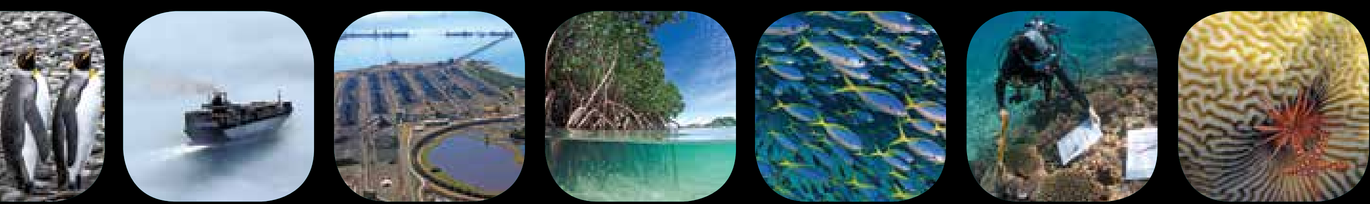
National Marine Science | **Plan** 2015–2025

Driving the development of Australia's blue economy



Prepared by the National Marine Science Committee
Chaired by John Gunn, CEO, Australian Institute of Marine Science

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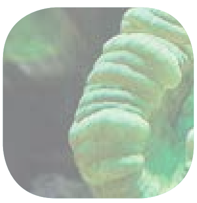



"Our culture and our view of oceans aren't fixed in time. They aren't held in an institution. They don't hang upon a museum wall. You won't find them searching the texts of the many scientists that have studied our people's ways. Oceans are a part of us, and we are a part of them."

Rodney Dillon, National Sea Rights Portfolio Commissioner

Sea Country—an Indigenous perspective

Foreword |

The *National Marine Science Plan* has been developed in response to the 2013 position paper *Marine Nation 2025: Marine Science to Support Australia's Blue Economy.*[1]

The paper recommended the creation of a decadal plan to focus investment on the biggest development and sustainability challenges facing Australia's marine estate[2], and the highest priority science needed to tackle these challenges and fulfil our blue economy's potential.

Many of our major trading partners have already recognised the nexus between science and blue economy growth with the development of investment plans and ocean policies.

"Science is the foundation upon which sound management of ocean and coastal resources is based."

John P. Holdren, Director of the White House Office of Science and Technology Policy and Co-Chair of the National Ocean Council.

It's a call to action that has led the Director of the White House Office of Science and Technology Policy, John Holdren, to announce a US National Ocean Policy that will strengthen the science, coastal economies, and sustainability of their great marine nation. "Science is the foundation upon which sound management of ocean and coastal resources is based," Mr Holdren declared.[3]

And it's a clarion call that our great marine nation needs to heed too, and one that Australia's marine science community has already recognised.

Australia has a strong, committed and united marine science community with a high international profile. This is exemplified by representatives of 23 research institutions, universities and government departments coming together to develop this *National Marine Science Plan*, under the auspices of a National Marine Science Committee.

In this Plan, we articulate the science required to address the grand challenges identified in *Marine Nation*, and we highlight a number of areas where national collaborations will strengthen both the science and engagement with end user communities.

We recommend increased investment in national research infrastructure and high-priority science programs where current resourcing is a significant impediment to achieving the desired outcomes.

We also emphasise the importance of international collaboration to Australia's marine science, and the critical need to engage and communicate with the Australian community about marine science and its role in achieving the outcomes of this Plan.

Collaboration and consultation have been central to the Plan's development, with the Committee placing significant emphasis on creating a document that truly articulates and represents the Australian marine science community and its end users.

Over 500 marine scientists and stakeholders have taken part in a process that began with the development of eight community white papers.[4] This involved different marine science sectors working with their research and industry partners to identify the challenges and science needs for each grand challenge. Eleven Commonwealth Government departments were also directly involved in the white paper process—and further development of the Plan—through their membership of the National Marine Science Committee (NMSC).

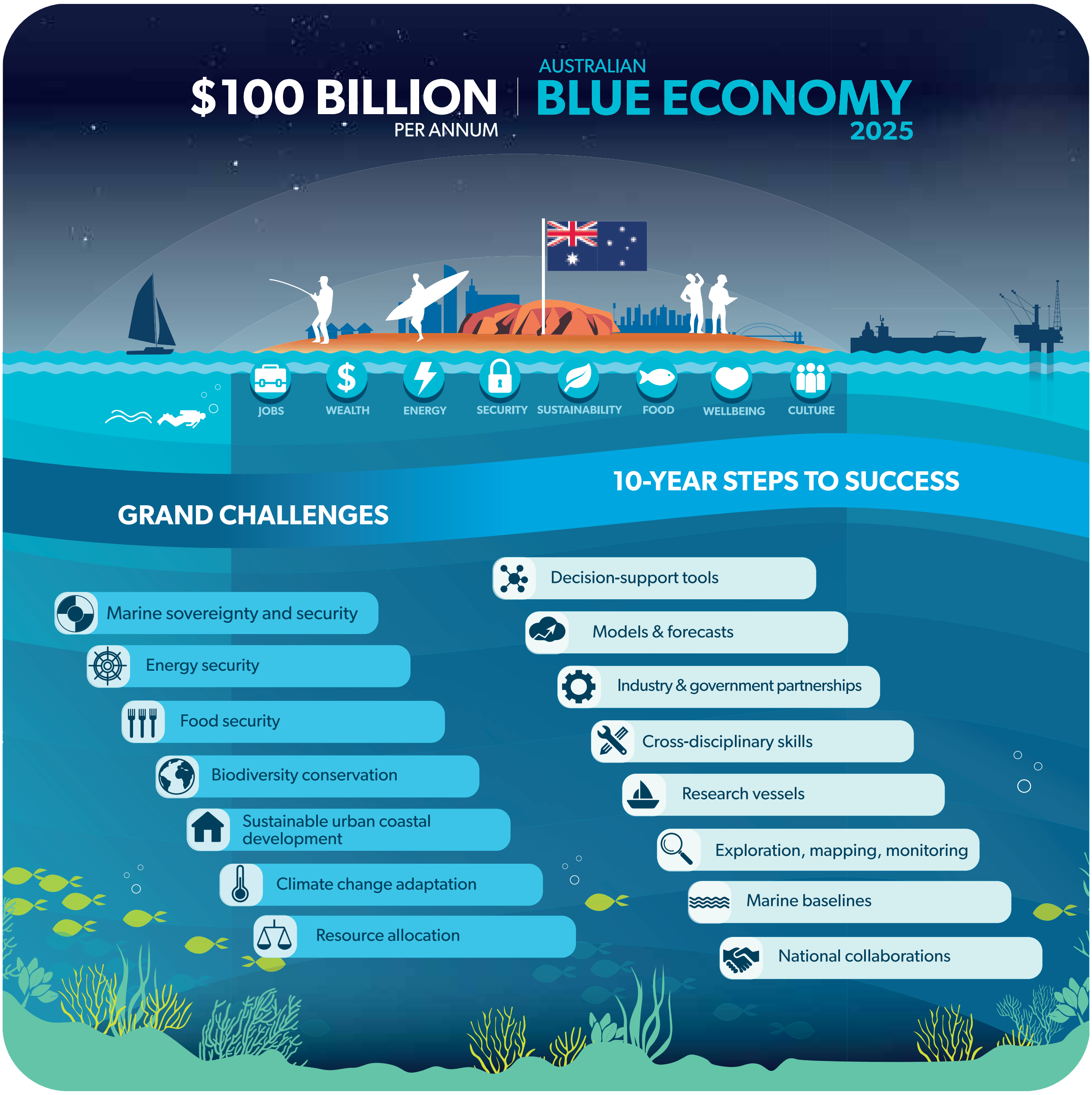
The white papers were presented and discussed at a National Marine Science Symposium in November 2014, and their findings were synthesised to create the Plan's challenge chapters and to help develop the big-picture priorities around synergies, capabilities and, finally, recommendations.

Two further consultations and 73 feedback submissions later, we believe that we have a Plan that speaks for our marine science community and its users.

We also see this Plan working hand in hand with the Science and Research Priorities set by the Commonwealth Science Council[5], and with a number of other national and international efforts to prioritise ocean, earth system and climate science.[6,7]

Finally, as a marine science community, we are committed to ensuring our science creates maximum benefit for the nation, and to working with end users across the private and public sectors to achieve this.

