Theme 4: Biodiversity Conservation and Ecosystem Health; a synthesis

Sabine Dittmann, Flinders University, School of Biological Sciences, Adelaide SA5001

Peter Doherty, Australian Institute of Marine Science, Townsville Q4810

Abstract

Australia has the third largest marine territory in the World and a commensurate responsibility to manage carefully its natural, economic and social capital. The diversity of seascapes in a marine jurisdiction stretching from the tropics to Antarctica is reflected in unique biodiversity values delivering a valuable flow of ecosystems goods and services. These values are under pressure everywhere but especially on the continental shelf where marine ecosystems face multiple pressures from human development and changing ocean climate.

Twelve white papers were submitted under this theme and inform this synthesis. They reveal that Australia has world class expertise in the requisite sciences and already contributes significantly to global programs. Regardless, Australia's vast marine domain is grossly undersampled and natural resource managers lack many classes of data essential to assess the effectiveness of the National Representative System of Marine Protected Areas and/or to implement adaptive management of marine ecosystems. The key knowledge gaps are identified and prioritised in a roadmap supporting the national commitment to Ecologically Sustainable Development.

Background

Australia's responsibility to support research into marine biodiversity and environmental protection arises from its sovereignty over the third largest marine Exclusive Economic Zone (EEZ) in the World; an area much larger than the continental land mass. The EEZ includes all climate zones (tropical to polar) and diverse habitats (estuarine to abyssal), and is inhabited by highly diverse ecological communities containing substantial endemism [1, 2, 8, 9]. Discovery of the extraordinary biodiversity in the Australian EEZ is still ongoing [2, 8, 9], while marine ecosystems are coming under increasing threat from cumulative pressures by multiple anthropogenic and natural causes [7, 11, 12].

In 2012, Australia completed the rollout of a National Representative System of Marine Protected Areas (NRSMPA) that was commenced in 1992 with the support of all governments. The NRSMPA was reaffirmed by Australia's Biodiversity Conservation Strategy 2010-2030 as a priority action for protecting biodiversity and building ecosystem resilience in a changing climate. The Strategy is a useful reference to the many dozens of international agreements (Treaties, Conventions, Protocols, etc) that have been signed by Australia committing to the protection of biodiversity. The Strategy contains an even longer list of the Australian policy responses including the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, which is the most comprehensive national legislation underpinning the Australian Government's responsibility for environmental matters [2, 4, 8, 10, 11].

Australia's Biodiversity Conservation Strategy 2010-2030 also endorses the importance of Ecologically Sustainable Development (ESD) supported by "whole-of-ecosystem management", hereafter referred to as Ecosystem-based Management (EBM). Ecosystem Health [7] is one of the most important values that must be conserved in any framework of EBM.

No attempt has been made in this synthesis to quantify with any precision the total workforce supporting marine biodiversity conservation and ecosystem health in Australia. The 12 white papers contributed to this Theme (see **References**) collectively suggest that it could exceed 1,000 specialists, spread across museums, herbaria, and universities in every State and Territory, State and Federal government departments (fisheries, environment), government agencies (AAD, GA, GBRMPA), publicly-funded research agencies (AIMS, CSIRO), natural resource management (NRM) bodies, and conservation organisations. The bulk of the funding for these positions comes from State and Federal governments and public sector sources. Private sector contributions include industry levies (fisheries, GBR marine tourism) and the environmental assessments required with development applications.

Australian researchers have high global impact in marine biodiversity and ecosystem science, through publications, leadership of international initiatives, and influence on the practice of others [2, 7, 8, 11, 12]. For example, James Cook University (JCU) and AIMS were the first and second most prolific source of global scientific publications on coral reefs over a 10 year period [11]. Similarly, Australian authors generated 25% of global publications on marine kelps (2002-11) [11], which was equal first with the USA, and have been world leaders in marine vertebrate conservation (publishing 28% of papers on sea snakes, 27% of papers on sharks, and 12% of papers on marine mammals) [8]. Despite being a relatively new subject, Australians have authored 12% of all papers on marine climate change [12]; strongly outperforming Europe and the USA on a per capita basis. Across all titles including the term "marine biodiversity" [2], the output from Australian authors has been second only to the USA and similar to Canada, France and the UK; all of which are nations with much larger populations. New and emerging programs such as marine microbiology have produced outputs disproportionate to population share (5% of global publications on microbial diversity and processes) [6] and been ranked as World class through the Excellence in Research for Australia (ERA) evaluations carried out by the Australian Research Council (ARC) across the tertiary sector.

