Australian Government

Oceans Policy Science Advisory Group

MARINE NATION 2025:

MARINE SCIENCE TO SUPPORT AUSTRALIA'S BLUE ECONOMY

PREPARED BY OPSAG

MARCH 2013

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Image: Steve Clarke © AIMS

Executive summary

Marine Nation 2025: Marine Science to Support Australia's Blue Economy provides the framework for a national discussion about a number of grand challenges facing Australia that relate to our ocean estate, and how marine science can contribute to their solutions. It identifies strengths and weaknesses in marine research infrastructure and capability and recommends development of a 10-year marine science strategy overseen by a formally constituted National Marine Science Advisory Committee.

Australia's boundaries are defined by our ocean: our land is separated from our neighbours by vast expanses of water. Most Australians live near the coast and have deep cultural connections with coasts and oceans. The great bulk of our valuable commodity trade is done by marine trade routes. An increasing proportion of our energy is derived from our marine estate. The ocean provides us with food and opportunities for recreation. Most importantly, the ocean provides critical ecosystem services such as climate regulation and nutrient cycling and therefore Australia's oceans are vitally important for our economy, our society and our environment.

The ocean contributes approximately $44 billion per annum to our current economy. This contribution will increase to approximately $100 billion by 2025 with expansion of current industries and development of new opportunities in renewable energy (waves, wind, tides) and food (aquaculture, under-exploited wild-catch fisheries). The threat to ocean and coastal ecosystems and human habitats may also increase as result of climate change, in the form of ocean acidification, increasingly frequent extreme events, sea level rise with impacts on coastal and marine infrastructure, and increasing sea temperature with profound effects, particularly in the tropical north.

Marine Nation 2025 outlines six interconnected grand challenges facing Australia, each of which has a significant marine dimension with gaps in understanding or tools that can be addressed by marine science (Section 2):

1. Sovereignty, security, natural hazards: enhancing operational oceanographic forecasting, increased effort on fine-scale hydrographic data and charts

2. Energy security: support for developing energy resources, particularly liquid natural gas and renewable energy, and mapping and modelling to find and develop carbon sequestration

3. Food security: research to support a booming aquaculture industry, data and tools to manage wild-catch fisheries better

4. Biodiversity conservation and ecosystem health: support to describe biodiversity in unexplored areas, develop functional understanding of ecological communities of seabed and water column habitats to find and develop national efforts in environmental monitoring, and development of tools to predict the nature and consequences of changes in biodiversity as a result of human intervention

5. Dealing with changing climate: refine understanding of the impacts of sea level rise, increasing sea temperature, the role of the ocean as a carbon sink and ocean acidification to support government efforts to mitigate and adapt to climate change

6. Optimal resource allocation: address critical policy and management issues by integrating social, economic and environmental information and developing tools and skills to assist in transparent, robust and accountable decision-making.

To meet these challenges, Australia needs to invest in the three traditional pillars of science: observation, experimentation and modelling (Section 3). Infrastructure is required for all these steps in the science process, ranging from observing technologies, through platforms such as research vessels, sustained observing systems, and experimental infrastructure, to data management, storage, manipulation and visualisation technologies. A stable, sustained and predictable commitment to maintaining, updating and transforming infrastructure, and the human resources to run it, is critical to ensure the initial investment in new infrastructure delivers long-term and sustainable benefits. Investment in human capability is also required: training, skills development, mechanisms and incentives for collaboration. Finally, investment in science communication is needed to improve application and acceptance of science in policy, legislation and regulation. This will require communication of the relevance and need for marine science and the benefits gained from previous and ongoing investment in this element of the national innovation sector.

Marine science cuts across many disciplines, and involves a range of institutions (Section 4). To enhance coordination and ensure that the significant investment already embodied in infrastructure is used to greatest advantage, the Oceans Policy Science Advisory Group (OPSAG) makes three proposals:

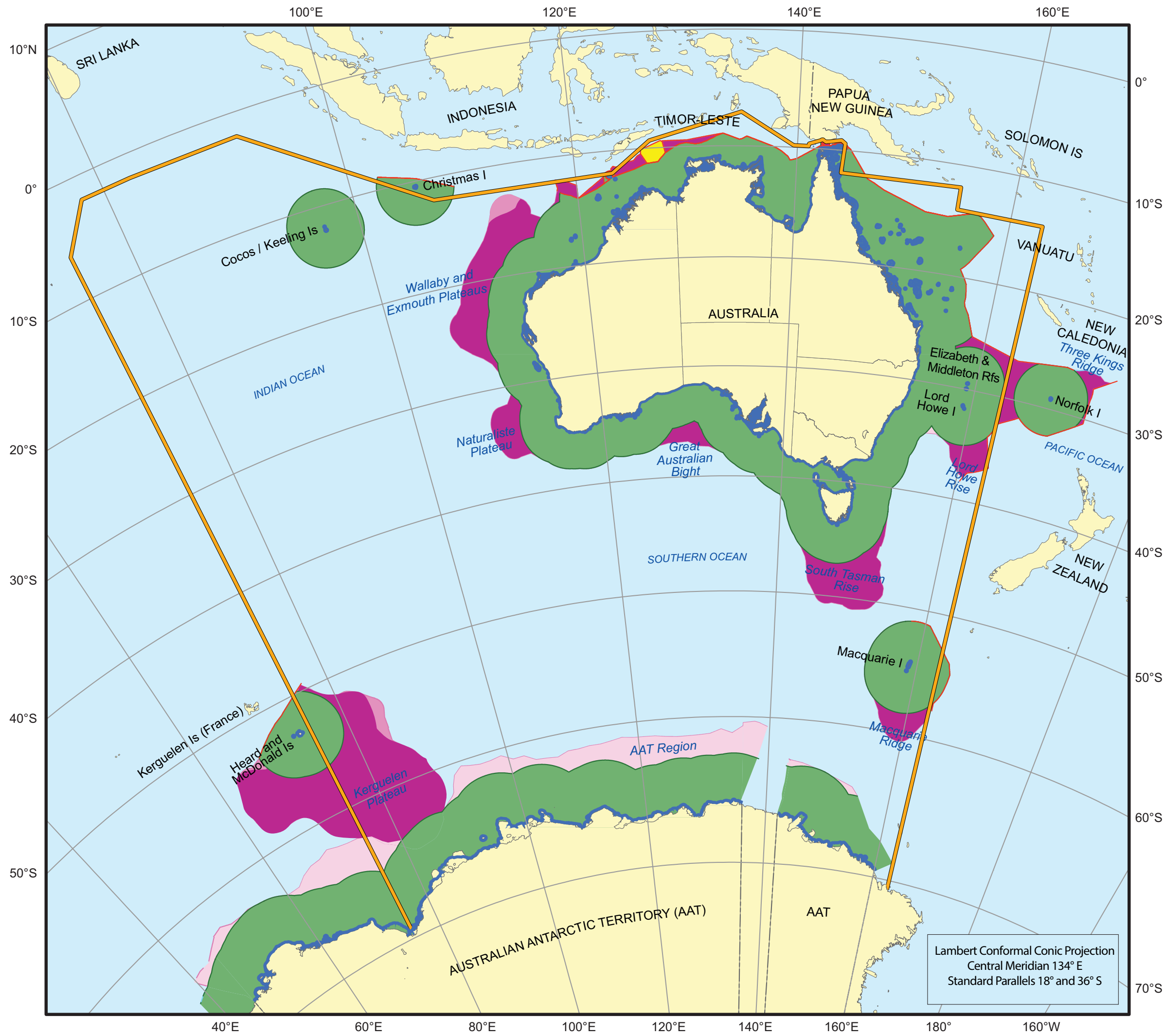
1. Expand the concept of national facilities to include significant national infrastructure such as data infrastructure and sustained observing systems, research vessels and large-scale experimental facilities to help coordinate across competing demands.

2. Commission a Decadal Plan for Marine Science to address the grand challenges, prioritise marine science effort and infrastructure.

3. Establish a formal National Marine Science Steering Committee with the specific remit to coordinate provision of strategic advice to government and develop the marine science strategy.

Marine Nation 2025 has benefited from wide consultation with a broad cross-section of the science provider and user communities. It is critical that both researchers and users continue to actively participate in development of a national decadal plan for marine science to ensure that a united research sector delivers future marine science that is targeted strongly at user needs and continues to contribute to Australia's prosperity.

Image: Wendy Pyper © Australian Antarctic Division



Australia's Maritime Jurisdiction

- *Australian Search and Rescue Region*
- *Treaty boundary with opposite or adjacent State*
- *200 nautical mile line off an opposite or adjacent State*
- *Area of Australia’s territorial sea and internal waters*
- *Area of Australia’s exclusive economic zone as defined by the UN Convention on the Law of the Sea and certain treaties (not all in force)*
- *Joint Petroleum Development Area under Timor Sea Treaty 2002*
- *Area of Australia's continental shelf beyond the exclusive economic zone as confirmed by the Commission on the Limits of the Continental Shelf and/or as defined by certain treaties (not all in force)*
- *Area of Australia's continental shelf beyond the exclusive economic zone considered by the Commission and yet to be resolved*
- *Area of Australia's continental shelf beyond the exclusive economic zone off the Australian Antarctic Territory that Australia requested the Commission not consider for the time being*

Figure 1 Australia’s total area of marine responsibility covers 14 per cent of the world’s oceans.