John Gunn
Chair
National Marine Science Committee


$100 BILLION
PER ANNUM
AUSTRALIAN
BLUE ECONOMY
2025
JOBS
WEALTH
ENERGY
SECURITY
SUSTAINABILITY
FOOD
WELLBEING
CULTURE
GRAND CHALLENGES
Marine sovereignty and security
Energy security
Food security
Biodiversity conservation
Sustainable urban coastal development
Climate change adaptation
Resource allocation
10-YEAR STEPS TO SUCCESS
Decision-support tools
Models & forecasts
Industry & government partnerships
Cross-disciplinary skills
Research vessels
Exploration, mapping, monitoring
Marine baselines
National collaborations

Executive Summary |

Australia's vast oceans are the heritage, heart and economic future of our country. The value of this marine estate to the homes, work, play, energy, food, safety and security of all Australians is matched only by the enormous economic and environmental wealth that this national asset affords us.

By 2025, Australia's marine industries will contribute around $100 billion each year to our economy, with our oceans and coasts providing a further $25 billion worth of ecosystem services, such as carbon dioxide absorption, nutrient cycling and coastal protection.

This marine economy is projected to grow three times faster than Australia's gross domestic product over the next decade, more than doubling its 2012 contribution of $47.2 billion.[8]

But you can't put a price tag on the priceless, with a coast-hugging population and a nation of beachgoers, sailors, surfers, fishers and Indigenous people placing great emphasis on the cultural and aesthetic value of our oceans.

More than 85 per cent of Australia's population live within 50 kilometres of the coast[9], and they expect our estuaries, beaches, coasts and oceans to be healthy and productive.

Australia's climate—a land of droughts and flooding plains, and one of the most variable on Earth—is also controlled by the surrounding oceans. Their very strong influence on our island home's weather, affects every Australian, every day.

A blue economy[10] can help realise these triple-bottom-line values by striking the right balance between reaping our oceans' economic potential and the need to safeguard their longer term health. In this economy, our ocean ecosystems bring economic, cultural and social benefits that are efficient, equitable and sustainable.

And for future Australian generations, even greater unknown benefits await. Our current blue economy projections are based on just a fraction of our marine territory and the tip of the emerging-industries iceberg.

We have yet to explore more than 75 per cent of our marine estate[11], and innovative technologies and products will open up exciting new possibilities. Meanwhile, Australia's lack of data on emerging industries means that blue economy projections have not included the full breadth of potential marine economic activity.

Knowledge is power for our existing industries too. Better understanding of the ocean and its influence on climate will help minimise the risk and maximise the opportunities in climate-sensitive industries such agriculture, aquaculture, energy and health.

However, to fulfil the known potential and yet-to-be-discovered possibilities of our ocean estate, we face seven challenges. These are:

- maintaining marine sovereignty and security
- achieving energy security
- ensuring food security
- conserving our biodiversity and ecosystem health
- creating sustainable urban coastal development
- understanding and adapting to climate variability and change
- developing equitable and balanced resource allocation.

To meet these challenges, we need to harness and enhance a key economic and environmental driver: marine science. This science will establish essential knowledge of ocean systems and resources, providing the evidence base for industry and government to plan, invest and mitigate risk.

It will also drive the development of new marine technologies and product innovation that will translate marine science discovery into industry development, job growth, environmental sustainability and economic prosperity for Australia.

So we have brought together the best and brightest of Australia's marine science community to develop the *National Marine Science Plan*, with a broad consultation process involving over 500 scientists and a wide range of stakeholders.

This Plan outlines the research, infrastructure, skills, partnerships and investment that will drive the required changes over the next 10 years, and deliver the best possible long-term returns to Australia.

Our commitment

The *National Marine Science Plan* will ensure that marine science addresses the grand challenges with cutting-edge research that integrates social and economic factors, and which is done at the scales required.

Collaboration and communication are also central to our commitment. Partnerships between scientists, industry, government and community groups, and effective engagement with the public about our marine science, will ensure that we meet these common challenges and enjoy shared success.

"Our marine estate is a valuable national asset that contributes significantly to our economy"

Call to action

We call on all marine estate stakeholders to act on the following recommendations, which we believe are key to this success. Marine estate stakeholders should:

1. Create an explicit focus on a sustainable blue economy throughout the marine science system.
2. Establish and support a National Marine Baselines and Long-term Monitoring Program to develop a comprehensive assessment of our estate, and to help manage Commonwealth and State Marine Reserve networks.
3. Facilitate coordinated national studies on marine ecosystem processes and resilience to enable understanding of the impacts of development (urban, industrial and agricultural) and climate change on our marine estate.
4. Create a National Oceanographic Modelling System to supply defence, industry and government with accurate, detailed knowledge and predictions of ocean state.
5. Develop a dedicated and coordinated science program to support decision-making by policymakers and marine industry.
6. Sustain and expand the Integrated Marine Observing System to support critical climate change and coastal systems research, including coverage of key estuarine systems.
7. Develop marine science research training that is more quantitative, cross-disciplinary and congruent with industry and government needs.
8. Fund national research vessels for full use.

Investing in our future

Investment in research and development is essential to achieving the knowledge, technology and innovation cornerstones of growth in our blue economy. Given the breadth of challenges and beneficiaries, it is clear that this investment must come from a broad base, including different levels of government, private industry and the community.

At an estimated $450 million[12], the annual spend on marine science has helped double the blue economy contribution over the last decade to the current $47.2 billion per annum.

Over the next decade, the blue economy is set to grow at 7.5 per cent per annum, far outstripping the projected 2.5 per cent growth rate of Australia's GDP.[13] Marine science investment will ensure that this impressive trend continues.

This Plan will ensure that current marine science funding gains greater traction by increasing the focus and coordination of existing science and research capability. This is particularly important given major investments in marine science infrastructure over the last decade.

We have also identified a number of priority initiatives for future investment, which focus on building a strong national blue economy. These include:

- a National Blue Economy Innovation Fund
- National Marine Research Infrastructure
- a National Marine Baselines and Monitoring Program
- a National Integrated Marine Experimental Facility
- a National Ocean Modelling Program
- a Marine Science Capability Development Fund.

Introduction |

Our land is girt by vast seas, and Australia's work, play, homes and identity are bound by them too. We are a marine nation that depends on the oceans for much of our wealth, wellbeing and security.

From Antarctica in the south to the Torres Strait in the north, from the Heard and McDonald Islands in the west to Norfolk Island in the east, our marine estate straddles three oceans: Indian, Southern and Pacific.

It is the third-largest marine jurisdiction of any nation on Earth—13.86 million km^2—giving us a natural security buffer and the responsibility for a search-and-rescue area that is over one-tenth of the Earth's surface.[14]

These oceans and coastlines are also teeming with a vast array of unique and globally significant ecosystems, as well as resources and industries, both known and yet to be discovered or developed.

And as a marine nation, Australians place enormous value on enjoying and maintaining this marine environment, while also expecting to derive significant economic benefit from our oceans.

Our marine nation—a valuable asset

By 2025, our oceans are expected to contribute $100 billion per annum to our economy, up from the current $47.2 billion annual contribution. This contribution includes existing industries such as tourism, ports, transport, shipbuilding, offshore oil and gas, aquaculture and wild fisheries.

Opportunities for further economic gains lie in biotechnology, wind, wave and tidal energy and innovation-based growth in established sectors.

The ocean's ecosystem services, such as climate regulation, temperature and freshwater variability, carbon dioxide absorption, nutrient cycling, coastal protection and oxygen production, are estimated to be worth a further $25 billion.

But the value of many ecosystem services[15]—along with the aesthetic and cultural importance we place on Australia's oceans—is not something you can put a price tag on.

Around 85 per cent of Australians call our coastal fringe home and, as a nation of beachgoers, fishers, sailors and seafood lovers, we value the recreation and food that healthy coastal waters provide.

A burgeoning marine tourism industry offers Australians and visitors from all over the world access to incredible biodiversity and unique marine icons such as the Great Barrier Reef, while the relationship between Indigenous communities and the ocean is a strong and ancient one.

It is the recognition and balanced management of these economic, environmental, social and cultural benefits that support the concept of a blue economy.

