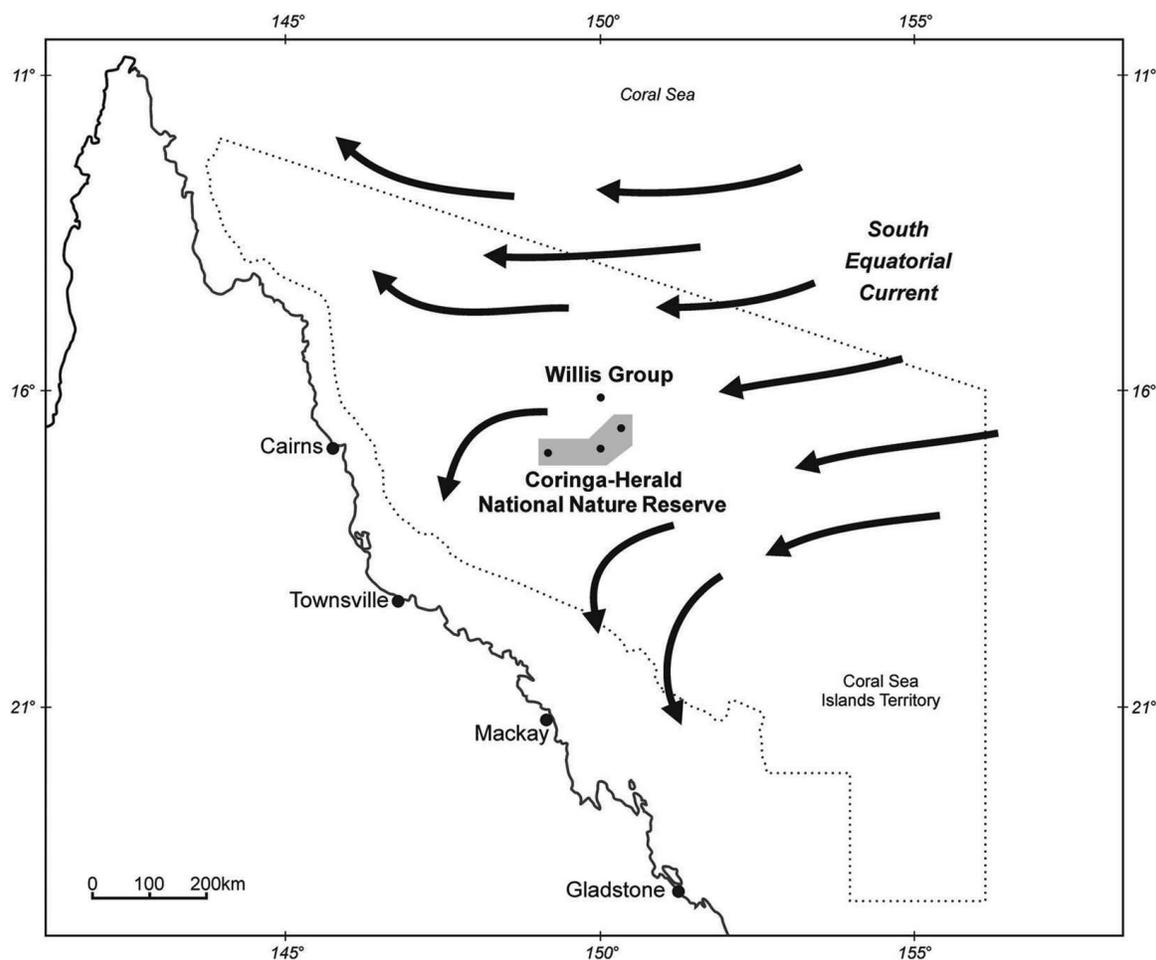


Figure 4. Broad-scale currents affecting the Coral Sea (from Batianoff et al. 2010).

Geology and Geomorphology

Coringa-Herald is located on the Queensland Plateau, one of four marginal plateaux off the east Australian continental shelf formed through the subsidence and faulting associated with the formation of the Coral Sea Basin. The Queensland Plateau is located between the Eastern Plateau and Papuan Plateau in the north and the Marion Plateau in the south (Brewer et al. 2007). The Queensland Plateau began to subside approximately 40 million years ago and reached its current level about 25 million years ago, which is believed to coincide with the formation of the current Coral Sea reefs (DiCaprio et al. 2010). Recent findings suggest that the reefs and cays located on the Queensland Plateau are not built on volcanic cones, but have developed on structural highs of the plateau (Keene et al. 2008). This indicates that coral growth on these reefs and cays has been sufficient to keep up with the ongoing subsidence of the plateau (DiCaprio et al. 2010). Furthermore, it suggests that the reefs were resilient to Pliocene and Pleistocene sea level oscillations (Keene et al. 2008). It has been hypothesised that Coral Sea reefs acted as refugia for Great Barrier Reef species during times when lower sea levels meant that the Australian continental shelf was largely exposed (Planes et al. 2001).



Soils of the Coringa-Herald cays were described in detail in recent terrestrial reports (Batianoff et al. 2008a). The soils are classified as “Inceptic Coral Calcarosols”, based primarily on their calcareous sediment composition. Organic content of the soils was found to increase towards the cays’ interiors and under the cover of well-developed plant communities (e.g. *Pisonia* forests), and the recent dieback of these plants has resulted in a loss of nutrients from the underlying soils. Burrowing wedge-tailed shearwaters also contribute to soil development.

Ecology

Ecological research on the reefs of Coringa-Herald has covered both the marine (coral reef) and terrestrial (vegetated cay) ecosystems. This Reserve is the site of perhaps the most comprehensive surveys of the terrestrial flora of isolated oceanic sand cays in Australian waters (Batianoff et al. 2010). Successive vegetation surveys have allowed for the production of a field guide to the plants of Coringa-Herald cays. (Batianoff et al. 2008b).

Systematic marine surveys of the Coringa-Herald reefs have been conducted over the last seven years (Oxley et al. 2003; Ceccarelli et al. 2008), with older surveys providing something of a baseline (Byron et al. 2001). One of the most striking observations in the more recent surveys has been the very low cover and diversity of live coral, almost seven times lower than on the GBR (Oxley et al. 2003). The subsequent survey found substantial differences between cays, but little or no overall recovery (Ceccarelli et al. 2008). Individual species of sharks and cetaceans have been the focus of studies carried out on the Undersea Explorer (Birtles et al. 2008), and nautilus have been studied at Bouganville, Osprey and Shark Reefs (Sinclair et al. 2007). However, these studies have not been integrated or compared with studies done at Coringa-Herald. The remoteness of the Coral Sea reefs and cays means that in-depth studies are difficult, and therefore the tracking of temporal dynamics is in its infancy.

The existing biodiversity of Coringa-Herald has been shaped by the history of the reefs’ development, the dispersal abilities of organisms, stochastic effects of currents, wind and other vectors of dispersal, and the availability and extent of suitable habitat (Oxley et al. 2003; Batianoff et al. 2008a). Marine surveys have noted the relatively flat, featureless habitat of exposed reef front, the lack of lagoonal habitat and the rarity of sheltered back reef habitats as possible reasons for the relatively depauperate reefs of Coringa-Herald (Ceccarelli et al. 2008). In general, it is expected that isolated coral reef systems are reliant to a large extent of self-seeding (Ayre and Hughes 2004), and molecular analysis may find that their isolation has led to populations of species that are genetically distinct on each reef (Planes et al. 2001). A gyre system in the ocean currents over the Queensland Plateau is a potential reason for the marine endemism found here (Brewer et al. 2007; Treml et al. 2008).

Benthic communities

Benthic communities of Coringa-Herald reefs are dominated by low turf algae on limestone pavement, resulting in a relatively featureless habitat structure. A survey



conducted in 2007 found that overall live coral cover was 7%, and species richness was also relatively low. However, historical surveys and accounts suggest that while cover was always low, it was closer to 15% during the 1980s (Ceccarelli et al. 2008). The coral community was noted for its absence of *Pavona* and *Psammocora*, and the rarity of *Montipora*, *Porites*, *Turbinaria* and *Fungidae* (Oxley et al. 2003), while the coral reef algal community was deemed typical of coral cays in the general GBR region (Millar 2001). The Coral Sea sponge community shows links to both GBR and western Pacific Islands (Brewer et al. 2007).

Range extensions from Pacific reefs and atolls are suggested for the corals *Pocillopora linguata* and *Siderastrea savignyana* on the Coringa-Herald reefs (Ceccarelli et al. 2008), indicating a biogeographic link between the Coral Sea and the wider Pacific. The currents within the Coral Sea run predominantly east to west, and this is the most likely direction of larval and gene flow (Brinkman et al. 2001).

Invertebrates

Densities of high-value holothurians were higher at Coringa-Herald than the adjacent GBR. The Coral Sea Fishery targets holothurians, but the status of holothurians populations on unprotected reefs of the Coral Sea is unknown (Oxley et al. 2003; Ceccarelli et al. 2008). The Royal Geographical Society of Queensland study reported 125 species of decapods crustacean, including nine undescribed species and 16 previously unrecorded in Australian waters (Davie and Short 2001). Additionally, 717 species of molluscs and 55 species of hydroids were collected (Loch 2001; Preker 2001). All species were characteristic of the wider Indo-west Pacific, with little indication of endemism (Davie and Short 2001).

Fish

The bioregionalisation of eastern Australian waters combined the Queensland and Marion plateaux on the basis of demersal (mostly deep-water) fish faunas (Last et al. 2005), but the extent to which the emergent reefs of the two plateaux may be genetically differentiated is currently unknown. One of the characteristics of Coringa-Herald reefs is a restricted number fish species compared with similar reefs elsewhere, probably due to the isolation, small size, high disturbance regime and smaller selection of suitable habitats (Oxley et al. 2003). For instance, fish assemblages found both in the Coringa-Herald and Lihou Reserves were characterised by a number of species that are not found on the GBR (e.g. *Pomachromis richardsoni*, *Chrysiptera taupou* and *Pomacentrus imitator*).

Populations of coral trout found on the GBR have been shown to be genetically connected to populations of the same species in New Caledonia (Van Herwerden et al. 2009a). These linkages can be crucial in times of widespread environmental stress, and the Coral Sea reefs are thought to act as stepping-stones for dispersal (Ceccarelli et al. 2008). Within the surveyed Coral Sea reefs, it has been postulated that the more eastern reefs (e.g. Lihou Reef) may act as sources, and more western reefs (e.g. Coringa-Herald) as sinks (Oxley et al. 2003). Genetic differentiation between the GBR and the Coral Sea



has been observed in at least one fish species with limited larval dispersal capabilities (Planes et al. 2001), and in populations of Nautilus (Sinclair et al. 2007).

Modern genetic techniques allowed the reconstruction of a phylogeographic history of a reef fish without a dispersive larval phase, and therefore with limited dispersal capabilities. This allowed the testing of the hypothesis of Coral Sea refugia from which a newly inundated GBR was colonised (Planes et al. 2001; Bode et al. 2006). The results of this study suggest that the Coral Sea reefs were colonised by adult migrants over large water gaps. Furthermore, they suggest that colonisation of the Coral Sea began on the northern reefs (i.e. Osprey Reef) after the Queensland Plateau was no longer attached to the Australian continental shelf.

Turtles

The monitoring of nesting turtles on the Coringa-Herald cays began in the early 1990s, primarily on North-East and South-West Herald Cays (Mattocks and Read 2000), but is currently on hold (Neil Gemmill, DEWHA, pers. comm.). Monitoring activities included the tagging of nesting turtles, which were almost exclusively green turtles (*Chelonia mydas*). By the 1999/2000 nesting season, 2,861 turtles had been tagged, and many of them were recorded multiple times as they displayed regional nesting fidelity (Mattocks and Read 2000). No surveys were conducted after the 1999/2000 nesting season, as the inaccessibility of the Reserve makes it difficult to design a cost-effective monitoring program.

Terrestrial ecology

The terrestrial communities of flora and fauna found on the Coringa-Herald cays represent a subset of species found in mainland habitats of similar type and latitude, and are typical of highly exposed, small and remote Indo-Pacific and Melanesian islands (Batianoff et al. 2008a). Terrestrial surveys have been conducted on a number of cays of the Coringa-Herald complex (Batianoff et al. 2008a; Greenslade and Farrow 2008). Up to 70% of plants found on the Coringa-Herald cays are of Melanesian provenance (Batianoff et al. 2008a). Species richness of plants varies little across the cays; 12 species were recorded on South West Herald Cay and Coringa Islet, 13 species on Chilcott Islet, 14 on North East Herald Cay and 17 on South East Magdelaine Cay (Batianoff et al. 2008b). Mapping units of similar floral assemblages – 17 distinct vegetation communities are described in Batianoff et al. (2008a) – and individual species have been observed throughout the Great Barrier Reef and the Pacific region (Batianoff et al. 2008a). Despite this, the current genetic pool of Coral Sea terrestrial plants is likely to be independent of the Australian mainland flora. It is likely that these species were dispersed along prevailing currents, such as the east-to-west South Equatorial Current, surface currents driven by the south-easterly trade winds and seasonal monsoon winds, and migratory seabirds (Batianoff et al. 2008a).

The dynamics of species turnover on any coral cay is a result of progressive and/or successional establishment and/or failure of permanent and transient species. The number of plant species present at any given time on the Coringa-Herald cays is dependent on



immigration, survival and extinction rates (Greenslade 2008). The Coral Sea cay flora has evolved without fire regimes, grazing by animals or common insect predation. As a result, some keystone species such as *Pisonia grandis* have not developed resilience to mainland pests such as scale insects (Batianoff et al. 2008a), further highlighting the risks of pest introduction by visitors and the need for enforced preventative measures.

The vegetation on Coringa-Herald cays provides important habitat for resident terrestrial fauna, especially nesting and roosting seabirds (Batianoff et al. 2008a). However, the dieback of *Pisonia* trees due to scale insect pests and prolonged dry conditions has been a cause for concern, and was extensively documented (O'Neill et al. 1997; Batianoff et al. 2010). The severity of the damage to the *Pisonia* forest prompted a program of biological control. This was partially successful in that the introduced predator controlled the pest insect, but only after large tracts of *Pisonia* forest had died (Smith and Papacek 2001b, 2001a; Smith et al. 2001a; Smith and Papacek 2002; Smith et al. 2002; Greenslade and Farrow 2008). Dieback was also recorded for *Argusia argentea* on all cays, but the cause of this has not yet been understood (Batianoff et al. 2008a). Climate change predictions include higher temperatures and longer droughts, possibly promoting the growth of woody over herbaceous plants and changes in vegetation structure (Batianoff et al. 2010).

Keystone species are potentially more important here in their role of promoting or protecting biodiversity. On coral cays, the keystone species of plants are those that are abundant and resilient enough to provide consistent habitat for other species of plants and animals; on the Coringa-Herald cays eight species have been identified as those most important for providing a plant cover that reduces temperature, wind and moisture stress for other species (Batianoff et al. 2008a). The presence and abundance of these species further affects the functional and species diversity of terrestrial invertebrates and vertebrates (Harvey et al. 2009). Conversely, the threat of pest outbreaks, thought to be in part related to climate variability, can threaten ecosystem balance and biodiversity (Greenslade 2008).

Terrestrial invertebrates have also been a matter of interest, especially as a result of the insect pests on *Pisonia* trees. The infestation of scale insect led to a shift in community structure in the invertebrate fauna. The Guinea ant, *Tetramorium bicarinatum*, was found to be a key driver of these communities, acting as a keystone species and indicator of active, above-ground invertebrates on these islands (Greenslade and Farrow 2008). There were differences in the invertebrate communities between groups of cays, driven by dispersal capacity, soil composition and moisture content, and the composition of vegetation communities (Greenslade and Farrow 2008).

Coringa-Herald seabird populations have been monitored regularly since 1992 on North-East Herald Cay, with occasional visits to other islets, mainly South West Herald Cay. Data collection aims to coincide with peak breeding periods. The cays host a significant proportion of Australia's breeding population of several species, including the red-footed booby (*Sula sula*), least frigatebird (*Fregata ariel*), great frigatebird (*Fregata minor*) and red-tailed tropicbird (*Phaethon rubricauda*). Seabird populations have remained mostly



stable during this period, especially populations of nesting red-footed booby, masked booby and red-tailed tropicbird (O'Neill et al. 1997; Baker et al. 2008a). Declines were noted in populations of frigatebirds and black noddies since 1998. The causes for the declines have not been tested, but have been attributed to a complex set of changes in food sources, suitable nesting habitat, sea surface temperatures and other climatic conditions since the 1997/1998 El Niño event (Congdon et al. 2007).

Gaps and Recommendations

The inaccessibility of the Coral Sea Reserves makes it difficult to design cost-effective research and monitoring strategies to track the health of the ecological communities through time. Nevertheless, some very valuable research programs have been carried out, especially on the terrestrial environments of Coringa-Herald. The frequency and methodology of this research allowed for a very comprehensive assessment of the Reserve's terrestrial ecology and its likely responses to future pressures, and could serve as a blueprint for other Reserves that have terrestrial environments. Marine ecological surveys have been less frequent, but if continued along the same lines, should provide useful information on long-term temporal dynamics. Connectivity is an important issue for isolated communities such as these, and should be investigated further. A number of reports from past surveys include comprehensive recommendations (Oxley et al. 2003; Baker et al. 2008a; Batianoff et al. 2008a; Ceccarelli et al. 2008; Greenslade and Farrow 2008). A synopsis of these, with additional recommendations arising from this review, includes:

- Investigate the viability of liaising with the Bureau of Meteorology to ascertain whether the weather station on Willis Island to the north of Coringa-Herald could provide a research platform for the Reserve,
- Design a monitoring program that takes into account past methodology and includes comparisons with 'control' locations outside the Reserves; continued monitoring of terrestrial and marine ecosystems to build up the capability of establishing temporal dynamics; integrate ecological monitoring with physical data,
- Geological and geomorphological studies to assess the age and evolution of Coringa-Herald, including deeper substrates in between emergent reefs,
- Studies of local scale hydrodynamics, to shed light on possible patterns of dispersal and help identify source and sink reefs,
- Genetic studies to assess patterns of connectivity among Coral Sea reefs (e.g. test the hypothesis that Lihou Reef is a source of larvae for Coringa-Herald), and investigate adaptation capacity and the effects of long-term isolation of terrestrial populations,
- Link ecological patterns to reef metrics and physical attributes e.g. habitat complexity, exposure regime, etc.,
- Investigate methods of cost-effective turtle nesting monitoring,
- Consider seasonal monitoring of breeding seabirds,
- Continue the seabird band-recapture project,



- Consider restoration of major nesting sites if there are declines in nesting seabird numbers (e.g. replanting of *Pisonia* trees, with monitoring of consequences).
- Liaise with AFMA to assess catch rates and location of catches by the Coral Sea Fishery, and
- Enhance and enforce quarantine controls.

LIHOU REEF NATIONAL NATURE RESERVE

The Lihou Reef National Nature Reserve (Lihou Reef) lies approximately 100km south-east of Coringa-Herald in the Coral Sea (Figure 1). Lihou Reef itself is a horseshoe-shaped reef open to the west, 100km long and approximately 60km at its widest north-south axis. The reef system is made up of 18 sand cays, and the Reserve, which includes surrounding waters, covers 8,440 km². Very little research has been carried out on Lihou Reef. Much of the geological, geomorphological, climate and oceanographic information reviewed for Coringa-Herald (see above) is also applicable to Lihou Reef. Therefore only additional information pertinent to Lihou Reef is added to this section.

Uses and Threats

Human uses of Lihou include research, tourism and recreation, and nearby commercial and charter fishing, commercial shipping and mineral exploration (Commonwealth of Australia 2001a). While extractive uses within the Reserve are prohibited, illegal fishing and collecting may occur. Research includes primarily marine monitoring of ecological characteristics, and has occurred only in recent years. An Automatic Weather Station is located on Turtle Islet on the eastern edge of the reef (Ceccarelli et al. 2009; Harvey et al. 2009).

Research activities may introduce pests, especially to the terrestrial environment, and cause localised damage (Commonwealth of Australia 2001a). Commercial and charter fisheries on reefs surrounding the Reserve may deplete sources of larvae to the Reserve's reefs, and therefore potentially reduce critical sources of replenishment after damage from natural disturbances (Oxley et al. 2004b). Pollution from passing ships (marine debris) is also a threat to terrestrial environments (Commonwealth of Australia 2001a). Illegal fishing may occur, and is likely to cause downstream effects through the depletion of source populations of reefs further to the west, such as Coringa-Herald. Existing pressures may be further exacerbated by sea level rise and sea surface temperature increases predicted in the future, especially with the tendency for high temperatures in shallower coral reef lagoon areas (Lawrence et al. 2007).

Climate and Oceanography

The climate and currents affecting Lihou Reef are very similar to those experienced by the Coringa-Herald reefs and cays. An Automatic Weather Station is situated on Turtle Islet, one of the cays at the eastern edge of Lihou Reef. However, this station has been in disrepair for some time, and no reliable information specific to Lihou Reef could be extracted. The Bureau of Meteorology is currently repairing the station (Neil Gemmill, DEWHA, pers. comm.). Temperature loggers have been deployed at various locations



throughout Lihou Reef, but resulting data have yet to be analysed and reported (Berkelmans 2009).

Geology and Geomorphology

Lihou Reef differs substantially from Coringa-Herald in shape, configuration and size. Lihou is a horse-shoe shaped reef, open towards the west, with 18 small sand cays set out along its perimeter. It rises steeply from water depths of over 1,000m near the edge of the Queensland Plateau, and from ~500 m water depth on the Plateau itself (Keene et al. 2008). It is approximately 100km long and there is an extensive lagoon, mostly unexplored (Oxley et al. 2005). No specific geological or geomorphological research on Lihou Reef was found.

Ecology

Only four marine ecological surveys have taken place at Lihou Reef (Oxley et al. 2004b; Oxley et al. 2005; Ceccarelli et al. 2009), and one terrestrial survey (Harvey et al. 2009). A description of an alkaloid extracted from a Lihou Reef sponge did not include information about the time or place of collections (Bowden et al. 2004). The extreme remoteness of this Reserve makes access difficult and costly. The first of the recent surveys found that Lihou Reef had similar ecological characteristics to Coringa-Herald, especially low coral cover, fish species that were distinct from the GBR and similar holothurian densities (Oxley et al. 2004b). In other aspects, however, the two Coral Sea reefs were found to differ substantially (Ceccarelli et al. 2009). The primary differences were the interconnectedness of the Lihou Reef system and the greater variety of marine habitats than at Coringa-Herald. For instance, Lihou Reef has a large lagoon and gradients of exposure and shelter, with considerably more sheltered back-reef than Coringa-Herald. The only survey of lagoonal habitats found large expanses of sand punctuated by sparse reef patches and a high percentage of fleshy macroalgae (Oxley et al. 2005).

Benthic communities and invertebrates

One of the marine surveys of Lihou Reef documented a major bleaching event, where 65% of the hard coral cover was bleached. Additionally, the coral community was exhibiting signs of early recovery from a previous possible disturbance (Oxley et al. 2004b). A follow-up survey found that after the bleaching event, 67% of surveyed colonies were healthy, while 18% were dead and 15% had suffered partial mortality (Oxley et al. 2005). Coral species less affected by bleaching included *Coscinarea columna*, *Porites lichen*, *Pocillopora edyouxi*, *Leptastrea inequalis*, *Turbinaria* spp., *Goniopora* spp. and *Astreopora* spp. The following survey found that *P. lichen* dominated some sites, while other areas were covered in plate *Acropora* communities typical of recovering reefs (Ceccarelli et al. 2009). Overall, coral cover had increased significantly across all surveyed reefs within Lihou Reef. The Lihou Reef system appears to be under considerable pressure from climatic events (Oxley et al. 2004b), but it currently demonstrates a high capacity for recovery (Ceccarelli et al. 2009).



