Strategic marine ecological research priorities for CALM Act marine parks and reserves 2016–2021

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ABSTRACT

The West Australian Department of Parks and Wildlife (Parks and Wildlife) undertakes and facilitates marine research that informs the management of marine parks and reserves created under the *Conservation and Land Management Act 1984* (CALM Act). Broad marine research priorities for management include understanding patterns in the distribution of marine assets and the processes that shape these patterns, improving the design and function of marine reserves, and understanding the ecology of threatened and specially protected marine fauna. More specific and targeted research priorities are required for efficient and effective use of resources. Research relating to the ecological assets listed in each indicative or final marine reserve management plan was prioritised using a framework that considered the ecological and social value of assets, the anthropogenic pressures acting on assets and the current state of knowledge relating to assets. Invertebrates, macroalgae/seagrasses, soft sediment habitat, and intertidal and filter-feeding communities were identified as fundamental research priorities in several marine reserves, whilst the effects of climate change on turtles, coral reef, seagrass, macroalgal and mangrove communities and the effects of fishing on finfish and invertebrate communities were identified as priorities for applied research. A list of >100 marine asset and park specific research strategies is presented, which in combination with fundamental and applied asset priorities identifies focal areas of Parks and Wildlife marine research, promoting efficient use of resources and facilitating collaboration with other research organisations.

Keywords: conservation management, knowledge transfer, marine protected areas, research prioritisation

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INTRODUCTION

Management of the natural environment should be founded on robust scientific information (Sutherland et al. 2004). The uptake of scientifically-derived knowledge by managers is, however, often low (Pullin et al. 2004), which is partially attributable to poor communication between scientific researchers and management practitioners (Cash et al. 2003). In some instances, managers may be unaware of relevant research (Cvitanovic et al. 2014), although it is also

possible that research does not meet the specific needs of managers (Fazey et al. 2005; Young & Van Aarde 2011), or researchers are unaware of managers' knowledge requirements (Cash et al. 2003). It is therefore imperative that management agencies clearly articulate and prioritise their research requirements to facilitate the strategic alignment of work undertaken by scientists (Rudd 2011; Cook et al. 2013). Importantly, the identification and prioritisation of research requirements needs to be carried out using a transparent and structured process that incorporates stakeholder input in an unbiased manner.

The Western Australian (WA) Department of Parks and Wildlife (Parks and Wildlife) is responsible for conserving the state's biodiversity through the management of terrestrial and marine parks and reserves created under the *Conservation And Land Management Act 1984* (CALM Act) and plants and animals through provisions of the *Wildlife Conservation Act 1950* (WC Act). To inform the management of marine parks and reserves and threatened or specially protected marine fauna, Parks and Wildlife undertakes and facilitates research to increase knowledge of the composition and function of marine ecosystems, and how human activities affect these ecosystems. The clear focus of research on management priorities aligns closely with the department's Strategic Directions (Department of Parks and Wildlife 2014), and is consistent with delivering conservation-based outcomes in initiatives such as the Kimberley Science and Conservation Strategy (Government of Western Australia 2011). Marine research undertaken by Parks and Wildlife scientists and collaborators is focused on improving knowledge for management, that may, for example, include informing planning for new marine reserves and improving the configuration of existing reserves. Scientific knowledge forms the basis of advice provided by Parks and Wildlife on development applications, permit requests and cross jurisdictional management initiatives such as national area management, fauna and oiled-wildlife response plans. Research also engages the community, stakeholders and partners in cooperative management of parks and reserves, and such participation promotes custodial roles (Mascia 2003). Importantly, research also contributes baseline data to the department's marine reserve monitoring program, which measures long-term trends in the condition of marine assets, the natural and anthropogenic pressure/s acting on these assets and the management response to these pressures within an adaptive management framework.

This document provides strategic marine research priorities for Parks and Wildlife, described as priority strategies and questions that relate to each of WA's existing marine parks and reserves, or to specific ecological assets in each reserve. We first describe broad, over-arching research themes and then employ a prioritisation framework (Simpson et al. 2015) to identify ecological assets of high research priority, and finally list high-priority research questions. Research priorities related to threatened fauna are included in instances where management plans specifically include species as marine reserve assets. Coordinating research programs across marine parks and reserves for these species should complement taxon-specific state or nationally focused plans, such as 'The Recovery Plan for Marine Turtles in Australia' (Environment Australia 2003) and 'Recovery Plan for the Australian Sea Lion' (Department of Sustainability, Environment Water Population and Communities 2013). Identifying and prioritising research in this manner clearly articulates research requirements for Parks and Wildlife and provides a mechanism for communicating and aligning research objectives with external collaborators.

BROAD RESEARCH OBJECTIVES

The major themes for marine conservation research in WA's marine parks and reserves can be broadly divided into three categories:

1. Determining biological, ecological and human use patterns and processes in marine ecosystems. Research should initially focus on describing marine biodiversity, determining the ecological functions of marine flora and fauna and identifying how key ecological processes and human activities (including climate change) either directly or indirectly influence spatial and temporal patterns in diversity and abundance.