Image: © Ed Roberts

1 Introduction

By 2025, the combined value of Australian marine industries — both existing and emerging— and ecosystem services is projected to be more than $100 billion per annum. In support of Australia's burgeoning 'blue economy', it is clearly in our national interest to ensure that the economic, ecosystem and cultural resources of the marine estate are well known, wisely used and carefully managed. This task can only be achieved with increased focus on marine science to inform industry development, policy and management.

The world is facing significant challenges to sustainable economic development. These challenges include the effects of climate change, food and energy security, biodiversity conservation, management of marine resources, resilience in the face of marine disasters, and issues with sovereignty and security[1]. Despite relative economic and social security and good environmental management, Australia is also vulnerable to these challenges. Many answers to global challenges lie in the sustainable use and management of the marine environment — by developing a blue economy. A blue economy is one in which our ocean ecosystems bring economic and social benefits that are efficient, equitable and sustainable. Used wisely, Australia's ocean resources can generate wealth, food, energy and sustainable livelihoods for generations.

Australia claims the third largest marine jurisdiction of any nation on Earth—13.86 million km^2 (Figure 1)—more than double the size of its land mass. Australia has sovereign rights over much this vast area of ocean, along with the fishery, mineral, and petroleum resources found within it. The marine estate is growing rapidly in value as a vital national asset as our population continues to grow and offshore oil and gas resources are developed. Activity continues to increase along the coastal fringe and new bulk commodity ports are servicing expanding resource-based export industries. The national value of production across marine-based industries (e.g. oil and gas exploration and extraction, tourism, fishing, boatbuilding, shipping, ports) was $42.3 billion in 2009–10 (compared with $39.6 billion from agriculture), a major contribution to Gross Domestic Product, employment and infrastructure at national, state/territory and regional levels[2] .

The economic value of Australia's marine estate

- **Ports**: In 2009–10, Australia exported nearly 950 million tonnes by sea, valued at $179 billion. 4344 ships traversed the EEZ, making 11 392 voyages and 25 162 port calls.
- **Offshore Oil and Gas**: 95 per cent of Australia's petroleum production comes from offshore sedimentary basins, valued at $21.8 billion in 2009–10. The industry employs over 10 000 people, and sanctioned developments of four LNG projects alone total $100 billion. The oil and gas sector is projected to contribute $66 billion to the GVP by 2020[2] (3.5% of the national economy)
- **Ecosystem Services**: the value of ecosystem services such as absorbing carbon dioxide, nutrient cycling and coastal protection is estimated at $25 billion
- **Tourism:** domestic and international marine tourism was valued at nearly $11.6 billion in 2009–10
- **Ship Building**: boat and ship building, including repair and maintenance, equipment retailing and infrastructure was valued at $ 6.7 billion in 2009–10
- **Fisheries and Aquaculture**: the gross value of Australian fisheries production — including state and Commonwealth wild-catch fisheries and aquaculture — was nearly $2.2 billion in 2009–10[3]. Recreational and customary fishing provide critical economic and social benefits to both national and regional economies.

[1]Department of Resources, Energy and Tourism, Fact Sheet 1, Australia's Offshore Petroleum Industry
[2]APPEA 2012 Advancing Australia: harnessing our comparative energy advantage
[3] Australian Fisheries Statistics 2010

1 UNCSD 2012, The Future we Want www.uncsd2012.org/content/documents/727The%20Future%20We%20Want%2019%20June%201230pm.pdf
2 *The AIMS Index of Marine Industry,* 2012 www.aims.gov.au

Because Australia is an island continent, our national security depends on maintaining our maritime borders[3], and our valuable primary export income relies on the marine estate[4], through both shipping routes and Australia's extensive port network. The marine estate is also becoming increasingly important strategically as the gateway to East and South-east Asia.

Australia derives substantial benefits from the oceans that are not easily quantifiable in market terms. The value of these 'ecosystem services' has been estimated at over $25 billion and growing[5]. They include regulating carbon dioxide in the atmosphere by ocean absorption, recycling essential nutrients and controlling pests and diseases as well as social and cultural benefits including sport and recreation, and inspiration for art, design and education.

In 2009 Australia's Oceans Policy Science Advisory Group (OPSAG)[6] released a strategic National Framework for Marine Research and Innovation, *A Marine Nation*. The framework highlighted the significant economic, social and environmental value of Australia's marine estate and the opportunities for research and innovation to support industry development and government policy development and regulation. *A Marine Nation* aimed to support Australia's quest to maximise wealth generation from marine assets while maintaining the health of the marine environment for future generations. It guided strategic planning and investment in national marine research and research capability, as evidenced by investment in a Marine and Climate Super Science Initiative in 2009. Through broad consultation with science providers and users, *A Marine Nation* ensured that investment was well connected to, and thus likely to have positive impact on, both government and private industry stakeholders. The concepts and recommendations within the document gained widespread community and political support.

Marine Nation 2025 re-examines the context for marine science in 2012, four years after *A Marine Nation* was released. In the last four years there have been a number of significant developments in maritime industries, the regulatory frameworks governing activities in the Australian Exclusive Economic Zone (EEZ), and Australia's investment in and approaches to marine research and innovation. Therefore, OPSAG has developed *Marine Nation 2025* to refocus attention on the role of marine science in Australia's complex marine policy and management environment.

3 *Australian Maritime Doctrine* 2010 www.navy.gov.au/media-room/publications/australian-maritime-doctrine

4 Bureau of Infrastructure, Transport and Regional Economics (BITRE) 2011, *Australian sea freight 2009–10*, Canberra ACT. www.bitre.gov.au/publications/2012/asf_2010_11.aspx

5 Eadie, L and Hoisington, C (2011), *Stocking Up: Securing our marine economy*, Centre for Policy Development, Sydney http://cpd.org.au/2011/09/stocking-up/

6 OPSAG comprises a broad range of representatives with interests in marine science, including leaders of national marine science agencies, universities and key government and industry stakeholders.

Image: © Royal Australian Navy

Developments since the release of the first *Marine Nation* (2009)

- A shift towards the Asia-Pacific and Indian Ocean Rim as regions of global strategic significance. Australia's current and future strategic interests are overwhelmingly positioned to the north, the north-west and north-east, and to the Indian Ocean Rim.
- Expansion of hydrocarbon extraction facilities offshore north-western Australia and new developments of gas processing facilities in both north-western Australia and the coast of central Queensland.
- Australia's first significant oil spill. The resultant review of environmental risk assessments and spill impact planning found many deficiencies in Australia's preparedness for such events.
- Booming resources sectors, driving increases in sea transport and massive investment in bulk commodity ports to service anticipated growth in exports.
- Developing ports and shipping channels in close proximity to the Great Barrier Reef, prompting a comprehensive strategic assessment of the Great Barrier Reef World Heritage Area and adjacent coastal zone.
- Completion of Marine Bioregional Plans and the National Representative System of Marine Protected Areas in Commonwealth waters, both significant drivers for research and monitoring. The marine protected area network forms the world's largest network of marine reserves, covering over 3.1 million km^2, over a third of Australia's EEZ.
- Increasing effort in planning for climate adaptation and increased global concern about potential consequences of climate change and variability. In Australia, a series of severe cyclones have rocked Queensland, and flooding associated with a strong La Niña event has devastated Queensland and Victoria (2011 was the wettest year since 1973). Over the last decade, average sea surface temperature has been the warmest since 1910, sea level has risen by an average of 3 mm per year, and the Southern Ocean has continued to acidify.
- A growing gap between fisheries production and consumption in Australia. The deficit is projected to increase by 50% between 2020 and 2050.
- Major investment in marine infrastructure by the Australian Government: a state-of-the-art marine research vessel to replace the RV *Southern Surveyor*, a major extension of the Integrated Marine Observing System network, new marine infrastructure investments in Sydney, Perth, Townsville and Hobart, and an upgrade to Australia's peak high-performance climate change computing capacity. These investments represent a step change in Australia's marine science capability and an irreversible shift in research culture towards greater collaboration and open access.

Marine Nation 2025 outlines six national challenges for which Australia's oceans hold key solutions. Addressing these challenges requires innovative marine research to unlock knowledge and understanding. *Marine Nation 2025* identifies gaps in infrastructure and capability that may act as impediments to solving national challenges, and sets out the case for development of a national Decadal Plan for Marine Science overseen by a formal National Marine Science Steering Committee. Such a plan would focus research efforts on the critical questions that need to be answered to deliver a sustainable blue economy for Australia.

The scope of this document

This document focuses on the challenges associated with the national marine estate, including the three oceans that surround Australia, our coastal seas and the continental shelf waters surrounding the continent, and our Antarctica and offshore island territories. Clearly, there are profound biological and physical interactions between these marine systems and the estuaries, rivers and catchments that feed into them. Indeed some of the major policy and regulatory challenges associated with the maintaining/ restoring the health of coastal marine systems demand interventions on land-based activities rather than marine industries. Thus, as the marine science community develops a Decadal Plan for Marine Science it will be essential that they work closely with the freshwater aquatic and estuarine science communities to focus and prioritise activities across the interfaces between these interrelated systems.

Image: Richard Brinkman © Woodside Energy Limited

2 National challenges

Australia's challenge in the next decades is to realise the potential economic benefits of the marine estate while maintaining social and environmental values. Policy-makers and managers are required to responsibly evaluate the tradeoffs between economics, social values and environmental sustainability. This balance is made difficult by the lack of knowledge about our vast and varied marine systems, their resources, and how their ecosystems function. Limited information is also available about social values and the economic tradeoffs that are important to the Australian people. While we grapple with limited understanding of our marine estate, Australia, and other societies around the world, face significant challenges as the oceans change as part of the world's changing climate. Already, the impacts of ocean and coastal change are being felt through increased coastal flooding, inundation and erosion, increasing frequency and intensity of extreme events, and growing effects on ocean ecosystems including acidification of the ocean and coral bleaching. These threats are already having profound and growing impacts on society.

