National Marine Science Plan
Biodiversity Conservation and Ecosystem Health
White Paper: Benthic Ecosystems

by

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Abstract

Benthic Ecosystems occupy Australia’s submerged lands, and interact with pelagic processes. They account for more land surface area than our terrestrial lands. This paper demonstrates our strengths in research into benthic ecosystems as well as our weaknesses. We need to continue to support existing facilities but there is also need for growth in facilities and approaches. Two immediate large areas of development would be to develop a Long Term Ecological Research (LTER) network for marine benthic research that could address the immediate need for time series ecological data, and to use successful models and platforms to develop Centres of Excellence in temperate, deepwater and Antarctic benthic ecosystems.

Background

What are benthic ecosystems?

Benthic ecosystems are ecosystems that are associated with the intertidal and submerged lands in Australia's marine estate. The Australian submerged lands cover nearshore and offshore islands, the intertidal and shallow subtidal (<20 m, or within Scientific Diving region), inner continental shelf (20 – 100 m depths), and the deep ocean – comprised of the outer continental shelf, continental slope and abyssal plains (>100 m depth). These depth-defined regions loosely relate to jurisdictions with State waters being nearshore and offshore islands; most of the continental shelf, the slope and deeper being Commonwealth waters managed as the Exclusive Economic Zone. Areas of Australia's Antarctic Marine Jurisdiction are managed by the Commission for the Conservation of Antarctic and Marine Living Resources (CCAMLR).The composition and distribution of benthic communities on Australia's continental shelf and continental margin is highly correlated with depth (Last et al. 2010). Beyond the coastal region, biologically meaningful depth zones can be summarised as Inner shelf (<100 m), Outer shelf (100-200 m), Upper slope (200-700 m), Mid-slope (700-1500 m), Lower slope (1500-2000 m), and Rise and abyss (>2000 m) (Fig 1). These zones are separated by transitions and show some variation between biogeographical regions.

Within the Australian continental EEZ (excluding offshore territories; Fig. 1), waters under State jurisdiction (typically within 3 nautical miles of the coast and <100 m depth) make up 428,885 km^2, or 6% of the total area. Continental rise and abyssal depths comprise half the seabed, the inner shelf over one-quarter, and the outer shelf and continental slope the remainder (Table 1).

Table 1 Depths zones delimiting benthic biota showing plan area of seabed

Depth range (m)	Area (km^2)	% of total
Inner shelf (0-100 m)	1,842,219	27%
Outer shelf (100-200m)	298,707	4%
Upper slope (200-700 m)	355,522	5%
Mid-slope (700-1500 m)	682,377	10%
Lower slope (1500-2000 m)	371,113	5%
Rise and abyss (>2000 m)	3,344,633	49%
Total	6,894,572	100%

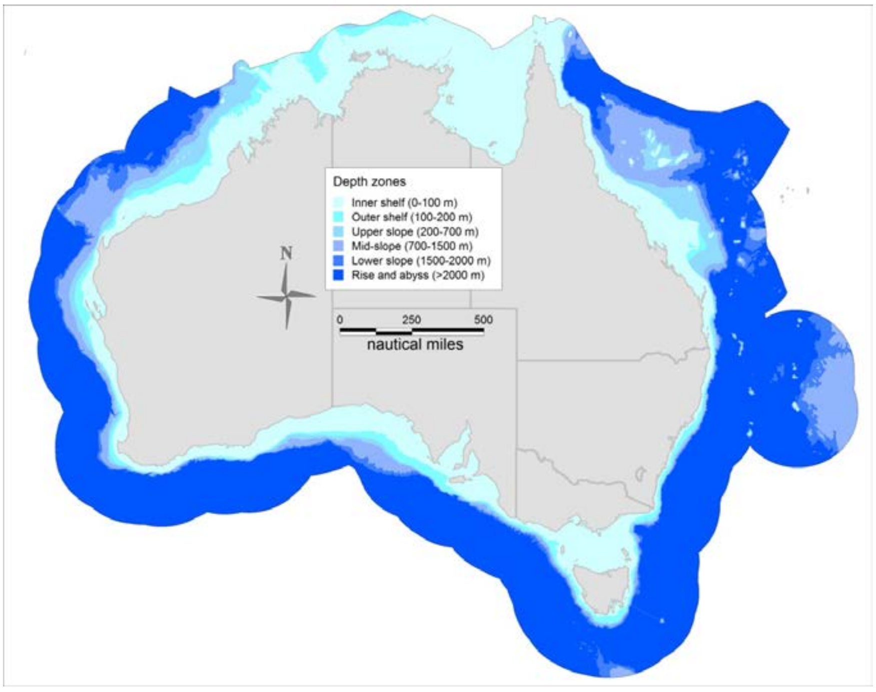

Figure 1: Distribution of depth zones that are meaningful for benthic biota in Australia's EEZ (without Antarctic and subantarctic territories) by water depth.

Significant continental shelf habitat occurs within the 20 m depth zone (Fig 2). The greatest extents are in the Northern and North Western Continental Shelves where mining and oil and gas industries are the most developed, but where population densities are among the lowest in Australia. Other significant shelf areas include Shark Bay, Great Australian Bight, Spencer Gulf and Bass Strait, all important sites of biodiversity, economic value both in fisheries and oil and gas and near centres of human population.