2. Improving the design and configuration of marine protected areas to protect the full range of ecosystems, at levels that ensure ecological viability and reflect the diversity of the system. Creation and management of WA's marine parks and reserves are dependent on knowledge that will optimise the location, size and zoning configuration of individual reserves and assist configuring marine reserve networks to optimise biodiversity conservation outcomes while accommodating compatible commercial and recreational activities. This requires a focus on topics like benthic habitat mapping and improved understanding of processes like connectivity to ensure habitats and sources of new recruits are adequately protected. In addition, effective monitoring of marine reserves requires research to identify appropriate techniques and indicators of asset condition, the pressures acting on these assets and measures of management effectiveness.

3. Determining ecological processes and assessing anthropogenic pressures relevant to managing threatened marine fauna. A number of marine faunal species that occur in WA's marine parks and reserves are also listed as threatened or requiring special protection under the WC Act. These species, which include marine reptiles, mammals and birds, may be recognised as key ecological assets of marine reserves, while in some cases also being the subject of specific management programs or recovery plans that may list knowledge gaps and research requirements across their wider distributions. Research on such species within marine parks and reserves can provide information on local population

demographics, habitat use, reproductive and trophic ecology, historical populations and the effects of threatening processes, which can contribute to broader conservation objectives and improved knowledge of how marine reserves can contribute to fauna management.

PRIORITISING RESEARCH FOR MARINE RESERVE ECOLOGICAL ASSETS

The prioritisation process focuses on the ecological assets identified and listed within indicative or final management plans for marine parks and reserves created under the CALM Act. Ecological assets are the physical, geological, chemical and biological characteristics of a marine reserve that may be significant with regard to ecosystem integrity or biodiversity. Ecological assets may also have cultural and socio-political significance. These assets are highlighted in marine reserve management plans as a key focus of conservation management.

The process

Research priorities have been identified for ecological assets in marine reserves using a framework that considers their ecological, cultural and socio-political value (V), pressures (P) that affect those assets and the current state of asset knowledge (K) (Simpson et al. 2015). Under this framework, a series of criteria were scored (1–3) to assess V, P and K. Criteria used to assess value consider the ecological, biodiversity and social significance of the asset, whilst criteria that assess pressures consider the spatial, temporal, biological and political consequences of a pressure multiplied by the probability of that pressure occurring within the lifetime of the management plan. The state of asset knowledge was evaluated using criteria that reflect current understanding of an asset's spatial and temporal distribution, processes that influence its distribution or condition, and the adequacy of information for system modelling, forecasting and setting management thresholds. Parks and Wildlife staff associated with marine reserve management and research collectively scored criteria relating to V, P and K and used the framework to prioritise ecological assets for fundamental (Table 1) and applied (Table 2) research. We assumed that differences between a score of 1 and 2 were the same as those between 2 and 3 and used geometric means to calculate a measure of central tendency for related criteria to overcome problems associated with non-independence among some criteria. Final values for V, P and K all ranged from 1–9, ensuring they had equivalent weighting when calculating fundamental and applied research priorities.

Fundamental research seeks to address knowledge gaps relating to the distribution and abundance of biodiversity, how these patterns vary spatially and temporally, and the function and significance of key ecological processes (Sutherland et al. 2004). Within this framework, fundamental research is prioritised based on a function of the relative value of the asset and the adequacy of knowledge associated with it (V × K). In contrast, applied research relates to studies that investigate the interaction between anthropogenic pressures and natural systems, describing impacts and exploring strategies that might be used to reduce the effect of pressures. Prioritisation of applied research is a function of the anthropogenic pressures affecting an asset, the knowledge relating to that interaction and the asset value (P × K × V). Parks and Wildlife is particularly focused on applied research that enhances understanding of asset resilience, recovery and adaptation in relation to threats, such as climate change, commercial and recreational fishing, industrial and foreshore development (including the impacts of dredging), introduced marine species and pollution, including oil spills and industrial waste discharge. Scores from the prioritisation framework provided a basis for discussions among Parks and Wildlife staff associated with marine reserve management, and the final allocation of high-priority research assets was based on a combination of these discussions and scores from the framework.