Evidence of international impact by Australian scientists includes prize winning contributions to sustainable fish production in an EBM framework, global uptake of software tools for marine spatial conservation planning (MARXAN) and marine ecosystem modelling (ATLANTIS). Australian scientists inform key programs for management and conservation of resources and environment in the Southern Ocean and Antarctica (ACAP, CCAMLR, CEP, IWC). Australian climate scientists have senior and influential roles in the UN-sponsored IPCC, and biodiversity scientists have occupied leadership roles in the CBD, the CoML and other international fora.

The ERA confirms that Australia's universities contain many pockets of excellence at or above World class standard in applicable disciplines, and the tertiary sector continues to supply the market with more than enough entry-level graduates trained in marine and environmental sciences. The heavy reliance on public funds for biodiversity and ecological research, however, provides a bottleneck for progress with professional careers. Nowhere is this more obvious than the reduction in the curatorial staff retained by Australian museums and herbaria, where recruitment has not kept up with retirements [9]. The lack of career paths led the Federation of Australian Science and Technology Societies to declare in 2003 that “taxonomy is now considered a discipline in crisis”. Equally, recent trends towards smaller government have led to PFRA (AIMS, CSIRO) cutting back on foundation disciplines, large reductions among State fisheries research and extension services, and contractions in the public sector workforces dealing with environment and climate change. Apart from agency appropriations, there are no funds for long-term ecological research.

Relevance

Marine biodiversity has great intrinsic ecological value and as a resource that can be exploited either directly (capture and culture fisheries) or indirectly (marine tourism attractions, sources of bioinnovation), yet the non-market value of the ecological goods and services provided by healthy marine ecosystems is estimated to far exceed the total value of conventional marketed economic goods and services [4]. Ecosystem services must be valued in appropriate ways to fully realise ecosystem-based management [4].

Australia’s Biodiversity Conservation Strategy 2010-2030 calls for robust national monitoring, reporting and evaluation [2]. State and Commonwealth environment departments require status and trend data for State of Environment reporting. Data are required to assess the effectiveness of management actions for conserving populations, ecological communities or maintaining ecosystem services [2, 8] and to predict impacts of climate change [12]. Surveys and biodiversity inventories are required to identify Key Ecological Features (KEF), conservation values, species of conservation concern, and Vulnerable Marine Ecosystems (VME) [2, 8, 9, 11]. Spatial classification and mapping through IMCRA (Integrated Marine and Coastal Regionalisation of Australia) have provided the basis for bioregional planning underpinning the NRSMPA [2, 10]. Planning and management agencies are increasingly reliant upon decision support tools that incorporate ecosystem processes [7].

Ecosystem-based management is required most urgently in the most impacted marine environments, which are estuarine and coastal waters [5]. As the most contested spaces, these also have the most end-users: local and State/Territory governments, commercial industries (fishing, shipping, ports), recreational industries (fishing, tourism), conservation NGOs, and the public [5].

Non-indigenous (invasive) marine species pose a known and growing threat to indigenous marine biodiversity with great potential to damage marine industries (especially aquaculture) or natural ecosystem services (clean water) [3]. Consequently research in this under-resourced area has many stakeholders and end-users including industries (fisheries, ports, shipping), regulators, and public.

Other benefits from marine biodiversity research include innovations arising from biodiscovery and marine biotechnology [1]. This broad area includes new chemicals of commercial value, better biofuels, more effective remediation after chemical spills, rapid assays for water quality, and cost-effective monitoring of ecosystem health. The greatest potential for such discoveries comes from the marine microbiota, invertebrates and algae [1, 6]. Discoveries for development of marine biotechnology –based industries will deliver private and public benefits to a broad range of end-users [1].

Science needs

Modern marine management is based on multi-sectoral consensus, rather than enforceable property rights [4]. Consequently, the management paradigm must be shifted from a focus on optimising single outputs (e.g. fisheries production) to more holistic, adaptive management of all ecosystem values including public goods such as biodiversity and ecosystem health. Ecosystem services, including intangible benefits, will need proper valuation. Obtaining the required knowledge for evidence based adaptive management of the mostly data deficient vast area of Australia's marine jurisdiction requires filling the following knowledge gaps.