Figure 2: Continental shelf within the 20m isobath

Maturity (brief history of benthic ecosystem research):

Marine benthic research has occurred in Australia for almost two centuries. The diversity and uniqueness of the organisms found on tropical and temperate reefs in Australia have interested initially the explorers and scientific missions to Australia followed by the first European colonists. Formalizing research into marine benthos occurred in the early years of the 20th Century. Hammond (1994) gives a short summary of the early development of marine research into Australia. His section on the growth of Institutions outlines their importance in developing our knowledge of the marine biology of Australia. He indicated that in the late 19th Century, the 6 Universities and state museums were the basis for the home-grown increase of Australian endeavours in marine biology. More recently, the establishment of CSIR: Fisheries Section in 1936-37 at Cronulla, NSW and its expansion into the Division of Fisheries and Oceanography in 1956, and subsequent evolutions established CSIRO Marine Science as a prominent contributor to the development of our knowledge on marine benthic ecosystems across Australia's EEZ. By the 1960s and 1970s, state fisheries research organisations were prominent on all states and accounted for a large fraction of total marine benthic research. A rapid expansion of our knowledge of Australia's marine territory in the 1970s can be credited to the establishment of marine biology teaching at many universities and the establishment of the Australian Institute of Marine Science (AIMS) with its broad mandate to conduct marine research and special focus on understanding the impacts of human population growth on the Great Barrier Reef. Since the late 1970s, AIMS and CSIRO have expanded their research agendas, while Universities have grown their Marine Biology research and teaching portfolios. This collective growth and diversification of marine benthic research over the last 3 decades has resulted in a relatively mature understanding of shallow (nearshore and inner continental shelf) benthic ecosystems with some examples of good local to regional scale understanding of individual processes. However, this understanding is often fragmented and rarely placed into a broader ecosystem context.

Australia has a 40-50 year history of shallow water research on corals, kelp beds and seagrass meadows as well as pioneering intertidal studies. The AIMS, University of Queensland (UQ) and James Cook University (JCU), along with NSW Universities and the Australian National University (ANU), have focussed on the Great Barrier Reef - predominantly on hard coral and reef fish ecology/ biology. Less effort has been given to coral reefs in western and northern Australia and to non-coral, reef invertebrates, although recent programs like the 5 year Ningaloo Research Study, funded through WAMSI and a CSIRO Flagship Research Cluster, has started to redress the imbalance. Maturity of coral reef research is demonstrated by the world leading research concentration through the Centre of Excellence in Coral Reef Studies under the leadership of Hughes, Hoegh-Guldberg and McCulloch at JCU, UQ and University of Western Australia (UWA), that accounts for a significant fraction of all coral reef scientific publications globally every year. This is the product of decades of substantial research investment, demonstrating that with similar strategic knowledge-investments Australia would establish international leadership in other benthic marine ecosystems.

In temperate Australia intertidal and subtidal research is also indicative of a mature research community, with concentrations of researchers in every major city in national and state research clusters including CSIRO, Museums, Herbaria, Universities and State Government Research Laboratories. For example, a quick look at Marine Institutes around temperate Australia shows the following: Sydney Institute of Marine Science (UNSW, U. Sydney, Macquarie U.) in NSW; Institute of Marine and Antarctic Research (UTAS), CSIRO and Antarctic Division (AD) working in the Southern Ocean, Antarctica, Tasmania and Victoria; Victorian Marine Science Consortium (Deakin, RMIT, Victoria, Monash Universities, University of Melbourne, CSIRO, EPA Victoria, and Fisheries Victoria) in Victoria, and; the Oceans Institute (UWA) and Indian Ocean Marine Research Centre (UWA, CSIRO, AIMS) in Western Australia. Australia has a very strong history in marine experimental field ecology that is needed to elucidate cause-effect relationships. In the decade 2002-2011, Australia published over 100 publications on kelp ecology, which with an equal output from USA, accounted for half of the publications worldwide (Smale et al. 2013). The main focus has been on shallow water (<20m), with less in deeper areas and on the shelf. Australia has led the world in research into intertidal rocky shores – notably through Underwood and others at U.Sydney, Keough and others at University of Melbourne, and the legacy research effort they have created. Standards in benthic ecological and environmental monitoring and assessment used globally have originated in academia in Australia. Research in restoration ecology (e.g. oyster reefs, living shorelines, underwater forests, seagrasses) is relatively young and underdeveloped relative to elsewhere in the world, although is growing in importance. Sandy beach research is undeveloped (Dittmann 2007), and is a real research gap given that beaches are part of the Australian national psyche and we have the most sandy shorelines of almost any country in the world.

Research of benthic ecosystems on continental shelves has advanced significantly over the past decade with the application of airborne and satellite remote sensing and multibeam sonar technology to the mapping and characterisation of the seafloor. In Australia, multi-beam swath mapping has provided new insights into the form, composition and evolution of a wide range of benthic environments including coral reefs (living and relict), temperate reefs, seagrasses, sediment communities, submarine canyons, seamounts, continental slope and the abyss. Coupled with advances in seabed imaging (towed video, AUV) and new approaches to sampling design (e.g. spatially balanced stratified techniques), our understanding of these benthic systems has evolved from basic description of seabed features to the analysis of biophysical processes driving the observed patterns. In Australia, benthic research has dealt with the challenge of a very large marine estate by applying predictive spatial modelling to develop maps of seabed types (e.g. substrate hardness, sediment type) at a range of spatial resolutions in data poor areas. Australia has no submersible capacity (i.e. to non-destructively or precisely targeted sample biota from deep waters).