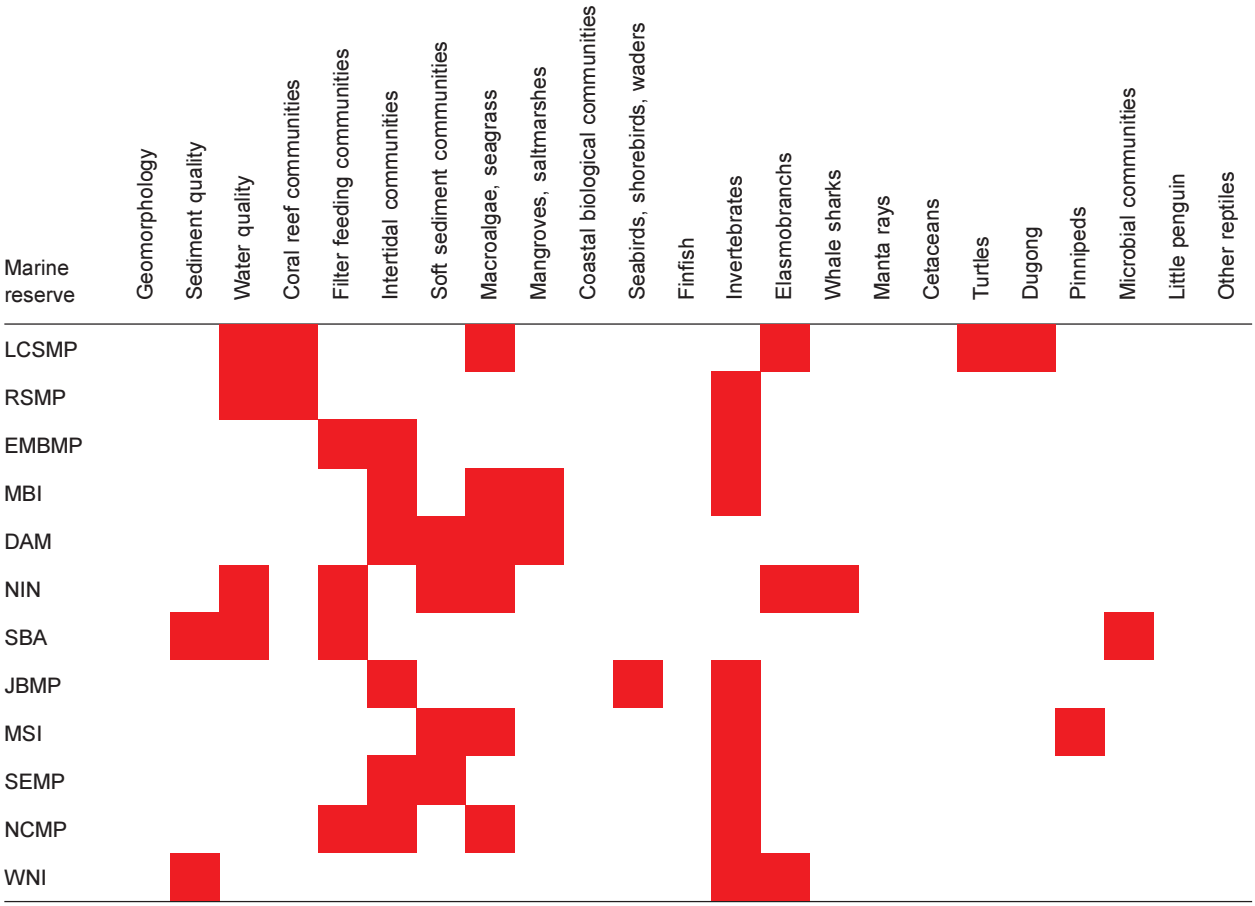
Reserve level priorities

The prioritisation process identified invertebrates, macroalgae/seagrasses, soft sediment habitat, intertidal and filter-feeding communities as assets that warrant more fundamental research in four or more marine reserves (Table 1). Prioritisation for fundamental research on these assets partially reflects their prominence within parks and reserves, the high number of species within these communities, and a lack of baseline information on their abundance, distribution and the natural processes that influence demographic patterns of many species with high ecological or social value.

Applied research exploring the effects of climate change was a high priority for 11 different assets. Climate change was identified as an area of future research in three or more reserves for turtles, coral reef, seagrass, macroalgal and mangrove communities, emphasising the high susceptibility of these assets to shifts in climate (Hoegh-Guldberg et al. 2007; Ihlow et al. 2012; Koch et al. 2013). Applied research on the effects of fishing on finfish was also recognised as a high priority in nine of the marine parks and reserves (Table 2), reflecting the widespread nature and potential effects of fishing (Jennings & Kaiser 1998; Halpern et al. 2008). Similarly, the effects of fishing on invertebrates, filter-feeding and rocky-shore communities were identified as a high priority research topic in six of the reserves. The effects of fishing on finfish were not a priority in all marine reserves as there was already considerable local knowledge on the topic, or because finfish were of relatively low ecological and social value in a particular

Table 1

Strategic fundamental research priorities (highlighted) for ecological assets associated with marine parks and reserves created under the CALM Act, as identified by marine science and management staff and joint management partners (Lalang-garram/Camden Sound Marine Park), following the methods of Simpson et al. (2015). All have high ecological and social value and low levels of inventory, baseline or process-orientated knowledge within the associated marine reserve.