A range extension from Pacific reefs and atolls – primarily Tonga and northern Fiji – was recently suggested for the clam *Tridacna tevoroa* on Lihou Reef (Ceccarelli et al. 2009), indicating a biogeographic link between the Coral Sea and the wider Pacific. The currents within the Coral Sea run predominantly east to west, and this is the most likely direction of larval and gene flow (Brinkman et al. 2001).

Within the surveyed Coral Sea reefs, it has been postulated that the more eastern reefs (e.g. Lihou Reef) may act as sources, and more western reefs (e.g. Coringa-Herald) as sinks (Oxley et al. 2004b). In general, however, it is expected that isolated coral reef systems are reliant to a large extent on self-seeding (Ayre and Hughes 2004), and their isolation means that genetic analysis would find that populations are distinct on each reef (Planes et al. 2001).

Fish

Lihou Reef, with its higher habitat complexity, probably supports a more complete complement of Coral Sea fish than Coringa-Herald (Ceccarelli et al. 2009). Additionally, populations of coral reef predators at Lihou Reef were comparable to those recorded on strictly protected Preservation Zones on the GBR, and densities were significantly higher than those recorded at Coringa-Herald (Ceccarelli et al. 2009).

Terrestrial ecology

Vegetation communities, terrestrial invertebrates and macrofauna on the Lihou Reef cays were assessed for the first time in 2008 (Harvey et al. 2009), after brief surveys in the late 1990s aimed at assessing the damage from scale insects to terrestrial vegetation (O'Neill et al. 1997). The vegetation of the surveyed cays was made up of ten species that formed eight vegetation communities. The species recorded were typical of vegetation on highly exposed coral islands of the seasonally dry tropics, but no tree species were found. As on Coringa-Herald, plants have dispersed to the Lihou Reef cays by a number of means, including ocean currents (70%), seabirds (60%) or vegetatively (50%). Human dispersal is also possible, but probably highly infrequent (Harvey et al. 2009).

The invertebrate community was dominated by species with long-range dispersal capabilities, and there was considerable variability in the invertebrate communities of the four surveyed vegetated cays (Harvey et al. 2009). The cover of particular plants was the best predictor of the composition and abundance of invertebrates. Most invertebrates were generalist feeders, forming a complete and self-sustaining food web (Harvey et al. 2009). Unlike Coringa-Herald, no potential pest species were recorded.

Abundant nesting seabirds were initially quantified in 1997 and observed again in 2008 (O'Neill et al. 1997; Harvey et al. 2009). The four vegetated cays hosted nesting and roosting communities of 15 species of seabirds, and very high densities of green turtle nests. Previously, observations made on East Diamond Islet, some tens of kilometers to the west of Lihou Reef, recorded fairy terns (*Sterna nereis*), previously unrecorded in Australian waters (Mustoe 2006; Carter and Mustoe 2007). Harvey et al. (2009) provide a



detailed flow-diagram model of the key links between terrestrial and marine habitats of Lihou Reef (Figure 5).

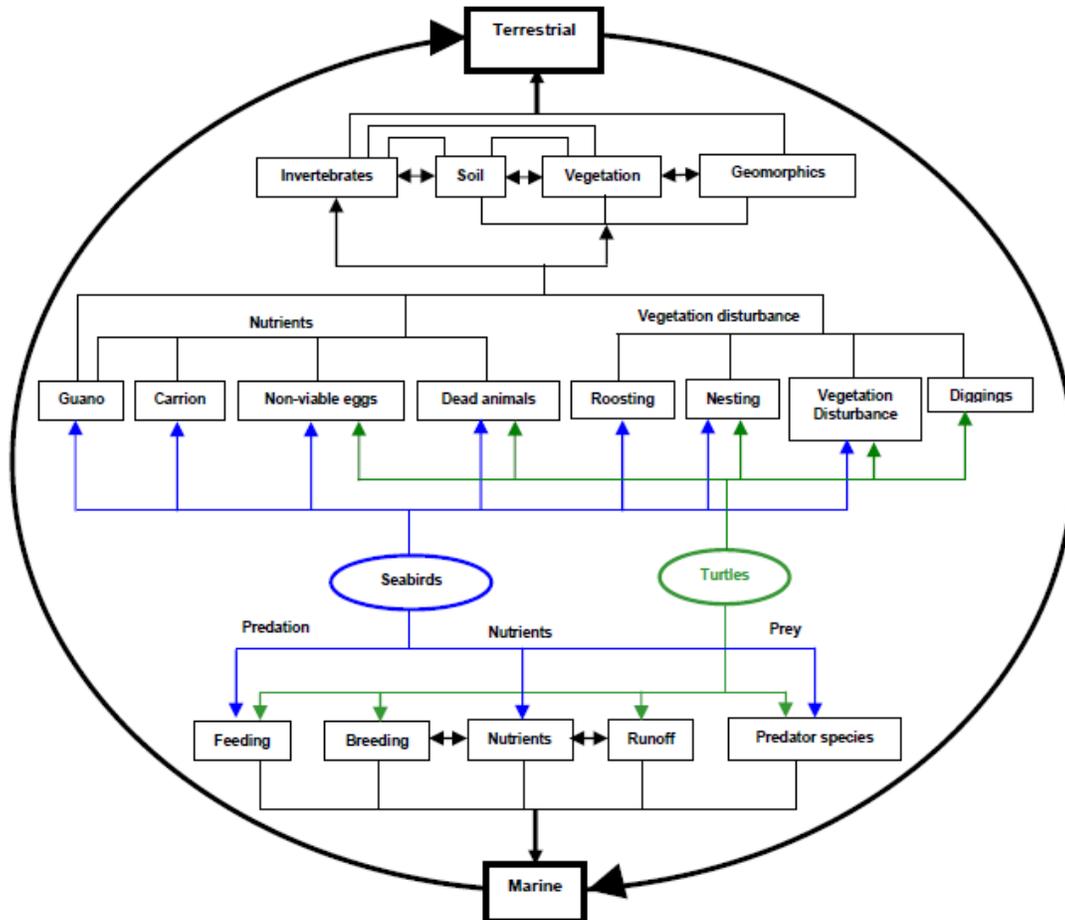


Figure 5. A simplified diagram demonstrating a selection of direct and indirect linkages between the terrestrial and marine environments of Lihou Reef, mediated by seabirds and marine turtles. Blue arrows: potential linkages between seabirds and the marine and terrestrial environments; green arrows: potential linkages between marine turtles and the marine and terrestrial environments; black, double-ended arrows: two-way linkages (from Harvey et al. 2009).

Existing information highlights a strong link between habitat size, habitat diversity and species diversity (Harvey et al. 2009). For instance, plant species richness was greater in the Coringa-Herald / Willis Island region (Batianoff et al. 2008a) than in the Lihou Reef terrestrial environments (Harvey et al. 2009). The Coringa-Herald / Willis Island cays are also larger, with greater soil development (Batianoff et al. 2008a), than most of the surveyed Lihou Reef cays. Functionally, the Coral Sea's terrestrial environments are typical of pioneering species with resistance to extremely stressful conditions (Batianoff et al. 2008a). Successionally, larger cays tend to support more species typical of later successional stages than smaller cays. Landscape diversity, however, is relatively high because the plant species are taxonomically not closely related to one another, which



promotes greater resilience (in the form of a larger diversity of possible responses to disturbance) and greater overall biodiversity (by providing a greater range of different habitats for animals) (Batianoff et al. 2008a). The constantly changing nature of the physical environment also means that colonisation and extinction may occur relatively rapidly, and single surveys can provide only snapshots of the overall biodiversity present over a longer period of time (e.g. decades or centuries).

Gaps and Recommendations

The inaccessibility of the Coral Sea Reserves makes it difficult to design cost-effective research and monitoring strategies to track the health of the ecological communities. The paucity of empirical studies on Lihou Reef means that the gaps are substantial and encompass all areas of research and monitoring. The continuation of ecological surveys, and their integration with physical data, will assist the understanding of ecological processes and temporal dynamics. Connectivity is an important issue for isolated communities such as these, and would benefit from further investigations, especially in view of hypotheses that Lihou may act as a source reef for other Coral Sea reefs (Oxley et al. 2004b; Ceccarelli et al. 2009; Harvey et al. 2009). Recommendations for Lihou Reef include:

- Investigate the viability of liaising with BOM to ascertain whether the weather station on Willis Island to the north of Coringa-Herald could provide a research platform for the Reserve,
- Continue monitoring surveys at intervals of 2-3 years with comparable methods, refining key indicator species for rapid surveys and to detect change over time,
- Develop consistent methodology for use by successive surveys,
- Correlate ecological data with physical and chemical data,
- Conduct regular fly-over 'spot-checks', and spot checks from Customs vessels using two experienced scientists, in 5 days, including video transects on a subset of the sites,
- Support and encourage relevant fisheries management agencies to continue to increase the use of Integrated Computerised Vessel Monitoring Systems (ICVMS) on commercial fishing vessels working in the Coral Sea, in particular the aquarium and line fisheries,
- Repeat terrestrial survey, drawing on expanded methods from studies on Coringa-Herald islets and cays (Batianoff et al. 2008a)
- Use species identified in the baseline survey (Harvey et al. 2009) as indicators of terrestrial invertebrate communities,
- Initiate dedicated seabird and turtle nesting surveys, tagging and genetic studies, and
- Enforce and update current quarantine regulations.



SOLITARY ISLANDS MARINE RESERVE (COMMONWEALTH WATERS)

The Solitary Islands Marine Reserve (Commonwealth Waters) (SIMR) is located 600km north of Sydney, off the coast of northern NSW (Figure 1). The SIMR covers 160km² and lies adjacent to the State - managed Solitary Islands Marine Park (SIMP). The SIMR protects a diverse environment that includes open ocean, subtidal reef and soft-sediment assemblages. Pimpernel Rock, a submerged pinnacle that rises from the ocean floor to within a few meters of the surface, is the most significant feature of the SIMR, as it attracts large pelagic fish and marine mammals, including grey nurse sharks *Carcharias taurus*, black cod *Epinephilus daemeli*, and marine turtles. The SIMR is located in a mixing zone between temperate and tropical ecosystems, and includes communities at the edge of their geographic ranges (Commonwealth of Australia 2001d).

The environments of the SIMR and SIMP are closely linked, making it difficult to distinguish between some of the studies conducted in one or the other. A recent literature review included the natural values of both areas (NSW Marine Parks Authority 2008a). The SIMP has benefited from consecutive strategic research plans which were recently reviewed (NSW Marine Parks Authority 2008b). The accessibility of the SIMP means that there is a much greater volume of research available than for the SIMR (Smith 2005). Patterns and processes described for one jurisdiction have a high probability of being applicable to the other, and the natural values of the two are also similar. Both are subject to similar human pressures, especially those related to rising populations along the adjacent coastline (Smith et al. 2008).

Uses and Threats

Commercial and recreational fisheries operate within the SIMR, with only a small area around Pimpernel Rock fully protected from fishing. Tourism, whale watching, recreational SCUBA diving and mineral exploration and development also occur inside or in the vicinity of the SIMR (Commonwealth of Australia 2001d). Over 100 commercial fishers operate in the SIMP and SIMR, and most fisheries are managed at the State level by NSW Fisheries (NSW Marine Parks Authority 2008b). Commonwealth-managed fisheries that may operate in the SIMR, albeit usually at a very low level, include the Southern Squid Jig Fishery, the East Coast Tuna and Billfish Fishery, the Jack Mackerel Fishery and the South East Non-Trawl Fishery. Previous work suggests that as much as 40% of the trap and line fisheries catch may come from inside the SIMR. Recreational fishers take a large number of fish species using a variety of methods (Commonwealth of Australia 2001d).

Commercial and recreational fisheries have the potential to cause direct impacts to the ecological values of the SIMR. Trawling and anchor damage can directly disturb benthic communities and damage habitat for mobile species. Over-exploitation of certain trophic or functional groups (e.g. predators) can lead to broad changes in food webs and ecological structure. Human interaction can disturb megafauna and species especially protected within the boundaries of the SIMR, such as whales and grey nurse sharks (Commonwealth of Australia 2001d). With high levels of boating and offshore mineral and petroleum exploration, marine debris and pollution can also become threats to



environmental values. Future potential climate change impacts include increased sediment and pollutant runoff from the nearby mainland, higher water temperatures, and the loss of species currently living at the edge of their geographic range (Lawrence et al. 2007). Range expansions are predicted for tropical species from the Great Barrier Reef, potentially resulting in shifts in fish community structure (Figueira and Booth 2010).

Climate and Oceanography

The SIMR is located in a subtropical zone off the north coast of New South Wales, characterised by warm and humid weather in summer and dry cool conditions in winter. The majority of the rainfall occurs during prevailing easterly winds between December and May. The SIMR is often exposed to high wave-energy conditions from south-easterly swells.

The East Australian Current carries a mixture of tropical and subtropical waters from the Coral Sea, Great Barrier Reef and southern Queensland into the more temperate area of the NSW continental shelf before separating from the coast south of the Solitary Islands (Zann 2000). This current converges with the colder water of a northward-flowing inshore current, combining species and communities typically associated with the Great Barrier Reef with those characteristically from Tasmania. The meeting of the two currents can sometimes result in nutrient-rich upwelling that supports aggregations of marine life (NSW Marine Parks Authority 2008a).

There are 14 estuaries and approximately 500 hectares of estuarine waterways directly landward of the SIMP and SIMR. The six main estuaries from north to south are the Sandon, Wooli Wooli and Corindi Rivers, and Arrawarra, Moonee and Coffs Creeks, with southern estuaries more urbanised and prone to discharging nutrient-rich run-off than northern estuaries. Estuarine discharges are generally transported in a northerly direction by the prevailing wind and swell, while the fast-flowing East Australian Current disperses terrigenous and nutrient discharges further offshore, contributing to the maintenance of high water quality in the SIMR (Commonwealth of Australia 2001d).

Geology and geomorphology

The SIMR is located adjacent to the New South Wales coastline in the Clarence Morton Basin. This sedimentary structure was formed during the Triassic and early Cretaceous periods and comprises a sequence of Mesozoic sediments and volcanics resting on folded Palaeozoic rocks (Commonwealth of Australia 2001d). The geological formations of the SIMP and SIMR are mostly derived from marine sediments of the Coffs Harbour Sequence, which is approximately 350–280 million years old (NSW Marine Parks Authority 2008a). Erosion has removed the softer layers, leaving the harder rocky outcrops as a north-south line of islands and submerged reefs (Commonwealth of Australia 2001d). Major rivers in the region have led to the presence of extensive Quaternary fluvial sediments. The SIMR is located on a part of the continental shelf that is 12–20 nm wide, with a steep continental slope offshore. Island and headland rock formations, consisting of more resilient strata that have survived weathering, generally range from north to south parallel to the coast (Commonwealth of Australia 2001d). On



the eastern sides of islands and outcrops the weathering has resulted in underwater gutters (Ingleton et al. 2007). Variations in sea level have also influenced the geomorphology of the area (NSW Marine Parks Authority 2008a).

The SIMR is characterised by three main habitat types: subtidal reefs, soft substrate sediments and open ocean habitats. Subtidal reefs occur throughout the SIMR and include deeper midshelf reefs, offshore reefs and submerged pinnacles; they were first surveyed in 1997 and 1998 (Commonwealth of Australia 2001d). Deep midshelf reefs host the highest diversity of marine life. Offshore reefs are low outcrops made of rubble and broken rock in waters deeper than 35m, dominated by sponges, soft corals and encrusting algae. Three submerged pinnacles have steep slopes with encrusting algae, sponges and ascidians (Commonwealth of Australia 2001d). Pimpernel Rock is the most striking and well-known example of a submerged pinnacle in the SIMR. It is a large pinnacle of rock in about 50m of water, rising to approximately 12m of the surface, and containing a large cavern.

Ecology

The Solitary Islands region supports over 150 species of algae, over 90 species of corals, over 280 species of fish, numerous marine reptiles and mammals, and sea and shore birds (Commonwealth of Australia 2001d). Species of particular interest are those at the southern or northern limit of their latitudinal range, and those listed as threatened, such as the humpback whale, southern right whale, marine turtles, grey nurse shark, great white shark, little tern and wandering albatross (Commonwealth of Australia 2001d).

A number of mapping and video surveys have recently helped to define habitats and ecological features of the SIMR. Habitats were explored, mapped and classified during a swath mapping survey in June 2007, covering 115 km² of seabed (Ingleton et al. 2007). A towed video survey of the benthic environment in the marine reserve identified five types of reef habitat: three types of patchy reef, continuous reef, and pinnacle reef (The Ecology Lab 2006).

Benthic communities and invertebrates

The proximity of the SIMP to the coast and the interest in coral communities growing towards the limits of their latitudinal range has led to a large body of coral research in the SIMP. This research began in 1990 (Harriott et al. 1999), has been conducted in the shallow areas around the Solitary Islands themselves (Fairfull and Harriott 1999; Harriott and Smith 2000), and on rocky reefs to the north and south (Harriott et al. 1999). This region contains the southernmost extensive coral communities in coastal eastern Australia (Zann 2000). Coral larvae are most probably transported south from the southern Great Barrier Reef by the East Australian Current, with some self-recruitment taking place. The delayed rise in SST in the summer compared to the GBR means that the synchronous spawning of most corals in the SIMP takes place later in the year (Wilson and Harrison 2003).



Subtropical and temperate coral species dominate in terms of percent cover (Harriott et al. 1994), with coral species typical of high-latitude reef communities including *Acanthastrea* sp., *Goniastrea australensis* and *Turbinaria* sp. (Harriott et al. 1999). Early studies on these coral communities documented a total of 90 species from 28 genera and 11 families (Veron et al. 1974; Harriott et al. 1994). Recruitment studies suggest that the fast growth of macroalgae may make space a limiting factor by increasing post-settlement mortality in corals (Fairfull and Harriott 1999). Rarer species may appear and disappear multiple times due to variable recruitment and mortality patterns (Harriott et al. 1999).

Hypotheses on limits of coral reef development have included a reduction in reproductive viability of corals at high latitudes (Veron et al. 1974), reduced capacity of corals to compete with temperate algae or fouling organisms (Fairfull and Harriott 1999), and high rates of carbonate solution at high latitudes associated with greater development of epilithic and other algal communities (Smale et al. 2010). However, there has been evidence that coral reproduction and recruitment occur successfully at high latitudes (Harriott 1992; Babcock et al. 1994; Wilson and Harrison 2003, 2005), and the growth rates of a number of species were found to be similar to that of tropical corals (Harriott 1999). However, high post-settlement mortality and generally slow growth rates certainly contribute to the low rates of coral recruitment in this region (Harriott and Banks 2002; Wilson and Harrison 2005). Recent research suggests that coral disease is contributing to increasing coral mortality in shallow habitats of the SIMP (Dalton and Smith 2006).

Studies on algal communities, also primarily from the SIMP, have identified 162 species of benthic macrophytes in the Solitary Islands region (Millar 1990), with new records added recently (Millar 2004). Tropical algal genera account for a total of 55% of the total number of species and are represented by taxa such as *Halimeda*, *Valonia* and *Galaxaura*. Warm temperate algal genera such as *Ecklonia* and *Homosira* account for a further 42% of the species present. The distribution and density of these species is determined by a combination of substrate stability, water temperature, nutrient input, and levels of grazing by herbivorous fauna (Commonwealth of Australia 2001d).

Algal-dominated communities have high species diversity, are very important for primary production, and provide structural complexity for many other organisms including juvenile and adult fish. Because they have not been comprehensively surveyed in the SIMR, functional relationships are poorly understood (Commonwealth of Australia 2001d). Results from a five year study of permanent quadrants suggest that, with the exception of kelp, most macro-algal plants are ephemeral and there is little evidence to suggest that algae have an adverse effect on corals at the offshore islands. In certain habitats, corals may suffer greater mortality due to competition from tube-building polychaetes (Smith and Harriott 1998). Close to shore, kelp and other macro-algae are dominant and interactions with corals are common (Fairfull and Harriott 1999). It is therefore likely that the importance of coral/algal interactions varies along a cross-shelf gradient in the SIMP and SIMR (Zann 2000). Sea anemones that host anemonefish are particularly abundant in this region. This has led to a number of studies on the life history of both the host anemones and the resident fish species (Scott and Harrison 2008, 2009).



Muddy, sandy and gravelly seafloor habitats dominate the SIMR spatially, and the nature and size of the sediments has been found to be a strong predictor of benthic communities (The Ecology Lab 2006). Data the ecology of these habitats, especially in deeper waters of the SIMR, have only been gathered recently (Zann 2000; The Ecology Lab 2006). The NSW Marine Park Authority and others that have collected data at Pimpernel Rock classified the habitats around the rock into three broad depth-related zones: 1) 10 m to 18 m water depth: dominated by barnacles and sea urchins, with patches of cunjevoi (*Pyura stolonifera*), encrusting sponges and filamentous algae; 2) 18 m to 30 m: high % cover of *P. stolonifera*, with hydrozoan epiphytes and some gorgonians; and 3) > 30 m depth: dominated by the stalked ascidian *Pyura spinifera*, sponges and sea whips (The Ecology Lab 2006).

More recently it was found that small patches were dominated by specific biota, but at the broader scale the benthic community is dominated by either coral and/ or other mixed invertebrate communities or macroalgae, in particular the kelp *Ecklonia radiata* (Malcolm et al. 2010). Variation was high even during recruitment, highlighting the stochasticity of larval input in shaping these communities (Rule and Smith 2005). Species richness, taxonomic composition and diversity were found to increase with depth, with the highest species richness recorded at the 50 metre depth contour within the SIMR, and distinct communities characterizing deep and shallow sites. Benthic studies regularly report new species (Hughes and Lowry 2006). Depth has been shown to strongly influence assemblages in different taxonomic groups, including fish (The Ecology Lab 2006) and motile invertebrates (Rule and Smith 2007).

Fish

Recently sampled reef fish species include 338 species from 79 families. The most species-rich family was found to be the wrasses (Family Labridae: 59 species overall, 43 single counts), followed by the damselfish (Family Pomacentridae: 38 species overall, 32 single counts). These two families accounted for 29% of all species recorded, and seven families accounted for another 50% (Serranidae and Chaetodontidae third equal; Carangidae fifth; Acanthuridae and Mullidae sixth equal). Most of the remaining families contributed less than 1% (Malcolm et al. 2010).

Pelagic fish species recorded in the SIMR include yellowtail, slimy mackerel, and predatory fish such as kingfish, Spanish mackerel and tunas, while demersal species include the blue spot flathead and red spot whiting. Potentially threatened fish species include the giant Queensland groper *Epinephilus lanceolatus*, the Bleekers devil fish (or blue devil fish) *Paraplesiops bleekeri*, and the regionally endemic black cod *Epinephilus damelii*. Anemonefish are highly abundant in the region, with some of the world's highest densities (Scott and Harrison 2008).

Open ocean habitats are generally poorly studied, but are known to support a wide variety of species of commercial and conservation interest. This includes cetaceans (whales, dolphins and porpoises), larger pelagic fish, jellyfish and other invertebrates, and tiny



planktonic plants and animals. Pelagic food chains are strongly linked with benthic ones. For example, bottom dwelling fish species often feed on pelagic baitfish species (Commonwealth of Australia 2001d).

A study combining a number of fished and unfished areas in Australian waters, including the SIMR, found that unfished MPAs had significantly more large (>30 cm) fishes and higher total fish biomass than nearby fished reference sites. Fish densities were not found to vary significantly, however, and the response of fish species richness to protection varied significantly between MPAs (Edgar and Stuart-Smith 2009). This corresponds to other research findings that document latitudinal shift over 100s of kms, and significant variability within single marine parks, in fish communities in NSW coastal marine parks (Malcolm et al. 2007).