Australia’s deep sea makes up the great majority of the Commonwealth Marine Reserve System (CMRS), most individual reserves, and highly protected zones; for example, depths >200 m make up > 98% of both the Coral Sea CMR and its Marine National Park Zones. In contrast, deep sea benthic ecological research has historically been poorly represented. Seamounts and submarine canyon were recognised as ‘special’ types of geomorphic surrogates for biodiversity hot spots (Harris 2007) – but relatively few (52 of 258 seamounts and 15 of some 700 canyons) have had any systematic (often sparse) sampling of their benthic ecosystems [CSIRO, unpublished data]. The study of benthos on continental slopes and abyssal plains is very much in its infancy. Knowledge of Australia’s deep sea ecosystems – including those of deep shelves, the continental slope and rise, abyssal plains, seamounts, and submarine canyons – has increased dramatically over the last 2 decades – driven by the expansion of deep-water fisheries, increased concern about conserving deep-sea biodiversity, and by access to, and adoption of, enabling technology. Despite considerable advances in the spatial and depth coverage of deep-sea ecological research and progress in biodiversity inventories, many important aspect of deep-sea functioning remain incompletely understood. For example, the extraordinarily high biomass of benthic megafauna on rocky bottom in 2300 m depth off Tasmania is unexplained [Thresher et al 2011]. Data from CSIRO deepwater invertebrate megafaunal collections (2000-2008) indicate generally lower richness on the continental slope than shelf in six invertebrate groups but how much of this trend is due to sampling density and design is unknown (Figure 3).

An indicator of both progress and knowledge gaps in Australia's deep ocean are data on deep water corals – identified as conservation assets, and a prominent indicator used globally to identify benthic 'vulnerable marine ecosystems' (VME) in assessments of human impacts. Although the number of known species in Australian waters has increased rapidly from 135 to 457 over the last 15 years [Alderslade et al. 2014], deep water corals have been systematically collected from only 24 of 67 CMRs, and most collections are sparse in terms of species numbers and total specimens [CSIRO, unpublished data]. This limited sampling of fauna in deep water also applies to other major benthic invertebrate groups including sponges, ascidians, anemones and molluscs).

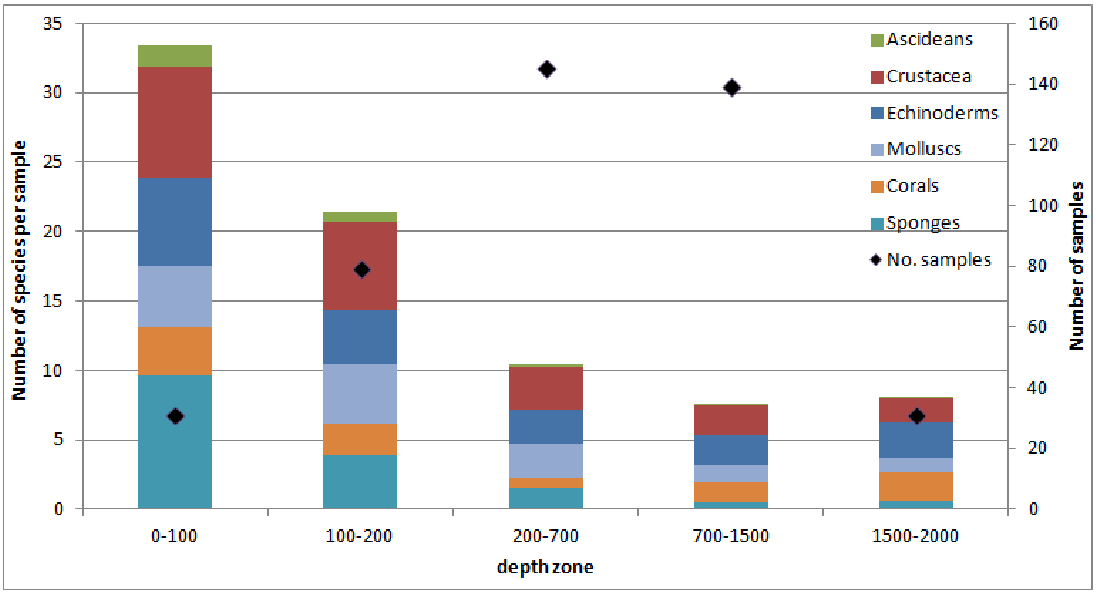

Figure 3: Diversity (number of species per sample) in relation to sampling density for 6 major invertebrate groups from CSIRO invertebrate collections made between 2000 and 2008.

There are few empirical data available to estimate the representativeness of the CMRS in terms of deep sea benthic community composition, distribution, structure and connectivity, although recent work by the NERP Marine Biodiversity Hub has collected baseline biological, geophysical, and geological data in selected CMRs. There are few empirical data available to estimate the vulnerability of deep sea benthic systems, including in CMRs and Key Ecological Features. There also has been no attempt to understand the links between natural and cultural assets of deep sea reserves, for example the roles of shipwrecks for benthic megafauna including deep water corals.

Deep Southern Ocean and Antarctic communities are also poorly understood – recent Census of Antarctic Marine Life has addressed this to some degree across Antarctica – but that initiative has now ended, with little prospect for continued effort into the future. Discovery of amazingly field-like aggregations of hydrocorals that support diverse communities, for example, show how much there is yet to be discovered and understood in these ecosystems. These are regarded as VMEs. Again most studies focused on inventories – still large gap in understanding of ecological process. VMEs have also been declared in two areas of the Australian Antarctic Territory. The detection of vulnerable hydrocoral communities in just two areas is insufficient to fully characterise the habitat requirements of these species, and to therefore model their predicted distribution.