Biodiversity discovery and classification: A basic pillar for marine conservation actions and EBM is knowledge of the distribution and abundance of organisms. With a small percentage of the EEZ mapped with precision [2] and most of the marine biota from the continental shelf and deep sea still undescribed [2, 9], empirical data collections are needed to fill basic knowledge gaps, inform management, and support biodiscovery [1, 4, 8, 10, 11]. In the last decade, two near endemic dolphin species have been described in Australian waters [8]. Even commercially important species like blue swimmer crabs have been recently differentiated into four species using molecular taxonomy [9], which is important knowledge for effective fisheries management. More complete inventories backed up by national archives of flora and fauna are needed to refine IMCRA and ensure that the NRSMPA satisfies the principles of comprehensive, adequate, and representative conservation of marine diversity in the Australian EEZ [2, 4, 9]. Further work is needed to establish a nationally-consistent habitat classification scheme [2, 7].

Monitoring and reporting: Robust, quantitative and adequate time-series are required to report trend indicators from ecosystems, including indicators of healthy ecosystem processes, in accordance with legislative requirements [2, 3, 4, 10]; especially in a time of rapidly changing climate [6, 12]. In an EBM framework, essential indicators for monitoring programs must be agreed by consensus involving biophysical scientists, ecological economists, managers and other stakeholders [4]. All monitoring in depths greater than 30m is a challenge, especially for the deep sea and extreme environments, and reliant on specialised technologies [2, 11]. Comprehensive inventories and monitoring will allow reserves to be used as reference sites for off-reserve management in other places [2, 10, 11].

Organism-habitat relationships: Knowledge of organism – habitat relationships is needed to identify KEF and VME as part of marine planning [2, 7, 9, 11]. While the need is obvious in remote and poorly sampled ecosystems (e.g. deep sea hydrocoral communities), other knowledge gaps include assessments of biogenic habitat complexity [7] and of species that use multiple habitats during their life cycle. For example, many species underpinning commercial and recreational fisheries on the continental shelf have planktonic larvae and a high proportion of those use estuarine or wetland habitats as juvenile nurseries [5, 10]. Knowledge of such connectivities is required both for appropriate fisheries management and for appropriate valuation of the ecosystem services provided by the nursery habitats [4, 7, 8, 10]. It can also guide investments in ecosystem repair [5].

Ecosystem dynamics: Observations and experimental studies on the structure and function of marine communities and ecological processes are required to estimate the capacity of an ecosystem to deliver ecological goods (e.g. fisheries production) and ecological services (e.g. carbon sequestration) [2, 4, 5, 6, 7, 12]. The complexity of ecosystems (with many links, feedback loops, and interactions) must be embedded in a new generation of models designed for ecosystem-based management in a changing world [4, 7, 11, 12]. This will require new knowledge from poorly characterised food webs in sediments and pelagic ecosystems where microbiota and microbes dominate trophic processes [6, 10] and are highly likely to be sensitive to changes in the temperature, currents and chemistry of the environment [12]. Data from long time series and experiments on marine species and systems will inform managers directly about the adaptability and resilience of marine biota to climate change; at the same time, enhancing risk assessments and the robustness of model forecasts [2, 11, 12].

Cumulative impacts: As ecosystems are under threat from multiple pressures, it is essential that ecosystem-based management is able to identify and track cumulative pressures in order to be able to deliver on objectives outlined in “Australia’s Biodiversity Conservation Strategy 2010-2013”, or “A Plan for a Cleaner Environment (2013)” [2, 4, 7, 11, 12]. Outcomes from targeted monitoring and modelling of status, trends, drivers and pressures will allow informed and transparent evidence-based decision making for environmental management of marine resources [2, 4, 7, 8]. Understanding effects of land-use and climate change on catchment to coast linkages will inform adaptation planning and management, especially given the pervasive effect of coastal water quality upon marine biodiversity and ecological processes (e.g. primary production) [5, 12].

Ecosystem models: If management is to become more adaptive, managers will need to be able to explore the resilience of ecosystem components to both acute and chronic stressors in scenario models that have been tested and validated with real data [7, 11, 12]. Such models will need to be inclusive of all major drivers and be able to predict all major responses. This will require novel trans-disciplinary approaches to integrate across multiple scales (microbial to macro scale), and value systems (biophysical to human) [4, 6, 7, 11, 12]. Furthermore, they will need to operate at scales independent of jurisdictional boundaries to accommodate straddling stocks and large-scale processes/threats [7]. The development of appropriate software will allow managers and stakeholders to evaluate alternative plausible futures and to negotiate consensus outcomes better informed about the trade-offs inherent in the choices [4, 7]. When coupled with monitoring that delivers data streams on ecosystem indicators at appropriate scales, managers will have the key tools to implement adaptive management [4, 6, 10].