LCSMP = Lalang-garram/Camden Sound Marine Park; RSMP = Rowley Shoals Marine Park; EMBMP = Eighty Mile Beach Marine Park; MBI = Montebello and Barrow Islands marine reserves; DAM = proposed Dampier Archipelago marine reserves; NIN = Ningaloo marine reserves; SBA = Shark Bay marine reserves; JBMP = Jurien Bay Marine Park; MSI = Marmion and Shoalwater Islands marine parks; SEMP = Swan Estuary Marine Park; NCMP = Ngari Capes Marine Park; WNI = Walpole and Nornalup Inlets Marine Park.

reserve. Physical or behavioural disturbance to assets from human activities such as dredging, boating and coastal development was identified as an area that requires applied research at multiple reserves. Notably turtles, coral reef, intertidal and mangrove communities are susceptible to a range of disturbances and the high ecological and social values attributed to these assets afford them a high applied research priority.

RESEARCH QUESTIONS

Specific research questions relating to the identified fundamental (Table 3) and applied (Table 4) research priorities have been drawn from marine reserve management plans, workshops with Parks and Wildlife marine park managers and marine scientists and, where appropriate, management plans for marine fauna. Relevant questions from publications that identified and prioritised research requirements to improve marine reserve management (Cvitanovic et al. 2013) and the understanding of climate change effects on fish (Wilson et al. 2010) were also included if they related to high priority assets in particular areas. These questions were identified by canvassing Australian marine conservation managers and scientists, including those from Parks and Wildlife, and academics with expertise in research on marine reserves or the impacts of climate change on fish. In collecting research questions it was noted that some were considered important by management staff but were not identified as high priority assets in Tables 1 or 2. As a consequence, these specific questions are

Table 2

Strategic applied research priorities for marine parks and reserves created under the CALM Act. Highlighted squares indicate assets listed in indicative and final management plans where Parks and Wildlife marine staff and joint management partners (Lalang-garram/Camden Sound Marine Park), following the methods of Simpson et al. (2015), agreed there was a high probability of anthropogenic pressures having major ecological and socio-political consequences. These were all assets with high ecological and social value, and with low levels of knowledge on how pressures and the asset interact. Letters within highlighted cells are indicative of the major anthropogenic pressure that requires applied research. Abbreviations of marine reserve names are as in Table 1.

Marine reserve	Geomorphology	Sediment quality	Water quality	Coral reef communities	Filter feeding communities	Intertidal communities	Soft sediment communities	Macroalgae, seagrass	Mangroves, saltmarshes	Coastal biological communities	Seabirds, shorebirds, waders	Finfish	Invertebrates	Elasmobranchs	Whale sharks	Manta rays	Cetaceans	Turtles	Dugong	Pinnipeds	Microbial communities	Little penguin	Other reptiles
LCSMP				CD				C				F					D	CFD	CF				
RSMP			C	CD								F											
EMBMP						D						F						D					
MBI									CD			F						CD					
DAM									CD			F	F					CD					
NIN				CD		FD					D	F			D			CD					
SBA			C		F			C	CD												CD		
JBMP								FC				F	F				D			FD			
MSI						FD		C			D									D		CD	
SEMP						D	D																
NCMP	D		P			FD						F	FD				D						
WNI	C											CF	C										

F = fishing or extraction, either direct or indirect effects; D = coastal development or physical/behavioural disturbance due to human activities (e.g. four-wheel driving, pests and feral animals, dredging, noise and light pollution, anchor damage, reef walking, boating/shipping disturbance, wildlife watching); C = climate change (e.g. long-term change in storm activity, rainfall, sea surface temperatures, sea level); P = pollution including marine debris.

included in Tables 3 and 4. Similarly, questions that relate to developing methods or sampling strategies to achieve more efficient monitoring were solicited through discussions with staff responsible for monitoring assets and are included as applied research questions (Table 4). In many cases the same question is applicable to multiple assets in several marine reserves, indicating that a spatially and taxonomically broad research program may be required. Those questions that were applicable to three or more of the prioritised park assets in Tables 1 and 2 were considered to be of broad geographic or taxonomic relevance, whilst those relevant to two or fewer of the prioritised park assets were considered specific.

IMPLEMENTATION

The list of research strategies and questions presented here is extensive, and even when questions are addressed there is often a gap between knowledge acquisition and implementation into management (Knight et al. 2008). While Parks and Wildlife will undertake a number of these projects, this paper is equally focused on identifying opportunities for developing management-related collaborations with the broader marine science community. Collaborative projects that include Parks and Wildlife scientists will help to ensure that research aligns closely with conservation priorities and facilitates the effective uptake of final recommendations into management

Table 3

High-priority strategies and questions for fundamental research strategies and questions for marine parks and reserves created under the CALM Act. The abbreviations used for marine reserve names are as described in Table 1 (RBMP additionally identifies the proposed Roebuck Bay Marine Park). Broad questions are those that address three or more park assets, and specific questions address two or fewer park assets prioritised for fundamental research (Table 1).