The use of molecular markers in understanding connectivity is a fairly recent development in marine systems, particularly in temperate Australian systems. Molecular markers can provide information on genetic connectivity for many species, in particular those which are difficult to study using more traditional demographic methods. Key research papers have alluded to significant breaks in connectivity across temperate Australian waters, some of which are common among taxa (e.g. Bass Strait, Ayre et al. 2009), while others are less obvious (e.g. segregated by depth Miller et al. 2011). Genetic connectivity has wide ranging implications for the development of marine protected areas, regional and local management, and conservation and restoration actions. Many benthic marine organisms, particularly the key habitat forming species, such as seagrass and macroalgae, are sedentary species, but contain effective dispersal phases in their life cycles. Gaps in knowledge were highlighted for seagrasses in Kendrick et al. (2012). Several recent papers suggest that marine systems operate on a regional basis under the strong influence of boundary currents (Coleman et al. 2013, Wernberg et al. 2013b), and some species may be well served by the current system of marine reserves (Coleman et al. 2011).

Success of the research

Increasingly, research into benthic ecosystems is being linked to an understanding of livelihoods, ecosystem services (including carbon burial and sequestration) and the complex socio-ecological systems which underpin the health of these ecosystems (e.g. Hughes et al. 2005). Australia's research footprint in the broader Indo-Pacific and globally cannot be under-estimated.

Benthic ecological research from Australia has been particularly important in influencing science and management, globally. For example:

- Australia leads the way in coral reef research as described above.
- Seagrass and mangrove research is strong internationally (and influential, given the areas of these habitats and diversity of species). This has led to recent growth in seagrass and mangrove restoration that has developed international collaborations (e.g. Lee 2008, Statton et al. 2012).
- Temperate reef research also has a strong national and international influence especially with climate change effects on species distributions and fisheries (Wernberg et al. 2011, Smale et al. 2013).
- Work on Australia's deep sea seamounts has contributed significantly to changing paradigms at a global scale (Althaus et al. 2009; Clark et al. 2010; Rowden et al. 2010; Schlacher et al. 2010; Clark et al. 2012)
- Habitat and biodiversity mapping the continental shelf, slope and deep sea has led to the development of both techniques and technology that is world leading; including spatial modelling methods (Dunstan et al. 2011, 2012), hydroacoustics (Kloser et al. 2007), and image techniques (Schlacher et al. 2010), and platforms to deploy them (AUVs, towed sleds etc.) (Shortis et al. 2008).
- Standards developed for experimental design and monitoring, assessment of benthic habitats (Williams et al. 2011), and benthic habitat mapping have penetrated throughout the world.
- Australia is a leader in Antarctic marine environmental research, particularly in regard to science leading to management outcomes such as remediation and changes in environmental management practices. Also leads in conservation planning and management for example is a key player in CCAMLR and Antarctic fisheries management including impacts on benthic ecosystems.

Climate Change research and adaptation in marine benthic ecosystems leads the world. The past decade seems to be a decade of catastrophic disturbances to coastal marine benthos and a lot of effort has been spent on understanding the implications both ecologically and to society of loss of major primary producers like kelps and seagrasses and their associated animals (e.g. seagrasses – Thomas et al 2014; Fraser et al 2014; kelps – Wernberg et al. 2103a, Smale & Wernberg 2013 Ling et al. 2009; demersal fish - Verges et al 2014). Australia has 2 subtropical transitional zones for tropicalization (WA Abrolhos Islands and EA Solitary Islands) and leads the way globally in terms of tropicalization research (Verges et al 2014, Figueira and Booth 2010, Wernberg et al 2013a).

Current funding (who funds this work currently)

- Australian Government through AIMS, CSIRO, GA, Department of Defence.
- Australian Research Council through Centre of Excellences, ARC Discovery, ARC Linkage and other programs.

- National Environmental Research Programs (e.g. Marine Biodiversity Hub) through the Department of the Environment (DoTE)
- Department of Industry (National CO2 Infrastructure Plan)
- Fisheries Research and Development Corporation (FRDC) – funds research that supports the fishing industry
- Fishing and aquaculture industries fund research that enhances their businesses
- Mining industry (including petroleum) for environmental assessments and management plans as well as environmental offsets. (e.g. the oil & gas industry are now starting to invest in understanding deep sea ecological systems - BP in the Great Australian Bight, Serpent program).
- State agencies with a responsibility for natural resource management funded by States. For example: in South Australia: PIRSA, DEWNR, EPA; in New South Wales: NSW Environmental trust; in Victoria: Department of Environment and Primary Industries, and; in Western Australia through the WA Marine Science Institution, a joint venture between state government, commonwealth research providers and state universities and Fisheries Department, Office of the EPA and Department of Parks and Wildlife.
- National and international philanthropic grants and foundations (e.g. Hermon Slade foundation, Great Barrier Reef Foundation).
- Australian Antarctic Division (AAD), Dept of Environment, funds research around Australia's stations and in Australia's Antarctic territorial claim and EEZ.

Relevance

Who are the end users who benefit/will benefit from this research (directly or indirectly).

An important component of marine benthic ecosystem research is exploratory and discovery science for the advancement of knowledge. The end users are the scientists themselves both nationally and internationally. Application of this knowledge to other end users may take years to decades but the value of discovery cannot be underestimated as it is the foundation to basic (base-line) knowledge of Australia's benthic marine biota and to Australia's competitiveness in marine science globally.

The application of research in marine ecosystems feeds policy, planning and management at Commonwealth, State, regional and local scales. Selected examples (below) demonstrate the benefits from marine benthic ecosystem research across these scales and including non-government end users like industry, tourism and scientists.