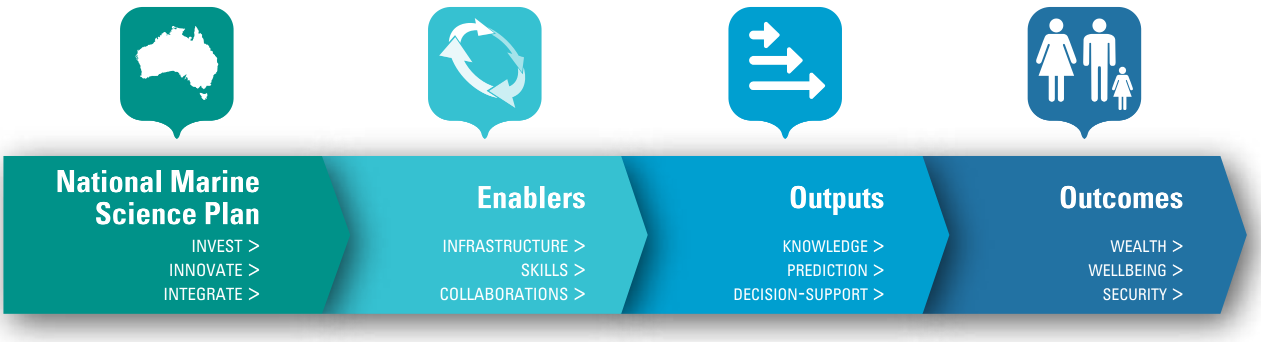
Across the world, there is a growing acceptance that a blue economy is the key to unlocking the economic benefits of the ocean while also providing environmental stewardship.

Major trading partners, such as the European Union, China and the US, have heeded this clarion call with the development of blue economy strategies, national ocean policies, and investment in marine research and development. Used wisely, Australia's ocean resources can also generate increasing prosperity, security and sustainable living for generations.

The challenges we face

Australia is grappling with development and sustainability goals in the face of seven grand marine challenges.

These are: marine sovereignty, security and safety; energy security; food security; biodiversity conservation and ecosystem health, urban coastal development; climate variability and change; and resource allocation.



Used wisely, Australia's ocean resources can generate increasing wealth, food and energy and support sustainable living for generations.

But among these challenges lie national opportunities too.

The tropical north is Australia's gateway to the rapidly growing Indo–Pacific region and an area that all levels of government have recognised as uniquely positioned for national growth.

Here, we find most of Australia's known mining and offshore oil and gas resources, which are supplying our regional neighbours and driving massive expansion of bulk commodity ports and processing industries.

However, 'The North' is also home to Australia's iconic coral reef and mangrove systems, major fisheries and a multibillion-dollar tourism sector. 'Sea countries' are also the spiritual and cultural heart of Indigenous people across this northern marine region, and all around Australia's coastlines, where they seek to be acknowledged as custodians and marine managers.

Meanwhile, the coastal environments around our major cities face the impacts of a century of development, and the challenges of competing demands and multiple stressors are most pronounced in these areas.

The impacts of climate change are being felt right across Australia, a country with one of the most variable climates on Earth.

Climate-sensitive industries, such as agriculture, aquaculture and energy, are particularly vulnerable, while our marine estate is threatened by climate change impacts such as ocean acidification, sea level rise and increased sea temperatures.

Many of these impacts arise from processes and fluctuations far out to sea, such as the Indian Ocean Dipole, the El Niño–Southern Oscillation in the Pacific Ocean and ocean–ice interactions in the vast Southern Ocean. These oceanic influences on our coastal and terrestrial environments require us to build and maintain 'bluewater' marine science capabilities and to improve global climate models.

Policy requirements and evidence

Good policy requires good information if it is to be founded on solid evidence, be well implemented and receive broad support across Australian society.

But large swathes of our marine estate remain uncharacterised, leaving Australia with major gaps in understanding of its marine systems, and an inability to measure their resilience to change or use. There are also large gaps in our understanding of social, cultural and economic drivers, and how they affect decisions.

Australia's ocean territory is the third largest on Earth

This knowledge shortfall hampers our understanding of development limits, and therefore the growth potential of industries. It also means that we lack a robust approach for assisting industry and governments to make decisions on the use and protection of the estate.

These factors have created controversy and division on issues such as port development, world heritage protection, climate change mitigation and fisheries management. Such diversity of interests can complicate policy development, as does the involvement of multiple levels of government, often in the same decision.

Marine challenges meet their match

Australia's marine science will provide the knowledge, technology, tools and innovation that will deliver solutions to the seven grand challenges, and drive the development of our blue economy.

Our marine science community has a history of excellence and international prominence. Over the past few years, we have increasingly worked together to produce the large-scale science needed to address the national and global challenges facing our marine estate.

Government departments, industries and regulators have also increasingly recognised the importance of marine science. Some have strong established relationships with marine science, which they incorporate into their business, while others are recognising the growing need for science to support their decision-making.

Meanwhile, Government investment has helped marine science drive the development of Australia's blue economy so far.

Over the past decade, investment in marine research and development has helped achieve a blue economy worth $47.2 billion. At an estimated $450 million[12], this annual spend represents less than 1 per cent of our current blue economy's value.

But with 2025's blue economy potential in our sights, and complex challenges to overcome, there is more that needs to be done, and no one organisation or institute can do it alone.

We need to build on our reputation, research and relationships to develop a coordinated, national approach that harnesses the collective capability of our marine science community, and which works together with industry, government and community.

We need to build on this capability and develop the infrastructure, skills and collaborative frameworks that will deliver critical data and research, and translate these into the next decade's knowledge, innovation, technology and tools.

Our marine science will also be central to meeting the Science and Research Priorities such as Soil and Water, Environmental Change, Food, and Energy and Resources.

The *National Marine Science Plan* therefore sets out the science, the capability and priorities needed for the coming decade and the bright blue future that awaits all of us.

CASE STUDY

MARINE SCIENCE RETURNS

A fisheries study on the socio-economic and environmental impacts of proposed marine protected areas (MPAs) in south-east Australia highlights marine science's return on investment.

The $68,000 study, funded by the Fisheries Research and Development Corporation and undertaken by the University of Tasmania in 2006, returned a staggering 578:1 benefit–cost ratio, or $42 million value to the community when it resulted in revision of the proposed boundaries for the protected areas.

Benefits of the revised boundaries included:

- ***less impact of the displaced catch, lower financial impact of foregone sales, and less impact on industry profits***
- ***less potential unemployment***
- ***less impact on industry providers such as processors, repair suppliers and maintenance suppliers***
- ***lower compliance costs due to greater industry ownership of the revised MPAs***
- ***more efficient development of MPAs for other Australian fisheries***
- ***improved set of biodiversity and conservation assets***
- ***less impact on localised fishing communities***
- ***reduced social costs of disruption and dislocation of families, particularly in Tasmania.***

The big picture | **a vision in blue**

This Plan will help Australia realise the triple-bottom-line benefits of our marine estate while protecting the values and natural assets we all hold so dearly.

So what will 2025 look like when the National Marine Science Plan is delivered?

1. Australia's blue economy will reach its $100 billion per annum growth potential, and ocean ecosystem services will be maintained.

Australia's diverse portfolio of existing and emerging marine industries will drive this growth in response to evolving economic, social and environmental conditions. This growth will be supported by developments such as:

- the expansion of ocean renewable energy resources, such as wind, wave and tide, using innovative new technologies
- the realisation of marine biotechnology potential, including the culture of a range of micro and macro marine organisms for biofuels, bioremediation and bioproducts
- the growth of green engineering, ecological restoration and other innovative methods for preventing environmental damage
- the identification, ranking and development of offshore geological basins for oil and gas potential, and for CO_2 storage
- increased market value of fisheries through sustainable harvest practices
- the doubling of aquaculture value through the development of new sectors, the growth of existing ones through new breed, feed and disease management, and the export of intellectual property to the global market
- the sustainable development of northern Australia based on better marine system understanding and baselines
- long-term sustainability of Australia's marine world heritage and growth in tourism, one of our largest and most valuable marine industries.

2. Decision-making by governments, nongovernment organisations and industries will be efficient, effective and more likely to be built around concensus.

This will be based on greatly improved, openly available data as well as better understanding of the cumulative impacts of development, climate change and socioeconomic factors on marine ecosystems.

Our decision-support tools will deal explicitly with uncertainty and enable evaluation of trade-offs between multiple uses. We will also determine the cumulative impacts of multiple stressors and inform community debate regarding 'social licence to operate'.

This will:

- increase administrative efficiency and speed in regulatory decision-making
- increase marine management coherence across the Commonwealth and states
- increase certainty and competitiveness and reduce costs for industry and governments
- reduce the likelihood that decisions are contested, through improved transparency
- reduce environmental risk
- increase sustainability.