Oceans are inextricably linked to some of the most pressing challenges facing society, both in Australia and globally, in the next decades: maritime sovereignty and security, energy security, food security, biodiversity conservation and ecosystem health, climate variability and change and the policy challenge of equitable resource allocation. Marine research and innovation is an essential input to informed policy and management and is critical to developing solutions to and opportunities from these challenges.

2.1 Maritime sovereignty, security and safety

The protection and security of national sovereignty, for both Australia's territory and people, and the safety of the population are essential responsibilities for the government. These responsibilities support our national values and the advancement of the social, environmental and economic well-being of our nation.

Maritime sovereignty, security and safety are particularly important for Australia because of our economic reliance on the oceans for transport, trade, energy, international communication and food. We are separated from our neighbours by oceans, and rely on good order at sea to promote peaceful and prosperous relations. Our national interests need to be protected against maritime security threats that include the illegal exploitation of natural resources, illegal activity in protected areas, maritime terrorism, piracy, robbery or violence at sea, and compromise to biosecurity and marine pollution. Substantial growth in oil and gas developments and shipping of resources has meant that our ability to protect the much expanded ports, shipping and offshore infrastructure from attack such as terrorism is vital to our economy. There will also be greater risk of oil spills requiring improved management to minimise impacts on biodiversity. Adapting to a changing climate will place greater demand for assessment of risks in the protection of assets, the safety of maritime operations and occurrence of natural hazards to allow adequate preparedness.

The physical environment of our EEZ is extraordinarily complex. It ranges from tropical seas with strong tidal flows, cyclones and areas where breaking internal waves belie a smooth sea surface, to the huge swells and storms of the wild Southern Ocean. To facilitate safe navigation for maritime trade routes, manage commercial fisheries and to undertake patrols, rescues and Defence activities successfully in these waters, it is necessary to understand and predict the waves, current systems, tides and other oceanographic phenomena. Accurate hydrographic data and charts are essential for safety of navigation for maritime trade and recreational users alike. They are also crucial for defining changing maritime boundaries of legislative jurisdictions and assist in substantiating our sovereign claims. Hydrography also assists in the exploration and management of seafloor resource exploitation and responses to natural or human disasters. However, significant parts of Australia's marine jurisdiction are not adequately charted.

The impact of extreme events, such as tsunamis, cyclones and severe storms, on communities and infrastructure is a significant issue for Australia's maritime security[7].To improve our ability to predict the impact and risk of these and other marine natural hazards, and better plan for emergency response, fine-scale coastal bathymetric and oceanographic data and advanced risk-based modelling approaches are needed.

Safety of life at sea also depends on reliable predictions about the behaviour of the marine environment. Maritime incidents caused by a lack of appropriate information can be potentially catastrophic in terms of loss of human life, economic impact, degradation of the environment and the maintenance of safe navigation. Crucially, surveillance and security activities require legally robust data to support prevention and compliance activities and enhanced operational forecasts for the ocean, atmospheric and geohazard domains. Limited blue water and tsunami forecasting capacities exist for the open ocean and to some extent near shore, but long term commitment is required to develop a national operational oceanographic and geohazard forecasting capability with an enhanced coastal component. To provide real benefit to the Australian community, these operational forecasting systems will need to focus on

7 Annual statement of national security science and innovation statement of priorities, 2011 www.dsto.defence.gov.au/attachments/Annual-Statement-of-National-Security-Science-and-Innovation-Priorities.pdf

achieving true forecasting skill at fine spatial and temporal scales, predict seabed and shoreline conditions and be able to provide a clear indication of the reliability of the forecast. These aspirations will need to be supported by a wide range of observations, collected both remotely and *in situ*, to feed into forecasting and compliance systems. Future sensors collecting these observations will need to be able to adjust to the limitations of environmental conditions such as turbidity, waves and other effects caused by the weather. Methods used to analyse the data, integrate and calculate the forecasts will also need to improve. As we acquire ocean data at finer scales and in real (or near real) time, the demand for efficient and interoperable data systems will become critical. National ocean observation and data systems will provide rapid, more accurate and accessible forecasts of Australian ocean and geohazard conditions, potentially saving lives, averting major incidents, reducing industry operating costs and improving the efficiency of our Defence and other compliance forces and enhancing our ability to predict the impact and risk of marine natural hazards.

2.2 Energy security

Access to secure, affordable, reliable, and sustainable energy is vital for ensuring Australia's societal and economic security. Australia's energy policy strives to deliver energy security, facilitating economic development, and meeting clean energy goals. The Australian Government's recently released energy white paper[8] includes two core priorities relevant to marine research:

- developing Australia's critical energy resources, particularly Australia's gas resources
- accelerating our clean energy transformation.

Energy reserves in Australia's vast maritime jurisdiction, from sub-seabed oil and gas deposits to renewable wave, wind and tidal energy, are yet to be fully explored. Nevertheless, they will play a vital role in securing Australia's future energy needs and those of its regional neighbours and long term trading partners, by providing a diversity of reliable supply.

The Australian liquid natural gas (LNG) export market is predicted to grow from around 20 million tonnes per annum to 107 million tonnes by 2034[9]. Capital expenditure for new LNG projects currently approved or planned totals more than $170 billion.

To sustain this scenario, more gas resources must be found. The quest for more gas and oil is being driven by increasing demand, particularly from China, India, Korea, and Japan. As known hydrocarbon fields mature, it is urgent to explore more reserves. Although more than 75 per cent of Australia's known hydrocarbon reserves occur in our maritime jurisdiction, less than 10 per cent of the area of known offshore reserves is under exploration permit.

Decreasing greenhouse gas emissions to the atmosphere is one of the key issues facing Australia and the world. Emission reduction will require a full suite of responses: increased use of renewable energy, greater energy efficiency, fuel switching, and increased sequestration of greenhouse gases away from the atmosphere, particularly geological storage of carbon dioxide. The vast majority of the carbon dioxide storage capacity in Australia is offshore. To develop the potential of this capacity, research is required to further understand and model the architecture of offshore sedimentary basins, and the geomechanical behaviour and likely fluid flow at potential carbon storage sites.

Australia's oceans have great potential to generate electricity with zero or low carbon emissions from tides, wind[10], waves and ocean thermal energy. An initial resource assessment has identified world-class wave energy resources along the western and southern coastline, and valuable tidal energy resources in the northwest of Australia[11]. Marine hydrodynamic models are critical to predict the best places for installation of wave and tide converters, but the models are constrained by lack of data in the areas most suited to energy production (e.g. remote north-western Australia). Further investment in both observation and modelling capability is critical for efficient development of ocean renewable energy and to assess potential impacts on marine ecosystems from ocean and wave energy facilities.

Sustainable energy development in Australia requires strong and sustained engagement between industry and marine researchers. The changing energy profile presents new technological and engineering challenges for industry and opportunities for scientific research.

Systematic research and sustained exploration will result in a more comprehensive understanding of Australia's offshore sedimentary basins. New geophysical and rock property data that can be visualised to 6000 m below the sea floor would mean that deep earth fluid systems — the flow of water, oil, gas and carbon dioxide through sedimentary rocks — could be modelled accurately for monitoring

8 Energy White Paper www.ret.gov.au/energy/facts/white_paper/Pages/energy_white_paper.aspx
9 Australian Energy Resource Assessment 2012 Geoscience Australia and Bureau of Resources and Energy Economics, Canberra
10 http://multi-science.metapress.com/content/yh6030v753325152/
11 http://adl.brs.gov.au/data/warehouse/pe_aera_d9aae_002/aeraCh_11.pdf

injection or extraction of fluids. Development of offshore injection sites for carbon dioxide storage could be well advanced by 2020 allowing Australia to meet its greenhouse gas emissions targets.

Investment in research, analysis and exploration of Australia's marine estate will also result in discovery and exploitation of new oil provinces, natural gas reserves and ways to exploit renewable energy sources, reducing Australia's reliance on oil imports. This will contribute positively to the national economy and provide long term energy security for all Australians.

2.3 Food security

Food security is fundamental to social and political stability. Seafood plays an important and growing role in providing food for both developing and developed countries. World fish food supply has grown dramatically in the last five decades, largely as a result of rapid growth in aquaculture. In 2009, fish accounted for about 16 per cent of all animal protein consumption. Globally, as population heads towards an estimated 9.2 billion by 2050 (about the maximum carrying capacity of the planet, according to the UN Food and Agriculture Organization), fishing and aquaculture will need to play a large part in meeting world demands, especially aquaculture.

Image: Tim Simmonds © AIMS

The global aquaculture industry currently accounts for nearly half of the world's food fish consumption, a significant contribution to world food security[12]. Global growth of aquaculture is expected to continue and has the potential to meet the bulk of the estimated demand for an additional 40 million tonnes of aquatic food by 2030 to maintain the current per capita consumption.

Science is central to fisheries management and aquaculture in Australia[13], and will become increasingly important to harness the opportunities presented by the Asian Century[14]. Australian aquaculture focuses on premium products that generate significant economic value. Australian aquaculture production, and associated total value, has increased substantially over the past decade, from $0.68 billion in 2000 to $0.87 billion in 2010 (almost 40 per cent of total fisheries value in 2010[15]). Strong growth in local and global demand for premium seafood, particularly from our near neighbours in Asia[16], highly suitable on-shore and near-shore marine aquaculture production sites, together with Australian advances in environmental management, aquaculture breeding and sustainable aquafeeds present a very significant opportunity for sustainable growth of the Australian aquaculture industry and export of Australian knowledge and technology to increase global production.