Commonwealth Government:

- Department of Environment: Wildlife, Heritage & Marine Division and Parks Australia Division - benefits as the agency responsible for managing Commonwealth Marine Reserves by receiving science products that are used (1) for reserve design and to support setting priorities for spatial zoning; (2) to develop and refine ongoing management plans; and (3) to promote awareness and understanding of marine ecosystems; and
- The Australian Fisheries Management Authority relies on system-level benthic research to inform the development and implementation of ecosystem-based management principles – in line with best-practice approaches and the requirements of Australia's EPBC Act (e.g. Smith et al. 2007). There are long-term benefits to the deep-sea fishing industry because marine reserves ameliorate fishing impacts on commercial species and fishery ecosystems including benthic habitats (Smith et al. 2011).
- Department of Defence
- Great Barrier Reef Management Authority
- Department of the Environment, Australian Antarctic Division – Benthic research around Australia's Stations and in the Southern Ocean has lead to changes in environmental management practices, fishing practices and management (e.g. benthic trawl fishing around Heard Island)

Industry:

- Offshore Industries (Oil and Gas exploration and production): through access to information on marine environmental baselines and national scale maps of seabed structure (geomorphology) and composition (sediments). Research provides environmental assessment, and supports the social license to operate, as extractive industries such as deep seabed mining expand their activities into the deep sea (Schlacher et al. 2013). Human activity at petroleum resource frontiers such as the Great Australian Bight now extends to the lower continental slope (>2000 m) where knowledge of benthic ecosystems is virtually absent (Rogers et al. 2013).
- Tourism Industry (AMPTO): Science communication/education products based on scientific discoveries and advances in understanding of benthic ecosystems build public awareness of and interest in marine environments, which stimulates marine-based tourism, and; Habitat mapping and monitoring has the potential to support the identification and management of new or alternative sites for sustainable tourism and provide useful information for tourism agencies.
- Port Authorities
- Fishing and Aquaculture Industries

State and Local Government:

- State fisheries management and environment agencies.
- Coastal councils and regional Natural Resource Management Groups. Both rely heavily on spatial data (and characterisation) of coastal habitats and marine resources for conservation, sustainable resource use and spatial planning purposes.
- Local communities/general public (biogenic habitat important in mitigating coastal erosion/flooding; aesthetic values of coastal environment are largely derived from coastal ecosystems; recreational activities; mental and physical health)

Research Community (national to local)

- Open access to products (e.g. bathymetry, national repositories such as GA sediment archive, underwater imagery now on NCI) that are available to support research under Creative Commons Licencing.
- Biodiscoveries: many benthic organisms relevant for pharmaceutical industries
- Food webs in coastal and marine ecosystems, overall functions and services provided by benthic organisms, relevant to evaluate processes and effects of human interference, including climate change assessments.

Current uptake of research (Evidence indicating end-user engagement - if available).

- The international community (e.g. IPCC reports on climate change)
- Committee for Environmental Protection (CEP) of the Antarctic Consultative Treaty Meetings. Australian benthic environmental research presented to CEP has influenced recommendations made with regard to Antarctic environmental management.
- Uptake of research by marine managers, particularly in the design of Commonwealth Marine Reserves and offshore fishery closures, has contributed substantially to safeguarding marine biodiversity in Australia's deep sea. (Williams et al. 2011; Williams et al. 2012; Williams et al. in review). Recent examples include: rezoning of the Great Barrier Reef Marine Park; rezoning of other Australian Marine Parks (e.g. Ningaloo Marine Park); MPA planning in SA, Victoria, NSW, WA and Tasmania.
- Development of marine protected areas and conservation/management in Antarctica
- Critical information (for Commonwealth, State/Territory agencies) to inform coastal and marine development and environmental assessments and approvals (including coastal infrastructure, aquaculture, seabed mining, etc.). Recent developments include: the national

Water Quality Protection Plan; NOPSEMA who nationally regulates oil and gas well integrity, safety and environmentally manages Australia's offshore petroleum industry

- Critical Information to State Government to evaluate effects of management practises. Examples include: Water management to the Coorong and the effect on benthic communities in relation to drought/flood cycles; In estuaries or bays that include Ramsar listed areas, there's also a need by government to assess ecological character and quality. (e.g. The NSW state government uses the outcomes of and is in general engaged with research on benthic communities)
- Open access to commonwealth funded data portals including: the e-Atlas that is linked to NERP research projects; AODN – Ocean Data Portal is user friendly and accessible; ALA – Atlas of Living Australia.
- Local Government Authorities have also used outcomes of research to inform estuarine and coastal management

Science needs

(2 pages)

Key science gaps/needs/challenges

Australia's marine estate generates100s of billions of dollars direct wealth and indirect ecosystem services per year. The annual estimates of economic value of Australian marine benthic ecosystems varies from $A39.1 billion for tidal marsh/mangroves, $A53.5 billion for coral reefs, $A175.1 billion for seagrass/algal beds, and $A597.9 billion for shelf systems (Blackwell 2005, in Polonczanska et al. 2007). Despite the value of our marine estate there are major limitations to our basic understanding of the benthic ecosystems and environmental drivers and threats to them.

We need to improve our understanding of the relationship between scale and connectivity in marine environments, long term resilience of ecological communities, and the function these communities provide in terms of ecosystem services and food production. Widespread species and communities, such as temperate macroalgae or seagrass communities and tropical reefs are becoming increasingly fragmented, largely through anthropogenic activities. When species and communities become fragmented at distances beyond their ability to naturally recruit through dispersal, systems break down. Long term recruitment studies would allow the identification of temporal shifts in recruitment of benthic organisms with climate change, which will have further repercussions including community structure, food web dynamics, benthic-pelagic coupling and loss of ecosystem services.