3. Iconic systems, such as the Great Barrier Reef, Ningaloo Reef and Antarctica, and multiple-use systems such as marine parks, key estuaries, and the urban coastal ribbon, will enjoy long-term health and sustainable use.

Enhanced scientific information and improved environmental management performance will support this development.

Robust and fit-for-purpose long-term monitoring programs on urban and agricultural catchments, sewage outfalls, ports, coastal development and marine protected areas will provide an evidence base for evaluating the performance of environmental regulations and conditions and effective adaptive management.

These will reduce the risks of environmental damage and provide early warning when ecosystems become severely degraded or near tipping point, and thus reduce the huge costs associated with remediation.

4. We will increase operational safety, reduce costs and improve planning decisions of marine industries through enhanced prediction of ocean currents, sea state and ocean health.

New observing and monitoring technologies will extend our exploration and monitoring capability, and reduce the cost-per-data point.

The next generations of models will improve estimates and management of:

- oil spill and pollutant dispersion
- dredge spoil movement
- impacts of sediments, nutrients and chemicals from agricultural run-off
- coastal fisheries and aquaculture
- ocean productivity and health.

Improved estimates of wind, current and wave fields will also benefit:

- recreational boating
- the shipping industry
- search-and-rescue operators
- the Australian Defence Force (ADF)
- the offshore engineering industry, which can reduce costs incurred by over-engineering platforms and sub-sea structures.

5. Industries and governments will reduce disaster risk associated with extreme events and sea level rise through greatly improved information and intelligence on the oceans, climate variability and change.

Improved ocean observations, climate systems modelling and climate adaptation strategies will benefit every Australian as well as many different industry sectors, such as insurance, energy, water, infrastructure and health. Other examples include:

- the agriculture, fishing and aquaculture sectors, which will benefit from improved understanding and prediction of ocean-driven climate and weather processes
- local, state and Commonwealth governments, which will benefit from studies of ocean warming and Antarctic ice dynamics and improved estimates of sea level rise, allowing them to more effectively prepare for rising sea level impacts
- managers of infrastructure, fisheries and marine parks, aquaculture producers, and the tourism industry, who will benefit from improved estimation of warming trends and impacts, allowing them to plan and adapt their businesses to new states.

6. We will discover potential new hydrocarbon reserves, seabed mineral deposits, bioproducts, fisheries and other biological resources, along with hundreds of new species, habitats and ecosystems.

We will do this by doubling (to 50 per cent) the proportion of our marine estate that has been multi-beam swathe mapped, and by conducting multidisciplinary baseline surveys.

New observing and monitoring technologies will extend our exploration and monitoring capability, and reduce the cost per data point.

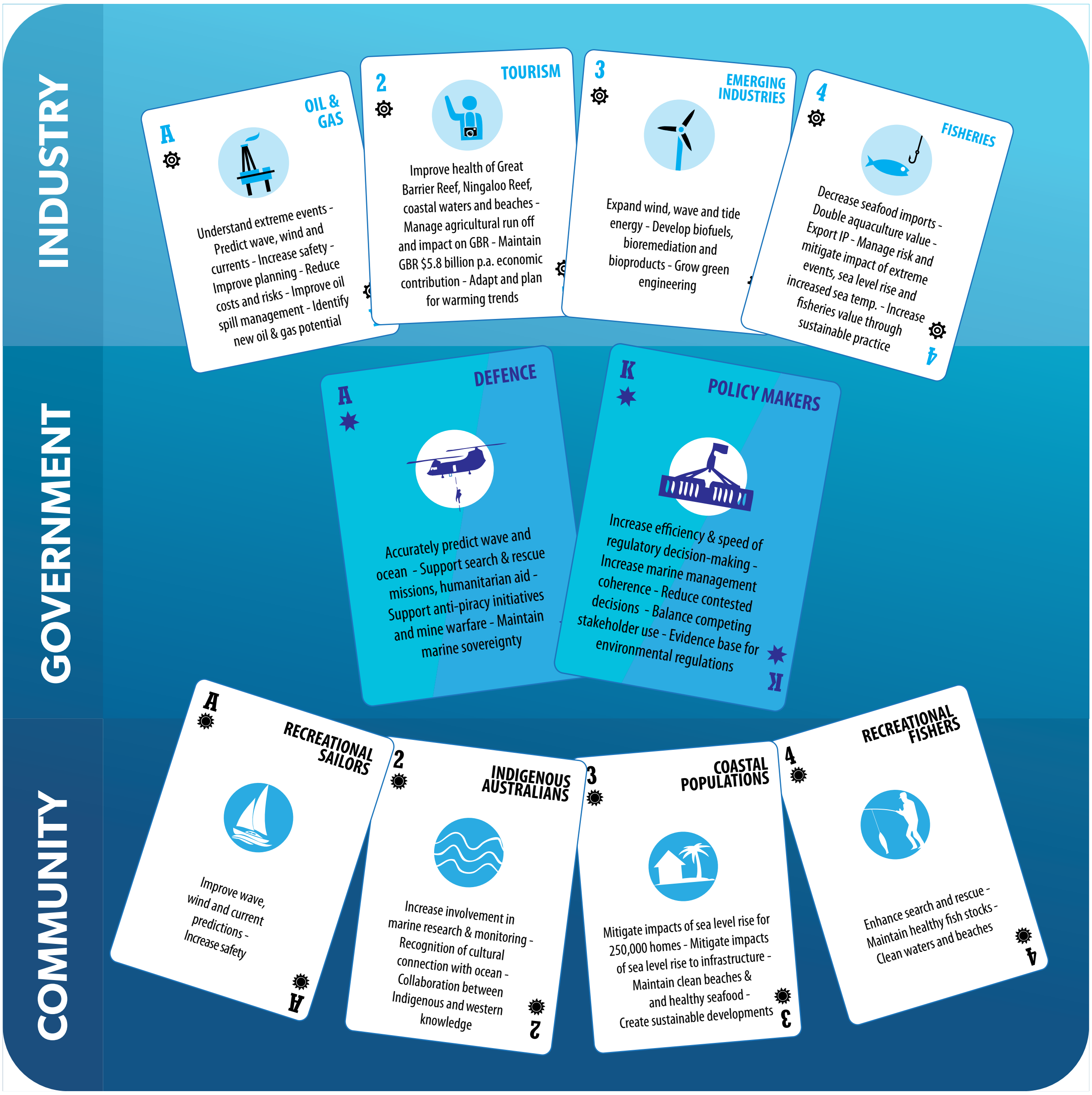
By building a comprehensive knowledge of our marine estate, we will also demonstrate a national commitment to use and manage our marine assets, and help meet under international obligations under the United Nations Convention on the Law of the Sea.

7. End users in the public, industry and community sectors will increasingly work together with the marine science community as part of major collaborative programs.

These programs will address national priority needs, enhance international relations, and build marine science's reputation for 'walking the talk' in aligning our research to improved triple-bottom-line benefits.

This includes increased emphasis on and investment in:

- joint research projects
- marine science graduates with capabilities required by industry
- joint supervision of postgraduate students and postdoctoral fellows across universities, publicly funded research organisations and industry research groups
- shared access to research vessels and major experimental facilities
- increased accessibility to data, regardless of who paid for their collection.



IF WE PLAY OUR CARDS RIGHT - BENEFITS AND BENEFICIARIES OF AUSTRALIA'S BLUE ECONOMY

The seven | **grand challenges**

We have outlined seven interconnected grand challenges facing Australia and the marine science needed to deliver their solutions.

The grand challenges are:

- marine sovereignty, security and safety
- energy security
- food security
- biodiversity, conservation and ecosystem health
- urban coastal environments
- climate variability and change
- resource allocation.

Marine sovereignty, security and safety

The challenge

Our marine estate is a vital yet challenging contributor to Australia's sovereignty, national security and safety.

ABOVE: **Energy security underpins Australia's domestic and export economy.**

Marine stakeholders, including the shipping industry, coastal managers, port operators, the offshore oil and gas industry, defence, border protection, the aquaculture and fishing industries, tourism, recreational boating, coastal engineers and emergency managers, all require accurate and up-to-date information about sea state, atmospheric conditions and geohazards, to support their multiple uses of the jurisdiction.

There is a constant need for information at timescales that stretch from hours to weeks—whether it is for industry operations, or for prediction, prevention, mitigation or compliance activities, out at sea or along the coast.