Research strategy or question	Ecological asset	Region or marine reserve	Broad (B) or specific (S)
What are the relationships between coral reef, macroalgal, seagrass, mangrove, saltmarsh and intertidal communities with regard to, for example, energy transfer, ontogenetic and/or temporal movements of species and biological filtration?	Coral, mangrove, macroalgal, seagrass, intertidal	SBA, NIN, DAM, MBI	B
How do corals persist under extreme environmental conditions? What factors impede or promote recovery of corals after disturbance?	Coral	LCSMP, RSMP, DAM, MBI, NIN, SBA	B
What is the distribution and composition of filter-feeding communities within the park? What environmental factors influence the distribution and diversity of filter-feeders?	Filter-feeding invertebrates	SBA, EMBMP, NIN, NCMP	B
How important are large predatory fish to maintaining healthy ecosystems?	Finfish, elasmobranchs	All marine reserves	B
Assess the ecological significance of herbivory on temperate algal-dominated reefs.	Finfish, invertebrates, macroalgae	JBMP, MSI, NCMP	B
What processes drive the distribution and abundance of ephemeral seagrasses, and how does this influence dugong behaviour?	Seagrass, dugong	LCSMP, SBA, DAM	B
Assess the diversity and distribution of macro-invertebrate and fish species inhabiting different species of perennial seagrass.	Seagrass, invertebrates, finfish	NCMP, MSI, JBMP, SBA	B
Describe nutrient dynamics of macroalgal and seagrass communities. Where do the nutrients that sustain large meadows come from and where do nutrients go when algae and/or seagrass breaks down?	Seagrass, macroalgae	All marine reserves	B
How does the distribution of seagrass and algae influence the abundance and species composition of herbivores e.g. finfish, turtles, dugong?	Seagrass, macroalgae, finfish, dugong, turtles	All marine reserves	B
Assess relationships between sediment and water quality.	Sediment quality, water quality	All marine reserves	B
How do water and sediment quality vary naturally within marine reserves?	Sediment quality, water quality	All marine reserves	B
What are the key physical, biological, ecological and chemical processes that link different habitats (e.g. inshore-offshore, benthic-pelagic or lagoonal-deep water) within a marine reserve and how significant are such links?	Various	All marine reserves	B
How does the loss and fragmentation of marine habitats affect connectivity between communities in marine reserves?	Various	All marine reserves	B

Map marine and relevant coastal conservation reserve habitats at a scale and accuracy that is appropriate for conservation planning and/or management.	Various	All marine reserves	B
Assess the significance of coastal habitats within and adjacent to the marine park for migratory birds.	Birds	LCSMP	S
Map seabird and shorebird foraging, breeding and roosting areas of the marine park.	Birds	NCMP, WNI, DAM, MBI	S
Assess the food requirements of shorebirds and seabirds and relate diets to prey availability in the marine park where regular foraging occurs.	Birds, invertebrates, intertidal	NCMP	S
Spatially and temporally characterise the use of the marine park by humpback whales, including the identification of high-use calving and nursing areas. Determine temporal patterns in whale residence and fine-scale habitat use in staging/resting areas.	Cetaceans	LCSMP, NIN, NCMP	S
Identify habitats of ecological significance for dolphins (e.g. areas used for feeding or reproduction). Describe the distribution, abundance, residency and habitat use of tropical inshore dolphins. What are their movement patterns?	Cetaceans	SBA, LCSMP, NIN, SEMP, MSI, DAM	S
Describe and map hard coral communities in temperate marine reserves.	Coral	SBA, JBMP, MSI, NCMP	S
What is the composition of coral communities in deep water (>10 m) areas of the lagoon and outer margins of the shoals? How do these differ from shallow water communities, and how well are coral communities within and between the shoals connected?	Coral	RSMP	S
Assess the regional significance of marine reserves for dugong (*Dugong dugon*) conservation and the relative importance of marine reserves as dugong habitat. What are the critical seagrass habitats for dugong in parks and reserves, and how are these habitats used by dugong of different ages? How has our knowledge of dugong in parks and reserves been informed by traditional ecological knowledge?	Dugong	MBI, DAM, NIN, SBA, EMBMP, LCSMP, RBMP	S
When and why do dugongs move, and over what spatial extent are these movements? How do these movements differ demographically? Determine the genetic structure and connectivity of dugong among different marine reserves.	Dugong	MBI, DAM, NIN, SBA, EMBMP, LCSMP, RBMP	S
What is the abundance and demographics of the dugong population?	Dugong	MBI, DAM, NIN, EMBMP, LCSMP	S
Quantify seasonal whale shark aggregations in the vicinity of Dirk Hartog Island.	Elasmobranchs	SBA	S
What are the large scale movement patterns of whale sharks that pass through the marine park? Do these whale sharks form part of a discrete population? How do these movements change the sort of risks that they expose themselves to, and thus influence injury and mortality?	Elasmobranchs	NIN	S

Table 3 (cont.)