Perspective and priorities

Australia occupies a unique position as an island nation state solely responsible for managing a marine jurisdiction that spans tropical to polar environments [4]. Consequently, the Australian marine domain is highly diverse and contains many endemic species [1, 2, 8, 9]. The documentation and understanding of this richness is a great challenge for a relatively small population, especially where the ability to leverage imported knowledge and expertise is low. As a result, Australia must continue to train and employ World class expertise in marine biodiversity and to develop local solutions to the very challenging problem of ecosystem-based management of Australia's marine environment. As demonstrated by the successful export of the MARXAN and ATLANTIS technology, locally-generated solutions have great potential to lead the World in marine management. Meanwhile, the fastest return on investment will be achieved by restoring/repairing ecosystem function in local places already degraded through inappropriate uses [5].

To prioritise research for biodiversity conservation and ecosystem health over the coming decades (see **Appendix**), this Synthesis has reduced the many specific issues in the dozen white papers to a much smaller set. Consequently, a number of issues valued by the specialists in these subdisciplines can only be recovered by reading the original submission (see **References**). We were guided by current priorities, realisation potential and the likely return on investment.

<u>Inventories and discoveries</u>

Biological collections and associated metadata inform multiple applications (from bioregionalisation to biodiscovery), and documenting marine biodiversity is a responsibility shared by State/Territory and Federal governments [2, 9, 10]. Australian museums and herbaria must complete the huge task started in the last decade of converting their records to a searchable electronic database in order to maximise value from historical investments [9].

Australia must find a solution to the vanishing workforce with skills in marine taxonomy and systematics that impede this task. This is less about the training of new graduates than it is about the lack of career options. It might be alleviated by providing a bridge between training and secure employment [9].

A heightened risk of allowing non-indigenous marine species (NIMS) into local ecosystems from the increased volume of international shipping through Australian ports should be met by upscaling biosecurity research [3, 9]. The National Priorities for Introduced Marine Pest Research and Development 2013-2023 suggested that more than 400 non-indigenous species have established in Australian waters, yet a 2012 capability audit identified that CSIRO and State/Territory organisations employ just 15.5 FTE research staff in this area. Identification of invasive species has to be pursued with traditional and molecular techniques [9].

Australia's marine fauna and flora contains many potentially vulnerable species where lack of data prevents a proper risk assessment and determination of their conservation status [8]. Even among the well-studied fish community, a quarter of the endemic chondrichthyans (sharks, rays, skates, and elephant fish) are classed as "data deficient". In the case of cetaceans (whales, dolphins, porpoises), three quarters of the known species are data deficient despite their cultural and legal importance [8].

Migratory species (e.g. large sharks, seabirds, turtles) roam across multiple jurisdictions and cannot be protected by spatial management arrangements in any one jurisdiction [5, 8, 10]. Consequently, there is a need to identify and track the movements of animals at risk because of their mobility. Seabirds are often at risk because of their interactions with foreign fishing fleets in distant waters [8].

Australia's unique marine biodiversity contains great potential for the discovery of novel chemicals (e.g. antifoulants, herbicides, pharmaceuticals, health foods) and bioinnovation research will benefit from collections and taxonomic research [1]. The microbial community offers the most potential to discover valuable new bioproducts, including strains suitable for bioremediation or biofuel production [1, 6]. It is also the furnace for major geochemical cycling and thus provides many key ecosystem services. Hence, for different reasons, data gaps involving microorganisms should be weighted equally with data gaps for large charismatic species.

Monitoring and reporting

Marine habitats and biodiversity provide an essential input layer to regional marine plans and models of ecosystem services [2, 4], yet just 28% of the Australian EEZ has been mapped by sonar (only 6% at high resolution) as of 2013 and so little biological sampling has been done that only 10-13% of all species in the Australian marine territory have been described [2, 9]. Consequently, the closure of existing knowledge gaps is both an immediate and enduring priority. Over time, the NRSMPA and regional marine plans should be updated, tested and validated with richer information sources, since they were created in large part on surrogates and imperfect proxies for biodiversity values [2, 10]. Recovery plans for threatened marine species also require time series data in order to know when to alter and adapt management strategies [8].