Marine megafauna

The SIMR hosts a variety of species of megafauna such as marine reptiles (seasnakes *Pelamis platurus*, and *Disteria major*), turtles (loggerhead turtle *Caretta caretta*, green turtle *Chelonia mydas*, the hawksbill turtle *Eretmochelys imbricata*, and the more oceanic and less commonly sighted leatherback turtle *Dermochelys coriacea*) seabirds (many from the tropics, but also temperate species such as the yellow-nosed albatross, blackbrowed albatross, southern giant petrel), raptors (~14 species), pinnipeds, dugongs and cetaceans (Commonwealth of Australia 2001d). No specific research exists on marine megafauna in the SIMR.

Grey nurse shark

The SIMR contains significant habitat from the critically endangered eastern population of the grey nurse shark *Carcharias taurus*. These sharks prefer habitats with gutters and submarine caves, as found especially around Pimpernel Rock. Surveys conducted along the NSW coast have observed aggregations of up to 15 grey nurse shark at Pimpernel Rock, one of 13 locations to host aggregations of five or more grey nurse sharks (Commonwealth of Australia 2001c). This site has been thought to provide pupping or mating habitat. Great white sharks (*Carcharodon carcharias*), internationally protected, are sighted occasionally in deeper waters of the SIMR (Commonwealth of Australia 2001d).

Fisheries Research

The SIMR is zoned for multiple use, with the current zoning put into place in 2002 (Malcolm et al. 2010) and subsequently examined through a bioeconomic model (Greenville and MacAuley 2006). Approximately 140 commercial fishers operate in the combined State and Commonwealth waters, mostly licensed by NSW Fisheries (NSW Marine Parks Authority 2008a). Commonwealth fisheries managed by the Australian Fisheries Management Authority (AFMA) which potentially have access to the SIMR include the Southern Squid Jig Fishery, the East Coast Tuna and Billfish Fishery, the Jack Mackerel Fishery and the South East Non-Trawl Fishery (Commonwealth of Australia 2001d). Targeted species include pearl perch, snapper, school shark, mulloway, jew fish and spanner crabs. Fish trapping methods are used to harvest snapper, leatherjackets and



sweep in summer within the SIMR. The value of commercial fisheries and the proportion of the catch taken specifically from within the SIMR has not been estimated (Zann 2000). A survey of commercial fishers from Wooli indicates that around 40% of trap and line trips are conducted within the boundaries of the SIMP and SIMR (Zann 2000).

Recreational fishing is one of the most important economic drivers for the region (Greenville and MacAuley 2006). Boat based trolling, breath-held spearfishing and reef line fishing are the most popular forms of recreational fishing in the SIMR. There are no estimates of the number of private recreational fishers that utilise the SIMR and no firm estimates of the overall recreational fishing catch and effort in the SIMR (Zann 2000). Regional surveys of small boat anglers reported that 21% of boat anglers fished once a week, and 27% once a month, and the average duration of a fishing trip was three hours and the catch per unit effort averaged 1.1 kg/person/hour. Further studies found that 60% of boat-based recreational fishing trips that commenced at Coffs Harbour took place at sites located within the SIMP and SIMR (Zann 2000).

Gaps and recommendations

It is difficult to separate data collected from the SIMP and SIMR, especially for studies on larger-scale processes such as hydrodynamics, fisheries and pelagic ecology. There is a dedicated monitoring program for the SIMP (NSW Marine Parks Authority 2008b), but it does not extend to the deeper waters of the SIMR. The most efficient and cost-effective program is likely to be one that combines the two jurisdictions. This would also acknowledge the connectivity between the SIMP and SIMR, as ecological processes in the two areas are likely to be closely linked. A comprehensive research program exists for grey nurse sharks. Management of the SIMR may benefit from regular reporting of data collected specifically within its waters. Recommendations for future research and monitoring falls into four major categories, which could all be incorporated into a comprehensive cross-jurisdictional program:

- Regular reporting on the monitoring of physical characteristics – monthly or seasonal reporting of water quality, nutrients, turbidity, light and other physical parameters that support ecological processes in the SIMP and SIMR.
- Regular monitoring of ecological communities in deeper waters, using methods comparable to those of existing surveys and including ‘control’ locations.
- Dedicated surveys of marine megafauna and pelagic communities, using either aerial or boat-based methods.
- Monitoring of potential impacts, including dedicated surveys of fishing catch and effort inside the SIMP and SIMR by recreational and commercial fishers, and reporting mechanisms for pollution, shipping, interactions with megafauna and plastic marine debris.
- Transitional zones such as the one around the SIMP and SIMR are those most likely to show early responses to climate change. In addition to recording and reporting environmental data, a set of ecological indicators should be established to provide information on potential community responses to climate change.



COD GROUNDS COMMONWEALTH MARINE RESERVE

The Cod Grounds Commonwealth Marine Reserve (Cod Grounds) covers a 1,000m radius from a point at 152° 54' 37" East and 31° 40' 52" South, and was declared in 2007. It covers an area of about 300 hectares and was designed specifically to protect important habitat of the critically endangered grey nurse shark *Carcharias taurus* (Commonwealth of Australia 2001c). The east coast population of grey nurse shark is highly vulnerable to extinction due to its low reproduction rate and high historic fishing mortality. The Cod Grounds protects a number of underwater pinnacles around which grey nurse sharks typically aggregate. The NSW Department of the Environment and Climate Change maintains a Grey Nurse Shark listening station and temperature data loggers that were originally installed in September 2005 (Paul Anderson, DEWHA, pers. comm.). Only two ecological surveys have been undertaken.

Recreational fishers have been recorded as targeting grey nurse sharks in a number of areas in the past, including the Cod Grounds. However, together with Pimpernel Rock in the SIMR, the Cod Grounds were found to account for 16.4% of the observed grey nurse shark population off the coast of NSW. Large numbers of mature female and male individuals were reported from this site, with large aggregations being common especially during the period between May and October (Commonwealth of Australia 2001c).

Uses and Threats

The Cod Grounds are highly protected and the only activity permitted inside its boundaries are scientific research, diving and snorkeling, and recreational boating. A code of conduct exists for diving with the protected grey nurse sharks. Pollution and introduced species are unlikely to pose a threat to the Reserve at present (Stuart-Smith et al. 2009). However, commercial and recreational fishing occurs in the area, and evidence has been found of illegal fishing within the Reserve. This is of concern because of the small size of the Reserve, as even the removal of a few individuals of important species may have large ecological repercussions. For instance, previous research in NSW showed that the removal of large predators of urchins, such as blue groper (*Achoerodus viridis*) and pink snapper (*Chrysophrys auratus*), may cause increasing abundances of urchins, which in turn can affect densities of algae and invertebrates and create 'urchin barrens' (Stuart-Smith et al. 2009).

Climate and Oceanography

The Cod Grounds is situated in subtropical to temperate waters, influenced by warm and humid weather in summer and dry cool conditions in winter. The surrounding waters are primarily influenced by the strongly southward-flowing East Australian Current. Topographic variations of the seafloor interact with the East Australian Current to create a high-energy environment that sometimes results in nutrient-rich dinoflagellate blooms (Oke and Middleton 2001). The East Australian Current transports subtropical species into temperate regions of NSW (Brewer et al. 2007).



Geology and Geomorphology

An initial swath mapping study in the Cod Grounds found a central rocky reef outcrop that rises from 42m to approximately 21 m in depth from an otherwise relatively featureless seafloor, surrounded by boulders and cobbles progressively interlaced with sandy sediments as they slope downward. This central peak of the Cod Grounds consists of sharp outcrops with steep slopes. The peaks appear to consist of Tertiary volcanics of the Comboyne Beds, with the deeper parts of reef apparently composed of a different rock type to the central pinnacle, thought to be sedimentary facies of the Tertiary Camden Haven Beds (Davies et al. 2008). It is the northern-most and shallowest of a series of similar subsurface rocky outcrops in the region.

At least two distinct rock types were recorded in the Cod Grounds (Davies et al. 2008). Underwater video surveys further distinguished four substrate types, including solid consolidated rocky reef outcrop, unconsolidated boulder and cobble, unconsolidated sand with cobbles, and sand with shell grit. These substrates form a variety of habitats, including steep outcrops, shallow gutters, boulder/cobble slopes, and sand expanses (Davies et al. 2008).

Ecology

The first ecological survey of the Cod Grounds documented community structure and biodiversity within the Reserve and at external reference sites (Stuart-Smith et al. 2009). This was the first dedicated survey of this area, with previous information concerning the distribution and abundance of the grey nurse shark *Carcharias taurus* (Commonwealth of Australia 2001c). The baseline survey documented and described the key features of the Reserve and surrounding habitats, including the dominance of cool temperate species, distinct depth zonation of benthos, the lack of macroalgal cover, encrusting algae and sessile invertebrates, very high fish biomass and abundance of large pelagic fishes exploited elsewhere and the presence of a number of rare and threatened species (Stuart-Smith et al. 2009).

Benthic communities

The shallowest benthic communities were typical of urchin barrens found elsewhere in NSW (Rule and Smith 2007). Deeper areas were distinguished by the dominance of different sessile invertebrates, such as sponges, ascidians, soft corals and hard corals. Forty-eight taxa or cover categories were documented, with crustose coralline algae dominating overall. The distinct communities were zoned in narrow depth bands, forming discreet ecotones. The patterns were thought to be fundamentally driven by urchin grazing activities (Stuart-Smith et al. 2009).

Invertebrates

High densities of the grazing sea urchin *Centostephanus rodgersii*, a typically barrens-forming urchin species, were found in shallower areas, coinciding with the urchin barrens habitat. Overall, a total of 35 mobile macroinvertebrate species were recorded, with 29 of these found on transects inside the Cod Grounds. The mobile macroinvertebrate



community was dominated by echinoderms, especially sea urchins (Stuart-Smith et al. 2009).

Fish

Overall, 69 species of fish were recorded along transects of the baseline survey, with 66 species recorded within the Cod Grounds. As with benthic communities, the fish community could also be partitioned into shallow and deep assemblages, and was dominated by higher-order carnivores and planktivores. The most abundant species were mado (*Atypichthys strigatus*), silver sweep (*Scorpiis lineolata*), and one-spot pullers (*Chromis hypsilepis*), and the most frequently recorded were Maori wrasse (*Ophthalmolepis lineolata*), girdled parma (*Parma unifasciata*) and half-banded sea perch (*Hypoplectrodes maccullochi*). Species encountered primarily in the Cod Grounds, apart from rare species, include those typically aggregating around prominent undersea features, such as highfin amberjack (*Seriola rivoliana*), yellowtail kingfish (*Seriola lalandi*) and rainbow runner (*Elagatis bipinnulata*). High densities of large wobbegong sharks (*Orectolobus halei* and *O. maculatus*) were also recorded inside the Cod Grounds. Average abundance and biomass of fish, especially exploited species, were significantly higher inside the Cod Grounds than at nearby fished reference sites.

Rare species noted inside the Cod Grounds were the grey nurse shark *Carcharias taurus*, which is listed as ‘critically endangered under the EPBC Act, and the black cod *Epinephelus daemeli*, listed as ‘vulnerable’ under the NSW Fisheries Management Act and by Pogonoski et al. (2002) and which are protected in NSW waters. A rare pipehorse, *Solegnathus dunckeri*, was observed at one of the sites outside the Cod Grounds. This species is otherwise largely unknown except from trawl catches taken from depths between 75 and 140 m (Stuart-Smith et al. 2009).

Fisheries Research

A socio-economic impact assessment undertaken prior to the establishment of the Reserve focused primarily on the fisheries value of the Cod Grounds (Schirmer et al. 2004). The Cod Grounds is a strictly no-take area, protected as such since 2007. Prior to this, commercial fishing occurred in the area, with a multi-method, multi-species fishery operating for a number of decades, and high catch rates recorded (Schirmer et al. 2004). Recreational fishing also took place, but data are very limited. Illegal fishing is of great concern in the Cod Grounds, due to its proximity to the coast, small size, and difficulty in monitoring and policing compliance (Stuart-Smith et al. 2009). The recent ecological survey observed both fishing activities and evidence of recent fishing such as fishing line and sinkers within the Reserve boundaries. Illegal fishing is expected to have major consequences for the health of the Reserve (Stuart-Smith et al. 2009).

Gaps and Recommendations

Research and monitoring in the Cod Grounds has only just begun, although a wealth of background information exists at the regional scale. The baseline survey conducted recently provides an excellent foundation on which to build a comprehensive monitoring



program (Stuart-Smith et al. 2009). The resulting report included a useful set of recommendations for designing such a monitoring program, including:

- Regular monitoring of physical characteristics – monthly or seasonal reporting of water quality, nutrients, turbidity, light and other physical parameters that support ecological processes in the Cod Grounds,
- Continued monitoring to build up a temporal dataset to compare with the baseline set by the 2009 survey; repeat and enhance methods, intervals 1-3 years, use the set of univariate indicators in the study report,
- Incorporate additional sites for monitoring, especially additional control sites outside the Reserve, located further afield but in comparable habitats and depths,
- Include a timed swim around the pinnacle for closer sampling of grey nurse sharks, and
- Consider a buffer zone around the Reserve boundaries.

ELIZABETH AND MIDDLETON REEFS MARINE NATIONAL NATURE RESERVE

Elizabeth and Middleton Reefs Marine National Nature Reserve (Elizabeth and Middleton) is situated in the Tasman Sea, north of Lord Howe Island (Figure 1). The Reserve encompasses the two southern-most platform reefs in the world: Elizabeth Reef and Middleton Reef. This site is also the eastern-most location of conservation significance in Australia. These reefs, which are essentially the peaks of volcanic seamounts, are home to a unique and highly diverse assemblage of tropical and temperate organisms, and are protected both as a CMPA and as a Ramsar site (Lee Long 2009b). They are also one of the few remaining intact habitats of the Galapagos shark, *Carcharhinus galapagensis*, and the black cod, *Epinephelus daemeli*. The Reserve is managed in two zones; Middleton Reef is a strict no-take Nature Reserve, while some recreational fishing is allowed at Elizabeth Reef (Commonwealth of Australia 2006).

Three biological features have been highlighted as important and unique for the Reserve (Oxley et al. 2004a; Choat et al. 2006):

1. It lies on the latitudinal boundary of coral reef formation, and supports a mix of tropical, temperate and cosmopolitan species;
2. The high degree of isolation of these reefs has led to an expectation that they would support endemic species or species that were generally rare over most of their range; and
3. Their relative isolation indicates that they could support populations of species that have been impacted by fishing in other parts of their range and thus serve as refugia.

The relative proximity of the Reserve to Lord Howe Island means that a variety of research programs have been conducted to explore the reefs' geology and geomorphology, as well as their ecology.



Uses and Threats

Uses of Elizabeth and Middleton include some recreational fishing at Elizabeth Reef, scientific research activities and recreational boating, snorkeling and diving. Surrounding areas support commercial demersal longline fisheries for blue-eye trevalla and rosy jobfish (Commonwealth of Australia 2006). Threats to the Reserve are few and include primarily the impacts of fishing on Elizabeth Reef, and the potential for illegal fishing on both reefs (Choat et al. 2006). Pollution from fishing vessels and passing ships may threaten the Reserves, and potential future threats are those associated with rising sea surface temperatures, range expansion of marine pests, increased storm activity and petroleum and mineral exploration and mining (Commonwealth of Australia 2006; Lawrence et al. 2007). A major concern for this Reserve in the future will be climate change induced changes to the East Australian Current, potentially leading to significant changes in larval supply and physical environmental conditions (Lawrence et al. 2007).

Climate and Oceanography

The most important oceanographic influence on Elizabeth and Middleton is the convergence of the East Australian Current and the Tasman Front. The position of the Tasman Front means that while Lord Howe is generally influenced by the colder Tasman Sea water, Elizabeth and Middleton generally receive warmer water from eastward-flowing eddies of the East Australian Current (Brewer et al. 2007). These eddies transport larvae from the extensive area of coral reefs to the north. Additionally, the NSW coastal ecosystems to the west are a potential source of propagules of temperate and subtropical species, so there is a diverse fauna comprising both coral reef and subtropical elements. Water temperatures vary from 19 to 26°C. The prevailing winds are from east to southwest, resulting in very exposed reef front habitats on the southern face of the reef. However, waves wrapping around the western and northeastern aspects of the reef ensure that these sides are also exposed to heavy seas (Kennedy and Woodroffe 2004b). Average monthly wave height data show that Elizabeth and Middleton are more frequently exposed to large oceanic swells than the GBR (Choat et al. 2006). Temperature loggers have been deployed at Elizabeth and Middleton Reefs (Berkelmans 2009).

Geology and Geomorphology

Both Middleton and Elizabeth Reefs are atoll-like structures or platform reefs associated with a seamount chain that extends northward from Lord Howe Island (Woodroffe et al. 2004), rising from a depth of 2,000 m (Kennedy and Woodroffe 2004b). Reef morphology and vertical accretion rates during the Holocene appear similar to those on tropical reefs (Kennedy and Woodroffe 2004b), and reef characteristics are thoroughly described in Lee Long (2009b). Each reef consists of an extensive lagoon surrounded by a well-defined reef crest with characteristic spur and groove formations, broken only by channels on the northern edges (Choat et al. 2006). Sediment sampling in the lagoons found that sediment was predominantly composed of coral, molluscs, *Halimeda*, coralline algae and foraminifers (Kennedy and Woodroffe 2004b).

Woodroffe et al. (2004) conducted detailed geological and geomorphological studies at Elizabeth and Middleton, including drilling, vibrocoreing, seismic profiling, and dating, to



document the reef framework's Holocene origins. They also noted the porous nature of the reef framework, formed by branching rather than massive corals (Woodroffe et al. 2004).

Ecology

The two most recent ecological surveys (Oxley et al. 2004a; Choat et al. 2006) contain the most comprehensive collection of information on the biological and ecological features of Elizabeth and Middleton Reefs. Previous surveys focused primarily on corals, in order to establish a taxonomic baseline relevant to the particular reef habitats provided by the Reserve. A first comprehensive species list of hard corals and a summary of coral distribution and status was compiled in 1981 and followed up in 1984. The Australian Museum expedition in 1987 (Australian Museum 1992) added estimates of coral and fish biodiversity. These surveys also provided information on the abundance and activity patterns of crown of thorns starfish (Benzie and Stoddart 1992).

Benthic communities

The work summarised by the Australian Museum (1992) indicated that live coral cover at Elizabeth Reef was significantly greater than at Middleton Reef. This was confirmed by both of the more recent surveys (Oxley et al. 2004a), which yielded mean coral cover estimates of 25% at Elizabeth and 12% on outer reef slopes of Middleton. Possible interpretations of this pattern are that either coral cover on the outer reef slopes of Middleton is consistently low and a reflection of the natural dynamics of this reef system, or a recent history of disturbance in which crown of thorns, bleaching and storm damage have reduced outer slope coral from a traditionally much higher level (Choat et al. 2006).

Original research in the 1980s identified a total of 121 coral species, of which 111 were also recorded in 2003 (Oxley et al. 2004a). The coral community was found to be unique, differing significantly even from Lord Howe Island, despite its relative proximity (Australian Museum 1992). The reefs were reported as being in a state of recovery from disturbance, and the relatively low coral diversity has been attributed to the high degree of exposure and the limited number of reef habitats (Australian Museum 1992). Some differences were found between the reef communities of Elizabeth and Middleton Reefs, indicating that small-scale stochasticity in larval input and post-settlement survival are important, and extinction risk is potentially high (Noreen et al. 2009).

Choat et al. (2006) cautions against comparisons of Elizabeth and Middleton with lower latitude reefs, for the following reasons: the relative lack of high-intensity pulse disturbances, such as cyclones and bleaching events, found in the tropics; the high abundance of scraping and excavating fishes at Elizabeth and Middleton, whose effects on coral are both beneficial (by removing algal biomass) and detrimental (by removing live coral and coral recruits); a historically low cover of live hard corals; and the patchy nature of potential disturbances (e.g. *Acanthaster* outbreaks).



Invertebrates

Commercially important invertebrates, such as holothurians, were first surveyed in 2003 (Oxley et al. 2004a). Very high densities of the high-value *Holothuria whitmaei* (133.3 individuals per hectare) were recorded, representing the highest densities reported anywhere in Australia (Oxley et al. 2004a). Elizabeth and Middleton Reefs also support populations of endemic molluscs (Lee Long 2009b).

Fish

The survey conducted in 2003 (Oxley et al. 2004a) raised the number of species of reef fish previously recorded to 311; the 2006 survey further raised this number to 322 (Choat et al. 2006). The community structure of reef fishes was compared to the GBR and to Coringa-Herald in the Coral Sea, and was found to differ in the absence of some tropical taxa, and the presence of temperate species, as well as lower overall species richness. Functionally important fish recorded in high densities included the endemic doubleheader wrasse *Coris bulbifrons* (Randall and Kuitert 1982), excavating and scraping parrotfish and large herbivorous browsing fishes (Choat et al. 2006).

Black cod (*Epinephelus daemeli*) abundance was estimated at 4 cod/hectare in 2003, (Oxley et al. 2004a), which appeared similar to densities recorded in 1987. In 2006, an overall average of 2.9 ind/ha with habitat specific densities between 1.2 and 4.1 ind per ha, were recorded (Choat et al. 2006). Comparisons of visual estimates of lengths of black cod between 1987 and 2003 suggest that proportionally more large fish were present in 2003, where the larger individuals reached lengths of 1.5m. Galapagos sharks were also recorded in high densities, with the 2006 survey reporting 12 ind/hectare in some habitats (Choat et al. 2006). High numbers of small Galapagos sharks were found in the Elizabeth Reef lagoon, and it was suggested that this lagoon provides a nursery area for this species (Oxley et al. 2004a).

Aside from whole-reef ecological surveys (Oxley et al. 2004a; Choat et al. 2006), research has focused on genetic analyses of potential pest species such as COTs (Benzie and Stoddart 1992), on corals (Noreen et al. 2009) and on key protected species such as the black cod (Appleyard and Ward 2007) and Galapagos shark (van Herwerden et al. 2008). Together with Lord Howe Island, Elizabeth and Middleton are unique representatives of reefs at the latitudinal limit of their range, and these edge habitats are evolutionarily interesting (Choat et al. 2006). In their analysis of COTs genetics, Benzie and Stoddart (1992) found that unlike Lord Howe Island, which appeared as an outlier, Elizabeth and Middleton formed a subgroup within the reefs of the GBR. Furthermore, larval recruitment from external sources, including long-range migrants from the GBR, serve to replenish Elizabeth and Middleton's coral populations (Noreen et al. 2009).

Otolith analysis on yellowtail kingfish revealed that the Elizabeth and Middleton population is also likely to be self-sustaining to some degree (Patterson and Swearer 2008). Given the proximity of Elizabeth and Middleton reefs to each other, the genetic structure of black cod in the Reserve was found to be from a single stock (Appleyard and Ward 2007; van Herwerden et al. 2009b). The same result was found for the Galapagos



shark, but it was further established that the Elizabeth and Middleton population was distinct from that of Lord Howe Island (van Herwerden et al. 2008).

Marine Megafauna

Small numbers of green turtles (*Chelonia mydas*), as well as a variety of marine mammals and seabirds, have been recorded at Elizabeth and Middleton. The turtles use the reefs primarily for food and shelter, as there is insufficient land for nesting. Seabirds are also primarily seen foraging there (Lee Long 2009b).

Gaps and Recommendations

Comprehensive geomorphological information exists for Elizabeth and Middleton; the setting of these reefs at the southern limits of reef growth has sparked enormous interest in this area for answering questions on reef formation and development. Coral biology and ecology has also been relatively well-studied, although the large gap between surveys precludes the identification of temporal patterns. General surveys of the ecological communities that may be useful as baseline studies for monitoring programs are fairly recent, but will be useful in determining the methodology of a more comprehensive monitoring program.