Meeting these needs is a constant challenge, but particularly so in the case of extreme weather events which remain poorly understood and a challenge to predict. Their impact is also disproportionately strong, and climate change is predicted to increase the intensity and frequency of some events.

BELOW: **The Australian Defence Force requires accurate ocean and wave predictions.**

CASE STUDY

MARINE SOVEREIGNTY

1. ***The booming oil and gas sector is moving further offshore, with planning horizons of decades, and design criteria accounting for a greater frequency of weather events that generally happen once every 10,000 years.***
2. ***The Australian Defence Force requires accurate ocean and wave predictions to support search and rescue, anti-piracy initiatives, route planning, mine warfare, anti-submarine warfare, amphibious operations, and preparation/readiness for delivery of timely humanitarian support.***

These extreme events include both physical and biological natural hazards such as destructive winds, waves and storm surges, tropical cyclones, flooding, surface and subsurface currents, temperature extremes, beach erosion, algal blooms, coral bleaching and invasive species.

The science

To maintain Australia's marine sovereignty, and improve security and safety, we need a long-term strategy to better understand, monitor and predict sea state (winds, currents and waves) and extreme events in Australia's marine environment, including the vast area beyond our borders over which we have international search-and-rescue responsibilities.

To do this we need to:

- create a comprehensive national observing system, covering open ocean to coastal and littoral zones, and which includes in situ measurements, remote sensing and a national information infrastructure
- develop short-to-medium range (days to weeks), uncoupled and coupled biophysical models for analyses and forecasts, from open ocean to coastal and littoral zones
- support the above capability with state-of-the-art national computational infrastructure
- use overseas experiences and expertise through collaboration wherever possible and appropriate
- improve delivery of information and services to the private and public sectors
- establish a national research focus on marine extreme events and a national committee of government, research community, industry and the Australian Defence Force, for short-term, fast-track priority implementation.

Energy security

The challenge

Energy security underpins Australia's domestic and export economy by ensuring access to affordable, reliable and sustainable energy sources.

Access to a diversity of primary energy sources supports our domestic energy requirements and helps us grow and sustain our export gas markets.

In 2013–14, exports of liquefied natural gas (LNG), Australia's third-largest goods and services export, were valued at $16.3 billion. This export market is predicted to grow from around 20 million tonnes per annum in 2012–13 to 76.6 million tonnes per annum by 2020[16].

Our economy's reliance on imports of crude oil and refined petroleum products is also expected to grow at around 3 per cent per annum over the next 20 years.

These needs are coupled with increasing global societal demands for renewable energy sources that produce less carbon dioxide, such as natural gas and renewable energy, or for conventional sources allied with CO_2 capture and storage.

Many of this Plan's recommendations for improving our understanding of ocean state and variability would support the further evaluation of alternative energy sources such as wind, wave and current energy.

In addition to these demands for renewable energy sources, Australia's marine estate is largely underexplored. Petroleum activity is extending into deeper waters, and the well-established regulatory approval process for energy development has to accommodate the concerns and interests of the public and many overlapping users.

BELOW: **We need to improve delivery of critical information for ship operators.** Image: Meredith Banhidi

Australia needs to protect our marine environment and the sustainability of its resources by considering the environmental risks and socioeconomic impacts associated with energy resource exploration, development and production.

Scientific research is therefore needed to support the development of policies and regulations governing the exploitation of emerging marine energy sources, and to ensure that current energy-related industries continue to operate under leading practice regulatory frameworks.

The science

To increase Australia's energy security, we need to understand the origin and accessibility of energy resources and the environmental impacts associated with their discovery and recovery. This includes development of mitigation procedures to address ecological effects and studies on the socioeconomic consequences of commercial energy developments.

To do this we need to:

- complete high-resolution seabed and sub-sea geologic mapping of Australia's marine jurisdiction to identify and rank offshore geological basins for oil and gas potential
- assess wind and wave potential at all potential sites and create a renewable resource atlas
- establish baseline environmental assessments and a national approach for data sharing and accessibility
- develop better environmental effects monitoring techniques for monitoring the impacts of future energy development operations, including improved remote sensing and in situ technologies to map and assess the myriad seafloor environments and ecosystems, as well as fluid and gas seepages
- study and establish the resilience and/or threshold limits of marine environments and ecosystems to resource development, including noise and environmental persistence of contaminants associated with exploration and production, and unplanned incidents
- develop mitigation options and technologies to address environmental impacts such as seismic surveying noise, operational waste discharges and oil spills
- develop multipurpose offshore structures that reduce the scale of environmental impacts, and support innovative ideas for environmentally sustainable uses of decommissioned energy infrastructure
- determine the hydrodynamic history of offshore sedimentary basins to assess productivity of conventional hydrocarbons and disposal of CO_2
- develop high-performance computing and high-performance data services to synthesise, analyse and access data to assist decision-making.

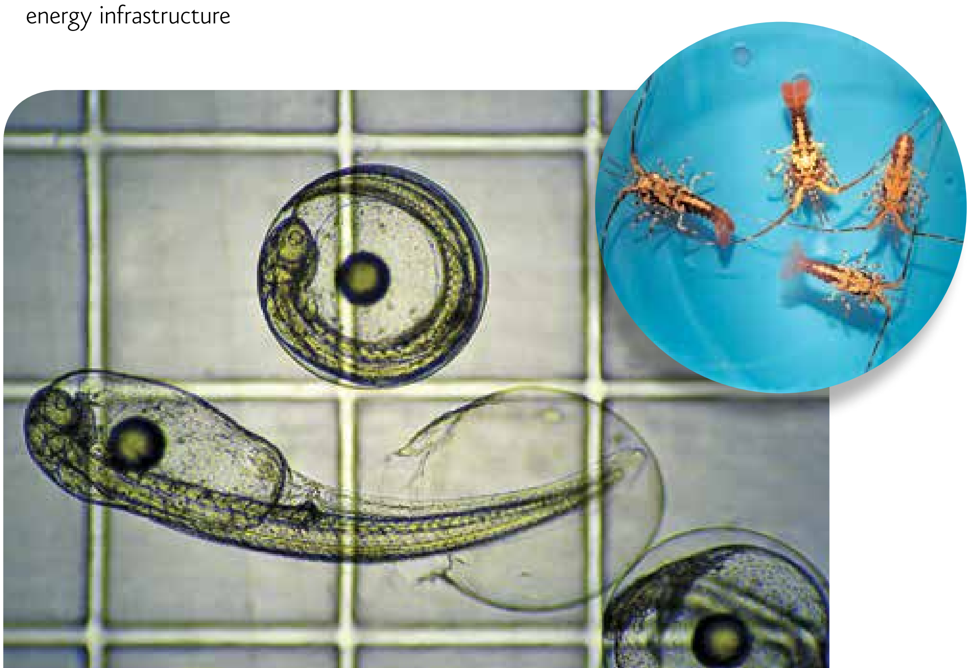
Food security

The challenge

Australia needs to address our current and potential future gaps in food self-sufficiency and improve production as part of reducing our reliance on imports.

We currently import 72 per cent[17] of our seafood, despite our country's considerable capacity for meeting both existing market demand and potential future growth in demand.

Meanwhile, environmental change, regional conflict, greater public scrutiny of natural resource management, and uncertain resource access could affect proposed seafood production, both here and globally.



We currently import 72 per cent of our seafood despite our country's considerable capacity for meeting both existing market demand and potential future growth in demand.

Australian fisheries are small by world standards, in terms of production, but have a large geographic, ecological, social and political footprint. Our aquaculture production has almost doubled in the last decade, with even greater room for expansion and diversification, and an opportunity for sustainable growth.

Significant opportunities also exist for Indigenous, social and economic benefit from improved access to marine resources.

By developing the potential use of our marine jurisdiction, Australia could supply food to countries whose production falls abruptly. Aquatic products are predicted to have some of the largest real price increases among the major global food sources—and the greatest growth is expected in our region.

However, infectious diseases are an ongoing threat, and healthy stocks are important, not only for the protection of our natural resources but also to enhance our competitiveness, and to maintain and grow market access.

Seafood safety and production issues include pathogens, biotoxins and contamination, longer and more complex supply chains, and emerging international regulations.

This is a global challenge that provides an opportunity for us to export our knowledge and services. We will therefore need to maintain and increase our effective international partnerships.

Importantly, many of the changes needed for long-term food security require multidisciplinary research planning and implementation, so Australia needs to implement key strategies to prepare for critical and emerging issues.