Microbes are known first responders to all environmental changes, so the sensitivity of marine microbes should be used to create rapid assays for specific anthropogenic threats (e.g. aquatic pollution) [6]. Applications will include monitoring of environmental health in enclosed waters and seafood security for coastal aquaculture [6].

Long-term ecological research

In an era of rapid change driven by climate and other natural and man-made pressures, continental shelf ecosystems require baseline surveys and monitoring designed to detect ecosystem responses (involving both species and functionally-important processes), monitor ecosystem health, and support adaptive management. Australia's Biodiversity and Conservation Strategy 2010-2013 proposes to implement a long-term monitoring and evaluation framework [2]. Recently, the Australian Academy of Science endorsed the need for such investment with the "Ecosystem Science: Long-Term Plan" (2014). An integrated national network of long-term observation sites should take advantage of the NRSMPA to offer potential reference points for off-reserve changes and conversely to evaluate the benefit of spatial closures [2, 6, 8, 10, 11, 12]. Because of our ignorance about micro-invertebrates and microbial communities, research is needed to identify the critical indicators that must be monitored and included in EBM models [6, 12].

Modelling and decision support tools for ecosystem health

Estuaries and sheltered coastal waters are the primary receiving waters and transition spaces for all materials shed from the land and discharged to the oceans [5]. The biogeochemical models embedded in existing models (e.g. eReefs) [6, 12] need to be better calibrated/validated with appropriate data streams from high profile ecosystems (e.g. the iconic Great Barrier Reef).

Models for ecosystem-based management (e.g. ATLANTIS), supported by adequate monitoring of key indicators, need to be tested and validated with stakeholders in order to become more trusted tools.

The paradigm for managing public goods such as marine biodiversity and ecosystem services must shift from optimising single outputs (e.g. fisheries production) to more holistic and adaptive management of ecosystems. This will require new ways of bringing complex and fuzzy data into consultations and decisions about management choices [4]. It will require the development of trusted and tested scenario models offering plausible futures and risk-based choices [2, 4, 6, 7, 8, 11, 12].

Ecosystem repair

Estuaries and sheltered coastal waters are crucial for safe seafood production and marine recreation, yet include the best known examples of the most damaged marine ecosystems [5, 8]. These environments need urgent repair aimed at rebuilding ecosystem services where that is still possible through improved water quality and habitat restoration (e.g. extensive shellfish beds, seagrass recolonisation). Such actions require baseline data, experimentation and monitoring of outcomes.

International links

Greater investment in marine biodiversity conservation and ecosystem health will enhance Australia's already strong position in global programs [1, 2, 3, 8, 9, 13], where expert involvement provides for repatriation of the World's best knowledge. On this basis, Australia should participate in new initiatives to assess ecosystem health including the Ocean Health Index [8], and the Marine Ecosystem Services Partnership (MESP) for spatially explicit data on economic valuation of ecosystem services [5]. Australia should also partner in international networks to manage the local threat of marine invasive species [3], and to develop new export markets based on marine biotechnology [1]

Realisation

Greater knowledge, transdisciplinary collaboration and research partnerships will be required to deliver the long-term goals of effective marine biodiversity conservation and of ecologically sustainable development in an adaptive management framework [4, 7, 11, 12]. To realise these goals, human capabilities, infrastructure, and funding will need to be aligned.

Surveys and Mapping

Given the deficit that exists today with respect to mapping Australia's vast EEZ and characterising the diversity of its natural values, the collection of primary data is an immediate priority. Beyond State territorial limits (3nm), surveys are dependent on suitable vessels and Australia is not well supplied in this regard [2, 6, 11]. Although the Australian Government has committed to replace the single ice-breaker (*Aurora Australis),* the logistics of resupplying the Antarctic bases and fluctuating budgets have not allowed orderly forward planning of marine science voyages in the Southern Ocean. Similarly a new National Marine Facility Vessel (*Investigator*) has been delivered to CSIRO in 2014 but without funds to operate to its capacity. The selection criteria currently used to task the MNFV are another impediment (precluding voyages of discovery, or monitoring). Regardless, the bulk of operations of the *Investigator* will be in deep or distant sections of the EEZ where the human footprint is lightest. There are a few coastal research vessels capable of servicing the continental shelf and upper slope margins (e.g. AIMS, SARDI, universities) but these lack even the most basic mapping tools (e.g. multi-beam swath) available on the MNFV. Latent capacity in these vessels could be realised through co-ordination linked with investment in appropriate technology [2, 6, 11, 12].