Given its latitudinal position, this Reserve has attracted some research on genetic characteristics of protected species (Appleyard and Ward 2007; van Herwerden et al. 2008; van Herwerden et al. 2009b). These studies set an important foundation for further research in this area, especially with regards to connectivity between the Reserve and potential source and sink populations. There is still a gap in oceanographic knowledge that can be linked to genetic patterns in order to explain possible dispersal and connectivity pathways. Recommendations include:

- Repeat the past surveys to develop a long-term dataset, including 18-month spot-checks to detect any obvious signs of disturbance and the status of key features and species. Support involvement of Lord Howe rangers in the monitoring of Elizabeth and Middleton, as they have the opportunity to coincide with suitable weather conditions in which to undertake surveys,
- Compare species targeted by fisheries between the two reefs with intent to detect the effects of fishing. Investigate the option of closing both reefs to fishing,
- Examine levels of gene flow between Elizabeth and Middleton and protected areas off the NSW coast, Norfolk Island, New Zealand and Lord Howe Island, to establish possible pathways of stock replenishment,
- Support genetic work on the doubleheader wrasse and other endemics, and
- Investigate seasonal changes in diversity, abundance and functional groups or productivity of fish and invertebrate communities, to further understand the dynamics of these highly changeable systems and possible processes of recruitment and stock fluctuations, and to create a baseline dataset to monitor possible future change of these dynamics.



LORD HOWE ISLAND MARINE PARK (COMMONWEALTH WATERS)

Lord Howe Island Marine Park (Commonwealth Waters)(Lord Howe) follows the 1,800-metre depth contour outlining the base of the seamounts that underlie the Lord Howe Island and Balls Pyramid (McDougall and Green 1988). The sea area of the Park is estimated to be 300,510 hectares. The island and Balls Pyramid are part of a chain of seamounts that are the remnants of a volcanic system active in the late Miocene. The island itself belongs to the State of New South Wales (NSW) and is surrounded by State waters (out to 3 nautical miles) and Commonwealth waters out to a distance of 200 nautical miles. The Reserve adjoins the Lord Howe Island Marine Park (State Waters), and the combined area includes most of the marine environs of the Lord Howe Island World Heritage Area.

Lord Howe is considered the southern-most locality in the world with a well-developed fringing coral reef that includes a lagoonal system (Zann 2000). It hosts a mixture of temperate and tropical species and a very high level of endemism. The marine environment is considered largely undisturbed, and the diversity and density of corals, fish and benthic algae have been noted (Commonwealth of Australia 2002b). Some of the seamounts in the Reserve appear to be isolated marine systems harboring species believed to be relics of groups that disappeared in the Mesozoic age (225-65 million years ago). Black cod (*Epinephilus daemeli*) and other species of conservation significance are found in the Reserve (Commonwealth of Australia 2002b).

Uses and Threats

Most human uses and activities are undertaken in State waters closer to the island itself. Commonwealth waters are used for activities such as charter and recreational fishing, including big game billfish fishing, and some sailing (Commonwealth of Australia 2002b).

Unregulated fishing by Lord Howe Islanders for sale and consumption on the island is said to have increased in Commonwealth waters in recent years, as catch rates in State waters have declined. Threats from fishing, especially unregulated fishing, include direct damage to marine habitats and the depletion of fish stocks (Commonwealth of Australia 2002b). Fishing often targets a disproportionate amount of species near the top of the food web, leading to a potential trophic shift and flow-on effect for entire ecological communities (Mumby et al. 2006). Recreational boating and dolphin viewing may result in disturbances to marine megafauna through inappropriate human behavior, and indirect impacts may result from trawling operations and petroleum exploration and mining outside the boundaries of the Reserve (Commonwealth of Australia 2002b). A major concern for this Reserve in the future will be climate change induced changes in the East Australian Current, potentially leading to significant changes in larval supply and physical environmental conditions (Lawrence et al. 2007). Warming ocean temperatures are also expected to result in greater survival capabilities of tropical species, potentially resulting in shifts in community structure (Figueira and Booth 2010).



Climate and Oceanography

Lord Howe Island is exposed to easterly and northeasterly winds and is often subject to weather extremes. Strong winds of over 34 knots and heavy rainfall can occur, especially in winter. Summer temperatures range from 17 to 25°C and winter temperatures from 14 to 18°C. Water temperatures vary from 17°C in winter to 25°C in late summer (Commonwealth of Australia 2002b). Monitoring of SST is ongoing (Berkelmans 2009).

Lord Howe Island is located at the convergence of tropical water from the Coral Sea and temperate water from the Tasman Sea. It is also in the path of seasonal offshore pulses and eddies of the East Australian Current (Nilsson and Creswell 1980). The Tasman Front moves seasonally in a north-south direction, and contributes to alternating cooler (19°C) and warmer waters (25°C) around the Lord Howe Island Group. The local hydrodynamics interact with the seamount chain to form eddies, tides, and trapped and internal waves (Commonwealth of Australia 2002b). Currents sweeping past the seamounts transport food for benthic organisms attached to the seamounts' surface, including planktonic organisms, fish, squid and prawns (Koslow 1997). These processes enhance local productivity and support a rich fauna associated with the seamounts.

Geology and Geomorphology

Together with Balls Pyramid further to the south, Lord Howe Island forms the southernmost and youngest in a chain of seamounts extending north to the Elizabeth and Middleton Reefs. The seamounts are located on the Lord Howe Rise, which is believed to be a drowned section of continental crust left behind when the Tasman and New Caledonian Basins opened up in Cretaceous times. Lord Howe Island has evolved from a volcanic island (guyot), believed to have been active 6 or 7 million years ago over a period of roughly 500,000 years. The chain of seamounts on the Lord Howe Rise has recently been explored with multibeam sonar swath-mapping (Exon et al. 2004). This revealed small volcanic cones that were subsequently dredged to investigate the volcanic rocks forming the structures. The composition of dredged foraminiferans indicated that sediments originated in the Early Miocene (approximately 16 million years ago), and were deposited in cool water (Woodroffe et al. 2006). The chemical composition of the hard sediments further suggested strong hydrothermal influences associated with hot-spot volcanism.

The Commonwealth waters of the Park contain parts of the structure of the seamount proper, a large proportion of the shelf area, the topographic discontinuity known as the drop-off zone where the shelf falls steeply into depths greater than 2000 m, and the deep-sea pelagic environment (Dickson 2006). Studies in this region have been conducted by national and international teams, most notably on the R/V Seismic vessel. Research programs have investigated many aspects of the evolution of the Lord Howe chain of volcanoes, with studies on Lord Howe Island focused on carbonate shelf sedimentation (Kennedy et al. 2002), reef development and lagoonal sedimentation (Kennedy 2003; Kennedy and Woodroffe 2004a; Woodroffe et al. 2005), and aspects of its coastal geomorphology (Brooke et al. 2003; Dickson et al. 2004; Dickson 2006). A geomagnetic field station is also located on Lord Howe Island (Lewis 2008a).



On-going processes are also the focus of geological and geomorphological studies (Woodroffe et al. 2005). The most common type of sediment overlaying the structure of the seamount above the carbonate compensation depth is biogenic ooze composed of calcareous and siliceous microfossils and sponge spicules. Across the shelf, sediments are calcareous, except in close proximity to the island where there is significant volcanic content. Coralline algae, coral, bryozoans, *Halimeda* and foraminifera are the common grain types, with rhodoliths and molluscs occurring near the shelf edge (Kennedy et al. 2002).

Bathymetry studies were the first to attempt to define habitats to aid in the identification of conservation priority areas (Dickson and Woodroffe 2002). This was followed by multi-beam swath mapping, which recorded a high degree of benthic complexity in Commonwealth waters. The submarine shelf of the islands is rugged and generally 10–20° or steeper, with thick pelagic sediments and volcanic outcrops. Features include downslope flow structures (e.g. old lava flows or coarse sediment debris flows), canyons, cones and pinnacles, many 150–300 m high, including over 20 parasitic cones. The submarine slopes were found to be mostly rocky volcanic outcrops with thin patches of sediment, while the shallow channel between the two islands contained very coarse sediments (Kennedy and Woodroffe 2002). Researchers have stated that such a complex substrate indicates the existence of diverse ecosystems, perhaps similar to those found on the Tasmanian seamounts.

More recently, the near-horizontal basalt and calcarenite shore platforms around Lord Howe Island have been described (Dickson 2006). Whereas the prolific mid-Holocene reefs might appear to reflect warmer sea-surface temperatures, the pattern of dates and reef growth history are similar to those throughout the Great Barrier Reef and across much of the Indo-Pacific and are more likely correlated with availability of suitable substrate (Woodroffe et al. 2005). Due to its position at the latitudinal limit for reef growth, Lord Howe provides an opportunity to examine possible changes in reef growth during periods of climate change (Kennedy et al. 2007).

Ecology

Most of the research on ecological features of Lord Howe Island's marine environments was conducted in the State Waters. Comprehensive species lists are available for fish (Allen et al. 1977; Francis 1993; Francis and Randall 1993), corals (Veron and Done 1979) and algae (Millar and Kraft 1993, 1994a, 1994b; Kraft 2000). Over 305 species of algae, 83 species of scleractinian coral, 65 species of echinoderms and 400 species of fish have been identified for the Lord Howe Island Region. An Australian Museum review of samples taken from waters more than 40 m deep shows a species-rich fauna with 13.1% endemism. It is suggested that the deeper shelf fauna may have higher endemism than the shallow water fauna.

Much information about the deeper waters of the Reserve was deduced from knowledge of other seamounts in the region, with specific ecological information assembled during a



dedicated biodiversity survey in 2003 (Clark et al. 2003). It is known that they support a unique deep-sea environment characterised by strong currents and high species diversity, and provide habitat for endemic, rare and endangered species of plants and animals (de Forges et al. 2000; Roberts et al. 2002; Clark et al. 2010). Samples taken from four seamounts on the Lord Howe Island Rise revealed 108 species of fish and macroinvertebrates, including four new genera, of which 31 % were new to science and potential seamount endemics (de Forges et al. 2000). The sessile benthic fauna is dominated by suspension feeders, and some species appear to be relicts of groups believed to have disappeared in the Mesozoic age (225–65 million years ago). There is generally little overlap between species distributions on seamounts, leading to very restricted and localised ranges. Researchers consider the seamounts in the Lord Howe Island region to provide an exceptional opportunity to examine evolution and speciation in the deep sea (de Forges et al. 2000; Clark et al. 2010). Several studies highlight the exceptionally high diversity in the south-west Pacific (Poore and Wilson 1993; Poore et al. 1994).

Benthic communities and invertebrates

Considerable research effort has gone into describing shallow-water benthic communities, especially corals (De Vantier and Deacon 1990) and algae. Of special interest has been the association between tropical species at the southern range of their geographic distribution, and subtropical species not found on the GBR. The coral communities tend to be dominated by a few abundant species, including *Acropora palifera*, *A. glauca*, *Porites* spp. and *Pocillopora damiconis*. There has been some debate about whether Lord Howe Island reefs are reliant on replenishment of larvae from the Great Barrier Reef or from local brooding corals, and whether long-range dispersal of broadcast spawning species may occur in isolated and sporadic events (Veron and Done 1979; Harriott 1992; Ayre and Hughes 2004; Harrison 2008; Noreen et al. 2009). Research has found that Lord Howe Island corals have relatively low genetic diversity and populations are genetically isolated and most probably derived from few colonists, especially for brooding corals (Ayre and Hughes 2004; Noreen et al. 2009).

There was some concern over the possibility of COTs outbreaks in the second half of the 1980s (De Vantier and Deacon 1990). Genetic research on COTs found that the Lord Howe population was distinct from all other Australian populations, including those on nearby Elizabeth and Middleton Reefs (Benzie and Stoddart 1992). There is some concern that affected coral communities may be much slower in recovering from disturbance events due to their largely self-seeding nature and the environmental controls on coral growth such as temperature and habitat availability (Harriott 1999; Harriott and Banks 2002; Ayre and Hughes 2004). The relationship between recruitment and endemism was recently investigated using reef fish species, and it was hypothesized that “*either local adaptation enhances recruitment in endemics through higher larval replenishment rates or reduced post-settlement mortality, populations of widespread species at the periphery of their range are poorly adapted to local environmental conditions and therefore experience lower and more variable settlement and post-settlement survival rates, or both*” (Crean et al. 2010).



Due to its isolated location, considerable research has focused on genetic analyses of potential pest species such as COTs (Benzie and Stoddart 1992), on corals (Noreen et al. 2009) and on key protected species such as the black cod (Appleyard and Ward 2007) and Galapagos shark (van Herwerden et al. 2008). Lord Howe Island, together with Elizabeth and Middleton Reefs, is a unique representative of reefs at the latitudinal limit of their range, and these edge habitats are evolutionarily interesting (Choat et al. 2006). In their analysis of COTs genetics, Benzie and Stoddart (1992) found that Lord Howe Island appeared as an outlier. The genetic structure of the Lord Howe population of Galapagos shark was found to be distinct from that of Elizabeth and Middleton (van Herwerden et al. 2008). Molecular studies using a sea star have established that this species dispersed eastward across the Indian Ocean during the Pleistocene (Waters and Roy 2004). It remains to be tested whether this is true for other species.

Algae are a striking and well-documented component of the shallow Lord Howe Island benthos. There is a mixture of tropical and subtropical genera, such as *Padina* and *Dictyota*, but in large thalli not seen in the Great Barrier Reef (Allen et al. 1977). There are more than 305 species of benthic algae, including 47 (15%) endemic species (Millar and Kraft 1993, 1994b, 1994a). Additionally, Lord Howe Island holds the world's highest latitude populations of the genera *Neomeris*, *Boodlea*, *Valoniopsis*, *Ventricaria* and *Trichosolen*, and is the site of the highest latitude populations of particular species in the genera *Halimeda*, *Polyphysa*, *Caulerpa*, *Chaetomorpha*, *Chlorodesmis*, *Codium*, *Avrainvillea*, *Struvea* and *Dictyosphaeria*. New species have recently been described and molecular techniques have allowed phylogenetic studies (Millar and Freshwater 2005).

Three dedicated studies exist of the Park's deeper-water benthic communities; a collection by the Australian Museum in the 1960s and 1970s, and the much more recent AIMS and NSW DECCW and NSW MPA surveys (Speare et al. 2004; Neilson et al. 2010). Samples dredged in 1960 and 1976 offshore of Lord Howe Island and Balls Pyramid included the following species within 30 nm of the islands in waters deeper than 40 m: 3 crustaceans; 16 annelids; 12 echinoderms; 1 sipunculid; 1 bryozoan; 360 molluscs; and 7 brachiopods. The one deep-water sample, from a depth of 2,738 m beyond the 12 nm boundary, consisted of very fine foraminiferan ooze and clay. The sample contained only 8 molluscs, of which only 1 could be recognised as an existing species. Nothing can be said about endemism in the deep-water sample because of the small amount of data available and the lack of comparable material from elsewhere in the Tasman Sea. The Australian Museum determined that the shelves had a high conservation value due to their relatively pristine – and untrawled – state compared to other Australian shelves, and because of the high endemism of the Island's fauna (Commonwealth of Australia 2002b).

Two dedicated surveys have explored deeper waters within and surrounding the Reserve. Firstly, in May/June 2003, a multi-agency team of Australian and New Zealand scientists conducted biodiversity surveys of the Lord Howe Rise and Norfolk Ridge, targeting depths of at least 1,500m (Clark et al. 2003). Using primarily trawl sledge and cameras,



the team captured and identified over 500 species of fish and 1,300 species of macroinvertebrates. Further identification work was conducted at various institutions and museums, but it was suggested that 20% of the fish species were either new records for the region, or new to science.

Secondly, in February/March 2004, the Australian Institute of Marine Science undertook surveys of benthic habitats and fish faunas in the deeper Commonwealth waters of the Lord Howe and Balls Pyramid rises (30 – 200m) (Speare et al. 2004). The survey used towed underwater cameras and BRUVS. A fossil coral reef was located extending to a depth of 45m, providing habitat for sparse stands of brown and green algae (Kennedy et al. 2002). Beyond this limestone structure was a sandy seafloor extending to the shelf break. The steep shelf slopes were composed of finer silty sediments flowing down between bedrock outcroppings, providing a topographically complex habitat, inhabited by sessile benthos and fish. Deep-water solitary corals and algal communities were recorded on the shelf of Balls Pyramid.

Fish

The complex habitat at approximately 200 m depth, beyond the penetration of sunlight, hosted the highest densities of fish. Large kingfish, *Seriola lalandi*, redfish, *Centroberyx* sp., rosy jobfish, *Pristipomoides multidens*, and large unidentified groupers, Epinephelinae, were noted (Speare et al. 2004). Additionally, three new fish records were made for the island in the baited video surveys: the smooth hammerhead shark, *Sphyrna zygaena*, the lancer *Lethrinus genivittatus*, and the gilded triggerfish, *Xanthichthys auromarginatus*. The most ubiquitous species recorded in all areas by the baited videos were the Galapagos whaler shark, *Carcharhinus galapagensis*, the blotched fantail ray, *Taeniura meyeni*, the black-spot pigfish, *Bodianus unimaculatus*, and the brown-spotted wrasse, *Pseudolabrus luculentus*. The authors of the report noted that shark densities recorded in these surveys greatly exceeded the numbers seen before using the same BRUVS technique on tropical mid-shelf reefs of the GBR, on oceanic atoll reefs of the Rowley Shoals, off north-east Australia, and in the sub-tropical algal reefs of the Great Australian Bight (Speare et al. 2004). BRUVS surveys were also conducted in 2007 (Heagney et al. 2007) and 2009 (Neilson et al. 2010), confirming the patterns found by Speare et al. (2004) and providing additional information on the differences between the Sanctuary Zone (no-take) and Habitat Protection Zone (line fishing permitted).

Fish were also surveyed and collected extensively by the Australian Museum, both in shallow and deep waters. Currently, 447 species and 107 families have been recorded around Lord Howe Island. Brown puller (*Chromis hypsilepis*) and orange wrasse (*Pseudolabrus luculentus*) were among the most common species at depths below 35 m. The protected black cod (*Epinephelus damelii*) is also found in the Park. Deep-water pelagic species include marlin (blue and striped), sharks (Galapagos, whalers, some tigers, whites and makos), sailfish, dolphin fish, yellowfin tuna, wahoo, trevally, bonito, yellow-tail kingfish and spangled emperor (Commonwealth of Australia 2002b). Deep-water demersal fish species caught on set droplines include deep-sea trevally, rosy jobfish



and large-sized kingfish; no record or analysis of the by-catch currently exists (Commonwealth of Australia 2002b).

The description of endemic fish is ongoing (Francis and Randall 1993). The Australian Museum identified three fish species of possible conservation significance in depths greater than 40 m around Lord Howe Island and Balls Pyramid. These species are the half-banded angelfish *Genicanthus semicinctus*, the Ballina angelfish *Chaetodontoplus ballinae* (but see Speare et al. 2004), and a species of bullseye or sweeper, *Pempheris adpersus*. Recent surveys of pelagic and demersal fish using BRUVS, visual counts and sonar found clear associations between fish species composition and environmental variables such as habitat structure and current speed (Heagney et al. 2007; Patterson et al. 2007; Lindsay et al. 2008). Low flow environments were favoured by *Carcharhinus galapagensis*, *Seriola rivoliana* and *Scomber australasicus*, while *Seriola lalandi* was associated with higher flow environments (Heagney et al. 2007). There are no known surveys of bathypelagic species.

Seabirds

Lord Howe Island itself provides important breeding habitat for seabirds, especially in spring and summer (Commonwealth of Australia 2002b). Fourteen species of seabirds breed on the islands, including masked boobys, grey ternlets, sooty terns, white terns, common noddys, black noddys, red-tailed tropic birds, little shearwaters, wedge-tailed shearwaters, flesh-footed shearwaters, black-winged petrels, whitebellied storm petrels, Kermadec petrels and Providence petrels. Ball's Pyramid is the only known Australian breeding ground of the Kermadec petrel, and Lord Howe Island provides the only breeding ground for the eastern Australian populations of flesh-footed shearwaters (Baker and Wise 2005). None of these species are currently threatened on the islands, but all are vulnerable to impacts on their oceanic feeding grounds as well as at their breeding grounds (Hutton 2004; Thalmann et al. 2009). Additionally, it was calculated that the mortality of flesh-footed shearwaters in pelagic longline fisheries was a significant threat to this population (Baker and Wise 2005; Thalmann et al. 2007; Thalmann et al. 2009).

Megafauna

Whales are rarely sighted or recorded in the Commonwealth waters of the Park. Migratory dolphins, such as the spinner dolphin, the dusky dolphin and pan tropical spotted dolphin, may pass through Lord Howe Island waters, and the bottlenose dolphin *Tursiops truncatus* is common (Commonwealth of Australia 2002b).

Fisheries Research

The main species targeted by fisheries in Commonwealth waters surrounding Lord Howe Island is the yellowtail kingfish (*Seriola lalandi*) (Commonwealth of Australia 2002b). There is evidence to suggest a decline in the stock of this area, but no recent formal stock assessment exists. Genetic research on this species suggests a high degree of self-recruitment, and indicates that a location-specific management strategy would be of benefit (Patterson and Swearer 2008).



Gaps and Recommendations

Shallow areas around Lord Howe Island support the southern-most well-developed coral reef in the world that includes a lagoonal system, and have therefore attracted a large volume of geomorphological and ecological research. The island is readily used as a base for such research, making it logistically cost-effective. Deeper waters in the Commonwealth Reserve are less accessible, but have nevertheless attracted some scientific attention due to the widespread interest in seamount ecology. Its lower accessibility, however, means that a comprehensive monitoring program does not exist, and an extensive baseline survey was conducted fairly recently (Speare et al. 2004; Neilson et al. 2010). As with Elizabeth and Middleton, genetic research is also recent, and hydrodynamics are not well-understood. Recommendations include:

- Support research that can use the island as a base,
- Develop indicators for rapid ecosystem health assessment,
- Closer investigation of the benthic communities of the hard and soft seafloors of the Commonwealth waters to determine biodiversity, ideally with ROV,
- Investigate habitat associations of important species of fish and invertebrates to assist in establishing a stratified sampling design,
- Repeat previous BRUVS surveys, ideally annually or biannually,
- Assess stocks of exploited species,
- Investigate food webs; focusing on the question of why they support such a large biomass of sharks,
- Investigate the location of predator aggregations in the deeper waters of the shelf drop-off,
- Replicate genetic studies carried out at Elizabeth and Middleton, and
- Undertake dedicated megafauna studies.



SOUTH-EAST MARINE REGION

SOUTH-EAST COMMONWEALTH MARINE RESERVE NETWORK

The South-east Marine Region extends from the south coast of New South Wales, around Tasmania and Victoria and west to Kangaroo Island off South Australia. It is the first Region to have a network of large, offshore, deep-water CMPAs. The network covers 226,458 km², and protects representative examples of the seafloor features in the South-east Marine Region (Figure 6). The CMPAs include the continental shelf and slope, abyssal plains and underwater canyons and mountains, and the diverse marine life associated with these features. Very little research so far has specifically addressed the characteristics of the CMPAs themselves, except for work done during the bioregional planning that preceded the establishment of the Reserve network (National Oceans Office 2002d)(Table 4).