The effect of multiple stressors is becoming increasingly important in marine benthic ecological research (e.g. Przeslawski et al. 2005; Fraser et al. 2014; Wernberg et al. 2011, 2012; Verges et al. 2014). More studies are needed (in all ecosystems) on effects of multiple stressors particularly trans-disciplinary studies (e.g. economists, sociologists, ecologists: Hughes et al. 2005). Also there is a need to understand the compensatory mechanisms, inherent to natural systems, which resist multiple stressors to maintain ecosystem stability. These mechanisms are often cryptic and therefore undervalued, yet they hold entire systems within particular ecological states of value (e.g. kelp forests). This will require monitoring of processes in addition to constituents, as subtle changes in underlying processes often are indicative of altered resilience and impending phase shifts (e.g. Wernberg et al 2010, Hughes 2005).

There is a real need to integrate of microbiological and macrobiological data and perspectives into both monitoring and experimental studies taking on a holobiont approach to ecosystem health. Also, eDNA monitoring and microbial diversity monitoring shows potential and should be a focus for research and development.

There are major spatial gaps in our knowledge especially for the extensive deep continental shelf, slope and abyssal benthos of the Australian EEZ. We know more about intertidal and shallow water temperate and tropical reefs near population centres and in the GBR and Ningaloo regions. Yet both tropical and temperate reefs are poorly studies over much of the southern and north-western parts of the country. The tropical/temperate transition zones on both the east and western coasts are understudied and also require investment. We need to develop a capacity, improved methodologies and cost effective platforms (such as AUVs and ASVs and manned submersibles) for characterizing and monitoring sensitive habitats over time that will assist in the discovery, delineation and characterisation of benthic ecosystems

Long time-series data is lacking for many benthic ecosystems and should be a priority for funding into the next decades separate from research funding. Long term ecological research (LTER) areas, much like the NSF funded LTER program in the USA need to be developed for intertidal and subtidal benthic ecosystems around Australia, either using the TERN model or developing more benthic ecological monitoring platforms within IMOS. These studies need to be at appropriately large spatial scales as well. There is a need to reconcile and integrate small-scale experimental research with larger scale monitoring to understand causality at large scales where experimentation is challenging. LTER approaches allows for this integration of remote sensing, empirical studies, monitoring and modelling approaches. Funding for LTERs needs to be clearly ear marked and dedicated – the current system is not working as even government agencies tasked with monitoring do not have the capacity or funding over longer time scales.

There is an immediate need to develop centres of research excellence in temperate and deep marine waters that like the Centre of Excellence in Coral Reef Studies focuses on resilience or recovery of temperate benthic ecosystems and potential trajectories and rate of change associated with multiple stressors on temperate and deep marine benthic ecosystems. Australia has a unique southern shelf, and the ‘temperate’ conditions here much milder than in temperate regions of the northern hemisphere, with different dynamics and different threats. These differences in the biophysical environment need to be framed in a uniquely Australian socio-ecological context.

There needs to be better integration of biodiversity data including taxonomic records from all regions in Australia’s marine estate. The collection, storage and ease of access to marine data collected over the past decades should be expanded through the Australian Ocean Data Portal or a similar structure is a priority for the next decades. We must protect the rights of collectors as well as developing a long term research memory through proper documenting and databasing of publically funded research.

Key outcomes/ national benefit that would flow from investment in this area

by 2020

- An ecososystem scale program like TERN and the US-LTER program for the collection, analysis and interpretation of long time series broad spatial scale data. This program should also address process studies that address the relationship between scale and connectivity in marine environments, long-term resilience of ecological communities, and the function these communities provide in terms of ecosystem services and food production. This would allow us to better understand risks to benthic communities in response to environmental change and anthropogenic impacts/developments across a range of benthic community types in representative geographic locations.
- Development of Temperate Centres of Excellence based on the successful model of the Centre of Excellence in Coral Reef Studies. These new Centres of Excellence will address our need to understand processes maintaining or driving marine benthic ecosystem shifts and the impacts to biodiversity from shallow coastal environments to the abyssal depths.
- Standardized sampling, data archiving and base analytical methods. The outcome would be improved value from information resources.
- Knowledge about how marine communities are being modified under a changing climate will inform management decisions on fishery management, marine parks, etc. Develop a social climate change adaptation framework to coordinate proactive targets for social resilience against climate change. If communities such as kelps/ corals/ seagrasses disappear under climate change or other anthropogenic causes the entire coastline changes - impacting all end users.

by 2025

- More than 5 years of trans-disciplinary research programs through the TERN/LTER program and the Centres of Excellence that bring together physical, biological, social and economic components to address the big threats to benthic ecosystems and strategies to manage and protect Australia's benthic biodiversity. Next socio-ecological models should be explored and developed to allow managers to understand the implications of, and interactions between, different development scenarios. This will be key for optimal resource allocation.
- From the earlier developments a nation-wide risk assessment for broad threats of climate change and ocean acidification and more regional effects of catchment management, mining and energy and fisheries management on benthic communities and ecosystem functions and services of Australia's EEZ. This will build on previous Ste of the Oceans studies

by 2035

- A more complete inventory of benthic communities in coastal, shelf and deep seas around Australia.
- A national trend analysis of longer term changes in benthic communities and implications for functions and services.
- Assessment of the most efficacious policy and management applications to enhance both biodiversity and wealth from the benthos in the Australian ocean estate.

<u>Perspective</u>

(3 pages)

Specific science priorities (including linkages to international efforts, and why Australia needs to do this work, particularly if we are not already world class)

The surface area Australian margin (not including the Australian Antarctic Territory and Heard Island) add up to a total area of just under 8.6 million km^2 comprising of geomorphic areas of the continental shelf (1.3%), slope (23%), rise(44.5%) and abyssal plain (31.3%) (Harris et al 2005: Table 1).