The critical research challenge for the growing Australian marine aquaculture industry is to develop and apply the required knowledge and technology with sufficient speed and scale to enable the Australian industry to achieve its full potential for sustainable growth and take advantage of Asian markets. These include:

- developing cost-effective aquaculture feeds that minimise or eliminate the use of wild harvest fishmeal and fish oil, while maintaining key quality parameters expected in high quality, healthy seafood
- integrating climate change and resource use research into an aquaculture spatial planning framework that encompasses environmental and social values, species selection, production systems, market demand and other uses of adjacent environments
- increasing the speed of transition from reliance on wild broodstock to the use of domesticated, selectively bred high-health stocks.

The ability to develop and apply globally competitive aquaculture research in Australia is critically dependent on the appropriate infrastructure, particularly controlled environment seawater facilities. A recent major upgrade of the controlled environment seawater facilities at the Bribie Island Research Facility in Queensland will be a key factor in enabling Australia to achieve a quantum increase in production efficiency and substantiality of warm water marine aquaculture. There is a critical need to establish equivalent research infrastructure in temperate waters to support research on Atlantic salmon, Australia's largest, most valuable and fastest growing seafood industry.

Australian commercial fisheries are relatively small by world standards yet have disproportionately large ecological, social and political footprints. A large proprtion of the catch is high-value species that are mostly exported. After a period of declining catches and value — in 2010 these were 160 000 tonnes and $1.4 billion respectively — Australia's wild-catch fisheries are in a rebuilding phase and their value and profitability is expected to increase slowly as stocks increase. During this phase the industry is focussed on value-adding of species previously considered (and discarded) as by-catch, and for this challenge research into ecological sustainability and economic viability (including social acceptability and approaches to marketing) is required. In the next decades additional challenges for wild fisheries management are to improve data concerning fish stocks, mortality, total economic value, community views and other data to track performance, and to move towards ecosystem or multi-species approaches to fishery management[17, 18]. This will require more detailed understanding of complex food web dynamics, the effects of changing baselines on fish stocks and the ecosystems that sustain them, and the social and economic drivers and impacts of fisheries[18].

Recreational fishing and indigenous customary fishing are not currently managed in the same way as commercial wild-catch fishing but the same stocks are targeted in some cases. It has been estimated that up to 3.4 million Australians participate in recreational fishing, contributing $2.5 billion to the national economy[19]. Yet robust information on the species, location and volume of catch is scarce even though recreational catch is greater than commercial catch of some species[18]. Fishing and shell-collecting is a very

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12 FAO 2012 *State of the world's fisheries and aquaculture* www.fao.org/docrep/016/i2727e/i2727e00.htm

13 National Food Plan Green Paper (2012) www.daff.gov.au/__data/assets/pdf_file/0009/2175156/national-food-plan-green-paper-072012.pdf

14 House of Representatives Standing Committee on Agriculture, Resources, Fisheries and Forestry (2012) Netting the Benefits: the role of science for the future of fisheries and aquaculture www.aph.gov.au/parliamentary_business/committees/house_of_representatives_committees?url=arff/fisheries/report.htm

15 Australian fisheries statistics 2010 http://adl.brs.gov.au/data/warehouse/pe_abares20110830.01/AustFishStats_2010.pdf

16 Australia in the Asian Century white paper www.asiancentury.dpmc.gov.au/white-paper

17 Ridge partners (2009) Evaluating the performance of Australian marine capture fisheries. www.frdc.com.au/research/Documents/Final_reports/2006-071-20.pdf

18 Working Together: the national fisheries & aquaculture RD&E strategy (2010) www.npirdef.org/cms_strategy/4

19 Henry GW & Lyle JM (2003) The National Recreational and Indigenous Fishing Survey www.daff.gov.au/fisheries/recreational/recfishsurvey

important part of many Aboriginal and Torres Strait Islander people's cultural life. Harvesting is not only a cultural activity that satisfies personal, domestic, ceremonial, educational and communal needs; it also pre-empts expenditure on purchased food. However, economic and social data encompassing these activities are limited. The lack of information about recreational and Indigenous fishing catch and impacts hampers effective management and coordination across jurisdictions[14].

Fisheries and aquaculture industries are two of many users of the aquatic environment. There is a role for new methods and further research to assess the interactions among multiple sectors and monitor cumulative impacts from multiple sectors. Continued investment is required in innovative model frameworks that enable evaluation of alternative management plans and arrangements for multiple uses of the marine environment.

2.4 Biodiversity conservation and ecosystem health

Australia is a world-leader in biodiversity conservation, with internationally renowned marine protected areas such as the Great Barrier Reef and Ningaloo Reef, and the largest representative network of marine reserves in the world covers over a third of Commonwealth waters. Our primary environmental legislation, the *Environmental Protection and Biodiversity Conservation Act (1999)* establishes a robust legal framework to provide protection for the environment while at the same time allowing sustainable economic development. Frameworks such as Australia's Biodiversity Conservation Strategy 2010–2030[20] and Commonwealth marine bioregional plans[21] provide clear guidance to support future conservation and management of the marine environment. Nevertheless, critical gaps in knowledge about biodiversity, ecosystem function and processes limit the evidence base to support decision-making for biodiversity conservation. This is especially true in understanding the cumulative impact of, and management options for multiple stressors. Part of this evidence base will be built by focusing marine research on three key areas over the next 10–20 years: discovery, monitoring and decision-support tools.

Marine biodiversity is virtually unknown in vast areas of Australia's oceans. Every new voyage of discovery describes new species (typically 50 per cent of species recovered in deep water surveys are new to science) and habitats. Seabed environments in these areas are also poorly known and recent surveys have even found undocumented seamounts as large as Mount Kosciusko. The vast, deep and remote Southern Ocean holds unseen assemblages of life and remains very poorly understood. Understanding how marine biodiversity is distributed, the key ecological interactions and processes supporting biodiversity, how pressures are distributed and are changing and how marine species and ecosystems respond to cumulative pressures is essential to effectively manage competing uses of the marine estate while simultaneously protecting the biodiversity and ecosystem services that support those uses.

A fundamental limitation to effective marine management in Australia (with the notable exception of single-species fisheries management) is the lack of adequate, robust baseline information and clear measureable objectives[22]. Very few marine areas have been mapped or described adequately to allow assessment of change[23]. An added complexity is that marine systems are already changing irreversibly in response to global climate change meaning that in many areas we cannot return to earlier baselines or even expect to stay on the current baseline. Robust, innovative and cost-effective characterisation of the unmapped areas of our marine estate, coupled with monitoring at a national scale is required to evaluate and report on the ecosystem health of our oceans, the state of our marine biodiversity, the effectiveness of marine protected areas and the social and economic benefits of our marine environment. Well designed and comprehensive monitoring can underpin a national debate on what we want from the marine environment and how to achieve it. The National Plan for Environmental Information sets out the minimum needs for baseline information in the marine environment. The Integrated Marine Observing System (IMOS) provides part of the underlying framework to support ecological monitoring.

Sustainable regional development and ecosystem-based management rely on simultaneous consideration of harvesting and extraction of natural resources (for food as well as energy security and mining), maritime trade and transport, cultural services (indigenous values, recreation and tourism), climate change and variability and the provision of other ecosystem services (e.g. coastal protection, nutrient cycling). This requires sophisticated tools and data management to integrate and evaluate information on biodiversity, systems processes, cumulative impacts and values to provide clear scenarios and options for marine industries and biodiversity conservation under alternative future management regimes. Innovative and cost effective ways to predict how biodiversity, ecosystems, society and the economy might change under future scenarios at the appropriate scale while understanding the limits of our predictive capacity will provide the basis for more effective management to support biodiversity conservation and sustainable resource use.

20 DSEWPaC 2010 *Australia's Biodiversity Strategy 2010–2030* www.environment.gov.au/biodiversity/strategy/index.html

21 http://www.environment.gov.au/coasts/mbp/index.html

22 State of the Environment Report 2011 www.environment.gov.au/soe/2011/report/marine-environment

23 One of the conclusions of the Montara Inquiry investigating one of Australia's worst oil disasters, was that understanding of the environmental consequences of the spill was hampered by inadequate baseline knowledge.

2.5 Climate variability and change

The oceans play a critical role in global climate and Australia's regional climate variability. Climate variability and change also affect Australia's marine estate and our economic and social dependence on marine resources, operations, and biodiversity from the tropics to Antarctica. The key elements of climate change that will affect Australia's marine estate are increasing temperature, rising sea levels, changes in circulation patterns, increasing ocean acidity and changing frequency of extreme events.

The ocean is warming as a result of anthropogenic emissions of greenhouse gases. A warming ocean drives rising sea level through thermal expansion, melting of glaciers and polar ice caps and effects on the Antarctic sea-ice. Warmer oceans will hold less carbon and thus exacerbate atmospheric carbon dioxide concentrations. A warming ocean may also catastrophically alter global ocean circulation patterns by disrupting thermohaline circulation in the great ocean basins. Global ocean currents transport heat and set the large-scale patterns of temperature, rainfall and evaporation that determine global and regional climate. Australian science has a critical role to play in the study of the nature and extent to which changes in Antarctica and the Southern Ocean are driving global climate. This is particularly relevant given the diminishing investment by northern hemisphere countries that are increasingly focused on the future of Arctic ice cover and the Greenland ice sheet.