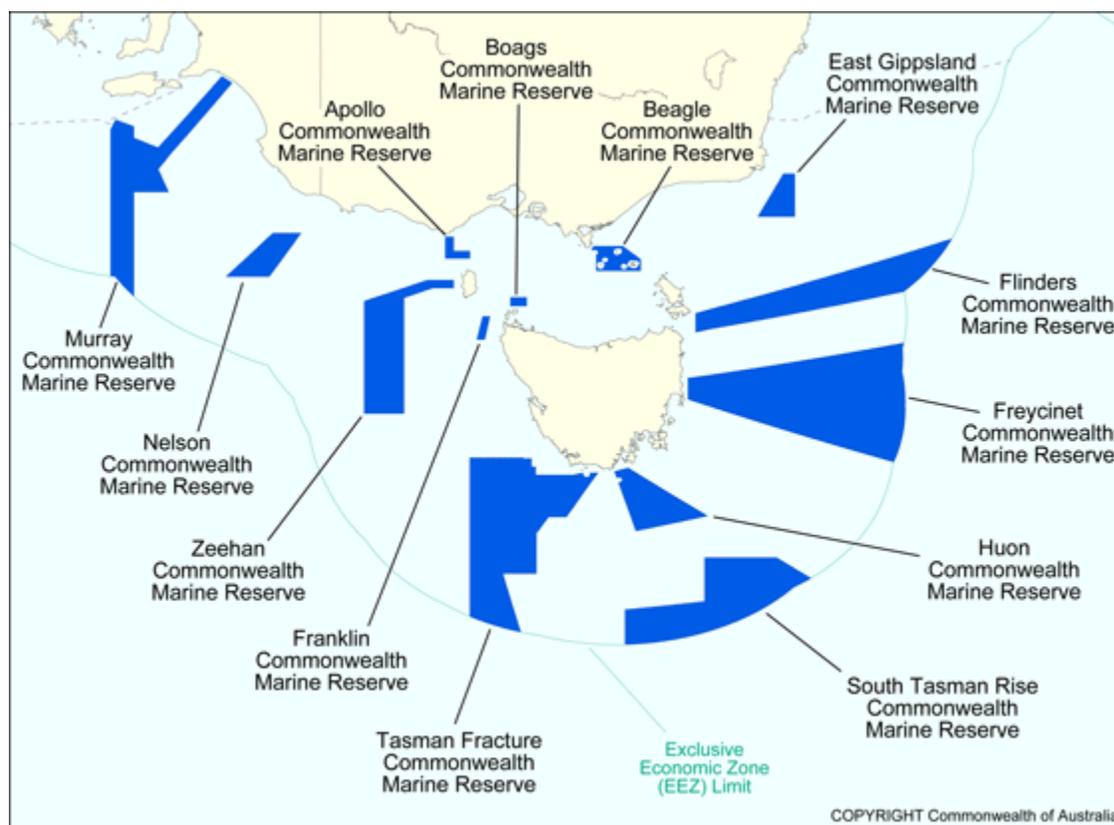


Figure 6. Location and names of individual Reserves within the South-east Commonwealth Reserve Network. Source: DEWHA.

During the work to establish the CMPAs, a nested set of bioregions were used to determine the establishment of representative areas. Geomorphic features were used as surrogates of marine biodiversity (Harris 2007; Harris et al. 2007), a method that was



recently analysed and reviewed by Williams et al. (2009b); this led to a discussion within the scientific literature that contributed to a more detailed understanding of the process of establishment of this first network of CMPAs (Harris et al. 2009; Williams et al. 2009a).

Reviews and plans were undertaken to support the development of a comprehensive ecological monitoring program (Williams 2006). Marine research in the Commonwealth waters of the Region, including the baseline surveys of three of the Reserves (Thresher and Williams 2008), is conducted primarily by CSIRO Marine Research. Other organisations and institutions that are active in the Region include the Australian Antarctic Division, Cooperative Research Centres (CRCs), Geoscience Australia, AQIS, the Bureau of Meteorology, and the Fisheries Research and Development Centre (FRDC). State agencies and organisations also conduct some research in the Commonwealth waters of the Region (National Oceans Office 2002c). Scientific research has been and is currently being conducted in small areas of many of the Reserves. Large areas to the south of Tasmania, including the Huon, Tasman Fracture and South Tasman Rise CMRs, are subject to benthic surveys by CSIRO. Additionally, the South Tasman Rise has been the site for geological studies (Fioretti et al. 2005) and for research into past climatic patterns through sediment cores (Moy et al. 2006).

Much of the Region's seabed has been covered by swath mapping, and detailed bathymetric data exist for many areas (DEWHA 2009a). The difficulty with sampling broad areas of seabed, especially over rough ground and at great depths, means that descriptions of the links between seabed landscape and ecological communities are still in their infancy (Kloser et al. 2001b). Numerous surveys have been undertaken of seabed characteristics and associated fauna, using benthic collection methods, remote video and still cameras, fixed and mobile fishing gears and vertical sounding acoustics (Barker et al. 1999; Bax and Williams 2001). However, the size and depth of large areas of the Region mean that a large amount of research still remains to be done. Species that are new to science or previously unrecorded in Australian waters are discovered with each survey, a phenomenon that is likely to increase as research methodologies make deeper areas more accessible (Barker et al. 1999).

Table 4. Studies conducted during the bioregional planning process for the SEMR.

Study	Conducted by
Production of a consistent, high quality bathymetric data grid for the South-east Marine Region	Geoscience Australia
Seabed characterisation of the South-east Marine Region (including seabed sample data)	Geoscience Australia
Upgrade of computer sediment model (GEOMAT)	Geoscience Australia
Refine broad scale bioregionalisation	CSIRO Marine Research



Study (province and biomes)	Conducted by
Upgrade deepwater nutrient, water properties and ocean current models	CSIRO Marine Research
Rapid assembly of ecological fish data (community composition and distribution) for the South-east Marine Region	CSIRO Marine Research, Museum Victoria, Australian Museum, NSW Fisheries
Rapid assembly of ecological data on key invertebrate groups of the South-east Marine Region	Museum Victoria, Australian Museum, CSIRO Marine Research
Bioregionalisation analysis for the South-east Marine Region: integration of geological, oceanographic and biological data as the basis for bioregionalisation	CSIRO Marine Research, Geoscience Australia

Uses and Threats

The South-east Marine Region is subject to a wide variety of uses, most notably commercial fisheries, petroleum and minerals exploration and development, commercial shipping, nature-based tourism, yachting and recreational fishing, scientific research and defense operations (National Oceans Office 2002c). Most of these activities are well-established and have a long history in this area. The multiple-use nature of the Region's CMRs allows for some extractive activities. Commercial fisheries target a large number of fish and invertebrate species and are collectively known as the South East Fisheries or SEF, comprising:

- Southern and Eastern Scalefish and Shark Fishery, combining:
 - Commonwealth Trawl and Scalefish-Hook sectors
 - Commonwealth Trawl sector
 - Shark Gillnet and Hook sector
- Commonwealth Great Australian Bight trawl sector
- Bass Strait Central Zone Scallop Fishery
- Southern Squid Jig Fishery
- South Tasman Rise Trawl Fishery
- Eastern Tuna and Billfish Fisheries
- Other fisheries including:
 - Eastern Skipjack Fishery
 - Small Plagics Fishery

Only 29.5% of the Region's seabed occurs at depths potentially accessible to demersal longline fishing and trawling. The SEF relies on the highly productive upwelling zones where oceanographic and topographical features interact to bring oceanic plankton and



micronekton to the shelf (National Oceans Office 2002d). Fisheries that target particular species (e.g. the orange roughy fishery) tend to focus on areas known to be preferred habitats for the target species (e.g. the South Tasman Rise) (Anderson and Clark 2003). Trawling primarily targets the soft-sediment habitats of the continental shelf and upper slope (Prince 2001).

The Region accounts for half of Australia's petroleum production (Larcombe et al. 2002). Widespread exploration for oil has occurred in the Region, but oil and gas occurs primarily in the Gippsland Basin, which has been Australia's dominant oil producing area for approximately thirty years. There are 17 fields currently in use, with 22 production facilities, a large fleet of vessels servicing the offshore oil platforms and a substantial submarine petroleum pipeline network of 500 km conveying petroleum products from Bass Strait to the Longford gas plant in Sale (Victoria) for processing and transmission (National Oceans Office 2002d). A number of different petroleum titles exist in the Region, including exploration permits (e.g. seismic surveys and drilling), retention leases (options for future development), and production licenses, allowing commercial exploitation of petroleum reserves (Larcombe et al. 2002). Some of the lease areas fall within the boundaries of CMRS, including Apollo and Huon CMRs, the Multiple Use Zone of Zeehan CMR and Franklin CMR.

Due to the offshore nature of the Region's CMRs, nature-based tourism (e.g. whale watching) and charter fishing tours are the primary forms of tourism. Charter boat operations are concentrated in Victorian coastal towns and cities, north-eastern Tasmania and on the southern coast of New South Wales (Larcombe et al. 2002). Yacht races are also a popular recreational activity in the area, with a number of high-profile races taking place each year (e.g. Sydney to Hobart). Many of these races cross the CMRs.

Most recreational fishing takes place in State Waters of the Region, but increasing numbers of charter fishing operations target areas of upwelling on the continental shelf edge, where aggregations of gamefish occur (primarily tuna and billfish). Offshore recreational fishing usually occurs within 20 nm of the coast. Areas of highest recreational fishing catches are those south of Adelaide, between Portland and Melbourne, and along the southeastern coast of New South Wales. Offshore recreational fishers target both demersal species such as rock lobster, tiger flathead, blue warehou, blue-eyed trevalla, flounder, snapper and demersal sharks, and pelagic species such as squid, tuna, albacore, striped marlin, yellow-tailed kingfish, barracouta, jack mackerel and pelagic sharks.

Defense activities in the Region include the transit of naval vessels, training exercises, ship building and repairs, hydrographic survey work, surveillance and enforcement, and search and rescue. There is a key naval transit route between Fleet Bases East (Garden Island Sydney) and West (HMAS Stirling, Western Australia). Hobart and Melbourne Ports are important international ports for overseas navies.



Threats from the primary human activities in the Region include overexploitation of targeted species, fishing-related changes in ecological communities, pollution, vessel strike of marine megafauna, and specific threats related to petroleum exploration and production activities. Trawling has been found to significantly affect benthic communities on continental shelves and slopes and seamounts. The life histories typical of cool-water organisms means that recovery after disturbance is likely to be slow, and therefore direct impacts to the seabed are likely to persist for longer than in shallower and warmer waters. However, there has been very little research on the effects of trawling specifically in the Region. Many of the Region's species targeted by fisheries are deep-water fish, which are typically long-live and late-maturing, making them extremely vulnerable to depletion.

The threat of pollution from land-based sources, commercial ships and petroleum production infrastructure is higher in this Region than elsewhere in Australia due to the dense population centres on land, the high levels of activity of the oil and gas industry, and the heavy commercial shipping traffic. The future impacts of climate change are difficult to predict here, but there is concern about rising temperatures, changes in ocean currents, species range changes and increased ocean stratification potentially leading to changes in productivity (Lawrence et al. 2007). Pollution can include marine debris and oil pollution. Recreational activities that pose a threat include primarily those likely to affect the Region's megafauna, such as whale watching. A literature review prepared during the planning stages of the Reserve Network categorized and rated all potential threats to the Region (National Oceans Office 2002b).

Climate and Oceanography

The waters in the Region are affected by a number of separate and interacting currents. Surface layers of the ocean are dominated by the southernmost reaches of the East Australian Current and Leeuwin Current to depths of 250 m; middle layers are under the influence of Subantarctic Mode Water (300–600 m), deeper water is affected mostly by Antarctic Intermediate Waters (800–1200 m); and below this are deep waters of various origins with less associated water movement (National Oceans Office 2002d). Surface waters over the continental shelf to the west of Bass Strait and extending to the southern tip of Tasmania are also affected by the Zeehan Current (Baines et al. 1983). In the southern parts of the Region, deeper layers are influenced by Circumpolar Deep Water (Moy et al. 2006). One of Earth's strongest currents, the Antarctic Circumpolar Current, affects the southernmost Reserves in the Region (Lilley et al. 2004). Seasonal changes in the current patterns and topographical features can cause upwellings, forming areas of high productivity and biodiversity, such as the Bonney Upwelling off the coast of South Australia (Butler et al. 2002b).

Geology and Geomorphology

The CMRs in the South-east Marine Region include the continental shelf and slope, abyssal plain, and features such as canyons associated with the slope and the Tasman Rise beyond the shelf. The continental shelf ranges in depth between 40 and 200 m; the 200 m depth contour is generally considered the edge of the shelf or shelf break (National



Oceans Office 2002d). Almost all Reserves include some continental shelf environments (except Nelson CMR, South Tasman Rise CMR and East Gippsland CMR). Reserves in Bass Strait (Apollo, Beagle, Boags and Franklin CMR) are entirely within the shallowest continental shelf habitats of the Region's Commonwealth Waters. The shelf is composed of large expanses of soft-sediment habitats, especially in Bass Strait, with some rocky substrata towards the edge of the shelf (Butler et al. 2002a).

Sediments on the continental shelf derive primarily from terrestrial and biological origins (e.g. sands, gravels, bryozoan sands). Inner-shelf sediments (at depths of ~40m) tend to be less stable, as they are influenced by strong surface waves and currents, while outer shelf sediments (~80m) are more stable (Bax and Williams 2001). Organic matter increases with depth and is higher in finer sediments, such as those found in central Bass Strait. In their mapping of the south-east Australian continental shelf, Bax and Williams (2001) stated that at a scale of tens of kilometres, the seascape can be visualized as a series of massive sediment flats ('soft-grounds') with reefs, bedrock and consolidated sediments ('hard-grounds') appearing as outcrops in dispersed patches. In their study, they found that sediment flats made up 89% of the seabed, with prominent hard-grounds making up only 11%. A subsequent desktop study (Butler et al. 2002a) also found this to be true for Bass Strait. Geological features such as rocky outcrops and canyons are usually associated with the continental slope, but can also occur on the shelf, where they affect hydrodynamics and productivity, and provide habitat for sessile fauna.

The continental slope has the greatest depth range and structural complexity, extending from 120-200m at the shelf's edge to below 3,000 m at the base of the slope. It is the only major substrate zone that includes significant areas of rocky substrate habitats and can therefore support much more diverse assemblages than soft-sediment habitats. Limestone, sandstone, and biologically derived (e.g. from bryozoans) substrata are the primary hard substrates in the Region (Bax and Williams 2001). Seamounts are especially prevalent south of Tasmania. For instance, the Tasmanian Seamounts Marine Reserve encloses a cluster of volcanic cinder cones in about 1,000-2,000 m depth on the mid-continental slope off southern Tasmania, approximately 170 kilometres south of Hobart (Williams 2006). Seamounts can be hotspots of both benthic and pelagic productivity and biodiversity.

The abyssal plain includes all areas from the base of the slope (generally deeper than 3,000 m) to the edge of the EEZ. The soft sediment habitat characteristic of the lower continental slope and abyss are by far the most extensive in the ocean, constituting 90% the global deep-sea floor. Recent deep sea-floor research in Australia has revealed a topography more complex than previously imagined (National Oceans Office 2002d). Very little is known about the ecological communities of the abyssal plains.

The deep mid-continental slope of the South Tasman Rise ranges from 1,200 to 3,000 m in depth, and supports a variety of unique ecosystems. The South Tasman Rise itself is a submerged ridge of continental rock of approximately 200,000 km², representing the last remnant of the link between Australia and Antarctica, which existed approximately 160



million years ago. The South Tasman Rise contains several volcanic seamounts, some of which have flat summits, indicating a period of exposure above the surface at some time (National Oceans Office 2002d).

Ecology

Benthic communities within this CMR Network are influenced largely by light intensity, the availability of suitable substratum for settlement and by the availability of food. Light penetration has a strong effect on the types of organisms able to proliferate. In shallower and / or clearer waters, algae and seagrasses are the dominant benthic structures, while in deeper and / or more turbid environments, the habitats are dominated by invertebrates (e.g. sponges, bryozoans, deep-water corals)(National Oceans Office 2002a). Very few studies have directly explored the ecological characteristics of the Region.

Benthic communities and invertebrates

Benthic fauna has been well-studied in some sections of the Region (e.g. shallower continental shelf areas), while other sections remain poorly understood (Beaman et al. 2005). For instance, the shallow parts of both the Tasman Fracture and Huon CMRs contain the most extensive stands of giant kelp (*Macrocystis pyrifera*) in Australia. Biogeographically, species richness tends to decline with increasing latitude, irrespective of substrate type. The development of benthic communities in the south-east is thought to be a combination of tropical immigrants, some endemic speciation, and historic factors related to the northward drift of the Australian continent (O'Hara and Poore 2000).

Bax and Williams (2001) undertook extensive benthic surveys in order to characterise the seafloor composition and associated biological communities. Butler et al. (2002a) reviewed all previous studies targeting sponge beds in Bass Strait. Benthic communities included encrusting, erect, branching, finger, plate, cup, bushy and fronded sponges, seaweeds (*Primnoella australasiae*), sea fans, stalked crinoids, bryozoans, ascidians (*Polycarpa* spp.), burrowing worms, seastars, sea urchins (*Phormosoma* spp.) and whelks (Bax et al. 2001). Benthic communities ranged from sparse (< 5% cover) to very dense (almost 100% cover), and some invertebrates present in high density on the continental shelf have high commercial fisheries value (e.g. scallops, Australian giant crab). Subsequent studies investigated the relationship between the underlying geology and the benthic communities in the area of the East Gippsland CMR, finding distinct faunal assemblages associated with geological features such as granite outcrops and unconsolidated sediments in different settings (Beaman et al. 2005).

The most frequently studied habitats beyond the continental shelf are the seamounts, where the topography, the availability of hard substratum and the often complex water movement sustain a rich and highly diverse fauna. There is evidence that shallower areas and seamounts of the South Tasman Rise CMR (500 to 1,000 m) are composed of massive colonies of the deep-water coral *Solenosmilia variabilis* (Koslow et al. 2001; Anderson and Clark 2003), which form habitat for a large variety of other invertebrates (e.g. black corals, ophiuroids, gorgonians) (O'Hara et al. 2008) and for a diverse assemblage of fishes, including the commercially valuable orange roughy. Seamount



fauna is renowned for high species richness and endemism, and a high incidence of rare species (Williams 2006). For instance, seamounts of the Tasman Seamounts Marine Reserve showed little faunal overlap with seamount faunas in New Caledonian waters (de Forges et al. 2000). Recent research questions the role of seamounts as endemism hotspots after more thorough taxonomic studies on seamounts of the south-west Pacific revealed lower proportions of endemism (O'Hara et al. 2008). Research in the deeper waters of these seamounts and other South-east CMRs is ongoing (Williams 2006; Thresher and Williams 2008).

Very little is known about the communities associated with the abyssal depths, with only few and relatively recent studies around the globe targeting broad groups of organisms (Glover et al. 2001; Brandt et al. 2005). The deep sea-floor (at depths below 3,000 m) is covered in a dense layer of flocculent organic matter, much of which is phytodetritus or 'marine snow' that falls from shallower waters, and which is available to deep-sea grazing organisms (Beaulieu and Smith 1998). Typically, the deep sea-floor is composed of fine sediments, and benthic fauna tends to be found inside the sediments, emerging to feed on the marine snow (Glover and Smith 2003). More complex substratum features tend to be preferred by many species, as they provide better anchorage points, vertical relief and a greater variety of food and prey items (Bax et al. 2001). The deep habitats of the Region are therefore likely to be characterized by large expanses of 'desert' punctuated by 'island habitats' of high productivity, density and diversity (National Oceans Office 2002a). The grazers, suspension feeders, scavengers and predators of the abyssal seafloor are usually holothurians, brittle stars, seastars, sponges, anemones, pycnogonids (sea spiders), decapods and other crustaceans, mollusks and tunicates (Bett et al. 2001; Billett et al. 2001). Deep-sea benthic communities have been thought to be temporally stable in the past, due to the relative stability of the physical habitat (Glover and Smith 2003). Recent studies, however, have found temporal variability in these communities, related to both long-term climate change and short-term variation in the availability of phytodetritus or 'marine snow' (Cronin and Raymo 1997; Billett et al. 2001).

Fish

The large diversity of habitats available in the Region support diverse fish assemblages, encompassing between 550 and 600 species (National Oceans Office 2002d), adapted to particular characteristics of the habitat. Approximately 85% of these species are endemic to the Region. Distinct fish assemblages are found in different depth strata, and different biogeographic provinces, associated with the major water masses influenced by the currents of the region and the resulting patterns in productivity. Larvae, juveniles and adults undertake daily or seasonal vertical migrations between water masses (National Oceans Office 2002d). Fish fauna generally differ between depth strata characteristic of the shelf edge (300-400m), upper slope (400-700m) and middle slope (700-1,200m). Biogeographic differences between demersal, continental slope fish communities may decrease with depth (Koslow et al. 1994), suggesting that shallower areas are more important for the protection of endemic or biogeographically distinct species and assemblages. Topographical features of the seabed also play a major role in influencing



the distribution and abundance patterns of fishes (Koslow et al. 1994). Fish communities also vary seasonally, primarily with food availability and reproductive cycles. Many of the fish species dwelling in deeper waters are long-lived with relatively low reproductive rates, and form large aggregations to spawn (National Oceans Office 2002d).

There is some evidence that the larvae and juveniles of a number of fish species may aggregate around phytoplankton blooms or complex benthic habitats, which offer both food and shelter (Prince 2001). A number of shark species frequent the Region, many of which are listed as vulnerable and protected. The most significant of these are the great white shark, the eastern population of the grey nurse shark and the whale shark. Great white sharks occur in the Region at all stages of their life cycle, but there is evidence to suggest that pupping grounds may exist off the Coorong bioregion off South Australia, and off Portland and ninety Mile Beach (Commonwealth of Australia 2002d). A public database of shark sightings is maintained for South Australian waters (PIRSA 2010). The Region is also home to populations of commercially important demersal sharks, such as the school shark, gummy shark and gulper shark. Some of these sharks are wide-ranging pelagic species (e.g. the great white shark and whale shark) while others have more limited distributions (e.g. school shark, Lucifora et al. 2006). Shark fauna endemic to the Region include a number of deep-sea species (e.g. dogfishes) that are relatively rare, long-lived and therefore highly vulnerable to overexploitation (National Oceans Office 2002d). Some sharks undertake extensive daily vertical migrations of 600 m or more (Prince 2001).

Seabirds

Among seabirds, penguins are the most easily tracked due to the relative ease of attaching tracking technology to individuals, and therefore most data on seabird feeding behaviour comes from penguins (Croll et al. 1998). The biology of some of the seabird species found in the Region are well-studied, such as the short-tailed shearwater (*Puffinus tenuirostris*), while others are poorly known. The general distribution and foraging and breeding ecology of most species is not well understood. The non-plankton-eating seabird species, such as the little penguin (*Eudyptula minor*), generally feed on small fish. The little penguin is widespread across the Region, with breeding colonies primarily on Bass Strait Islands (National Oceans Office 2002d). Australasian gannets breed in colonies at Lawrence Rocks, Port Danger, Port Phillip Bay, off the southern coast of Victoria, and a number of sites off the coast of Tasmania. They are a conspicuous marine predator, feeding primarily on pilchards and other small inshore pelagic fish and squid species. Recent increases in Australasian gannet populations have been attributed to warmer sea surface temperatures in Bass Strait and larger volumes of discarded pilchards by the South East Fishery (Bunce et al. 2002).

Marine mammals

As most of the Reserves in the Region protect large areas with oceanographic and topographical features that promote productivity, marine mammal foraging grounds occur in many of these areas. The Region supports some of the largest colonies of pinnipeds in Australia, with nine out of the ten Australian species represented (National Oceans Office



2002d). Many species of cetacean frequent the Region either permanently or temporarily, with 34 species having been recorded. The Bonney Upwelling, an area of high productivity partially protected by the Nelson CMR, is one of only 13 known aggregation sites for blue whales worldwide (Gill et al. 2005). Satellite tracking and aerial surveys are the two methods by which this aggregation is currently studied.

In deep sub-antarctic waters, vertical zonation of pelagic fauna is very strong, correlating with physical (temperature, salinity, light) gradients in the water column. Very little is known about these assemblages in the South-east Marine Region; studies exist for sub-antarctic communities of South Africa and South America, conducted primarily for the Southern Ocean fishing industries (Morley et al. 2006). It is likely that species lists produced by such studies could be applied to relevant areas in the Region, as many Southern Ocean species have circumglobal distributions (McDowall 2000). Key habitats for these species in the Region are likely to be south of Tasmania (e.g. Tasman Fracture, South Tasman Rise and Huon CMRs), with incursions further north for some species with wider temperature tolerance ranges.