Long-term data streams

The oceans are a dynamic environment experiencing long-term change as part of the Earth's climate system and the majority of marine organisms are highly responsive to changes in seawater. Thus there is an urgent need to track changes in the ocean environment and to track the responses of ecosystems and key biodiversity indicators.

IMOS: Since 2006, Australia has had an Integrated Marine Observing System (IMOS) that monitors short- and long-term variability in the marine weather and climate [2, 4, 6, 11, 12]. IMOS is a national asset that must be sustained and made even more relevant to biodiversity and ecosystem research. The greatest priority is to secure long-term funding for IMOS to convert a decadal investment into sustained data streams. As soon as possible, IMOS should be funded to increase observations from near shore and coastal environments where ocean variability generates the greatest impacts with the greatest cost.

LTER: To complement the IMOS investment in biophysical data streams, Australia needs long-term observations to capture the response of key marine ecosystems (including but beyond biophysical indicators) in order to inform the next generation of ecosystem-based models. This vision has been discussed for more than 25 years. The "Global Ocean Observing System" (http://www.ioc-goos.org/) with its coastal Nodes provides a modern albeit still evolving realisation of this vision. Realisation by Australia could include an expansion of existing infrastructure like IMOS, or linked with an emerging Long Term Ecological Research scheme in Australia. While there are rare examples of existing long-term time series for marine ecological variables, socio-economic equivalents are almost non-existent except for statistics on fisheries. For logistic and cost reasons, the majority of new data streams should come from the continental shelf with ownership and co-funding of the expanded program linked with the NRSMPA and marine planning by the States and Northern Territory.

Experimental facilities

The details of ecological processes will rarely emerge from monitoring data alone although the latter are excellent at generating hypotheses. The cost of research vessels makes them expensive platforms for testing hypotheses about processes. Consequently, shore-based facilities are a cost-effective adjunct to the national vessel fleet. Until recently, field stations operated by universities have been the main choice for extended process studies although much of the work done from such facilities concerns very local scales. Such facilities provide infrastructure (small boats, laboratories, and equipment) that should be developed into a coordinated network to become part of the national research fabric [12].

In 2014, AIMS opened the SeaSim Facility that was funded by the Australian Government to reduce the reliance on vessels to explore complex and long-term processes in tropical waters. This advanced research aquarium facility will be operated as a National Facility with competitive, open access. There is a strong argument for replicating this model to accommodate process studies for temperate and polar environments, where vessel access is even more costly. The small experimental facility at AAD has been profoundly valuable by allowing multi-generation studies on Antarctic Krill that would not have been possible from vessels at any cost.

Research Hubs

Since the launch of the Co-operative Research Centre (CRC) Program in 1991, Australian science has been delivered in part through transdisciplinary hubs formed by partnerships among research providers and research users, including governments and industries. The CRC program has supported research hubs for public-good environmental research (including Coastal Zone, Great Barrier Reef, and Antarctica). More recently, funding from the Environment portfolio has supported research hubs (e.g. Environmental Decisions, Marine Biodiversity, Tropical Ecosystems) as part of a National Environmental Research Program (2011-14) that will become the National Environmental Science Program (2015-20). While the NESP Marine Biodiversity Hub will be part of the solution for biodiversity and ecosystem science, the white paper submissions identify some significant gaps.

Species of Conservation Concern: In 2014, the Australian Government appointed the first Threatened Species Commissioner and the NESP will include a Threatened Species Recovery Hub. Under current guidelines, however, the TSR Hub will not include research on threatened marine species. In 2008, the AAD established the Australian Marine Mammal Centre (AMMC), which has administered a competitive grant scheme for research to improve the conservation of marine mammals through better understanding of their populations, and threatening processes. As of 2014, AMMC continues to exist but without funding for the small grants scheme in spite of the high proportion of Australian marine mammals listed as “data deficient” [8] for assessments under the EPBC Act 1999. The restoration of this line of funding for Australian researchers is highly recommended.