The ocean currently absorbs approximately a third of annual human emissions of carbon dioxide. This hidden ocean service has been estimated to represent an annual subsidy to the global economy of US$60 – US$400 billion per year. However this vital service comes with the cost of ocean acidification, the ecological effects of which are still largely unknown. Ecosystem modelling[24] suggests that major shifts in community structure and functioning may occur. In particular, in Australia, species such as commercially important abalone, oysters, lobsters and large predatory fish may decline both in abundance and quality with severe economic consequences for fishers. Australian research will need to play a leading role in the global effort to determine the consequences of ocean acidification for the marine biosphere, especially for coral reefs in our tropics and planktonic plants and animals in the high latitudes of the Southern Ocean. Others will not respond to these scientific challenges on our behalf.

Australia, more than any other continent, is subject to inter-seasonal climate variations such as the El Niño Southern Oscillation (ENSO) phenomenon, the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM). The frequency and intensity of ENSO events appear to have increased in the past two decades, although it is not yet possible to say whether this is an expression of human-induced climate change. Understanding of these coupled modes of climate variability is limited and requires further fundamental data collection and development of models to provide better weather prediction and climate projections important for Australia's economy, farmers and food security.

In Australia, cyclones and other severe storms have the largest economic impact of any natural hazard due to their extreme wind and rain, and associated waves and storm surge. Projected increases in storm severity resulting from climate change will intensify shoreline erosion and storm surge, and increase risks to maritime operations (e.g. shipping and defence) and infrastructure (e.g. ports, coastal cities, gas pipelines, processing facilities). Increases in storm frequency and severity may also affect ecosystem functioning with far-reaching social and economic impacts.

Climate change and the Great Barrier Reef

The impacts of climate change are expected to be greatest in the tropical north, where sea temperatures have risen by approximately 0.4 °C in the last 30 years, coinciding with mass bleaching, mortality and changes in community structure on coral reefs. Projections reveal that sea temperature may soon exceed the thresholds for coral bleaching on a yearly basis, with potentially severe consequences for reef health and biodiversity, food production and tourism, particularly on the Great Barrier Reef.

For example, recent analysis of long term monitoring data for the Great Barrier Reef showed that approximately 48 per cent of the decline in coral cover recorded between 1985 and 2012 was attributable to storms.

Intense storms are thought to be particularly important in the dynamics and evolution of reef ecosystems. The last three decades have seen the frequency of severe cyclones (category 3-5) almost double. An increase in the frequency of more severe (an increase in average severity rating by half a category) cyclones has been predicted to increase coral mortality by 60 per cent, with resultant impacts for reef dependent communities and industries.

24 Fulton, E.A., 2011. Interesting times: winners and losers and system shifts under climate change around Australia. *ICES Journal Marine Science* 68: 1329-1342

Predicted consequences of rising sea temperatures on ecosystems include range shifts of species, alterations in food web dynamics, and changes in growth and reproductive rates of some species[25]. Accurate prediction of impacts and development of adaptation and mitigation measures depends on further understanding of the individual and cumulative impacts of temperature, acidity and increasingly frequent extreme weather, and the ecosystem consequences.

The Australian climate change science and policy community has developed a plan for implementing climate change science in Australia[26] which articulates climate change research priorities. Australian marine science is integral to the global climate change research effort. Research into changes in sea surface temperature and the circulation of the Southern, Indian and Pacific oceans is crucial on a number of fronts – from understanding their influence on rainfall patterns across southern Australia to identifying the implications for the productivity of ocean ecosystems as our coastal boundary currents change. Reliable, robust projections of sea level changes and consequent shoreline movements will enable policy makers to more accurately judge the scale and timing of the response needed.

Image: Eric Matson © AIMS

25 Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006. Impacts of climate change on Australian marine life: Part A. Executive Summary. Report to the Australian Greenhouse Office, Canberra, Australia. September 2006 http://pandora.nla.gov.au/pan/102841/20090717-1556/www.climatechange.gov.au/impacts/publications/pubs/marinelife-parta.pdf

26 Plan for implementing climate change science in Australia www.climatechange.gov.au/climate-change/national-framework-science/plan.aspx

2.6 Resource allocation: optimal sharing of natural resources and environmental assets

Arguably the major challenge for politicians, policy makers and regulators in governing Australia's vast marine estate is to equitably balance the economic opportunities provided by marine resources — offshore oil and gas, fisheries, seabed minerals, tourism — with the demand for ongoing access to our coasts and oceans for public use and amenity, and maintenance of ecosystem health and function. Decision-making involves a complex suite of considerations overlaid by often emotionally and politically laden value conflicts. The equitable allocation of fish resources between recreational and commercial fishers, the development of a national network of marine protected areas, debates around the number of ports that should be allowed on the Great Barrier Reef coast, or processing plants for natural gas in NW Australia, are the most recent examples of the challenges for governments in our coastal and marine domain.

Australian governments have a commitment to ecosystem- and evidence-based decision-making, enshrined in policy and legislation at both Commonwealth and state levels. In 1998, Australia's Oceans Policy sought to integrate sectoral and jurisdictional interests with an ecosystem-based management approach and established new mechanisms and institutions. In 2012, the grand vision set out by by Oceans Policy is still relevant, but still unachieved.

Twenty-first century marine science (incorporating social and environmental science and resource economics) can provide a range of critical inputs into decision-making on resource allocation and environmental management:

- New remote and *in situ* observation technologies allow the development of cost-effective and sustained observations systems and monitoring programs that can be deployed from inshore coastal to deep oceanic waters. These provide critical data for determining baseline system condition, function and variability, and monitoring the impacts of development and management decisions.

- The collection of robust data and subsequent peer-reviewed analysis allows the biological, social and economic consequences of different actions to be quantified, and the trade-offs among different social, economic and environmental objectives to be evaluated.

- The complexity of marine systems often demands sophisticated analysis and simulations of different management/ allocations scenarios. Over the last decade the development of a suite of advanced decision support tools has provided a means of examining alternative management actions /regulatory scenarios even where there is considerable uncertainty about the ecosystem or human impact.

The power of these capabilities and tools, particularly when they are used objectively and the outputs are placed in the public domain, is that they provide a transparent and robust basis for making resource allocation decisions. Science cannot make the decision, but in collaboration scientists and resource managers can effectively evaluate options and work to reduce the risks associated with any decision.

The challenges faced by the science community in providing advice to government fall into three categories:

Need for appropriate data. As highlighted elsewhere in this document, social and economic data of relevance to decision-making is lacking in some areas. For example, informed management of recreational fishing is hampered by lack of social data on recreational activity, economic data on value, and biological data on catch. Data on ecosystem health and function, particularly for pelagic and deep-sea environments is very limited. The impacts of multiple uses and cumulative threats are largely unknown, despite the intensity of human use of the marine estate, particularly in the coastal zone.

Need for new tools. Robust, evidence-based decision-making requires management of large volumes of data and complex risk-based modelling coupling biophysical, economic and social models that include shifting baselines as the climate changes. The national data and computing infrastructure for this task is beginning to expand, as are innovative ways to combine and display information. A critical issue is that the tools need to produce robust, trustworthy and comprehensible advice of direct relevance to policy outcomes.

Need for new skills. Working within the science-policy interface is fundamentally different from traditional scientific research. Scientists providing advice for policy or decision-making need to be able to communicate complex and fuzzy issues to non-experts in ways that can used to achieve policy outcomes. A challenge for scientists is that they are asked to respond to management questions at scales that are outside current knowledge, and within severe time constraints. In turn, decision-makers are asked to specify management goals and acceptable risk levels. Both positions are uncomfortable and require negotiation and flexibility.

2.7 Conclusion

The challenges identified above are global in nature, but have particular relevance to our region which includes many countries that might also be characterised as Marine Nations. Japan and much of eastern Asia, the Pacific Island countries, the Indian sub-continent and China share many of Australia's vulnerabilities in terms of climate change, are seeking solutions to food and energy security, rely on sea-trade for their economic growth and are partners in regional security alliances. As the Asian Century builds momentum, the regional blue economy will grow in importance and Australia can and should play a leading role in regional efforts to ensure a sustainable and prosperous future for the region's ocean ecosystems and industries. This will require growing investment in and coordination of marine science. The Australian marine science community is already leveraging international research efforts; indeed, we are leaders of global research in many of the fields of marine science. There are, however, a number of challenges that require attention specific to Australia or our region and our recommendation is that we focus increasingly on building regional partnerships for the science required to support our interests in the Southern Ocean, eastern Indian Ocean and the western Pacific Ocean.

Image: © Geoscience Australia

Image: Peter Hoare © DSTO

3 Responding to the national challenges

Marine research, innovation and education are essential contributors to meeting the challenges identified in Section 2.

Australia's marine research and innovation sector is world class and diverse and has a great capacity for working across disciplinary and organisational boundaries on major initiatives supporting the generation of wealth from our marine resources and the protection of unique and valuable marine ecosystems.

Australia's marine science capability derives from its publicly-funded research agencies, the university sector, Australian and state government departments, including museums, and private industry. This capability consists of skills, infrastructure and relationships (Figure 2). It also includes the collaborative frameworks required to bring these components together at regional and national scales, and to enable Australia to be a strong partner in international marine science programs with a recognised leadership position in the Southern Hemisphere.