Six national goals have been identified to focus research, development and extension activities. We should:

- manage Australia's fisheries and aquaculture sectors in a risk-based manner that will ensure that they are publicly acknowledged as ecologically sustainable
- improve secure access to, and allocation of, fisheries and aquaculture resources
- maximise benefits and value from fisheries resources (productivity and profitability) and increase aquaculture production
- streamline governance and regulatory systems
- maintain the health of habitats and environments on which fisheries and aquaculture rely
- improve management of aquatic animal health.

The science

To meet these challenges and opportunities, our science must be collaborative, integrated[18], and internationally engaged. We must develop better tools for managers, better decision-making systems and new technologies. Our research must further quantitative modelling and address methods to better integrate coupled socioeconomic and biophysical approaches to resource assessment, including cumulative impacts.

LEFT: **Southern Bluefin larvae hatching prior to starting the journey metamorphosing into juveniles.**

LEFT INSET: **Juvenile Tropical Rock Lobsters (*Panulirus ornatus*) grown in hatchery.** Images: FRDC

CASE STUDY

ECOLOGICALLY SUSTAINABLE FISHERIES AND AQUACULTURE

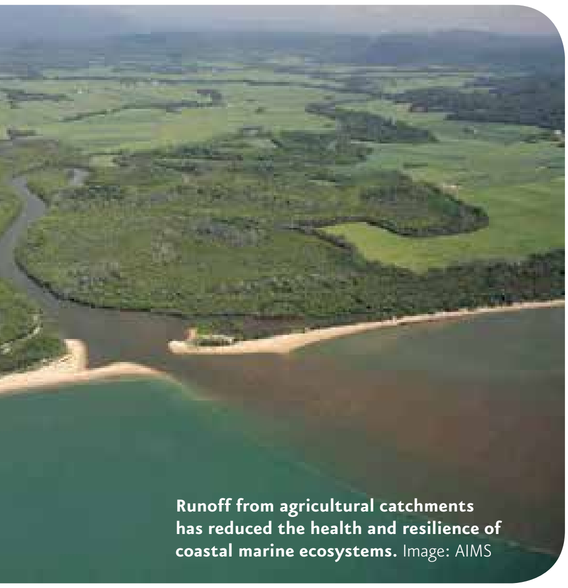
Over the past decade, Australian scientists have pioneered the development and adoption of risk-based approaches for ecologically sustainable fisheries and aquaculture management systems. These holistic approaches deal with ecological, social and economic components of a system. The United Nations Food and Agricultural Organization has since adopted them to assist with their food security program in developing countries. Other international bodies have also adopted the tools and frameworks as the basis for third-party certification schemes to demonstrate the sustainability of fisheries and to ensure ongoing public confidence.

ABOVE: **Reestablishing crayweed habitats on Sydney's coastal reefs.**

Image: Centre for Marine Bio-Innovation, UNSW

To do this we need to:

- fill critical information gaps about ecosystem processes and the implications of environmental change and variability
- develop a clearer understanding of the dynamic linkages between catchments, coasts and oceans, and their role in fishing and aquaculture production
- develop and promote consistent and cost-effective fishery management strategies across all jurisdictions, including Indigenous and recreational fishing, and data-poor fisheries
- undertake research on managing multiple uses, cumulative impacts and social licence to operate and define activities necessary to support debate around acceptable impacts and environmental standards
- develop aquaculture production systems, spatial planning and management frameworks that encompass environmental and social values, species selection, market demand and other uses of adjacent environments that lead to increased production levels
- improve Australia's capacity to respond to aquatic animal health, biotoxin and contaminant events, and develop appropriate risk management for emerging food safety issues
- increase knowledge of global and domestic demand, supply chains and country-specific preferences for seafood Australia can produce; and improve traceability systems and waste utilisation.



Runoff from agricultural catchments has reduced the health and resilience of coastal marine ecosystems. Image: AIMS

Biodiversity conservation and ecosystem health

The challenge

Australia's marine estate is home to some of the world's most iconic and diverse marine habitats and organisms, and includes several world heritage-listed areas.

Yet much of this estate remains unmapped and its species undiscovered, leaving us with limited understanding of the new opportunities that Australia's ocean territory contains.

Most Australians also enjoy living near the coast. However, this concentration of population and industries along the continental margin has placed a heavy burden on ecosystems in the coastal zone, and increasingly on adjacent seas.

Past actions have left damaging legacies ranging from the complete alienation of wetlands to barrages on marginal lands preventing fish passage. The combined impacts of agricultural and urban development on water quality are also a concern throughout Australia.

CASE STUDY

BIODIVERSITY

The algae in southern Australia are a vast untapped source of chemical diversity and opportunity for new industry developments. Collaborations between universities and industries, including international industry partners, have developed food, cosmetic, pharmaceutical and agricultural products from Australian seaweeds. This has attracted over $20 million investment in developing an industry potentially worth billions of dollars.

Poor water quality, nutrients, pesticides and sediments are having a significant, negative impact on the Great Barrier Reef.

Meanwhile, urban coastal Australians are demanding more from the scientific community as they grapple with trade-offs between social, economic and environmental outcomes.

Ocean warming has also caused several major bleaching events on the world heritage-listed Great Barrier Reef and Ningaloo Reef, and is changing the distribution of marine species. Ocean acidification and hypoxia are further threats to all marine ecosystems.

Increased vessel traffic across Australian borders and between coastal ports is an indicator of national wealth and prosperity, but it also raises the biosecurity threat from invasive marine species, underwater noise pollution and marine accidents.

Importantly, most stressors to marine biodiversity and ecosystem health are concurrent and cumulative, highlighting the need for integrated, multidisciplinary approaches.

The science

To conserve marine biodiversity and keep ecosystems healthy, we must explore and map our marine estate to fill in knowledge gaps; undertake experimental research on ecological processes; monitor key indicators of variability and change; and develop modelling tools and other techniques for evidence-based management.

Over the next 10 years, this science will focus particularly on building the knowledge base to support our new National Marine Reserve System.

To do this we need to:

discover and understand by –

- carrying out precision mapping of Australia's largely undiscovered seascape, and identifying key ecological features to prioritise management efforts
- establishing baselines using integrated habitat classification systems and marine ecosystem valuations as reference for future changes and impact assessments
- discovering and documenting biodiversity through growing skills in marine taxonomy and maintaining diversity archives
- studying key ecological processes that govern diversity, structure and function in response to environmental change, with a view to understanding thresholds of sensitivity and vulnerability
- exploring biotechnology potentials through bioprospecting of marine species

inform evidence-based management by –

- applying integrated monitoring of ecological, social and economic indicators to guide adaptive marine ecosystem management, including suitability of indicators and surrogates for rapid assessment tools
- developing smarter and more efficient approaches to monitoring through the integration of new and emerging technologies (e.g. autonomous and remote surveillance techniques/platforms)
- developing models and novel planning approaches as decision-support tools for complex marine systems
- examining the effectiveness of Australia's network of marine reserves, including assessment of management performance and tracking of long-term trends in key ecological features and/or condition proxies
- studying cumulative impacts and carrying out comparative risk assessments
- developing and trialling approaches for ecosystem repair using microbial remediation, habitat restoration or eco-engineering.[19]

Urban coastal environments

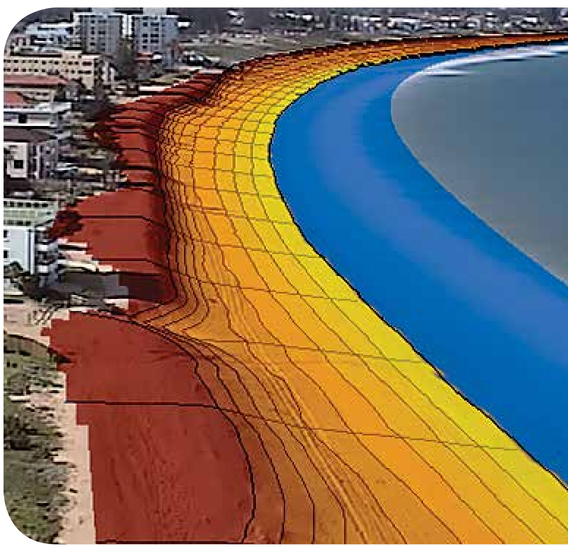
The challenge

Australia has experienced a period of pronounced urban economic development and infrastructure growth, which has been centred around coastal hubs.