Research strategy or question	Ecological asset	Region or marine reserve	Broad (B) or specific (S)
Describe shark and ray diversity, abundance and demographics with respect to different habitats and management areas in the marine park. What environmental factors influence these distribution patterns?	Elasmobranchs	LCSMP, EMBMP, WNI	S
Identify and assess the relative importance of finfish nursery, spawning and aggregation sites.	Finfish	All marine reserves	S
Assess the effect of coastal processes and geomorphological changes to the Geographe Bay shoreline.	Geomorphology	NCMP	S
Assess the impact of oceanographic processes on nearshore sediment movement.	Geomorphology, sediment	JBMP	S
Describe spatial and temporal patterns in the benthic invertebrate communities of tidal parts of the Frankland, Deep and Walpole rivers.	Invertebrates	WNI	S
What is the spatial and temporal abundance, diversity and distribution of benthic invertebrates?	Invertebrates	LCSMP, MSI	S
What species of jellyfish are present in the marine park? Quantify patterns of distribution and abundance in the marine park. What factors influence their occurrence and abundance?	Invertebrates	RSMP, NIN	S
Describe the distribution patterns and natural variability of deep (i.e. >10 m) reef communities with respect to anthropogenic pressures.	Invertebrates, filter feeders	NCMP	S
How important is Exmouth Gulf for the recruitment of marine organisms at Ningaloo reef? To what extent are these two systems connected?	Invertebrates, fish	NIN	S
Assess the composition of soft-sediment benthic invertebrate communities. How do these vary spatially and temporally?	Invertebrates, soft-sediment	NIN	S
Assess the recruitment, growth and physiology of mangroves (*Avicennia marina*) at Shark Bay in relation to environmental factors like salinity.	Mangrove	SBA	S
How does variation in the composition and structure of mangrove habitats influence their ecological function? How does this vary in relation to environment factors?	Mangroves	LCSMP, DAM, MBI, SBA	S
What organisms, or particular life stages of organisms, are associated with mangrove habitats? Is this use dependant on mangroves or opportunistic?	Mangroves	LCSMP, DAM, MBI, SBA	S
Describe the diversity and distributions of microbial communities, invertebrates and fish in Hamelin Pool.	Microbial communities, invertebrates	SBA	S
How have changes in prey availability influenced survival and reproductive viability of little penguins (*Eudyptula minor*)?	Penguins, finfish	MSI	S

What is the species composition and relative abundance of sea snakes in the park?	Reptiles	LCSMP, RSMP, DAM, MBI, SBA	S
Has there been a decline or shift in species composition of sea snakes as seen in neighbouring jurisdictions?	Reptiles	LCSMP, RSMP	S
Are crocodiles becoming more abundant at the southern end of their range?	Reptiles	EMBMP, DAM	S
Determine if the Shark Bay sea snake (*Aipysurus laevis pooleorum*) is a different species to the olive sea snake (*A. laevis*).	Reptiles	SBA	S
What are the composition, distribution and ecological significance of salt marsh?	Salt marsh	SBA, EMBMP	S
Assess natural variations in the distribution of perennial seagrasses at various spatial scales.	Seagrass	NCMP, MSI, JBMP, SBA	S
What physical, biological and/or chemical processes influence the distribution and composition of lagoonal macroalgae and seagrasses?	Seagrass, macroalgae	NIN	S
What is the ecological significance of wrack in relation to nutrient dynamics and energy transfer? How does wrack removal impact on such processes?	Seagrass, macroalgae	NIN	S
Identify sources of organic material within sediments and nutrient dynamics in the inlets.	Sediment quality, water quality	WNI	S
Assess Warnbro Sound benthic invertebrate fauna in a manner comparable with the 1991–1994 Southern Metropolitan Coastal Waters Study.	Soft-sediment, invertebrates	MSI	S
Where are the major nesting, inter-nesting and courtship areas for marine turtles?	Turtles	LCSMP, EMBMP, MBI, DAM, NIN	S
Identify key foraging sites for marine turtles and the demographics of animals using these areas.	Turtles	LCSMP, EMBMP, MBI, DAM, NIN, SBA	S
Define the genetic stock boundaries for each species to better understand the significance of turtles in marine parks relative to the broader populations.	Turtles	LCSMP, EMBMP	S
Identify migration routes and links between nesting and foraging areas. How do these relate to the marine reserve system?	Turtles	LCSMP, EMBMP, MBI, DAM, NIN, SBA	S
Identify groundwater systems and freshwater seeps. Assess the ecological significance of groundwater to coastal systems.	Water quality	EMBMP	S
Assess sources and cycling of nutrients in Hamelin Pool.	Water quality	SBA	S
Assess the spatial and temporal stability of salinity gradients in Shark Bay.	Water quality	SBA	S

Table 4

High-priority strategies and questions for applied research for marine parks and reserves created under the CALM Act. The abbreviations used for marine reserve names are as described in Table 1 (RBMP additionally identifies the proposed Roebuck Bay Marine Park). Broad questions are those that address three or more assets, and specific questions address two or fewer assets prioritised for applied research (Table 2).