Fisheries Research

Fish communities in the Region have been sampled primarily as stock assessments for the South East Fishery (SEF), or assessments of bycatch (Anderson and Clark 2003). Bruce et al (2002) compiled a literature review based on fisheries research in the Region. A study that used a wide variety of methods and sampling gears characterized fish species groups based on diet and morphology. A different study of the demersal fish community on the continental slope (800 – 1,200 m depth) across the whole Region found a total of 111 species of fish, belonging to 37 families (Koslow et al. 1994). The dominant species caught in this survey was the orange roughy (*Hoplostethus atlanticus*), which made up 23% of the catch in weight. The most abundant families (96% by weight) were the roughies (Trachichthyidae), sharks (Squalidae), oreos (Oreosomatidae), rattails (Macrouridae), cut-throat eels (Synphobranchidae), slickheads (Alepocephalidae) and deep-sea cods (Moridae) (Bulman et al. 2002). Biomass declined with depth for most families, while density declined for some species but increased for others. Catch rates were higher on the continental slope around Tasmania than along the Great Australian Bight sampling locations, suggesting that Reserves surrounding Tasmania and Bass Strait (Flinders, Freycinet, Huon, Tasman Fracture and Zeehan CMRs) may protect greater densities of demersal fishes on the continental slope than those further west (primarily Murray CMR). Overall, the fish community on the mid-slope of southeastern Australia was found to be distinct from Northern Hemisphere surveys at similar depths, indicating a unique fish community in the Region (Koslow et al. 1994). More recently, tagging programs and mapping surveys are used to ascertain the extent of potential habitat for valuable species, and for species of conservation significance such as the gulper shark (Williams 2008).

Gaps and Recommendations

The vast geographic extent of the Reserve Network means that designing a research and monitoring strategy to adequately encompass its important features will be challenging.



However, these are challenges that will be faced by all Reserve Networks, and the South-east has the opportunity to set a useful blueprint for research and monitoring programs in the other Networks. Initial surveys specifically aimed at setting a baseline for monitoring in deeper waters have been initiated, and a set of indicators has been proposed (Williams 2006). Numerous literature reviews have identified knowledge gaps for each discipline throughout the Region. Ideally, the next step would involve designing a set of indicators specific to each Reserve in the Network, with characteristics that include biophysical, economic or social/cultural uniqueness or importance and cost-effectiveness. For example, there are still gaps in the knowledge of the ecology and biology of many species, even key species of commercial value to fisheries, and it is unrealistic to expect research and monitoring programs to capture all this information for each species. It may be more useful for the management of the Network to identify key taxonomic or functional groups to represent each Reserve, chosen both for their importance to the ecosystem and for their ease of recording. Recommendations include:

- Map habitats for each CMR and oceanographic features within and between CMRs,
- Prepare of definitive species list for each CMR,
- List key ecological, geophysical and oceanographic features or indicators for each Reserve that would either benefit from more research, or that would provide useful monitoring data to measure changes in Reserve condition over time,
- Study movement patterns of currents, larvae and important species within and between Reserves and outside Reserves to improve understanding of patterns of dispersal and connectivity within the Network, and
- Build ecological models that incorporate geological features, geomorphological and oceanographic processes with ecological attributes and processes and trophic pathways.



EXTERNAL ISLAND TERRITORIES

HEARD ISLAND AND McDONALD ISLANDS MARINE RESERVE

The Australian Territory of Heard Island and McDonald Islands, protected within the Heard Island and McDonald Islands Marine Reserve (HIMI), is an external territory of Australia in the Indian Ocean sector of the Southern Ocean. This extremely remote and isolated island group is subject to the storms and currents characteristic of the intersections of Antarctic and temperate ocean waters. Heard Island, the primary island of the HIMI, is dominated by Mawson Peak, an active volcano topped by snow and ice. McDonald Island and the associated Flat Island and Meyer Rock lie 43.5 km west of Heard Island, and are also formed from volcanic origins. The HIMI contains unique and undisturbed examples of subantarctic species and communities. A dedicated program of research and monitoring has existed in the HIMI and the surrounding marine environment for many years, managed by the Australian Antarctic Division (AAD). The AAD is developing a strategic monitoring approach for all Australia's subantarctic marine protected areas—the HIMI Marine Reserve and the Macquarie Island Marine Park (see below) – to guide research and monitoring activities to provide information on the health of the marine protected areas and the effectiveness of management actions.

An informative website is maintained to document the research undertaken in this Reserve (AAD 2005). Research is classified as being either specifically produced for the Reserve's management requirements, or it is conducted because it represents science that cannot be undertaken elsewhere. Particular emphasis is given to research that can contribute to understanding the impacts of climate change on biodiversity, but a number of different terrestrial and marine studies are supported. A brief summary is given in Table 5 (below) for each category.

Examples of research and monitoring that are specifically useful for management include recording the number of vessels and people visiting the Reserve, determining the impact of human activities through the presence of facilities, equipment, sampling sites or spills sites, and recording wildlife deaths resulting from collisions with vessels, guy wires or scientific studies (AAD 2005). Monitoring the health of the Reserve results in annual 'State of the Park' reports.



Table 5. Classification of types of research undertaken in the Heard Island and McDonald Islands Marine Reserve (from (AAD 2005))

Terrestrial Research	Marine Research
Vegetation mapping	Physical and biological oceanography
Glaciology	Fish and invertebrates
Cultural heritage	Marine geology
Terrestrial ecology	
Seabird populations	
Marine ecosystem	

Uses and Threats

Commercial fishing, surveillance activities, scientific research and tourism are the primary human activities taking place in the HIMI. While it occurs in the HIMI's EEZ, commercial fishing is prohibited in the Reserve. Commercial operations target primarily mackerel icefish and Patagonian toothfish. The fishery is strictly managed under the guidelines set out by the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). Fishery-related research occurs in the Reserve under strict permit conditions. Tourism occurs in the form of expeditions of private scientific groups and mountaineering parties. This is limited by the frequent severe weather surrounding the HIMI and its remoteness. Surveillance activities are primarily limited to fisheries issues (AAD 2005).

The sustainability of the catch of both target and non-target species is subject to scientific research; however, overfishing remains a threat to the ecosystem of the HIMI (Ainley and Blight 2009). Illegal fishing is thought to occur outside the Reserve, but within the HIMI EEZ, and may put added pressure on fish stocks. Pressure on terrestrial habitats from scientific research and tourism is likely to be minimal (AAD 2005). Increasing glacier retreat, continuing temperature rise, changes in food web structure and altered feeding and migration patterns of megafauna are primary concerns for the future (Lawrence et al. 2007).

Terrestrial Research

Apart from research falling within the categories listed above (Table 5), Heard Island has been the site of collection of meteorological data since 1948 (Beggs et al. 2004), and geophysical studies of magnetic fields since 1947 (Hitchman 1988). Meteorological data collection was regular between 1948 and 1954, and again after 1992. Weather stations were set up by the Australian National Antarctic Research Expedition (ANARE) and the Australian Bureau of Meteorology. Local topography is known to affect local climate significantly; winds from the south are deflected by the highest peak (Big Ben), while westerly winds are influenced by Laurens Peninsula. Findings from research conducted over the 2000/2001 summer, with the aim of characterising local winds on the eastern end of Heard Island, found significant topographically-generated differences in wind characteristics between the eastern and western ends of the island (Beggs et al. 2004).



Vegetation mapping

The extent, health and species composition of terrestrial vegetation are important indicators of environmental change. The mapping of vegetation on Heard Island has been undertaken over 30 years, in order to provide information on the temporal dynamics of different types of vegetation cover. The study involves the use of aerial photographs, on-ground photo-monitoring, GPS surveys and the study of satellite images from the years 1980, 1986/87, 1987/88, 2000/01 and 2003/04. Further studies include patterns of colonisation and expansion, floristic affinities with other regions and genetic studies (Skotnicki et al. 2004; Bergstrom et al. 2006; van der Putten et al. 2010).

Six vegetation communities were identified on Heard Island: open cushion carpet, mossy fieldmark, wet mixed herbfield, coastal biotic vegetation, saltspray vegetation, and closed cushion carpet (Bergstrom et al. 2002). These vegetation communities were found to be arranged along a continuum, rather than in clearly delineated zones, and were affected in their distribution by altitude, wind, peat depth, bryophyte cover, extent of bare ground and sediment particle size. Further agents of plant expansion were found to be of biological origin, such as seal disturbance (Scott and Kirkpatrick 2005). The HIMI hosts a reduced vegetation species richness in comparison to other subantarctic islands, such as those north of the Antarctic Polar Front Zone, due to the small size of the island (Bergstrom et al. 2002). Climate change is expected to change the distribution, and perhaps even the species composition, of plants on the island (Frenot et al. 2005).

The flora of Heard Island was found to be characteristic and unique (van de Vijver et al. 2004), with numerous endemic species. Plants are believed to have colonized the island at the onset of accumulation of post-glacial organic sediment, when ice cover was incomplete and ice-free biological refugia were probably present even on the most glaciated islands (van der Putten et al. 2010). Dispersal is likely to be by sea or on animal hosts, but only adapted species are likely to survive and establish viable populations (Turner et al. 2006). Derelict buildings are providing opportunities to study colonization and succession *in situ* (Whinam et al. 2004), and it is suggested that the process of colonization is facilitated by symbiotic fungi (Frenot et al. 2005). Genetic studies on a species of moss found that there were high degrees of genetic diversity in populations of Heard Island (Skotnicki et al. 2004).

Glaciology

Glaciers cover approximately 70% of Heard Island. One of the primary indicators of climate change is the retreat of glaciers, and their extensive presence on Heard Island provides the opportunity for close study of this phenomenon (Thost and Truffer 2008). Glaciology is also at the core of the geomorphology of the HIMI, which was described in detail by Kiernan and McConnell (1999). The islands were formed through a combination of volcanism, glaciations and the actions of a marine environment that probably experiences some of the stormiest maritime weather on Earth. The inaccessibility of the islands has resulted in temporal gaps in glacier studies, which were addressed in the summers of 2000/01 and 2003/04. This research focused on the Brown



Glacier, a relatively small glacier with a comparatively simple geometry, on the north-eastern coast of the island (Thost and Truffer 2008). As one of the glaciers terminating on land, it is expected to be more sensitive to long-term changes in climate. The main focus of this study is the Brown Glacier's 'mass balance', or the difference between the input of snow and output of melt water, which will indicate whether the glacier is shrinking or 'retreating' (AAD 2005).

The general consensus is that since observations began in 1947, glacier retreat has been widespread (Thost and Truffer 2008). The overall retreat of Brown Glacier was calculated as a decline in the area covered in ice of 29%, and a loss in volume of approximately 38%. The mass loss corresponds with limited temperature observations in the area that indicate a +0.9° C warming over the same period. The ice loss is reported to be accelerating, with the area lost between 2000 and 2003 doubling the previous 57-year average (Thost and Truffer 2008).

Cultural heritage

Research into Heard Island's cultural heritage is primarily focused on sealing activities in the 19th century. This includes studies of written work of early sealers and expedition members, and the cataloguing and mapping of relics such as shards of pottery, ruins of huts and the foundations of cobble stone houses. A significant discovery was a sealers' cemetery on the vegetated slopes overlooking Doppler Hill, and a seal processing facility on Sealers Beach (AAD 2005). Budd (2007) described in detail the activities and contributions of expeditions to Heard Island between 1947 and 1971.

Terrestrial ecology

Apart from vegetation mapping, Heard Island's terrestrial ecology is the subject of numerous research projects, especially terrestrial invertebrates (Chown and Klok 2001; Marshall and Chown 2002). The island's isolation provides a rare opportunity to detect environmental change and its effects on a largely undisturbed wilderness. Heard Island is one of the locations used by an international Scientific Committee on Antarctic Research (SCAR) program to study the effects of climate change on Antarctic and subantarctic ecosystems - RiSCC (Regional Sensitivity to Climate Change in Antarctic Terrestrial and Limnetic Ecosystems). A research team is working on three island to determine the effects of climate change of species' performance and ecosystem structure, of which Heard Island is the most southern (AAD 2005). The other islands are the Îles Kerguelen (France) and Marion Island (South Africa).

The natural temperature ranges of the three islands (Îles Kerguelen is 2° C warmer than Heard Island, and Marion Island is 2° C warmer than Îles Kerguelen) allows for the investigation and modeling of possible responses of ecosystems to climate change, especially on the cooler islands. Primary aspects to this research include the structure and functioning of vascular plant species at different altitudes, the carbon uptake and loss of a common plant species and effects on its growth, and insect collections from a range of locations and altitudes (AAD 2005). As with plants, the terrestrial invertebrate fauna of



Heard Island has been found to be relatively depauperate, most probably due to the island's small size and considerable degree of glaciation (Marshall and Chown 2002).

Weevils have been at the centre of research searching for patterns of association between body size, temperature, resource limitation, seasonality and latitude (Chown and Klok 2003). It was found that on the relatively aseasonal Marion Island, body size increases with altitude, whereas on the more seasonal Heard Island the opposite was observed.

The remoteness of Heard Island also makes it ideal for studies into the impacts of biological invasions, which have a synergistic relationship with other human impacts. These species can have profound effects on ecosystem structure and function and are capable of influencing landscape values (Greenslade 2002). A warming climate increases the likelihood of exotic species establishing successful breeding populations (Greenslade 2002). Chown et al. (2005) explored the issue of invasive species on a range of Southern Ocean islands, including Heard Island. They found positive relationships between indigenous and exotic species richness at local scales across the Southern Ocean Islands. Exotic and indigenous plant and insect species richness was found to co-vary with energy availability and human visitor frequency.

Studies on the McDonald Islands are highly infrequent compared with Heard Island. These islands lie to the west of Heard Island on the Kerguelen Plateau. After they were discovered in 1854, they were investigated in 1874, 1971 and 1980 (Stephenson et al. 2005). More intensive study was prompted by a volcanic eruption, signs of which were detected around 1992 on Heard Island. Changes in the shape, size and ecological characteristics of the islands were documented through aerial and ship-based photography. The greatest changes observed were in the availability of habitat for colonies of macaroni and king penguins (Stephenson et al. 2005).

Seabird populations

Seabirds breeding on Heard Island have been the subject of studies since at least 1947. More recently, the locations of breeding sites and breeding populations have been mapped digitally and are subject to regular population counts. Seabirds are considered useful indicators of the state of the marine environment; providing signals on food availability and changes in the physical environment (AAD 2005).

Long-term research has documented changes in the locations of some nests and colonies and in the size of some breeding populations. This is thought to be related to changes in glacier position and extent. There is evidence that some species, such as king penguins and black-browed albatross, are increasing in number, potentially signaling a recovery from past exploitation or an increased availability of resources (Woehler et al. 2002). Other species, such as macaroni, rockhopper and gentoo penguins may be in decline, but there is uncertainty surrounding the rates and extent of decreases (AAD 2005). Foraging behavior of penguins has been found to vary seasonally, with associated changes in diet (Moore et al. 1999). Oceanographic and bathymetric factors also affect the foraging distance, diving depth and diet composition of penguins (Wienecke and Robertson 2006).



One of the major sources of anthropogenic mortality for seabirds is incidental mortality from fisheries (Wienecke and Robertson 2002; Lawton et al. 2008). Albatrosses are most vulnerable to this and tagging studies have found that it is illegal, unreported and unregulated fishing that poses the greatest threat (Lawton et al. 2008).

Marine ecosystem

Waters surrounding the Reserve support commercial fisheries (particularly the Heard Island and McDonalds Islands Fishery for Patagonian toothfish and mackerel icefish), potentially affecting ecological processes and food webs inside the Reserve. Historically, it was found that intensive fishing had depleted most of the fish stocks (Kock and Everson 2003), with a concomitant reduction in food for predators such as marine mammals and seabirds (Ainley and Blight 2009). This has led to studies specifically seeking to understand marine food webs and associated processes. Studies include the life histories of fisheries target species (Patagonian toothfish and mackerel icefish) (Kock and Everson 2003), predators feeding on those species (Green et al. 1998), and the distributions of both the fish and their predators. A comprehensive 'ecosystem-scale' study, involving concurrent terrestrial and marine research, was initiated in 2003/04. This study included tagging programs, dietary studies and genetic techniques (Gales and Constable 2004). Dietary studies on pinnipeds concluded that Antarctic fur seals fed on a variety of prey, rather than just mackerel icefish (Casper et al. 2007). Southern elephant seals are important top predators in this system, consuming primarily cephalopods (Field et al. 2007a).

The main predators in the tagging study included macaroni penguins (numbering in the millions), king penguins (numbering in the tens of thousands) and Antarctic fur seals (numbering in the thousands). Also tagged were black-browed albatross and light-mantled sooty albatross to establish the level of risk posed by the fisheries to the birds. Software was developed specifically to analyse the resulting tracks (HeardMap, Frydman and Gales 2007). The tagging data were combined with acoustic echo sounders (Buelens et al. 2009), ship-based trawls, remote temperature and other physical data (Gales and Constable 2004).

Tagging and other studies are helping to shed light on the population dynamics of protected marine mammals and seabirds, especially where populations were depleted in the past. For instance, the southern elephant seal experienced large population declines throughout its Southern Ocean breeding range from the 1950s to the 1990s (McMahon et al. 2005). Some populations have increased, but those on Heard Island have remained stable (Slip and Burton 1999), while those of Macquarie Island have continued to decline. The most likely causes are thought to be competition for resources with other species and recent environmental changes (McMahon et al. 2005) such as changes in the extent of sea ice (Slip and Burton 1999). On the other hand, populations of Antarctic fur seals have been increasing steadily since overexploitation ceased (Page et al. 2003).



Emerging results on the target fish themselves include the finding that the Heard Island population of mackerel icefish is a separate genetic stock from the sampled Atlantic and South Shetland Islands populations (Kuhn and Gaffney 2006). There is also restricted gene flow between Southern Ocean populations of the Patagonian toothfish, as this species is largely sedentary (Appleyard et al. 2002).

Marine Research

The primary directions of marine research around Heard Island have investigated physical and biological oceanography, fish and invertebrate populations and marine geology. Most of the current data were collected on a multidisciplinary voyage in the summer of 2003/2004, code-named HIPPIES.

Much of the ecology of these oceanic islands is influenced by the surrounding oceanography. Prevailing currents drive the patterns in productivity and the distribution of marine biota (such as plankton, invertebrates and fish). Oceanographic research aims primarily to understand the drivers of productivity in the area. A range of techniques were used to describe the principal oceanographic features, such as currents, fronts and eddies, together with their inherent variability and their influence on the distribution of primary productivity (AAD 2005). Fish and invertebrates in the Reserve were first subjected to in-depth study through a series of research trawls. Both midwater trawl nets and plankton nets were employed down to depths of 600 m (AAD 2005). The primary geological research program was initiated during HIPPIES. The study involved grab sampling to investigate the nature of the marine sediments surrounding the island. Sediments closer to the island were largely of volcanic origin, while those further away had greater proportions of shell material consisting of bivalves, barnacles, gastropods, corals and worm tubes (AAD 2005).

Gaps and Recommendations

The HIMI benefits from a comprehensive and targeted program that combines multidisciplinary research with records of historic research and data. Terrestrial research has ensured that there is a good understanding of Heard Island's terrestrial habitats and ecosystem, including how they have changed over time and their relationship with terrestrial ecosystems of other Southern Ocean islands. The terrestrial habitats of other islands in the HIMI are less well-known and would benefit from further research.

The marine environment of the HIMI has also been subject to research expeditions, but much of these data remain unpublished and difficult to access. Marine ecosystem studies have had a strong fisheries-related focus or have included mostly seabirds and pinnipeds. Studies on fish and invertebrates, oceanography, patterns of productivity and marine geology remain to be presented in a form that is easily accessible. Recommendations include:

- Continue systematic vegetation monitoring and mapping on Heard Island,
- Continue climate-related studies on terrestrial invertebrates on Heard Island,



- Design a comprehensive monitoring program for Heard Island’s marine ecosystems, including flora and fauna, key taxonomic and functional groups, current movements and patterns of productivity, and
- Map the HIMI’s seafloor characteristics to determine areas for further deep-water benthic sampling, using remote techniques.

MACQUARIE ISLAND COMMONWEALTH MARINE RESERVE

The Macquarie Island Commonwealth Marine Reserve (Macquarie Island) is located in the Southern Ocean, 1,500 km south east of Tasmania. This Reserve lies adjacent to the Macquarie Island Nature Reserve, which is managed by the Tasmanian Government and includes Macquarie Island itself, Judge and Clerk Islets and Bishop and Clerk Islets. Macquarie Island Commonwealth Marine Reserve covers approximately 16.2 million hectares, and includes a large portion of the submerged Macquarie Ridge, which stretches north-south through the centre of the Region. The Ridge interacts with the strong oceanic fronts to create several distinct oceanographic sections within the Region. It acts as a barrier to the Antarctic Circumpolar Current, which flows eastward around Antarctica and is a key driver for the southern hemisphere’s climate.

Due to its status as a Biosphere Reserve and a World Heritage Area, Macquarie Island has a dedicated research program run by the AAD. Research began there in 1820, and voyages conducted by the AAD have produced a large amount of oceanographic, geological and ecological information. Macquarie Island provides a base from which to launch research activities (Commonwealth of Australia 2001b). Multidisciplinary investigations have also been instigated by both Australian and New Zealand research teams (Rowden 2008).

In 1999, a cooperative research cruise was undertaken by the CSIRO, the FRDC, DEWHA and the fishing industry along the Macquarie Ridge. This research related to the Patagonian toothfish fishery and the benthic and pelagic fauna associated with the Macquarie Ridge. The study was carried out using a deep-water video system, trawling, acoustic soundings and an epibenthic sled. The cruise report, “*A Study of the Conservation Significance of the Benthic Fauna around Macquarie Island and the Potential Impact of the Patagonian Toothfish Trawl Fishery* (Butler et al. 2000),” has made an important contribution to furthering knowledge and understanding of the pelagic and benthic habitats of the Reserve.

Uses and Threats

The primary uses of the Commonwealth waters of the Reserve are commercial fishing and scientific research. The main fishery in the Reserve is for Patagonian toothfish and began in the late nineties. Some of the research in the Reserve is associated specifically with this fishery. The unique characteristics of the Macquarie Ridge have led to a large amount of research in the area, including multidisciplinary research cruises in the Commonwealth waters (Commonwealth of Australia 2001b).



Impacts associated with trawling are probably the greatest threat to the Commonwealth waters of the Reserve. Ghostfishing (the continued capture of marine organisms by lost or discarded fishing gear) longlining and trawling gear can pose a threat to larger animals in this environment. Fisheries can also effectively remove the food sources of marine mammals and seabirds, thereby affecting the values of the Reserve. Research activities targeting marine mammals and seabirds may alter the behavior of animals (Commonwealth of Australia 2001b). Climate change predictions for this area include changes in ocean circulation and productivity, rising sea temperatures and increased storm activity (Lawrence et al. 2007).

Climate and Oceanography

Benthic survey data suggests that the Reserve lies in a transition zone, with many species located at the southern or northern limit of their range (Butler et al. 2000). The major current flowing through the Reserve, the Antarctic Circumpolar Current, effectively divides the region into three main water bodies with two oceanic fronts. The interaction between the current and the Macquarie Ridge further divides the region into six different large-scale oceanic habitats (Commonwealth of Australia 2001b). The Antarctic Circumpolar Current is funnelled through gaps in the Macquarie Ridge, and one of these gaps is postulated as being the location of the Subantarctic Front (Rowden 2008). Variations in depth, currents, nutrient levels, wave activity and temperature affect the distribution and composition of benthic communities.