The 2008 Review of the National Innovation System[27] concluded that Australia's investment in marine research and maritime industries was underweight. The 2009 Super Science initiative[28] began to address this situation, and in particular emphasised the benefits of taking 'national facility' versus 'institution-specific' approaches to marine science capability development. We now need to lay out pathways that will sustain and enhance these recent, positive developments, taking into account the long-term drivers and challenges set out above.

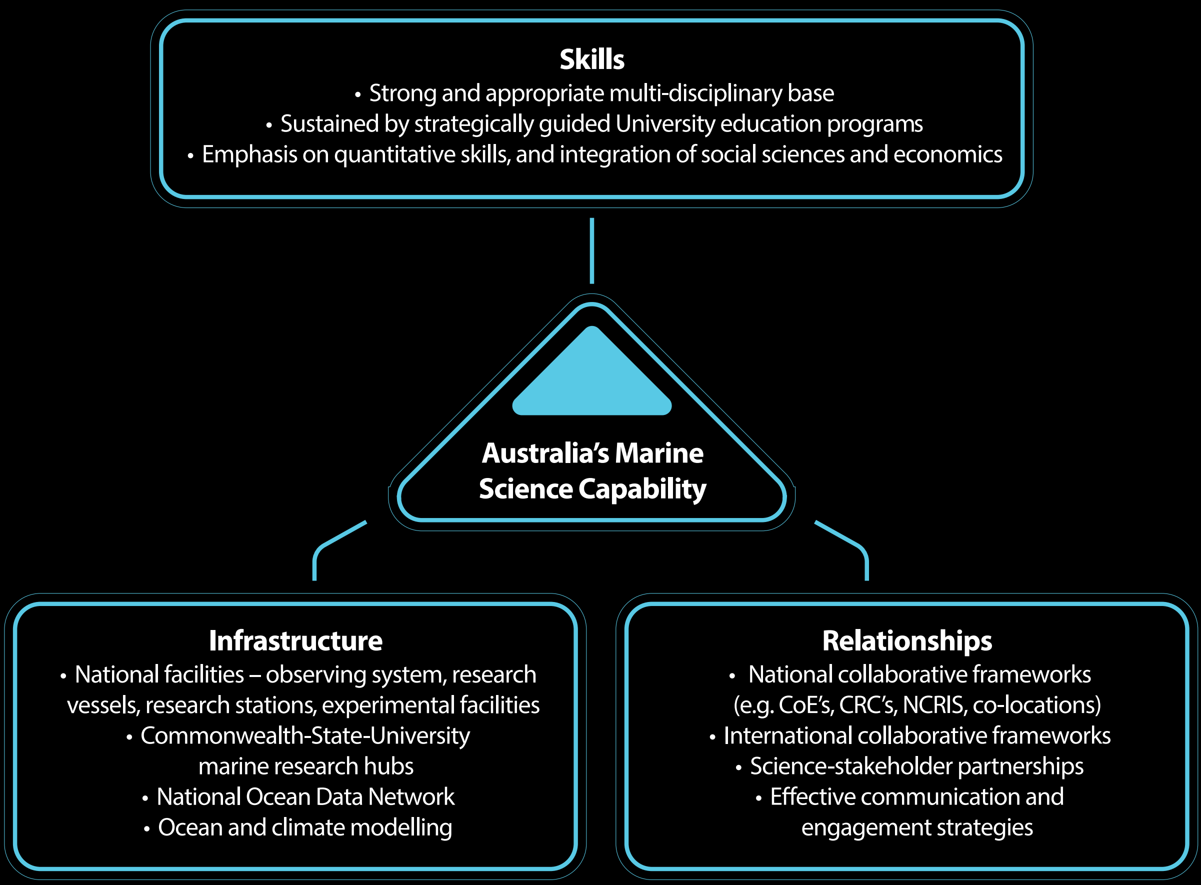

Figure 2 Australia's marine science capability is made up of skills, infrastructure and mechanisms for collaboration.

27 http://www.innovation.gov.au/Innovation/Policy/Pages/ReviewoftheNationalInnovationSystem.aspx
28 http://www.innovation.gov.au/Science/ResearchInfrastructure/Pages/SuperScience.aspx

3.1 Observational infrastructure

All the national challenges identify research priorities that require sustained observation of essential ocean variables.

Australia's Integrated Marine Observing System (IMOS) is a distributed set of equipment, data, and information services covering the oceans around Australia. It was established under the National Competitive Research Infrastructure Strategy (NCRIS) in 2007, and enhanced and extended through the Super Science initiative in 2009. IMOS is operated by ten different institutions from across the National Innovation System, working together to deliver a coordinated system that is making all observations and data available to the Australian marine and climate science community and their international collaborators. IMOS integrates from the open ocean onto the continental shelf and into coastal oceans, as well as across physical, chemical and biological properties. It supports a broad base of research relevant to detection and attribution of climate change, improving projections of change and impact, sustainable management of the marine environment, protection of ecosystems that are under threat from human influences, marine industries, national security and maritime safety. IMOS is recognised internationally as being a cutting-edge research infrastructure facility, which benchmarks favourably against marine observing systems in the United States, Europe and Canada. Funding for IMOS is only committed to June 2013. It has been so successful in changing the landscape of collaborative marine research and innovation that our ability to support sustainable use of Australia's marine assets would be severely compromised without it.

As highlighted in section 2, and in the 2011 Strategic Roadmap for Australian Research Infrastructure[29], expansion of marine observations and data holdings is critical, particularly:

- continuing investment in ocean observation, as the existing investments have achieved significant and internationally recognised benefits
- extension of coverage to fill significant gaps in observations, including areas such as the deep ocean, the coastal oceans, the seabed, the under-sea-ice environment and the Antarctic cryosphere
- expansion of data collected to include biogeochemical and biological data to support management of living marine resources, including monitoring of the new marine protected area network.

The IMOS information infrastructure has been used to create an Australian Ocean Data Network (AODN). The AODN is an interoperable, online network of marine and coastal data resources which serves data to support Australia's science, education, environmental management and policy needs i.e. Australia's marine digital commons. There is a critical need to secure funding for use of new national computational infrastructure and for continuing the AODN. There is a compelling case for national-scale investment in an information infrastructure that will potentially enable every publicly funded marine observation to remain discoverable, accessible and reusable in perpetuity.

As a developed nation with a large marine jurisdiction full of valuable resources, and located adjacent to the wild and inaccessible Southern Ocean, Australia has much to gain through efficient and pervasive uptake of earth observation technologies. The condition of the ocean surface is an essential boundary condition for constraining ocean modelling and forecasting, weather forecasting, and is arguably the most important interface in the global climate system. Remote sensing provides the only practical means of observing the ocean surface over large areas with consistency and at a time scale commensurate with important physical and biological processes. Ongoing access to long term satellite records underpins both monitoring for detection of changes, and investigative studies that advance understanding of the key ocean-ecosystem-climate processes and interactions.

Research vessels are a fundamental platform for observational studies of marine systems. The Australian Government currently supports one dedicated ocean going research vessel (operated by the Marine National Facility), and one polar supply and research vessel (operated by the Australian Antarctic Division), that can be accessed by the marine and climate science community. All other research vessels up to 35 metres in length are operated institutionally. The Australian Institute of Marine Science operates two 25–35 metre research vessels across northern Australia. There is a fleet of smaller research vessels operated independently by state agencies and universities. These, and other coastal research infrastructure, would benefit from sustained funding and a coordinated approach to the use of scarce and valuable infrastructure.

The 2009 Super Science Initiative included a commitment to build a new $120M state-of-the-art ocean-going research vessel for the Marine National Facility, to replace the aging and underutilised RV *Southern Surveyor*. The new vessel (RV *Investigator*), to be operated by CSIRO on behalf of the marine science community, will come into commission in 2013–14, and has the potential to provide a step-change in Australia's capacity to conduct blue-water marine science, increasing the range of accessible environments, the number of berths and amount of sea-time available to researchers. Ensuring that the vessel is sustainably funded to operate at full capacity is vital to ensuring that Australia derives maximum benefit from this investment. This involves investment not only in equipment and fuel but also in the human resources to run and maintain the vessel.

29 http://www.innovation.gov.au/Science/ResearchInfrastructure/Pages/default.aspx

Procurement of a new vessel with ice-breaking capability as part of an integrated approach to Southern Ocean and Antarctic research is a further time-critical priority as the *Aurora Australis* nears the end of its useful life. Even with two ocean-going vessels operating at full capacity only a very small fraction of Australia's marine jurisdiction will be accessible to marine scientists in any year.

Regional research stations operated by publicly funded research agencies, state agencies, museums and universities are located strategically around Australia's coast. They serve an important role in providing platforms for on-ground research in the areas closest to marine mining resources, fisheries and aquaculture production, and biodiversity in less impacted condition. They currently operate as separate entities. There is an opportunity to increase their effectiveness by establishing a co-operative network of research stations to focus regional efforts on a national approach to addressing the grand challenges facing marine industries and policy.

3.2 Experimental infrastructure

Australia's marine science capability is broadly-based, but it is unrealistic to expect that every institution involved in marine research and education will have its own world class laboratory and experimental facilities. This has led the Australian Government, and a number of state governments, to make investments that bring multiple institutions together to create regional hubs with critical mass in areas of natural advantage. For example, through the Super Science Initiative and Education Investment Fund, major hubs with new laboratory and experimental facilities have been created in Townsville for tropical ocean and coral reef research; Hobart for Southern Ocean and Antarctic research; Perth for Indian Ocean and north-west shelf research; and Sydney for sub-tropical and temperate ocean research. State government investments underpin hubs focused on marine innovation in South Australia and ecosciences in South East Queensland. These investments have created vibrant, creative precincts that support world-class marine science and encourage collaboration among institutions. As identified in the National Research Investment Plan[30], commitment to ongoing funding is required to capitalise on existing investment, and ensure continuing development of intellectual critical mass, world-class expertise, and support for the hubs as foci for international collaboration.