Our urban coastal environments are also under increasing pressure from population growth, sea level rise, conflicting stakeholder uses, catchment and industry impacts, and climate variability and change.

The great challenge for coastal managers and policymakers is to balance these multiple competing uses and the impacts of those uses.

BELOW: **Monitoring coastline change**
Image: Mitch Harley, Water Research Laboratory, UNSW



These impacts include: contamination from heavy metals, herbicides, pesticides, nutrients and plastics; the effects of warming, sea level rise, flooding and ocean acidification from climate change; increased biotic invasion from increasing coastal trade, aquaculture and recreational vessel movement; and foreshore armouring, construction of artificial structures and habitat loss due to port and coastal development.

How we manage these issues will have profound consequences for most Australians.

Around 85 per cent of the population live within 50 kilometres of the coast, which is also home to port development; oil, gas and mineral resources; tourism and recreation; Indigenous communities; shipping and transport; new marine industries; fishing industry; renewable energy; and water and food security.

Rural and remote areas face similar concerns, with nutrient run-off, mining development and competition among users creating major challenges.

Our coastal urban environments also fulfil important cultural, recreational and aesthetic needs, have intrinsic biological diversity values and provide essential ecosystem functions such as primary productivity, nutrient cycling and water filtration.

The science

To improve the management of our urban coastal environment, applied and basic strategic coastal research must underpin the repair and ongoing management of these high-value ecosystems for improved productivity and enhanced cultural and conservation values.

To do this we need to:

- provide targeted projections of sea level rise, including changes in extreme flood events
- better characterise catchment contaminant pathways, coastal morphologies and environmental processes, and define envelopes of natural variability and thresholds of concern
- understand stressor interactions and resource use, including the cumulative impacts of sea level rise; loss and continual degradation of coastal and estuarine habitats; and loss of productivity, ecosystem services and population connectivity
- develop innovative sensing technologies, including those based on new molecular tools, to provide cost-effective monitoring in the coastal zone
- improve data coordination and discoverability of coastal data from multiple sources
- incorporate quantitative and qualitative social and cultural perspectives into coastal decision-making
- develop, test and apply methods to mitigate the impact of coastal hazards, including eco-engineering and restoration approaches.

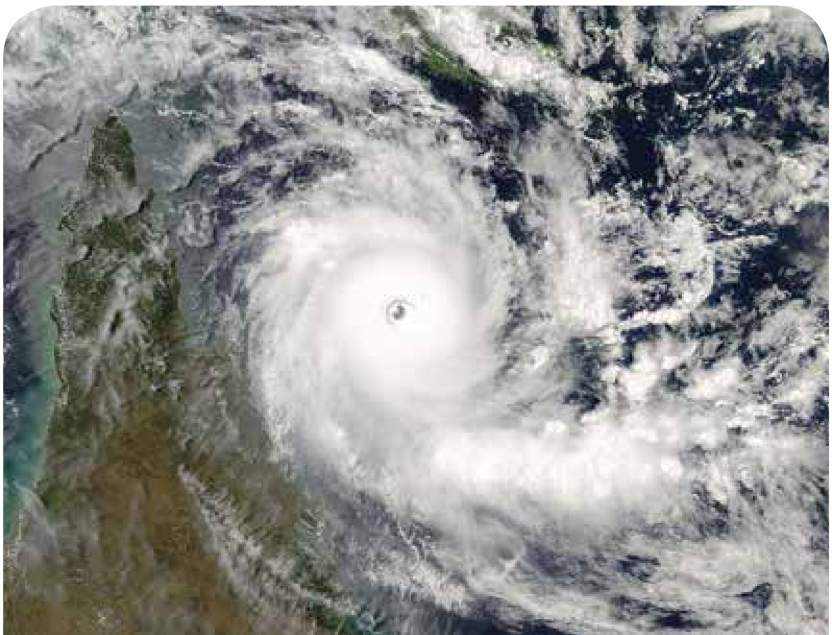
Climate variability and change

The challenge

Australia is particularly vulnerable to the impacts of climate variability and human-induced climate change. We are already experiencing impacts across the Australian economy, society and environment, and these are likely to be even greater in the future.

BELOW: **Australia is particularly vulnerable to the effects of climate change.**

Image: NOAA/Bureau of Meteorology



Investment in more technically and socially robust approaches to resource allocation are imperative for management of Australia's marine estate.

In the marine environment impacts include sea level rise, coral bleaching events, acidification, tropical cyclone frequency and intensity, changes in freshwater run-off, invasive marine species, ocean warming, extreme events and changes in hydrological cycles and ocean circulation.

For example, around 250,000 Australian homes, roads, rail, ports, airports, water and wastewater services, energy and communications infrastructure, public assets and commercial assets are vulnerable to a 1.1 metre sea level rise by 2100.[20] The estimated sum at risk is $226 billion.

Other sectors at risk of sea level and sea temperature rises include aquaculture and fisheries industries, worth about $2.23 billion, and the Great Barrier Reef, which contributes $5.7 billion to the Australian economy each year, most of it derived from tourism.[21]

Coral bleaching will also see a loss of biodiversity and degradation of fish stocks, increasing the risk to food security in the Australasian region.

BELOW: **Around 250,000 Australian homes are vulnerable to a 1.1 metre sea level rise.**

The range of affected stakeholders is wide. These include the defence forces, tourism, agriculture, offshore oil and gas and renewable energy industries, coastal planning, marine parks and regulatory authorities, international nongovernment organisations, and international, national, state and local governments.

The science

To understand the oceanic branch of the climate system, we must observe and model the storage and transport of heat, freshwater and carbon in the ocean, and their exchange to the atmosphere, at global, regional and local scales.

To understand the impact of climate on marine ecosystems, communities and industries, we must also observe and model their vulnerability and adaptive responses to climate variability and change.

Marine science also has a role to play in mitigating climate change through marine-based carbon storage technologies and reducing carbon emissions from marine industries.

To do this we need to:

- preserve and extend the ocean climate record through sustained observation programs, so that variability and change can be monitored and ocean and climate processes better understood and modelled
- better understand the response of the Pacific–Indian tropical oceans to climate change, given their role as complex drivers of seasonal, inter-annual and decadal variability, particularly the variability of tropical cyclones, heatwaves and droughts
- better understand the uptake of heat and carbon by the polar and mid-latitude oceans, the impact of warming on Antarctic ice, and the sensitivity of ocean circulation to these changes in the climate system
- bring broadscale climate information down to the level of Australian coastal and shelf oceans to characterise the impact of climate variability and change on these systems, and to help communities and industries develop practical adaptation strategies
- improve understanding of the paleo-climate of the Australasian region, and its sensitivity, feedbacks and biological responses to past change as an analogue for the future; provide understanding of variability and processes that operate on time scales greater than historical records; and improve global climate models and their change projections



- monitor ocean biogeochemical cycles and assess changes in ocean acidification to understand the impact of changing biogeochemistry and the adaptive responses of marine ecosystems and industries
- reduce uncertainty in estimates of past and future sea level change at global and regional scales with a better understanding of ocean heat and freshwater content
- better understand the incidence, cause and impacts of past and future marine extremes, including tropical cyclones, storm surges and waves, sea level rises and ocean heatwaves
- preserve and extend the ocean climate record.

Resource allocation

The challenge

Coastal and marine developments are increasingly the scenes for heated competition between a broad range of users, including different industry sectors, conservation groups, marine park stakeholders, recreational and Indigenous users, and the general public. This competition often involves high-profile, professional and expensive campaigns based on inherently different values.

The polarity in this debate intensifies where profound uncertainty exists on the nature and extent of risks to environmental and social values, and how these are best mitigated. Similarly, conflict is common where property rights are inadequately defined.

All stakeholders, and ultimately the nation, share the costs of natural capital depletion, the costs of delays and complexity in approval processes, and the costs of making decisions where the nature and extent of risk are poorly understood.

Politicians, policymakers and regulators will face the major challenge of balancing these different values when making development decisions and allocating resources over the next decade as we strive to double the size of our blue economy and continue urbanising our coastal fringe.

Given this growth, we need to develop and invest in more technically and socially robust approaches to decision-making processes for resource allocation, development and conservation.

The science

To improve the management of Australia's marine estate, marine science needs to develop improved methods and frameworks for marine resource allocation.