Geology and Geomorphology

Macquarie Island is 150 km² of exposed oceanic crust on the Macquarie Ridge, coinciding with the plate margin between the Indo-Australian and Pacific oceanic plates (Rowden 2008). The island is the only sub-aerial exposure of oceanic crust within an ocean basin on Earth, including all levels down to the mantle lithosphere. It therefore presents a unique opportunity to study oceanic crust that has not been affected by abduction and is still within its oceanic basin context (Goscombe and Everard 2001). The spreading centre of the Macquarie Ridge was formed through the rifting between the Resolution Ridge and Campbell Plateau approximately 40 million years ago (Commonwealth of Australia 2001b).

The island was systematically mapped at scales of 1:5,000 and 1:10,000 for the first time during 1994 and 1996. Previous work included the mapping of broad rock type distribution, and petrological, geochemical and geochronological studies. The first structural analysis of Macquarie Island was completed by Goscombe and Everard (2001), who discussed the structural and intrusive history on Macquarie Island and reconstructed the tectonic evolution of the region. Spreading-related volcanism ceased approximately 6 million years ago. Mosher and Symons (2008) explored and described the rotation and change in spreading direction that occurred during spreading, effectively changing the spreading centre into a transform plate boundary.



The structure of the substrate within the Macquarie Commonwealth Reserve is mostly unstable, deep and often very steep volcanic slopes and sediments in deep valley floors, resulting in a relatively barren seabed with sparse benthic fauna of mixed biogeographic origins. Recent research used a latitudinal transect of cores within the Reserve to investigate the temporal dynamics in biological productivity, shifts in the Antarctic Circumpolar Current, the relationship between the Current and the area's topography, distribution of microfossils, water chemistry and the influence of anthropogenic increases in CO₂ (Rowden 2008).

Ecology

Seamounts of the Macquarie Ridge offer a unique opportunity to study seamount ecology, and to investigate patterns of biogeography in general (Rowden 2008). Seamount ecology focuses on a number of central questions, including their role as stepping-stones for the dispersal of biota, the degree of speciation as a result of isolation and their potential as biodiversity and productivity 'hotspots' (de Forges et al. 2000; O'Hara et al. 2008). Sampling of the Macquarie Ridge before the expedition described in Rowden (2008) was rare, with most research focusing around Macquarie Island itself. The biodiversity sampling program of the expedition served to investigate the role of the Antarctic Circumpolar Current as a barrier to dispersal, as well as other questions of biogeography, evolution, dispersal and seamount ecology. The resulting study was combined with NIWA's FRST-funded Seamount Programme, seamount and biodiversity-related projects based at Australian institutes (including CSIRO and Museum Victoria), and was considered a component of the Census of Marine Life project CenSeam (Global census of marine life on seamounts) (Rowden 2008).

Biogeographic observations have been possible through the examination of fishery catches and species compositions of fish faunas, including skates (Last 2002) and echinoderms (O'Hara 1998). Analysis for Southern Ocean species has usually involved the examination of longitudinal gradients in species diversity, shared species distributions or dispersal mechanisms (O'Hara 1998). Interestingly, skates were found to be absent from the Macquarie Ridge, probably due to a deep ocean barrier at the southern end of the Campbell Plateau cutting off dispersal between this region and the Australian and New Zealand skate faunas (Last 2002). Many species of invertebrates are thought to disperse to Macquarie Island, and generally throughout the Southern Ocean, on floating objects such as kelp rafts (Smith 2002). The species of kelp or the type of floating object available is thought to dictate the species composition of dispersing invertebrates.

Samples of benthic invertebrate fauna contained at least 102 species. Communities were dominated by small macrobenthos (mostly small sponges, brachiopods, hydroids, hydrocorals, octocorals, anemones and holothurians). More stable substrates below 1,000 m hosted more species-rich communities of large macrobenthos (dominated by sponges and octocorals) (Commonwealth of Australia 2001b). Biogeographically, seamount fauna collected on the slope of the Macquarie Ridge between 500 and 1,500 m was closely related to seamount fauna from New Zealand, especially within habitats dominated by the cold-water coral *Solenosmilia variabilis*, which is host to a range of ophiuroid species



(O'Hara et al. 2008). Seamount benthic fauna has been found to be particularly vulnerable to anthropogenic impacts due to the slow growth rate of sessile organisms and the low dispersal potential of associated species (O'Hara et al. 2008).

The interaction between the prevailing oceanographic features and the Macquarie Ridge produces highly productive patches that support complex food webs (Tierney et al. 2002). Some sectors of the Southern Ocean, such as the South Atlantic, support krill-based food webs, whilst in the South Indian and Pacific sectors, it appears that fish and cephalopods play a more important role (Green et al. 1998). A thorough understanding of energy transfer through the system is limited by the lack of empirical information on key prey species (Tierney et al. 2002; van den Hoff and Morrice 2007). A study on fifteen species of mesopelagic fish, including samples from the Reserve, examined the calorific content of these common prey species (Tierney et al. 2002).

The open ocean environment provides important feeding areas for marine mammals and seabirds, some of which have extensive migratory and foraging ranges (Terauds et al. 2006). Research since the late 1990s has examined the foraging ranges, biology, vulnerability and genetics of marine mammals and seabird species (Terauds et al. 2006). Additionally, research has examined the effects of higher-order predators, such as great white sharks, killer whales and Pacific sleeper sharks, on marine mammals (van den Hoff and Morrice 2007). The Macquarie Island Reserve was established in part to protect these top-level predators (Commonwealth of Australia 2001b).

Large-scale food-web studies have included both empirical research and modeling. Findings have been useful for management, especially in the case of defining the overlap between fisheries and the diets and foraging ranges of marine mammals and seabirds (van den Hoff 2004). For instance, a tagging study found that juvenile southern elephant seals spent over 50% of their time foraging south of the Antarctic Polar Front and within fisheries management areas (Field et al. 2004). A molecular study of squid in the diets of Patagonian toothfish and southern elephant seals found that they consumed significantly different-sized squid, suggesting spatial (vertical) foraging separation because there is evidence that older, larger, squids live deeper than smaller individuals of the same species (van den Hoff 2004).

Most seabirds and mammals are known to forage in the central and northern parts of the Reserve, especially fur seals and penguins that breed on Macquarie Island. Macquarie is the only subantarctic island where there are co-occurring and sometimes inter-breeding populations of New Zealand fur seals (*Arctocephalus forsteri*), antarctic fur seals (*A. gazella*) and subantarctic fur seals (*A. tropicalis*). Since the cessation of sealing in the region, populations have increased slowly. A study tracking population recovery suggested that the reason for the slow increase may be low immigration rates due to distance from other populations, and relatively high rates of hybridization between the species (Goldsworthy et al. 2009). Additionally, the Reserve includes feeding grounds of breeding royal penguins (*Eudyptes schlegeli*), rockhopper penguins (*E. chrysochome filholi*) and king penguins (*Aptenodytes patagonicus*) (Wienecke and Robertson 2006).



Royal penguins are endemic to Macquarie Island, and it is the only known breeding location for king penguins and gentoo penguins (*Pygoscelis papua papua*) in the Pacific sector of the Southern Ocean (Commonwealth of Australia 2001b).

Recent research into the movements of seabirds such as giant petrels and albatrosses has found that not all species are adequately protected by the Reserve (Terauds et al. 2006; Trebilco et al. 2008). Some species spend a large proportion of their time, at least during parts of their life cycle, foraging outside the Reserve in areas that overlap considerably with fisheries operations (Waugh et al. 2007).

There is evidence to suggest that southern elephant seals (*Mirounga leonina*) and wandering albatross (*Diomedea exulans*) feed for some part of their lives within 200 nautical miles of Macquarie Island (van den Hoff and Morrice 2007), as their prey species are known to have local distributions. Elephant seals and albatross are known to travel through the marine area at least four times per year. Killer whales (*Orcinus orca*) are the most commonly recorded cetaceans, particularly during the breeding season of other marine vertebrates from September to January. Since the introduction of a killer whale sighting program at Macquarie Island in 1992, 238 killer whale sightings were recorded up to 1998 (Commonwealth of Australia 2001b).

Fisheries Research

A formally managed trawl fishery for Patagonian toothfish operates in the Reserve, and research associated with this fishery continues through various agencies (Commonwealth of Australia 2001b). Tagging studies have shown that Patagonian toothfish is a sedentary species, and genetic research suggests that depleted populations are not likely to be rapidly replenished (Appleyard et al. 2002).

Gaps and Recommendations

A wealth of data has been generated by multidisciplinary expeditions to the Macquarie Ridge area, but these have yet to be collated and presented in a way that makes the major gaps in research identifiable. However, transitional zones such as the one where Macquarie Island is located are likely to respond most rapidly to climate change through altered species distributions and environmental conditions. However, there is little knowledge on how this may manifest in deeper areas such as the Macquarie Ridge. It is recommended that a temporally consistent monitoring program be carried out.



SUMMARY AND DISCUSSION: RESEARCH AND MONITORING GAPS

This review identified 363³ individual research papers and reports relevant to the Commonwealth MPA estate, dating back to 1960 (Wyrki 1960). While not all these studies were conducted specifically or solely within CMPA boundaries, they all provided information relevant to the understanding of patterns and processes within CMPAs. The GABMP and Lord Howe MP have attracted the largest body of research, while targeted research in the Cod Grounds was only initiated after its proclamation (Table 6). The number of studies conducted in the sub-antarctic island Reserves are most likely to be underestimates, as research results were difficult to locate. The amount of research conducted in each CMPA is likely to be influenced by the remoteness of the CMPA from a land-based station, specific features of interest, proximity to research institutions, and the shifting research interests of the scientific community. The length of time since proclamation was not a significant factor in determining the number of studies conducted in each CMPA (Figure 7).

Table 6. Number of studies conducted in each CMPA, together with the year of proclamation of each CMPA.

CMPA	Year of Proclamation	Number of studies
All / General	NA	4
Cod Grounds Commonwealth Marine Reserve	2007	6
Cartier Island Marine Reserve	2000	11
Lihou Reef National Nature Reserve	1982	12
Macquarie Island Commonwealth Marine Reserve	1999	15
Elizabeth and Middleton Reefs Marine National Nature Reserve	1987	16
Mermaid Reef Marine National Nature Reserve	1991	19
Ningaloo Marine Park (Commonwealth Waters)	1987	26
Coringa-Herald National Nature Reserve	1982	27
Ashmore Reef National Nature Reserve	1983	31
Solitary Islands Marine Reserve (Commonwealth Waters)	1993	33
South-east Commonwealth Marine Reserve Network	2007	38
Heard Island and McDonald Islands Marine Reserve	2002	40
Lord Howe Island Marine Park (Commonwealth Waters)	2000	54
Great Australian Bight Marine Park (Commonwealth Waters)	1998	55

³ Note that some studies were relevant to more than one CMPA, and were therefore counted more than once where appropriate.

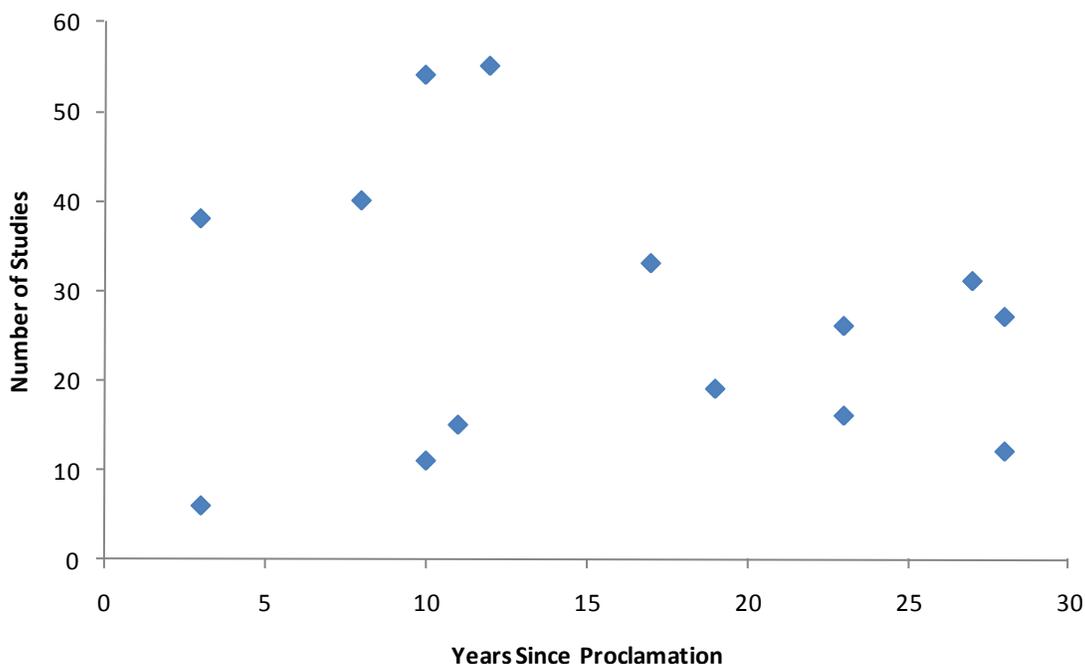


Figure 7. Relationship between the number of years since each CMPA was proclaimed and the volume of research (measured as number of studies) conducted there.

The volume of research available that is relevant to CMPAs has undergone an exponential increase since the 1960s (Figure 8). In many cases, research began many years before the proclamation of MPA status for an area, and usually contributed to the identification of these areas as deserving of protected status. There are references cited in recent reports and management plans that date from the 1960s, but only one report from this decade was available for this review (Wyrcki 1960). The first taxonomic summaries of marine life (Allen et al. 1977; Veron and Done 1979) and one of the first studies of coral ecology (Veron et al. 1974) were compiled in the 1970s, primarily in the more accessible locations such as the SIMP and Lord Howe Island. In the GABMP, the first studies on plankton and productivity also occurred during the 1970s (Motoda et al. 1978). Research conducted in the 1980s was also largely exploratory, with over 50% of research resulting in taxonomic reports and papers, and species lists were begun for CMPAs that were proclaimed during this time (Table 7). This decade also saw the beginnings of research into the underlying structural foundations of marine areas around Australia, with geology (McDougall and Green 1988), geomorphology (McLoughlin et al. 1988) and oceanography research (Baines et al. 1983; Bye 1983; Rochford 1986) relevant to current CMPAs appearing during this period. The first fisheries assessment in waters surrounding a CMPA (the GABMP) is also available from the 1980s (Burnell and Newton 1989).

During the 1990s there were still only five publications on oceanography, geology and geomorphology that were relevant to current CMPAs (James and Von der Borch 1991; James et al. 1994; Molcard et al. 1996; Kiernan and McConnell 1999; Taylor and Pearce 1999), but there was a rapid increase in ecological and biological research, especially



through relatively broad-scale surveys of benthic and fish communities (Koslow et al. 1994; Harriott et al. 1999; Skewes et al. 1999b) and distribution and abundance studies of species of interest (De Vantier and Deacon 1990; Smith and Harriott 1998). At Ashmore, detailed habitat mapping proved valuable for future research (Skewes et al. 1999b). Biological research was varied and included feeding biology, genetics, tagging and recruitment studies (Benzie and Stoddart 1992; Bruce 1992; Green et al. 1998; Fairfull and Harriott 1999). Though only four dedicated fisheries studies were found for this decade (Vail and Russell 1990; Newton and Klaer 1991; Morison 1996; Koslow 1997), many of the biological and ecological studies were also focused on species of fisheries value (Green et al. 1998; Skewes et al. 1999a). The first two literature reviews, one to aid in the preparation of the GABMP (Edyvane 1998) and one specifically for the protection of cetaceans in Australian waters (Bannister et al. 1996), became available in the second half of the 1990s.

Ecological surveys were primarily conducted between 2000 and the present; at least 103 separate studies into various ecological attributes were conducted in the last ten years (Table 7). As in previous decades, more than 50% of the research effort has been of an ecological and biological nature. While previous ecological surveys and monitoring activities were sometimes associated with current CMPAs by chance, most of the more recent surveys were conducted specifically as a requirement of each CMPA's management plan for the monitoring of ecosystem characteristics and health. In the early part of the decade, a number of dedicated oceanographic, climatic, geological and geomorphological studies were carried out, amounting to 17% of the research effort of the 2000s. New technology, such as remote sensing and multi-beam swath mapping, made increasing areas of seafloor accessible for mapping and bathymetry studies (Kloser et al. 2001a; Dickson and Woodroffe 2002). Additionally, new technology has been developed and employed for tracking individual animals, making megafauna studies more sophisticated (Gill et al. 2005; Frydman and Gales 2007; Meekan et al. 2008). The increasing availability of molecular tools has also made genetic, connectivity and biogeographic studies more accessible (Lukoschek et al. 2007; van Herwerden et al. 2009b). In this decade, the vulnerability of CMPAs to a range of threats also became apparent, with almost one-third of all literature reviews focusing on types of impacts relevant to protected areas (Smith and Rule 2001; National Oceans Office 2002b; Baker and Wise 2005).

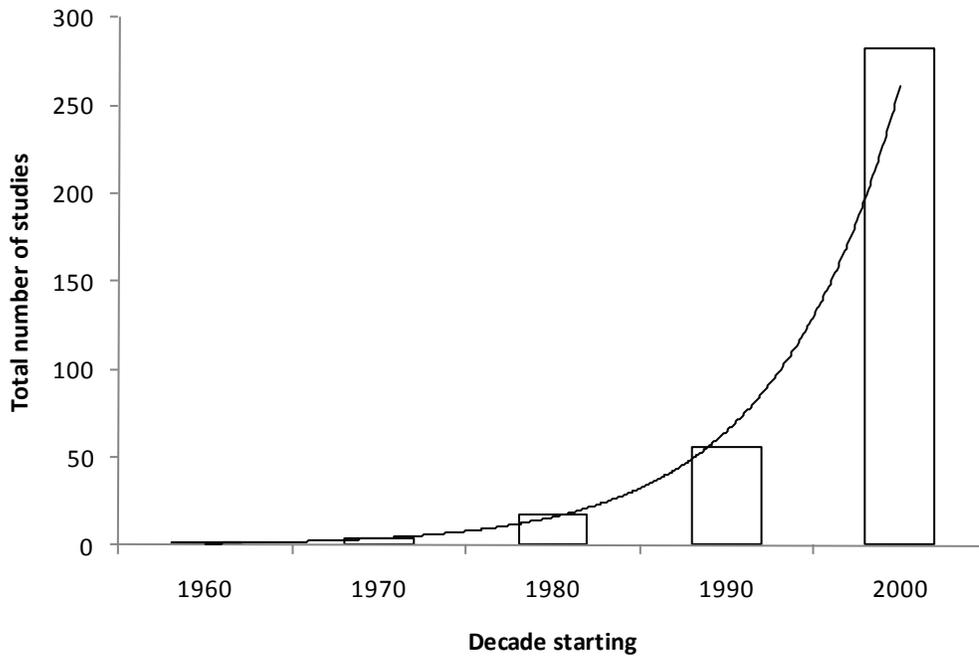


Figure 8. Number of research papers and reports produced during each decade between 1960 and 2000. The figures for the decade beginning in 2000 include 13 that were published in 2010.

Table 7. Numbers of papers and reports of research of each type available for decades between 1960 and 2000. The figures for the decade beginning in 2000 include 13 that were published in 2010.

Decade starting	Type of research	Number of studies
1960	Oceanography	1
1970	Taxonomy	2
	Ecology	1
	Plankton / productivity	1
1980	Oceanography	4
	Geology / geomorphology	3
	Taxonomy	9
	Fisheries	1
1990	Oceanography	2
	Geology / geomorphology	3
	Taxonomy	8
	Biology / genetics	15
	Ecology	21
	Biogeography	1
	Fisheries	4
	Review	2
2000	Oceanography / climate	15



Decade starting	Type of research	Number of studies
2000 (cont.)	Geology / geomorphology	34
	Taxonomy	5
	Biology / genetics	42
	Ecology	103
	Plankton / productivity	4
	Biogeography	9
	Fisheries	11
	Review - Impacts	14
	Review - General	37
	Other - conservation planning, geomagnetic research, glaciology, history, tourism, websites	11

Many papers and reports did not conform neatly to one category. The available papers and reports were therefore grouped according to their primary objectives. Research in each CMPA has tended to focus on the features of the area considered most important, interesting or vulnerable (Table 8). Ashmore was the only CMPA where successive ecological surveys could easily be tracked and related to previous and successive surveys. The recent nature of the proclamation of the Cod Grounds, the small size of this CMPA and the previous lack of interest in this specific area is probably the most plausible explanation for the small body of work characterizing it; however, work has been specifically directed at providing a baseline for future monitoring (Stuart-Smith et al. 2009). Ecological research in the Coral Sea has focused on the more accessible CMPA (Coringa-Herald), which could provide a useful blueprint for future monitoring of reefs and cays in this Region (Batianoff et al. 2008a). Elizabeth and Middleton and Lord Howe are considered interesting from a geomorphological, biogeographic and evolutionary perspective, and there has been an emphasis on studies of this kind. A relatively rich body of ecological work exists for Mermaid and Ningaloo in the North-west Marine Region. Some of this work also includes Ashmore and Cartier, allowing a clearer overall comparative assessment of the Region's ecology (Bryce 2006) than is possible in the East Marine Region, where no direct comparisons exist. The South-east Commonwealth Marine Reserve Network has the largest body of literature reviews, compiled to aid the establishment of the Network in 2002.

The patterns in which research has been conducted at each CMPA (Table 8) makes the specific gaps apparent for each. There is little CMPA-specific understanding of underlying environmental parameters such as oceanography, geology and geomorphology for a number of the CMPAs, and some still lack species lists. Although the general consensus is that research should move away from simply gathering species lists, the species present in each area provide the foundations of understanding biodiversity, functional groupings, patterns of distribution and biogeography, and the availability of indicators for monitoring. Patterns of productivity and fisheries activities relevant to each CMPA are also largely unknown. These are, respectively, important elements of ascertaining the nutrient pulses that may sustain demersal organisms, and the



potential for surrounding exploitation to affect the larval supply or organisms to the CMPAs.

A major gap for most research and monitoring programs in most CMPAs is the lack of consistent and reliable temporal data series, and the lack of research that incorporates reference or ‘control’ locations outside the CMPAs. While some CMPAs are relatively new, others were established in the 1980s (Lihou, Coringa-Herald, Elizabeth and Middleton, Ningaloo and Ashmore). A fundamental element of programs that measure the health of an ecosystem or the performance of management arrangement is the ability to detect changes over time (Gerber et al. 2005). This include both natural changes, changes due to interaction with, or impacts of, human activities, and perhaps most importantly, the rate of recovery from disturbance (Game et al. 2007). Ideally, trajectories of change would be measured repeatedly before and after the establishment of the CMPA, and before and after specific disturbances, at locations inside the CMPA and similar locations outside its boundaries. Divergent trajectories in measured variables (e.g. coral cover, biomass of species of interest, species richness, sediment or water quality, etc.) would elucidate which changes may be caused by protecting the area within the CMPA (Francini-Filho and Moura 2008). Ideally, setting aside CMPAs for protection from human activities would provide the conditions for an ecological community better able to resist or recover from disturbance (Mumby et al. 2006); only a temporally consistent monitoring program is likely to have the power to detect improved resistance or resilience.

CMPAs that have the closest thing to a useful time-series are Ashmore (reef ecology surveys) and Coringa-Herald (terrestrial and marine surveys). However, the ability to compare survey results from one sampling occasion to the next depends on the willingness of the new survey team (which has tended to be chosen from a different institution than the preceding one) to communicate with the previous team and to use comparable sites and methods. The HIMI has also attracted successive research expeditions, but there is no consistent temporal sampling for any of its components. Large bodies of work are available for Lord Howe and the Solitary Islands, but these are also made up of individual research projects, often conducted only once. Despite this, all CMPAs have baseline information of a quality that can inform the development of future monitoring programs.