The specific priorities will relate to increasing our understanding of benthic ecosystems and the taxa that play functional ecosystem roles, effect of climate change and multiple stressors on resilience and determining ecological connectivity to elucidate population maintenance and persistence. This section is organised under the following major themes: Discovery; Environmental Drivers and Threats; System Scale Integration, and; Value

Discovery

- Benthic Mapping: multibeam swath mapping coverage for priority areas (CMRs, high activity shelf areas) well advanced (i.e. approaching 20% of CMR area – currently at 5%)
- Targeted studies of connectivity and recruitment. An understanding about biology and environmental constraints of early life stages may affect impact assessments and predictive modelling. Many benthic organisms have a pelagic larval stage that may act as a bottleneck during changing environmental conditions due to lower physiological tolerance to stress than adults (Byrne 2012). Clearly this demonstrated the coupling between benthic and pelagic ecosystems.
- Determining the scale of biodiversity of Australia's marine ecosystems though taxonomy and systematics, genetics and genomics, utilizing state of the art methodologies and techniques like eDNA.
- Multidisciplinary collaborations between the computer vision, robotics, programmers, statisticians, marine biologists and ecologists need to focus on developing a "black box" software that can process images and compute habitat complexity metrics automatically. Once this process is established researchers across Australia and the world, will be able to

quantify and test the relationship between habitat structural complexity and benthic ecosystems.

Environmental Drivers and Threats

- Improved fine-scale models of nearshore hydrodynamics and sediment transport to understand fluxes and interactions between the coast and shelf
- Improved understanding of the vulnerability of benthic ecosystems to hazards and extreme events, particularly in the context of cumulative impacts (increased vulnerability due to runoff etc) and climate change (e.g. changes in cyclone frequency and intensity).

System Scale Integration

- International collaboration on development of ocean modelling systems to support predictive models and analysis of benthic habitat connectivity.

Value

- Our shelf and deep sea communities are economically valuable (deep sea prospecting, fisheries etc.) but we know considerably less about them than their shallow-water counterparts. Globally there is an increasing focus on deep sea research (i.e. initiatives such as CenSeam, InDeep, interRidge and especially links between Australia and New Zealand researchers) and Australia needs to ensure it is not left behind in protecting its deep sea assets.
- The global significance of Australia's tropical northern coasts (Halpern et al (2008), they are the most near-pristine tropical coastal ecosystems on the planet. Further, with regional (and global) degradation of these tropical benthic ecosystems Australia's waters are increasingly a major refuge of much of the region's tropical marine benthic diversity.
- Temperate benthic soft and hard bottom communities are among the most diverse on the planet but are under threat by tropicalization and ocean acidification associated with human induced climate change.

Priorities to 2020

- Development of a marine equivalent to Terrestrial Ecosystem Research Network (TERN) focussed on long term ecological research areas (LTERs). The main goal of the LTER approach will be to continue or develop long time series and spatially relevant standardized sampling of benthic ecosystems, LTERs can be managed and funded through collaboration across commonwealth and state science providers, research institutes and university researchers, and industry partnerships. A first step towards such an integrated LTER network would be to increase benthic biological monitoring in IMOS.
- Development of improved predictive models including cumulative impacts, resilience and climate change effects and their remediation, using the National Environmental Research Network, BoM, CSIRO and University and State research provider partnerships
- Develop funding sources and research needed to underpin fisheries stock assessment, offshore aquaculture development, oil & gas exploration on the shelf etc., and ability to assess the success of marine parks.
- Strengthen the AODN as a central data port for all Australia and to increase access to existing marine data. Also develop access to the broader community of data presently held by industry in Australia (i.e. IGEMS initiative: oil and gas exploration and development)
- Develop an economic analysis that determines actual value in billions of dollars of services provided by Australian benthic ecosystems. This will help to strengthen the case for their

conservation and restoration, in turn benefiting multiple end-users, stressing here that this does not imply that these services becomes tradable commodities that can be ‘bought out’ (Costanza et al 2014).

- Maintain and extend the Commonwealth Marine Park Network such that, with better protection, ecosystem services will increase.
- Continue to investigate the role of hydrodynamics on structure and diversity of benthic habitats through downscaling of existing national models to a scale relevant to inform coastal processes and drivers of composition, functional morphology and distribution of species and assemblages.
- Establish a better understanding of the importance of scale relationships between benthic habitats and oceanographic variables and their role in larval dispersal, settlement and variability in productivity
- Develop innovative marine spatial management of temperate coasts with science. Development of active management of valued assets via scientific engagement of business that facilitate conservation and education outcomes.
- Develop a standardized set of indicators of community health across a range of benthic community types in representative geographic locations

Priorities to 2025

- Understand options to mediate risks and remediate impacts from 2020 priorities above
- Operational models of ecosystem response and resilience under various scenarios with associated decision support tool (link to other white paper)

Priorities to 2035

- Demonstrable trajectory of recovery of ecosystem health through the successful application of adaptive management supported by management objectives from 2020

Realisation

(3 pages)

Key infrastructure and capability requirements/impediments

The key infrastructure and capability requirements overlap strongly with other White Papers. They can be summarized into: enhancing expertise and collaboration; National Monitoring Facilities (e.g. IMOS); National Fleet and ship facilities; Remote Sensing; shore-based facilities, and; data access, management and standards.