Many of the future advances in marine science will flow from advances in allied fields (e.g. material sciences and the suite of 'omics' approaches being pioneered in medical and plant sciences). Marine science will increasingly seek access to cross-disciplinary experimental and analytical facilities such as Bio-Platforms Australia and the National Synchrotron. To ensure that marine science applications are factored in to future investments in National Collaborative Research Infrastructure, we recommend that the marine science community be actively engaged in consultation on future infrastructure road mapping exercises and prioritisation of investments.

3.3 Research data infrastructure

Australia's ongoing marine research success depends on improved management of national and global marine research data and information, and the engagement of the marine research community and marine research institutions in improving and supporting marine research data infrastructure. Elements of research data infrastructure include modelling, high-performance computing and communication environments (including storage and cloud services), data services and 'virtual laboratories' for marine research data collaboration.

Marine science is highly quantitative, and use of models to understand, assess, forecast and project the behaviour of marine systems is both well established and increasing. Rapid development of marine sensors and platforms, and data management systems, numerical models, and visualisation techniques, combined with societal needs for better marine information, is driving very high demand for underpinning and integrated data infrastructure within the marine science domain.

In recognition of this need across many science domains, the Australian Government has been investing in a national collaborative eResearch infrastructure, based on the 'four pillars' of compute, networks, data and tools.

The marine science community has engaged strongly with development of this infrastructure, and is now reliant on sustained investment in infrastructure for computing, networks, data and tools, including co-located research cloud computing infrastructure, and collaboration tools, in particular marine and climate virtual laboratories. For example, the Marine Virtual Laboratory, being developed through the Virtual Laboratory program of the National eResearch Collaboration Tools and Resources project (NeCTAR), is a new development in modelling frameworks for researchers in Australia.

Sustained investment in national collaborative research data infrastructure will have the added benefit of enabling trans-disciplinary collaboration on cross cutting issues such as climate/carbon and coastal systems/natural hazards.

For any future investments in marine research data infrastructure, it is critical to understand and better leverage the factors that lead to optimal use of the infrastructure, striking the appropriate balance between marine-specific investments (e.g. IMOS) and investments that are national and promote interdisciplinary collaboration. For marine research, it will be important to recognise and make appropriate linkages to other substantial research data investments, including by state and territory governments.

3.4 Human capability

Australia has an ageing research workforce[31]. Attracting, training, and retaining the next generation of researchers and research leaders will become increasingly important over the next decade. There is a need within the broad framework of *Research Skills for an Innovative Future* for more specific initiatives in relation to marine science. Targeted initiatives to address the marine science workforce

30 www.innovation.gov.au/Research/Pages/NationalResearchInvestmentPlan.aspx

31 CoA 2011 *Research Skills for an Innovative Future* www.innovation.gov.au/Research/ResearchWorkforceIssues/Documents/ResearchSkillsforanInnovativeFuture.pdf

issues will not happen by chance but at the same time there are limited incentives for any one institution to address the problem beyond its own needs. Realistically, Australia can meet its needs only through the marine science community working collaboratively and with educators, industry and governments to expand and enhance the education and training of the future workforce.

Australian universities are the primary source of training for all marine research providers and are major providers of research in their own right. Both functions argue for a strong integration between the university sector and public research agencies. As a result of recent government initiatives such as NCRIS and the Super Science Initiative, together with greater university interaction with the commercial sector in areas such as oil and gas exploration and tourism, the university component of marine science is arguably more integrated with the activities of publically funded agencies and the blue economy than at any time in recent years. The challenge now is to work together to establish how future capability needs will be met.

Training

Marine research providers have identified a need for additional trained staff across a broad range of discipline areas with substantial growth required in areas such as climate science, mathematics, taxonomy and geoscience. The complex scientific challenges of the future require even greater skills in multidisciplinary areas and new and emerging fields such as integrated assessment modelling and earth system science that integrate information from diverse disciplines. Quantitative research skills will be critical but few specific tertiary programs are available (but see Box 4). Equally, skills in computational science and developing fields such as bioinformatics and the use of the new 'omics disciplines (e.g. metagenomics, proteomics, metabolomics) in systems biology will be key to innovative approaches to addressing the grand challenges. In the next decade it will be crucial to ensure bio-informaticians, bio-statisticians and computational scientists are increasingly embedded within marine laboratories, augmenting the critical mass of more traditional marine science capabilities. Integration of social, economic and environmental data in the study of complex marine management issues will require greater collaboration among researchers of different disciplines and more sophisticated modeling skills.

There is also a clear need to develop the means to integrate social, economic and communication training into marine science programs. This is both because of the need to incorporate social and economic data into modern, sophisticated models for marine management, as well as the need — made obvious in the last decade — for scientists to more effectively engage with and inform the general community and policy sectors. Many of the major activities that occur within Australia's marine estate, such as tourism and recreational fishing, are broadly based across the community, and training of modern marine scientists should include the capacity to engage broadly with the Australian public. For science and scientists to remain credible and continue to provide appropriate advice, it is critical that scientists learn to communicate effectively across the many elements of society.

Quantitative Marine and Antarctic Studies doctoral program

The Quantitative Marine and Antarctic Studies doctoral program provides an example of a tertiary program developed to meet the high demand for marine scientists with strong quantitative skills. Jointly funded by the University of Tasmania, CSIRO and the Australian Antarctic Division, students have access to world-class research infrastructure, scholarships, interdisciplinary research opportunities and over 100 scientists working in the three institutes. Such joint ventures focusing on quantitative science training are critical to fill the research workforce needs for development of Australia's blue economy.

While the future need for quantitative skills is clear, we know that participation rates in secondary and higher education in earth sciences, mathematics, chemistry and physics have been falling since 1992[32]. Undergraduate enrolments in information and communication technologies (ICT) also fell by 50 per cent over the period 2001–2010. Higher degree enrolments in physics and ICT have not increased sufficiently to meet projected research needs for 2020. These trends need to be reversed.

32 Office of the Chief Scientist, 2012 *Health of Australian science* www.chiefscientist.gov.au/2012/05/health-of-australian-science-report-2/

Australian marine science training is world-class in specific discipline areas (e.g. oceanography and marine ecology) but Australian universities currently do not offer a multi-disciplinary doctoral program that encompasses the spectrum of marine science: biology, chemistry, earth science, mathematics, engineering and physics. Such programs elsewhere in the world (Germany, Japan, UK, USA) constitute the global benchmarks, and Australia should develop such a program that will compete globally for students of the highest calibre and produce future generations of world-leading researchers.

Collaboration

The increasingly multi-disciplinary nature of marine research, incorporating input from the social and economic disciplines as well as traditional bio-physical disciplines, and the need to more effectively use national research facilities, demands increased collaboration among institutions. As well as integrating and collaborating among institutions, an important challenge for Australia's marine science strategy is finding the appropriate balance and blend of basic, strategic and applied research. While ultimately marine science should be in support of Australia's blue economy, this needs to be underpinned by strong and innovative basic research[33]. This is particularly critical as we look into the future and move to a more innovation-based economy.

NCRIS and the Super Science Initiative have been catalysts for collaboration between publicly funded research agencies and universities which had previously proven difficult to achieve. The success of IMOS is an example of what can be achieved when a funding source actively sets out to build a community around an agreed set of objectives and with the expectation that they would share resources. Having built this collaboration among the marine science community, there is strong support for continuation of the model. The National Environmental Research Program and its predecessor, the Commonwealth Environmental Research Facility, have also been instrumental in bringing together consortia of universities, research agencies and user communities to undertake public good research targeted at policy questions and geographic areas of strategic interest to policy-makers. These two programs involved competitive bids for funds in fixed, five-year tranches.

Some of the other major sources of funding for marine science in Australia tend to work against this broad scale collaboration. For example, although basic marine science is supported by the Australian Research Council (ARC) at universities through various schemes including university-only, fixed-term Centres of Excellence, the ARC funds very little applied marine science. Public good marine science also generally falls outside the guidelines for Cooperative Research Centre (CRC) funding because it is by definition not for commercial profit. When the CRC Program has funded collaborative, public good marine science — for example with the Antarctic Climate and Ecosystems CRC and the CRC Reef Research Centre — these major programs, along with the Centre of Excellence for Climate System Science, have made valuable contributions to climate prediction, environmental protection and systems understanding of critical parts of Australia's marine estate. There is a strong argument, recognised in the National Research Investment Plan, that the funding model for public good marine science needs to address key national priorities by providing for long-term collaboration among institutions and with stakeholders with sustained support for critical infrastructure.

Revised funding and institutional arrangements to enable collaboration and sharing of resources across institutions would encourage development of multi-institutional, multi-disciplinary teams. Major benefits would include enhancing the ability to address national priorities, enriching the training of doctoral students and postdoctoral workers by allowing them to work with research leaders from a range of institutions including industry, with attention to development of career paths that lead to retention of talented individuals and renewal of Australia's human resource base in marine and climate science.

International links & cooperation

The Australian marine research community maintains strong and enduring international connections as part of global and regional programs. Such collaboration increases intellectual critical mass and allows access to infrastructure not available in Australia. Involvement in large-scale international projects improves leverage for Australian funds[34] and data. International engagement also keeps Australian marine science current and globally relevant.