Research strategy or question	Ecological asset	Region or marine reserve	Broad (B) or specific (S)
How may long-term changes in temperature and currents affect coral reef accretion rates?	Coral	LCSMP, RSMP, DAM, MBI, NIN, SBA	B
How do we best monitor finfish in turbid water?	Finfish	EMBMP, LCSMP, WNI	B
What is the level and ecological significance of by-catch from commercial and recreational fishing?	Finfish	All marine reserves	B
How well are fish populations within marine reserves connected to those outside? To what extent are fish populations inside reserves connected, particularly those within different management zones?	Finfish	All marine reserves	B
How do environmental factors, particularly those affected by climate change, and fishing pressure interact to affect the abundance and diversity of invertebrates and finfish?	Finfish Invertebrates	All marine reserves	B
Assess the impacts of fish feeding and fishing on the behaviour of fish and elasmobranchs.	Finfish, elasmobranchs	RSMP, NIN, WNI	B
What are the movement patterns of targeted fishes in relation to current management zones?	Finfish, elasmobranchs	All marine reserves	B
Assess the effects of recreational and commercial fishing on marine reserve assets. How has fishing and its impacts changed over time?	Finfish, elasmobranchs, invertebrates	All marine reserves	B
Identify ecologically relevant and sustainable management targets for the take of fished species.	Finfish, invertebrates	All marine reserves except SEMP	B
Assess spatial and temporal variance in fishing pressure within marine reserves. Identify what species fishers are catching. Where are when are those species being caught?	Finfish, invertebrates	All marine reserves except SEMP	B
How will the coastline change in response to rising sea levels and cyclonic activity? What will be the ecological implications for flora (e.g. mangroves and saltmarsh) and fauna (e.g. birds and nesting turtles)?	Geomorphology, turtles, mangroves, birds	All marine reserves	B
Describe the distribution patterns and natural variability of intertidal communities with respect to anthropogenic pressures and management zones.	Intertidal	EMBMP, DAM, MBI, NIN, SBA, MSI, JBMP NCMP	B
What invertebrate species are being taken from intertidal habitats? What are the ecological consequences of removing organisms from intertidal areas?	Intertidal, invertebrates, soft-sediment	All marine reserves	B

What are the impacts of rock lobster fishing on marine habitats, the prey of lobsters and their competitors?	Invertebrates, macroalgae, seagrass, finfish, coral	NCMP, MSI, JBMP	B
Assess and quantify the nature, level and potential impacts of human activities on mangrove communities within the reserves.	Mangroves	LCSMP, DAM, MBI, SBA	B
Map the distribution of different seagrass species, particularly in nearshore areas and/or areas of high human activity.	Seagrass	All marine reserves	B
What is the concentration of sediment contaminants (e.g. hydrocarbons and antifouling paint) in mooring and anchoring areas relative to appropriate control sites?	Sediment quality	All marine reserves	B
Assess the level of turtle egg mortality, including that from introduced animals such as foxes, dogs and cats.	Turtles	EMBMP, DAM, SBA, NIN	B
Develop and document species and location specific methodologies for long-term monitoring.	Turtles	LCSMP, EMBMP, MBI, DAM	B
What is the relative importance of anthropogenic and natural processes within marine reserves that influence turtle populations? How do these relate to pressures outside marine reserves?	Turtles	LCSMP, EMBMP, DAM, NIN, MBI, SBA	B
What will be the impacts of climate change on the Shark Bay marine environment and especially the Faure Sill and Hamelin Pool.	Various	SBA	B
What are suitable ecological measures, indicators and methods for monitoring Aboriginal culture and heritage?	Various	LCSMP	B
How does the condition of biological assets within the park contribute to maintaining Aboriginal culture and heritage?	Various	LCSMP	B
What are reliable measures of sub-lethal impacts of climate change on fauna and flora? How will sub-lethal impacts differ among species?	Various	All marine reserves	B
How will the distribution of species change in response to climate change?	Various	All marine reserves	B
How will hydrodynamic regimes change in response to climate change? How will such changes affect propagule dispersion and connectivity between communities in marine reserves? How should this knowledge inform marine reserve planning?	Various	All marine reserves	B
What is the potential vulnerability of species or communities to climate change? Can their susceptibility and/or resilience be identified?	Various	All marine reserves	B
What is the optimal configuration (e.g. number, size and location) of sanctuary zones in marine reserves?	Various	All marine reserves	B
Develop an appropriate understanding and predictive capacity of the circulation and mixing of marine reserve waters, particularly in relatio to key ecological processes (e.g. nutrient supply and productivity, recruitment, connectivity) and threats (oil spill, introduced pests).	Various	All marine reserves	B

Table 4 (cont.)