Enhancing Expertise and collaboration:

- Prioritize funding to new research centres of excellence or CRCs (University/Research Institutes) that focus on temperate, tropical, Antarctic and deep water benthic ecosystems.
- Develop Long Term research through TERN/LTER Australian program, addressing long term ecological change in marine benthic ecosystems.
- Fully utilize the network of benthic marine ecologists in Universities and Government Agencies around Australia to address issues like tropicalization, ocean acidification effects, and the impact of population centres and industries on benthos.
- Investments in genetics, genomics and advanced ocean models to address questions of connectivity between populations in the deep sea.
- Investment in taxonomic research, career paths in taxonomy and accessibility of museum collections and identification tools for benthic organisms.
- Key infrastructure and capabilities needs to focus on enhanced image processing and software development, Ideally an increase in the number of national AUVs, at least up to

four, would be required to significantly increase the area mapped in three-dimensions within Australian waters.

- Downscaling of regional hydrodynamic models to a relevant spatial scale that will inform us of intra- and inter reef processes in coastal habitats
- Development and refinement of predictive methods and models for species and habitat distributions

National Monitoring Facilities (e.g. IMOS)

- Investment in Long Term Ecological Research through a marine LTER program like the terrestrial TERN program and the US NSF-LTER program.
- Support and further develop IMOS benthic facilities, especially the AUV program, gliders and AATAMs facilities.
- Smart and learning systems for sampling biodiversity using autonomous tools (gliders, AUVs, ASVs, submersibles). Australia requires several AUVs, a work-class ROV, and manned submersible capability that are capable of deepwater work and are equipped with cutting-edge technology and sampling capabilities (e.g. chemical sensors, cameras, navigation, sampling arms). Ideally, trials of these new systems need to be done early in the life of Australia's new National Research Vessel, the RV *Investigator,* but should not be restricted to this one platform.
- Advanced underwater sampling and visualisation capabilities.
- Telemetry for distributions/home ranges and migratory corridors.
- Strategic deployment of the Marine National Facility (MNF) to progress acquisition of national datasets (e.g. bathymetry in data poor areas).
- At the same time we need to acknowledge that the MNF is unlikely to adequately service inshore coastal waters (habitats most under threat) due to vessel size and design of instrumentation. Access to mid-size research vessels (25-35 m) capable of extended trips and working out to shelf edge is also a priority. We therefore need a capacity for national co-ordination and funding of fleet capacity and research for smaller oceanographic and geospatial survey vessels, autonomous surface and underwater vessels and manned submersibles (multi-institutional).

Remote Sensing

- Continued collection and databasing of satellite and airborne remote sensing for utilisation by researchers.
- LIDAR coverage of shallow waters (0-50m) of the coastline of coastal Australia. Already some states have some data. For example, 4000 sqkm of Victorian state waters have been mapped to a maximum depth of around 35 metres that have been applied for benthic habitat characterisation (Zavalas et al 2014).
- Multibeam mapping of the deeper Australian marine estate, with focus on KEFs and biodiversity hotspots.

Shore-based facilities

- Most key land-based national infrastructure is in tropical north (e.g. SeaSim at AIMS; free-air CO_2 experiments at Heron Is). It must be priority to get similar facilities for temperate, benthic ecosystems.
- Funding for more accessible state-of-the-art wet lab and mesocosm facilities like SeaSIM that can simulate estuarine, soft bottoms, seagrasses, reefs, Antarctic and deep water communities would drive Australian research to the forefront globally.

Data access, management and standards.

- Continued development of National standards for data collection and easy-access depositories for marine datasets.
- Retrievable database of existing SWATH, LIDAR and optical remote sensing of Australia's EEZ. Continued support and expansion of NCI under NCRIS

Funding and coordination requirements/impediments

A Long Term Ecological Research Network needs to be developed that encompasses the diversity of benthic ecosystems in Australia's EEZ and marine territories. The LTER program for Marine Ecosystems should utilize the strengths of the NSF (USA) LTER framework and the Australian TERN and funding should be independent of Institutional and political vagaries in long term funding. This would enhance existing long time series of predominantly physical oceanographic data collected under IMOS and the major national science providers (CSIRO, GA, AIMS, Department of Defence).

Linkage and coordination between key institutions and researchers to address the vast spatial envelopes and bioregions that marine benthic ecosystems encompass. One mechanism would be to prioritize funding to new research centres of excellence or CRCs (University/Research Institutes) that focus on temperate, tropical, Antarctic and deep-water benthic ecosystems.

A broader strategy is needed for Government to provide incentives for fishing and industry to engage at the interface of resource management and conservation research (e.g. SERPENT model provides one example of how science-industry partnerships can work well in deep water, WAMSI Dredging Research Node is another more applied science example).

Continued close engagement between researchers and end-users to identify priority areas for marine research that supports management of benthic ecosystems. This would involve continued funding support for national collaborations in marine research and encouragement of inclusiveness of national researcher participation through the Integrated Marine Observing System and National Environmental Science Program

Expand existing excellence in coral reef studies more broadly geographically, to include fringing reefs, shoals, banks and atolls in NSW, Western Australia and the Northern Territory through targeted funding to AIMS and partner Universities (Fisher et al. 2011).

Plan and fund targeted marine benthic ecosystem scale integration and modelling studies that go across disciplines and habitat boundaries, and draw together our often fragmented understanding of individual systems into a cohesive whole that is more easily available for managers to tap into. Some initial work in this area has been developed by CSIRO and should be further funded and supported.

Continued and enhanced funding to national data storage and retrieval facilities like the Australian Ocean Data Network.

Continued and expanded funding for National Infrastructure, strengthen national networks (e.g. National Estuary Network) and develop stronger linkages between national and state-sponsored research networks.

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