Marine Taxonomy: The Commonwealth Environment Research Facilities (CERF) Program that preceded NERP funded a Taxonomy Research and Information Network (2007-11) with a mission to accelerate research and discovery of Australia’s biodiversity. While TRIN invested primarily in terrestrial biodiversity, it was a successful model with many accomplishments from a four year program. The advantage of all Hubs is networking and critical mass for a period of time but the challenge identified by the marine sector is the lack of career paths for marine taxonomists to bridge the gap between ECR status and secure employment [9]. Consequently, a research Hub for marine taxonomy could provide such a bridge while ensuring that effort was directed to the most significant knowledge gaps in Australian marine biodiversity, including identification of introduced marine species [3, 9], and support for marine biotechnology [1]. As with TRIN, it should be co-ordinated with existing structures (e.g. ABRS, ALA) and stakeholders with strong interests in marine biodiversity.

Ecosystem modelling: New tools will need to be developed to support the adaptive management of ecosystems. Managers will require operational models able to replicate major signals from the managed system; ideally in near-real-time (NRT). Such models, or more likely suite of coupled models, must be able to digest and combine multiple data streams from different domains in order to be able to predict the biological, social and economic consequences of management actions upon a landscape formed by past actions, cumulative impacts, and changing external circumstances. Without a new generation of decision support systems, there is little prospect of the Nation obtaining an indefinite flow of ecological goods and services from healthy marine ecosystems as required by the ESD vision.

Above all else, the development of enhanced capability requires skilled people to create and test new ideas and tools in conjunction with practitioners. Looking beyond current concern about STEM skills in the Australian workforce, the challenges of realising new tools to support ecosystem management demand a multidisciplinary intellectual focus justifying a Centre of Excellence. In climate science, the need for advanced modelling is expressed by CAWCR; a joint venture supported by CSIRO and the Bureau of Meteorology. Since ecosystem science lacks such an obvious partnership, and is more multidisciplinary, the starting place is more likely a Centre of Excellence in the tertiary sector supported by the Australian Research Council (similar to the successful CoE for Coral Reef Studies).

A new generation of models for marine ecosystems will require vastly greater volumes of observations (from diverse data streams) to be stored in easily retrievable forms for sharing among multiple users. While the long-term need is for NRT tracking of multiple variables to create situational awareness and operational forecasts, the same time-series data will need to be easily retrieved (months and years after initial storage) for re-analyses and re-use in scenario models [2, 4]. As marine data will be collected, used and re-used by multiple users spanning multiple jurisdictions [4], they will be stored across a distributed network linked with the management of the NRSMPA supported by a LTER program. Consequently, provision must be made for adequate mass storage, high discoverability, fast transfer rates, seamless inter-operability, and super-computing power within the national network. This will require appropriate data sharing arrangements offering minimal barriers to open and free access [2, 7]. Existing mechanisms (e.g. AODN, ALA) should provide the backbone for national platforms and be enhanced with capabilities to meet the information needs of ecosystem-based management [9, 11].

Public Engagement

Public engagement will be an important and critical element of realisation because ESD is not cost free. This message is associated with conservation organisations but is rarely heard from the science community. As made clear, however, by Australia’s Biodiversity Conservation Strategy 2010-30, which is endorsed by the Australian Government, “**business as usual is no longer an option**”. This message needs to be restated clearly in the Australian National Marine Science Plan.

Funding

To date, the majority of investment in biodiversity conservation and ecosystem health studies has come from the public purse where there is always strong competition from other demands [7]. The “public goods” nature of ecosystem services means that oceans have been undervalued historically in both private and public decision making around use, conservation and restoration [4]. Australia’s unique marine biodiversity will not be conserved without more information, when most of it is still undiscovered and many charismatic species are in current decline [8]. The vision of healthy marine ecosystems providing a perpetual supply of ecological goods and services is an even great challenge to realise in the face of projected population growth and development. This challenge can only be met by short-term investments in the repair of essential ecosystems and long-term investments to halt or reverse declines in conservation values and/or ecosystem health [2, 7, 11].

References

This synthesis paper has been informed by the White Papers below, which were submitted by the Australasian marine community in response to a national call through the membership lists of major professional societies for marine scientists (AMSA, ACRS, ASFB). The Convenors thank every Lead Author in the following list as well as all persons acknowledged as Co-authors and Contributors in the individual submissions.

While the Synthesis has been informed greatly by the white papers, we have been forced to condense and summarise. As authors, we accept responsibility for all errors, oversights, or omissions in the Synthesis, and urge readers of this document to find the detail in the individual white papers. We thank the lead authors who provided feedback that improved this synthesis.

White papers on the Theme: Biodiversity Conservation and Ecosystem Health

[1] **Baker** et al. (2014): Marine Biotechnology; extracting value from marine biodiversity.

[2] **Bax** (2014): Discovery, prediction and monitoring.