Table 8. Number of research papers and reports on each broad type of scientific research in each CMPA.

CMPA	Research type	Number of studies	CMPA	Research type	Number of studies
Ashmore	Oceanography / climate	4	Lihou	Oceanography / climate	1
	Geology / geomorphology	1		Geology / geomorphology	1
	Taxonomy	4		Taxonomy	0
	Biology / genetics	4		Biology / genetics	1
	Ecology	13		Ecology	6
	Plankton / productivity	0		Plankton / productivity	0
	Biogeography	0		Biogeography	1
	Fisheries	1		Fisheries	0
	Review - Impacts	1		Review - Impacts	0
	Review - General	3		Review - General	2
	Other	0		Other	0
Cartier	Oceanography / climate	1	Lord Howe	Oceanography / climate	2
	Geology / geomorphology	1		Geology / geomorphology	14
	Taxonomy	1		Taxonomy	8
	Biology / genetics	0		Biology / genetics	10
	Ecology	8		Ecology	10
	Plankton / productivity	0		Plankton / productivity	0
	Biogeography	0		Biogeography	1
	Fisheries	0		Fisheries	1
	Review - Impacts	0		Review - Impacts	4
	Review - General	0		Review - General	3
	Other	0		Other - geomagnetic research	1
Cod Grounds	Oceanography / climate	0	Macquarie	Oceanography / climate	1
	Geology / geomorphology	2		Geology / geomorphology	3
	Taxonomy	0		Taxonomy	0
	Biology / genetics	0		Biology / genetics	2
	Ecology	1		Ecology	7
Plankton / productivity	1	Plankton / productivity	1		



CMPA	Research type	Number of studies	CMPA	Research type	Number of studies
Cod Grounds (cont.)	Biogeography	0	Macquarie (cont.)	Biogeography	3
	Fisheries	0		Fisheries	0
	Review - Impacts	1		Review - Impacts	0
	Review - General	1		Review - General	1
	Other - conservation planning, geomagnetic research, glaciology, history, tourism, websites	0		Other	0
Coringa-Herald	Oceanography / climate	5	Mermaid	Oceanography / climate	1
	Geology / geomorphology	3		Geology / geomorphology	2
	Taxonomy	1		Taxonomy	3
	Biology / genetics	4		Biology / genetics	0
	Ecology	12		Ecology	10
	Plankton / productivity	0		Plankton / productivity	0
	Biogeography	1		Biogeography	1
	Fisheries	0		Fisheries	0
	Review - Impacts	0		Review - Impacts	0
	Review - General	3		Review - General	2
	Other - tourism	1		Other	0
Elizabeth and Middleton	Oceanography / climate	1	Ningaloo	Oceanography / climate	2
	Geology / geomorphology	3		Geology / geomorphology	2
	Taxonomy	1		Taxonomy	1
	Biology / genetics	4		Biology / genetics	3
	Ecology	4		Ecology	11
	Plankton / productivity	0		Plankton / productivity	1
	Biogeography	0		Biogeography	0
	Fisheries	0		Fisheries	2
	Review - Impacts	0		Review - Impacts	1
	Review - General	2		Review - General	3



CMPA	Research type	Number of studies	CMPA	Research type	Number of studies
GABMP	Other	0	Solitary Islands	Other - tourism	1
	Oceanography / climate	6		Oceanography / climate	0
	Geology / geomorphology	9		Geology / geomorphology	2
	Taxonomy	2		Taxonomy	3
	Biology / genetics	7		Biology / genetics	10
	Ecology	14		Ecology	11
	Plankton / productivity	2		Plankton / productivity	0
	Biogeography	1		Biogeography	0
	Fisheries	5		Fisheries	0
	Review - Impacts	1		Review - Impacts	1
	Review - General	7		Review - General	4
	Other - palaeoecology	1		Other - economics, conservation planning	2
	HIMI	Oceanography / climate		1	South-east Network
Geology / geomorphology		3	Geology / geomorphology	3	
Taxonomy		2	Taxonomy	0	
Biology / genetics		2	Biology / genetics	2	
Ecology		23	Ecology	12	
Plankton / productivity		0	Plankton / productivity	1	
Biogeography		1	Biogeography	1	
Fisheries		4	Fisheries	2	
Review - Impacts		2	Review - Impacts	1	
Review - General		0	Review - General	9	
Other - glaciology, history, research overview, geophysics		4	Other - conservation planning, website	4	



Only a few studies have allowed comparisons of ecosystems inside and outside CMPAs. Researchers in north-western Australia have sometimes included some combination of Scott, Seringapatam and Hibernia Reefs and the Rowley Shoals in surveys that have also included Ashmore, Cartier and / or Mermaid (Berry 1986; Skewes et al. 1999a; Bryce 2006). The baseline surveys of the Cod Grounds and the GABMP included reference sites outside the Reserves (Currie et al. 2009; Stuart-Smith et al. 2009). Terrestrial surveys of Coringa-Herald also report on findings from the Willis Island Group (Batianoff et al. 2008a). Most research programs, especially those funded specifically to fulfil the management requirements of a CMPA, have not incorporated reference locations. The design of future research and monitoring surveys should take this into consideration. Two major obstacles have presented themselves in the past. Firstly, many CMPAs protect relatively isolated and unique habitats, such as islands and coral reefs surrounded by many hundreds of kilometers of open ocean (e.g. Lord Howe Island). However, research projects typically focus on certain aspects of the CMPA, such as vegetation cover, sediment structure, benthic communities and associated fauna. While it may not always be possible to find a reference location with the exact characteristics of the CMPS, a similar habitat subject to the same broad-scale climatic and oceanographic regime is usually available within Australian waters. For instance, the Coral Sea Reserves are subject to similar environmental conditions as other reefs and cays on the Queensland and Marion Plateaux; the Willis Islets to the north of Coringa-Herald and the Diamond Islets to the west of Lihou Reef could be explored as possible reference sites. Similarly, the three Rowley Shoals offer an opportunity for monitoring coral reef characteristics inside and outside the Mermaid CMPA. Where CMPAs encompass unique features or habitats, reference sites may need to be found elsewhere in the world, and collaborations or data sharing arrangements could be initiated with appropriate institutions. The HIMI is a useful model of this type of arrangement; research projects are occurring in collaboration with France and South Africa in order to include a number of islands in the Region (AAD 2005).

Perhaps the greatest challenge in designing successful research and monitoring programs for individual CMPAs and Reserve Networks is one of administration (Field et al. 2007b). A centralised organisation or group responsible for the design, implementation and reporting of research is the simplest format that may ensure continuity and consistency. Staff turnover is often a critical factor in ensuring continuity and consistency, regardless of the model chosen. A potentially useful model for conducting research in CMPAs is provided by the HIMI research program. This multidisciplinary scientific program is administered centrally by the AAD, with consistent research personnel and a structured research agenda. Current projects draw on past research, are often multidisciplinary and there is clear collaboration with fisheries management authorities. Furthermore, there is existing international collaborations to produce comparative studies that incorporate work on other islands subject to similar environmental conditions. Central databases contain the data and are used for regular reporting and publications. While research in other CMPAs is also administered centrally by DEWHA, it relies on a tendering process that results in different research teams with different research interests, favoured methods and objectives carrying out successive



surveys. This may have benefits such as updated methods and new perspectives, but it does not allow for the temporally consistent data collection that underpins a successful monitoring program.

Ideally, research and monitoring that is dedicated to providing information for management is carried out by a dedicated scientific research team. It would be beneficial to facilitate communication between teams responsible for different CMPAs, Reserve Networks or Marine Regions. The exchange of ideas, methodologies, strategies and information is invaluable for the development and constant improvement of useful and cost-effective research and monitoring programs. For example, expert workshops are useful for encouraging fruitful interactions between people and teams, and can stimulate the rapid advancement of protocol development. A centralized group would also facilitate the storage of data, databases, reports and publications.

In conclusion, no systematic research and monitoring program exists for the CMPA estate as a whole, and the management of CMPAs themselves does not draw on monitoring programs designed for the long-term tracking of changes. Specific research projects are usually driven by features of interest in each CMPA, and often reflect the specific values protected by the CMPA. The quality, quantity and type of information available therefore differs substantially between CMPAs. As the CMPA estate expands into large-scale Reserve Networks in the future, monitoring the effectiveness of protection and tracking changes over time will offer a challenge to managers. However, it will also offer an opportunity to design comprehensive, practical and cost-effective research and monitoring programs that fit into an adaptive management framework.



RECOMMENDATIONS

This review has resulted in recommendations for research and monitoring in each existing CMPA, and in the existing South-east CMPA Network (Table 9). In some cases (e.g. Macquarie Island), the large amount of data yet to be collated and reported means that it is not yet clear what the remaining knowledge gaps will be, and therefore the primary recommendation is the facilitation of reporting the data in a way that will make the gaps apparent. The highlighting of knowledge gaps and research needs for individual CMPAs can inform the establishment and monitoring of new CMR Networks. The lessons learned from reviewing existing research can be distilled into a number of recommendations that are directly relevant to the establishment of research and monitoring programs in new CMPA Networks. These recommendations include:

- Locate, collate, analyse and report on known existing datasets and databases. In some cases these existing data may suffice to fill existing knowledge gaps, precluding the need for further research.
- Carry out baseline studies to ensure that there is knowledge for key areas of each proposed CMPA in new Networks and existing CMPAs. This will greatly assist in the establishment on management systems that can direct activities to the correct places – for instance: indicators for monitoring, specific areas of value or concern to be more highly protected, areas for active management such as pest eradication or control, and genetic connectivity between areas.
- Decide whether to protect the “strong” or the “weak”, or both. This means identifying and scoring areas that may be classified as “strong” (e.g. high resistance or resilience to disturbance, intact trophic structure, stable environmental parameters, good recovery potential, high abundance and diversity of key organisms, high connectivity to larval sources) or “weak” (e.g. low resistance or resilience to disturbance, elements of the trophic structure low or missing – e.g. through historic overfishing of predators or invertebrates, poor recovery potential, low abundance and diversity of key organisms, low connectivity to larval sources). These considerations are most usefully set into a risk assessment-type decision-making framework (Game et al. 2007).
- Establish a temporally consistent system of environmental / ecological monitoring and compliance monitoring. The relative importance of types of monitoring will be dependent on the reserve type and usage patterns. If funds are short, compliance monitoring may be more important in some cases than environmental monitoring.
- Collect temporally consistent environmental as well as ecological data, and facilitate the linking between the two types of data.
- Regularly update this review with new information, to provide a central document that can act as a repository of current knowledge about CMPAs and CMPA Networks. Update the EndNote library with linked original electronic documents. The higher the frequency of these updates (e.g. annually), the lower the cost and time expenditure each time.



Table 9. List of recommendations for each CMPA, taken from individual sections above.

CMPA	Recommendations
GABMP	<ul style="list-style-type: none"> • Regular (preferably annual) sampling of benthic and pelagic communities inside the GABMP and outside reference or ‘control’ sites, repeating methods used in the baseline study, • A monitoring program for marine mammals and seabirds specifically from within the GABMP, • A risk assessment for exploration and mining or petroleum and minerals in the BPZ, • Regular collation and reporting of information on all bycatch from all fisheries, including sessile epibenthos, and especially from the vicinity of the GABMP, • Ongoing regular collation and reporting of interactions between fisheries and protected species, including capture and mortality of cetaceans, seabirds and pinnipeds, in the GABMP and surrounding waters, • An assessment to the extent to which the GABMP may protect important GAB fisheries stock, of both State- and Commonwealth-managed fisheries, • Regular collation and reporting of interactions between pinnipeds and rock lobster pots, active and derelict, • Regular reporting of logbook data, especially location information for all fisheries, to be regularly collated and information to be shared between Fisheries managers and GABMP managers, • Collection of quantitative data on the catches of recreational, indigenous and charter fishers, to be regularly collated and information to be shared between Fisheries managers and GABMP managers, • Monitoring of environmental parameters such as water quality, CO₂, temperature, etc., to assist in the interpretation of temporal dynamics, and • Coupling of ecological data in the GABMP with data on potential impacts from anthropogenic sources, e.g. fishing, mining and marine debris.
Ashmore and Cartier	<ul style="list-style-type: none"> • Collation and analysis of current knowledge from possible control locations outside the Reserves, • A detailed analysis of existing surveys both inside the Reserves and in surrounding areas, • A monitoring program for Ashmore, with standardisation of methods and repetition of surveys and monitoring activities for all species of concern, and for major ecological communities, within Ashmore and



Mermaid	<p>Cartier and at external, unprotected ‘control’ locations,</p> <ul style="list-style-type: none"> • Investigating the viability of using the vessel stationed at Ashmore for more regular research activities, • Incorporating a program of more frequent snapshot surveys carried out by staff stationed on the vessel, • Geology and geomorphology studies within the Reserves, • Integrating physical data such as temperature, current speed, water quality and salinity regimes, • Initiating or continuing genetic studies on species of concern and conservation significance, especially seasnakes, holothurians, trochus, dugongs and turtles, • Researching dugong movements, population size and preferred habitats, • Preparing a comprehensive risk assessment for the region’s turtle populations, and continuing turtle tagging and monitoring studies, • Further addressing the risk of oil spill/impacts on this CMPA, to be informed by the results of the assessment currently underway, • Monitoring and reporting of all illegal fishing activity, and • Centralised storing of all data collected in the Reserve. <p>• Establish a consistent monitoring program for the coral reef communities at all three reefs, with methods that allow comparisons with other CMPAS, with an additional reactive monitoring strategy to put in place after major disturbance events (cyclones, bleaching), and including density, size structure and health indicators for all important reef organisms and physical data,</p> <ul style="list-style-type: none"> • Collect demographic data for corals and fish, • Update reef fish species lists, including nocturnal, cryptic and pelagic fish, • Initiate mark-recapture studies of high-value invertebrates, • Research connectivity within and among reefs of the Rowley Shoals, and between the Rowley Shoals and other reefs and shoals in the region, especially for reef fish and commercially targeted invertebrates, • Investigate community-wide differences in reef fishes between fished and unfished reefs, including visual and BRUVS methods suited to deeper reef communities and shallower areas, • Study movements and migratory patterns of reef sharks to ascertain their vulnerability to fisheries operating outside the protected zones, • Develop a reporting mechanism for tourism operators that includes the nature and length of their visits and any observations of illegal fishing and harvesting, and • Centralised storing of data from research on all three reefs, with regular reporting on results.
Ningaloo	<ul style="list-style-type: none"> • Design a monitoring program for the Reserve’s water and sediment quality, and a reporting mechanism for threats and pressures,



Coringa-
Herald

- Initiate regular boat-based and aerial surveys of marine megafauna,
- Conduct further research on the planktonic composition of the pelagic habitats of the reserve, with a view to designing a monitoring program,
- Continuing deep-water surveys using high-resolution acoustic methods backed with video validation and grab sampling, using the methods and sites of the baseline survey and including ‘control’ sites outside the Reserve,
- Linking data on the Reserve’s specific hydrodynamics to its biological characteristics,
- Continue and expand whale shark tagging, mark-recapture, biopsy sampling and life history studies to identify migration pathways and life history,
- Maintain eco-tourism logbooks with annual analysis of data and reporting,
- Continue investigations for the reasons for whale shark decline,
- Expand, update and use the established photoidentification library; encourage international pooling of photo-ID libraries,
- Conduct risk assessments to assess the effects of the tourism industry and petroleum exploration activities on whale sharks, and the impacts of continued fishing on fish communities,
- Analyse exploitation levels of whale sharks internationally, and
- Forge international links and relationships to ensure better protection for whale sharks worldwide.
- Investigate the viability of liaising with the Bureau of Meteorology to ascertain whether the weather station on Willis Island to the north of Coringa-Herald could provide a research platform for the Reserve,
- Design a monitoring program that takes into account past methodology and includes comparisons with ‘control’ locations outside the Reserves; continued monitoring of terrestrial and marine ecosystems to build up the capability of establishing temporal dynamics; integrate ecological monitoring with physical data,
- Geological and geomorphological studies to assess the age and evolution of Coringa-Herald, including deeper substrates in between emergent reefs,
- Studies of local scale hydrodynamics, to shed light on possible patterns of dispersal and help identify source and sink reefs,
- Genetic studies to assess patterns of connectivity among Coral Sea reefs (e.g. test the hypothesis that Lihou Reef is a source of larvae for Coringa-Herald), and investigate adaptation capacity and the effects of long-term isolation of terrestrial populations,
- Link ecological patterns to reef metrics and physical attributes, e.g. habitat complexity, exposure regime, etc.,
- Investigate methods of cost-effective turtle nesting monitoring,
- Consider seasonal monitoring of breeding seabirds,



Lihou	<ul style="list-style-type: none">• Continue the seabird band-recapture project,• Consider restoration of major nesting sites if there are declines in nesting seabird numbers (e.g. replanting of <i>Pisonia</i> trees, with monitoring of consequences),• Liaise with AFMA to assess catch rates and location of catches by the Coral Sea Fishery, and• Enhance and enforce quarantine controls.
SIMR	<ul style="list-style-type: none">• Investigate the viability of liaising with BOM to ascertain whether the weather station on Willis Island to the north of Coringa-Herald could provide a research platform for the Reserve,• Continue monitoring surveys at intervals of 2-3 years with comparable methods, refining key indicator species for rapid surveys and to detect change over time,• Develop temporally consistent methodology for use by successive surveys,• Correlate ecological data with physical and chemical data,• Conduct regular fly-over ‘spot-checks’, and spot checks from Customs vessels using two experienced scientists, in 5 days, including video transects on a subset of the sites,• Support and encourage relevant fisheries management agencies to continue to increase the use of Integrated Computerised Vessel Monitoring Systems (ICVMS) on commercial fishing vessels working in the Coral Sea, in particular the aquarium and line fisheries,• Repeat terrestrial survey, drawing on expanded methods from studies on Coringa-Herald islets and cays (Batianoff et al. 2008a),• Use species identified in the baseline survey (Harvey et al. 2009) as indicators of terrestrial invertebrate communities,• Initiate dedicated seabird and turtle nesting surveys, tagging and genetic studies, and
	<ul style="list-style-type: none">• Enforce and update current quarantine regulations.• Regular reporting on the monitoring of physical characteristics – monthly or seasonal reporting of water quality, nutrients, turbidity, light and other physical parameters - that support ecological processes in the SIMP and SIMR,• Regular monitoring of ecological communities in deeper waters, using methods comparable to those of existing surveys and including ‘control’ locations,• Dedicated surveys of marine megafauna and pelagic communities, using either aerial or boat-based methods,• Monitoring of potential impacts, including dedicated surveys of fishing catch and effort inside the SIMP and SIMR by recreational and commercial fishers, and reporting mechanisms for pollution, shipping, interactions with megafauna and plastic marine debris, and• In addition to recording and reporting environmental data, and



Cod Grounds	<p>recognising that transitional zones such as the one around the SIMP and SIMR are those most likely to show early responses to climate change, a set of ecological indicators should be established to provide information on potential community responses to climate change.</p> <ul style="list-style-type: none"> • Regular monitoring of physical characteristics – monthly or seasonal reporting of water quality, nutrients, turbidity, light and other physical parameters - that support ecological processes in the Cod Grounds, • Continued monitoring to build up a temporal dataset to compare with the baseline set by the 2009 survey; repeat and enhance methods, intervals 1-3 years, use the set of univariate indicators in the study report, • Incorporate additional sites for monitoring, especially additional control sites outside the Reserve, located further afield but in comparable habitats and depths, • Include a timed swim around the pinnacle for closer sampling of grey nurse sharks, • Consider a buffer zone around the Reserve boundaries, and • Implement greater surveillance measures and enforcement of fishing closures.
Elizabeth and Middleton	<ul style="list-style-type: none"> • Repeat the past surveys to develop a long-term dataset, including 18-month spot-checks to detect any obvious signs of disturbance and the status of key features and species, • Support involvement of Lord Howe rangers in the monitoring of Elizabeth and Middleton, as they have the opportunity to coincide with suitable weather conditions in which to undertake surveys, • Compare species targeted by fisheries between the two reefs with intent to detect the effects of fishing, • Investigate the option of closing both reefs to fishing, • Examine levels of gene flow between Elizabeth and Middleton and protected areas off the NSW coast, Norfolk Island, New Zealand and Lord Howe Island, to establish possible pathways of stock replenishment, • Support genetic work on the doubleheader wrasse and other endemics, and • Investigate seasonal changes in diversity, abundance and functional groups or productivity of fish and invertebrate communities, to further understand the dynamics of these highly changeable systems and possible processes of recruitment and stock fluctuations, and to create a baseline dataset to monitor possible future change of these dynamics.
Lord Howe	<ul style="list-style-type: none"> • Support research that can use the island as a base, • Develop indicators for rapid ecosystem health assessment, • Closer investigation of the benthic communities of the hard and soft seafloors of the Commonwealth waters to determine biodiversity, ideally with ROV,



South-east Network	<ul style="list-style-type: none"> • Investigate habitat associations of important species of fish and invertebrates to assist in establishing a stratified sampling design, • Repeat previous BRUVS surveys, ideally annually or biannually, • Assess stocks of exploited species, • Investigate food webs; focusing on the question of why they support such a large biomass of sharks, • Investigate the location of predator aggregations in the deeper waters of the shelf drop-off, • Replicate genetic studies carried out at Elizabeth and Middleton, and • Undertake dedicated megafauna studies. <p>• Map habitats for each CMR and oceanographic features within and between CMRs,</p> <p>• Prepare of definitive species list for each CMR,</p> <p>• List key ecological, geophysical and oceanographic features or indicators for each Reserve that would either benefit from more research, or that would provide useful monitoring data to measure changes in Reserve condition over time,</p> <p>• Study movement patterns of currents, larvae and important species within and between Reserves and outside Reserves, to improve understanding of patterns of dispersal and connectivity within the Network, and</p> <p>• Build ecological models that incorporate geological features, geomorphological and oceanographic processes with ecological attributes and processes and trophic pathways.</p>
HIMI	<ul style="list-style-type: none"> • Continue systematic vegetation monitoring and mapping on Heard Island, • Continue climate-related studies on terrestrial invertebrates on Heard Island, • Design a comprehensive monitoring program for Heard Island’s marine ecosystems, including flora and fauna, key taxonomic and functional groups, current movements and patterns of productivity, and • Map the HIMI’s seafloor characteristics to determine areas for further deep-water benthic sampling, using remote techniques.
Macquarie	<p>A wealth of data has been generated by multidisciplinary expeditions to the Macquarie Ridge area, but these have yet to be collated and presented in a way that makes the major gaps in research identifiable. However, transitional zones such as the one where Macquarie Island is located are likely to respond most rapidly to climate change through altered species distributions and environmental conditions. However, there is little knowledge on how this may manifest in deeper areas such as the Macquarie Ridge. It is recommended that a temporally consistent monitoring program be carried out.</p>





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APPENDIX 1 – DATABASES, COLLECTIONS AND METADATA

This appendix contains a list of currently known databases, museum collections and metadata held by different institutions.

Institution	Link	Type of Information	Name
CSIRO	http://www.marine.csiro.au/marlin/	Metadata	CSIRO Marine and Atmospheric Research (CMAR) Laboratories Information Network
CSIRO	http://www.cmar.csiro.au/remotesensing/	Spatial / remote sensing information	Observing the Ocean Marine and Atmospheric Research Remote Sensing Facility
Geoscience Australia	http://www.ga.gov.au/library/ausgeoref/index.jsp	References	AusGeoRef is a subset of the GeoRef database published by the American Geological Institute
Museum	http://www.ozcam.org/	Database	Online distributed network of databases that contain information about the faunal (animal) collections held in Australian museums and other institutions, such as CSIRO.
Australian Antarctic Division	http://data.aad.gov.au/	Metadata	Australian Antarctic Data Center



APPENDIX 2 – UNAVAILABLE LITERATURE

South-west Marine Region

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