International participation gives Australian researchers opportunities to collaborate with overseas researchers and complementary capabilities apart from the sampling and observation technologies themselves. International collaborative projects also catalyse national partnerships. For example, the Australian consortium for the Integrated Ocean Drilling Program involves 14 Australian universities and three government agencies working with scientists from 24 other countries. The Census of Marine Life program that ended in 2010 involved over 170 Australian marine scientists collaborating with thousands of scientists from 80 other nations to study and synthesise information on marine biodiversity at an unprecedented scope and scale in all ocean realms. Australia's participation in the World Climate Research Programme (WCRP) provides most of the understanding and prediction of southern climate variability and

33 Commonwealth of Australia (2012) *National Research Investment Plan* www.innovation.gov.au/Research/Pages/NationalResearchInvestmentPlan.aspx

34 Australia's contribution to the Integrated Ocean Drilling Program is US$1.4 million per year, implying a leverage factor of over 100.

change, while membership of the Scientific Committee on Antarctic Research (SCAR) is crucial in coordinating high quality research in the Antarctic region and consistent with Australia's territorial claims.

Engagement with international scientific programs helps maintain Australia's leadership in marine research but requires support for participation and contribution. For example the Australian Strategic Plan for Earth Observation from Space[35] identifies coasts and oceans as a priority area, and a National Earth Observations from Space Strategic Infrastructure Plan (EOS-SIP) is currently under development. Support is required for national archiving and processing capability, a network of direct reception stations that provide complete regional coverage and adequate connectivity to enable sharing of data, sustained funding for high quality in situ observations for calibration and validation, and improved mechanisms to support membership of international mission science teams by Australian scientists.

Increasing effective engagement with, and leverage of, international marine science initiatives under the framework of the Global Ocean Observing System[36] and related programs, is key to strengthening Australia's marine research capacity and research outcomes. Securing ongoing and long-term support for participation in these initiatives will provide substantial returns for Australia's efforts.

Image: Scott Bainbridge © AIMS

35 http://www.science.org.au/publications/research-projects-and-policy.html
36 www.ioc-goos.org

Image: Bruce Barker © CSIRO

4 Marine science coordination and leadership

Extension of the National Facility concept

Extension of the concept of National Facilities to a wider range of marine research infrastructure (e.g. a national fleet of research vessels and major pieces of experimental or observational infrastructure) offers potential efficiencies and benefits to the marine science community and the nation through sharing of capability and by ensuring these capabilities are used to support science of the best quality and most relevant to national priorities.

For example, there will soon be two blue water research vessels with capability to work in the Southern Ocean: the *Aurora Australis*, which has icebreaking capability, and the RV *Investigator*, which is larger and has more science berths than its predecessor RV *Southern Surveyor,* and importantly, is ice capable and thus able to work down to the sea ice zone. *Investigator* is managed as a marine national facility by CSIRO while *Aurora Australis* is managed as both a research vessel and an Antarctic supply ship by the Australian Antarctic Division. Inclusion of vessels with coastal capabilities in a National Facility would likewise enable coordination of research to address national priorities in the coastal seas.

Similarly, providing funding and strong governance through the National Facility for key national assets such as the IMOS/Australian Ocean Data Network observing and data infrastructure and , and the major experimental facilities such as the tropical sea simulator would provide a significant boost to the nation's ability to conduct marine and climate science.

A critical requirement for these major national infrastructure investments is adequate long term funding and institutional support. In marine and climate systems science, research vessels, observing systems and major experimental facilities are the tools used to build and support long term records and time series that are essential to our understanding of change processes and supporting sustainable development of coastal and marine resources. The challenge for governments, and the research agencies responsible for the new capabilities, is to ensure that these are used as widely and effectively as possible, and directed towards the maximum national benefit. The model for support of National Facilities or key elements of marine research infrastructure must include the full costs of operation of the infrastructure as well as handling the vast amounts of data they produce.

The need for a national marine science strategic plan

Since 2009, Australia has articulated national science frameworks or research and extension strategies for climate change science, earth system science, Antarctic science, fishing and aquaculture. In addition, the Australian Government has released the National Research Investment Plan, and is currently developing a National Plan for Environmental Information which is intended to improve the quality and accessibility of environmental information for decision-making. All of these have significant marine components and requirements for investment in and coordination of marine, computing and data infrastructure and enhanced human capability. Yet to date there has been very little attempt across governments and government departments to take an integrated national approach.

Over the same period, the Australian Government has invested over $340 million in marine research infrastructure and capability development, and states have made significant co-investments in many new facilities. These investments provide greatly enhanced capability to understand, use and protect our marine environment and resources at a time when Australia's maritime industries are worth more than $40 billion per annum (more than agriculture), and there is unprecedented further development occurring in the offshore oil and gas, ports and shipping industry sectors.

Given the multitude of overlapping national science plans and strategic frameworks that involve marine science, and the huge investments the nation has made in infrastructure over the last five years, it is timely to develop a national Decadal Plan for Marine Science to:

- knit together marine components of the multiple science strategies and frameworks currently in place, and in particular, identify areas where integration of efforts would be of benefit
- identify and agree on marine science priorities that address the suite of national challenges
- identify national marine science capability strengths and weaknesses (encompassing infrastructure, skills and collaborations) and approaches to deal with the gaps
- outline a national marine science information management strategy to ensure that all data collected is stored and systematically described in metadata so that information is readily identifiable and accessible to stakeholders and users
- set out a regular process for engagement with stakeholders to allow evolution of the strategy as needs demand.

A national marine science steering committee

For marine science to be effective in answering the significant national challenges, we need to prioritise and coordinate

- advice to government about how marine science can contribute to sustainable development of Australia's blue economy
- monitoring and research questions to be addressed to support evidence-based decision-making
- infrastructure development and management
- development of human capability.

In the past, these roles were played by a number of committees that are now defunct—the National Oceans Advisory Group and its supporting Oceans Policy Science Advisory Group[37], and the Marine and Coastal Committee (MACC) of the Natural Resource Management Ministerial Council. Since the abolishment of these committees there is no formal mechanism for national coordination of marine science strategy and investment. The collaboration between OPSAG and the MACC provided an important bridge between the Australian Government and states in the coordination of national marine and coastal research priorities. OPSAG also played an active role in supporting and shaping marine science initiatives such as NCRIS Road Mapping, Marine and Climate Super Science and Australia's Ocean Data Network. Throughout this active engagement, OPSAG has remained an informal group, rather than becoming a ministerial or departmental committee.

In *A Marine Nation* (2009), OPSAG introduced the concept of a national steering committee for marine science and innovation. The need for a focused and formal advisory committee is still paramount. Such a national peak body would provide:

- the critical (and currently missing) link between marine science and marine industries, marine policy and implementation across all levels of government
- an integrated overview of national directions for science to contribute to expansion of Australia's marine industries and management of the marine environment
- high level priorities and directions for Australian national effort in marine research and innovation.

A ministerially appointed National Marine Science Steering Committee could include an independent chair and a membership of 6–8 expert marine scientists drawn from state and Commonwealth publicly-funded marine science agencies, universities, and private research and development (industry). The committee would need to be supported by a broad-based stakeholder reference group similar to the current OPSAG but potentially expanded to include representation from industry and non-government organisations. The national steering committee would act as a conduit for coordinated marine science advice on national-scale issues to the government from the broad marine science sector. It would also distil and communicate marine science priorities to the marine science sector and the broader public.

Image: Steve Clarke © AIMS

37 OPSAG continues to function as an informal and voluntary body to inform and coordinate institutional responses to national research matters in the marine domain. OPSAG includes representatives of all relevant Australian Government publicly funded research agencies (CSIRO, AIMS, DSTO), departmental research agencies (e.g. AAD, ABARE, BRS, GA, BoM), research funders (e.g. ARC, FRDC), representatives of universities (e.g. UTAS, SIMS), Australian Government departments (e.g. DSEWPaC, DCCEE, DIISR, DAFF/AFMA, AMSA[Australian Marine Safety Authority]) and marine science community peak bodies (e.g. AMSA [Australian Marine Sciences Association]).

Australian Government

Oceans Policy Science Advisory Group

The Oceans Policy Science Advisory Group (OPSAG) is an Australian Government advisory body. Its role includes promoting co-ordination and information sharing between Australian Government marine science agencies and across the broader Australian marine science community. OPSAG is made up of representatives of Australian Government agencies and additional members who assist the group to access stakeholder, industry, and research views and state/territory government considerations.

- Australian Antarctic Division
- Australian Bureau of Agricultural and Resource Economics and Sciences
- Australian Fisheries Management Authority
- Australian Fisheries Management Forum
- Australian Institute of Marine Science
- Australian Marine Safety Authority
- Australian Marine Sciences Association
- Bureau of Meteorology
- CSIRO
- Defence Science & Technology Organisation
- Department of Industry, Innovation, Science, Research and Tertiary Education
- Department of Sustainability, Environment, Water, Population and Communities
- Fisheries Research & Development Corporation
- Geoscience Australia
- Great Barrier Reef Marine Park Authority
- Institute for Marine and Antarctic Studies
- Integrated Marine Observing System
- Perth Regional Programme Office in support of UNESCO Intergovernmental Oceanographic Commission
- PISC RD&E Strategy for Fishing & Aquaculture, Research Providers Network
- Royal Australian Navy – Australian Hydrographic Service
- Royal Australian Navy - Hydrography, Meteorology and Oceanography Branch
- States and Territories Governments
- Sydney Institute of Marine Science
- UWA Oceans Institute