Research strategy or question	Ecological asset	Region or marine reserve	Broad (B) or specific (S)
How do we better integrate local knowledge systems into a comprehensive understanding of the natural environment?	Various	All marine reserves	B
How will climate change affect primary productivity and the flow of energy in marine systems?	Water quality, macroalgae, seagrass, mangroves	All marine reserves	B
Assess the impact of lighting on birds in the Swan Estuary Marine Park.	Birds	SEMP	S
What impact have artificial breeding shelters had on bird populations at the Rowley Shoals?	Birds	RSMP	S
Assess the ecology of shore and sea birds, particularly in relation to identifying nesting/roosting areas on mainland beaches, disturbance from human activities and trophic ecology.	Birds	All marine reserves	S
Describe and map coral communities, particularly around areas of human use (e.g. anchorages around the Montgomery Islands).	Coral	LCSMP	S
Are the current management zones within the park adequate, particularly with regard to humpback whales and the special purpose whale conservation zone?	Cetaceans	LCSMP	S
What is the distribution and population dynamics of Australian snubfin dolphin (*Orcaella heinsohni*) within the park? Assess the significance of anthropogenic threats to snubfin dolphins in the park.	Cetaceans	LCSMP	S
What is the distribution and abundance of dolphins in the park, particularly in St George Basin? Is the current zoning adequate for habitat and species representativeness and protection?	Cetaceans	LCSMP	S
What are the physical and behavioural impacts of increased vessel traffic, tourism, and industry on whales?	Cetaceans	LCSMP, NCMP, NIN	S
Assess possible climate change impacts on dugong at the southern edge of their distribution.	Dugong	SBA	S
What is the relative impact on dugong of exposure to vessels, particularly in areas of critical habitat?	Dugong	LCSMP, SBA, EMBMP, DAM, NIN	S
What effect, if any, does tourist activity have on individual whale sharks or the broader whale shark population (e.g. behaviour, physiology, reproductive biology, size structure etc.)?	Elasmobranchs	NIN	S
Assess ecological connectivity of coral trout within the Rowley Shoals and nearby reefs.	Finfish	RSMP	S
Describe finfish diversity, abundance and demographics with respect to different habitats and management areas in the marine park.	Finfish	LCSMP, EMBMP	S

Assess the levels and ecological impacts of the marine aquarium fishery in the reserves.	Finfish, corals, invertebrates	DAM	S
Assess the effects of reduced river flow on sedimentation of the Walpole and Nornalup inlets entrance channel.	Geomorphology	WNI	S
How have changes in water level, river flow and human disturbance altered estuary shores?	Geomorphology	WNI	S
What is the best method to measure and monitor erosion along estuary shores?	Geomorphology	WNI	S
How has collection of hermit crabs influenced their abundance and ecological role?	Invertebrates	EMBMP	S
How many shells have been removed from the system and what is the ecological impact of shell removal?	Invertebrates	EMBMP	S
Assess the population dynamics of cockles and oysters in relation to natural recruitment and potential human impacts.	Invertebrates	WNI	S
Assess the potential impacts of climate change on Hamelin Pool and its microbial communities.	Microbial	SBA	S
Assess the impact of recreational and commercial human activities on Australian sea lions (*Neophoca cinerea*) and develop sustainable management targets for these interactions.	Pinnipeds	MSI, JBMP	S
Assess the trophic ecology of Australian sea lions and New Zealand fur seals (*Arctocephalus forsteri*) by age and gender, particularly in areas of high human use. How have fisheries and marine reserve management influenced the abundance of pinnipeds?	Pinnipeds	MSI, JBMP	S
How do anthropogenic factors (including climate change) influence the mortality of sea lions at different life history stages? How important are these anthropogenic factors relative to natural factors within the park?	Pinnipeds	MSI, JBMP	S
Assess how climate change may impact the distribution and abundance of crocodiles, particularly through sea level rise on habitat and temperature increases on embryo viability?	Reptiles	LCSMP, EMBMP	S
Assess the impact of boat moorings and anchoring on seagrass communities.	Seagrass	NCMP, MSI, SEMP, JBMP, SBA	S
Assess how artificial light impacts on nesting turtles and hatchlings.	Turtles	MBI, DAM	S

decisions (Cash et al. 2003, Rudd 2011). Where research in WA's marine parks and reserves may be undertaken solely by external institutions, scientists are encouraged to pursue these strategies and questions and liaise closely with Parks and Wildlife staff to ensure that research ultimately informs management. Moreover, where parks are jointly managed with traditional owners, the priorities of Parks and Wildlife need to be developed in association with the relevant joint managers to incorporate traditional ecological knowledge and cultural values. Developing close working relationships between managers and researchers will ultimately result in more targeted research activity and help to close the research implementation gap (Cvitanovic et al. 2015).

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