[3] **Campbell** (2014): Nonindigenous marine species effects to biodiversity conservation and ecosystem health

[4] **Costanza et al.** (2014): Ecosystem services from healthy oceans and coasts.

[5] **Creighton** (2014): R&D priorities – Australia's estuaries, embayments and nearshore marine environments.

[6] **Doblin** (2014): Marine microorganisms form the foundation of healthy ocean ecosystems and successful marine industries.

[7] **Gillanders** (2014): Ecosystem health.

[8] **Harrison** (2014): Marine vertebrate conservation (including threatened and protected species).

[9] **Hutchings** (2014): Aspects of classifying, cataloguing, curating and systematics of marine biodiversity.

[10] **Kenchington** (2014): R&D priorities – Marine Protected Areas.

[11] **Kendrick** (2014): Benthic ecosystems.

[12] **Poloczanska** (2014): Climate change impacts

Appendix 1 Condensed summary from the Realisation section (above) of short-, medium-, and long-term actions to enhance Australia's capacity to conserve its unique marine biodiversity and to sustain a permanent flow of goods and services from its diverse marine ecosystems.

Action Area	Within 5 yrs	Within 10 yrs	Within 20 yrs
Ecosystem repair	Implement the FRDC prospectus for estuarine system repair, which has been supported by a positive cost/benefit analysis	Invest in additional restoration following critical evaluation of the ROI from initial investments	Track recovery of ecological goods and services
Vertebrate conservation	Restore funding for research on Australian mammals of conservation interest including species known to be "data deficient" Conduct risk analyses to identify species threatened by mobility	Expand funding for research on vertebrates of conservation concern to other Phyla (e.g. sea snakes, marine turtles, seabirds, marine fishes) after assessment of relative risk	Monitor all populations of key species supported by recovery plans
Ecosystem health	Increase investment in research on invasive marine species Develop rapid assays for known threats to water quality and seafood safety Develop a national consensus on indicators for ecosystem health	Fund IMOS to collect new data streams based on the consensus indicators for marine ecosystem health Inform and improve decision support tools for marine managers (below)	Continuous improvement of metrics and systems to monitor and manage for healthy marine ecosystems
Long-term ecological research	Establish long-term observation sites in conjunction with the NRSMPA to audit reserve performance and to provide reference data for off-reserve management actions	Understand the likely responses and limits of marine species to climate change	Sustain key data streams to inform operational models
Baseline surveys	Digitise historical knowledge on marine invertebrate biodiversity held by national collections (especially museums and herbaria) Close the most critical knowledge gaps on habitats and biodiversity for the NRSMPA	Evaluate the effectiveness of the NRSMPA against objectives Reverse the decline in national capacity for taxonomic studies Make national collections of biodiversity more accessible to biodiscovery research	Continue to prospect invertebrate communities and convert that knowledge to useful outcomes
Ecosystem services	Develop robust (calibrated/ validated) BGC models for the transport and transformations of terrestrial contaminants in coastal seas	Calculate proper values of ecosystem services from coastal marine ecosystems	Integrate into new generation models
Decision support systems for marine managers	Test the best available models for marine ecosystem management through consequential partnerships with NRM agencies responsible for managing iconic marine ecosystems (e.g. the Great Barrier Reef).	Enhance EBM models into scenario models of plausible futures and risk-based choices trusted by stakeholders and accepted in negotiations when trading present and future values	Continuous improvement of operational tools for managing marine ecosystems

List of ACRONYMS (not defined in the text)

AAD	Australian Antarctic Division
ABRS	Australian Biological Resources Survey
ACAP	Agreement on the Conservation of Albatrosses and Petrels
ACRS	Australian Coral Reef Society
AIMS	Australian Institute of Marine Science
ALA	Atlas of Living Australia
AMSA	Australian Marine Sciences Association
AODN	Australian Ocean Data Network
ASFB	Australian Society for Fish Biology
BGC	Biogeochemistry or Biogeochemical
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEP	Committee for Environmental Protection (Antarctic Treaty)
CoML	Census of Marine Life
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ECR	Early-career researcher
FTE	Full-time equivalents
FRDC	Fisheries Research and Development Corporation
GA	Geoscience Australia
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
IWC	International Whaling Commission
PFRA	Publicly-funded Research Agencies
ROI	Return on investment
SARDI	South Australian Research and Development Institute
STEM	Science Technology, Engineering and Mathematics