To do this we need to:

- improve the collection of data relevant to resource allocation, particularly for Indigenous use and rights, non-commercial activities, and other social and economic attributes
- improve problem formulation by integrating social and economic interests with environmental issues and concerns, and developing tools and platforms that are open to wide stakeholder engagement
- reduce the complexity of socio-ecological decision-making by developing and providing access to simplified tools for estimating the cost-effectiveness, or the cost–benefit ratio, of alternative policies or actions; and road-testing them in marine settings
- improve high stakes decision-making by improving the statistical and mathematical modelling of biophysical processes and the sophistication of social and economic modelling
- reduce ineffective emphasis on optimisation methods and recognise the full suite of social, cultural and economic interests in a resource by using approaches that confront the difficult trade-offs
- develop governance arrangements and institutional capacity for allocating marine resources in a way that generates socially, economically, ecologically and politically viable solutions that are robust to a range of plausible futures.

CASE STUDY

DATA CUBE

The Australian Geoscience Data Cube is a sophisticated new approach to storing, organising and analysing large volumes of satellite imagery and other gridded geospatial datasets covering the Australian continent.

Until now, the potential of this data has remained untapped, with traditional technology unable to analyse such massive datasets, and agencies unable to place this information into the public domain.

The Data Cube has been used for a number of terrestrial projects but holds great promise for the large-scale and complex research that marine science needs to undertake.

Marine science synergy | **leverage points for effective action**

By establishing the science priorities for each of the grand challenges, we have identified a number of science needs that are common to many of them. These present leverage points for tackling the interconnected, broadscale nature of the challenges, and maximising the success of this Plan.

National marine environmental baselines

Goal: Undertake systematic collection of environmental, social and economic baseline data of Australia's marine estate

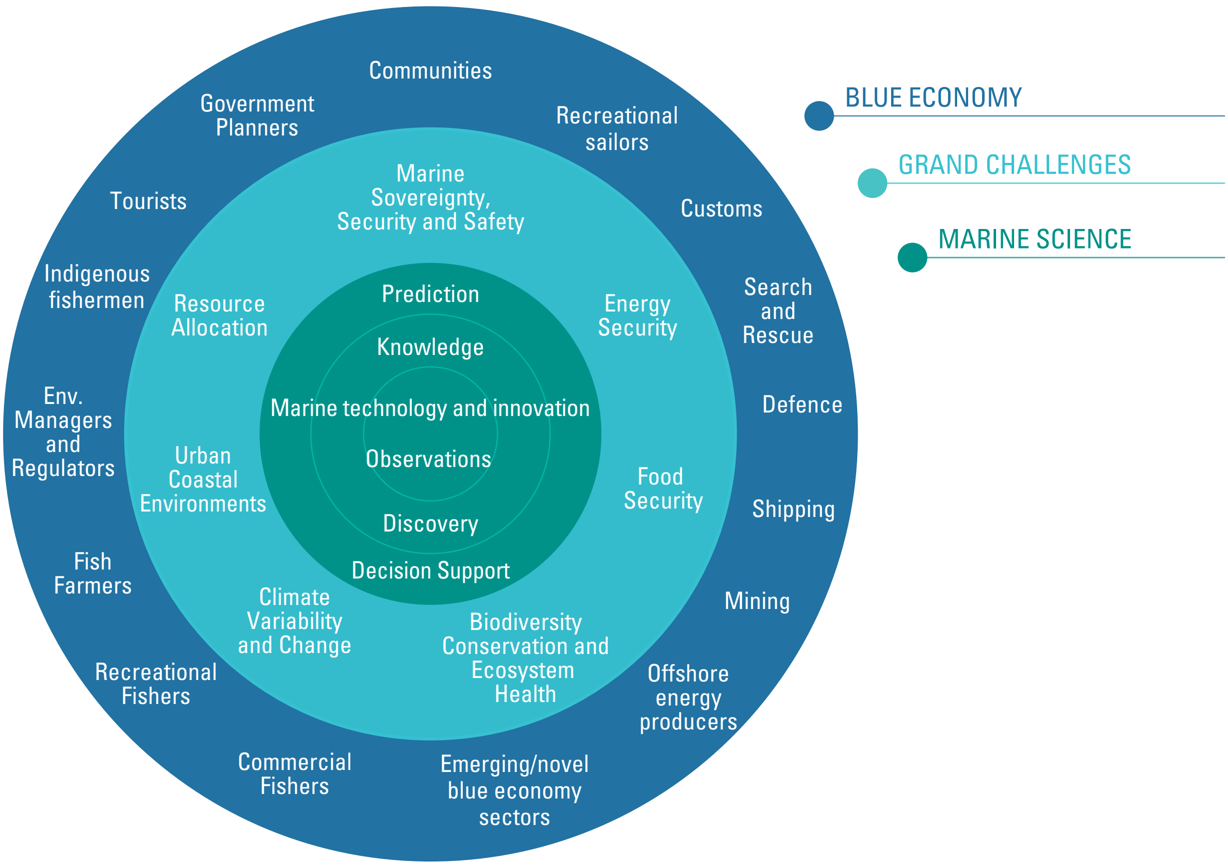
Environmental (incorporating geology, geomorphology, physics, chemistry and biodiversity), social and economic baselines provide fundamental reference conditions for resource evaluation, conservation, restoration, hazard effects, and climate variation and change.

We need these baselines to:

- improve seasonal and long-term climate prediction
- assess the oceans' potential to provide resources and bioproducts
- create an inventory of risks to environmental assets (including from noise) and assess them
- differentiate between the changes resulting from human use and those driven by natural variability
- evaluate the economic and social effectiveness of management actions.

And yet we have only studied, or mapped in detail, approximately 25 per cent[11] of the seafloor of Australia's marine jurisdiction, with only a fraction of that area described at the habitat level.

MARINE SCIENCE FOR A BLUE ECONOMY



To overcome this fundamental deficiency, we need to systematically expand our understanding of the marine estate, with our highest priority being areas where opportunities or risks have been identified, including north-west Australia, the Great Australian Bight and Torres Strait.

New baseline data should be augmented by the vast amount of information collected by industry, engineers and consultants as they develop environmental impact statements.

Local, state and Commonwealth authorities could also improve the routine collection of social and economic data to develop a national baseline on marine communities and industries. The integration of local Indigenous knowledge could also support the development of this baseline.

The first Australians have developed an in-depth understanding of coastal marine systems, capturing knowledge about system function and change over the past 40,000 years. This understanding informs traditional aquatic resource management systems, and there is increasing recognition of this knowledge base and the benefits of its integration with western knowledge.

BELOW: **Biodiversity is high after 30 years of gas production from Rankin.** Image: Woodside

National marine system monitoring

Goal: Establish a National Marine System Monitoring Program to track changes in the marine estate and to build a knowledge base for effective management and conservation

When combined with experimental process studies, long-term ecosystem monitoring provides the context and evidence base for the management of marine industries, the evaluation of regulatory regimes, and the conservation and/or recovery of high-value assets.

It also helps determine the effectiveness of marine conservation measures for marine protected areas in state and Commonwealth waters, as well as the effectiveness of those for unprotected areas, while the addition of social and economic parameters helps to determine 'socially acceptable impacts'.

By bringing a range of current disparate monitoring efforts into a coordinated, long-term national marine system monitoring program, we would be able to better understand the vulnerability and resilience of our marine systems, and better support the decision-making and resource management of marine park managers, policymakers, marine industries and regulators.

National focus on understanding the adaptive capacity of marine systems

Goal: Answer key questions about marine system function and resilience through nationally coordinated and intensive research using key experimental research facilities

There is an urgent need to test the short-term and long-term impacts of interactions among different and fluctuating environmental parameters, and to better understand these impacts at local, regional, national and global scales.

Experiments and process studies are critical for understanding the causality in these natural systems, and for directly teasing out the key mechanisms of change in our marine environment.

By taking a more integrated approach to the design, implementation and delivery of experimental marine science, we will be able to test system-level hypotheses for the drivers of changes of our coasts and oceans, including direct comparisons of anthropogenic impacts versus natural variability.

Taking a national, networked approach to obtaining measurements of internationally recognised quality will enable direct comparisons of research data and outputs from around Australia and with those of our international partners and collaborators.

The new fields of restoration ecology and eco-engineering rehabilitate degraded ecosystems and enhance the environmental compatibility of new marine developments and infrastructure.

National marine environment and socioeconomic modelling system

Goal: Establish a national effort in marine modelling, across the physical, biogeochemical, environmental and socioeconomic systems of both coastal and open ocean domains, which supports all users of the marine environment

Understanding and predicting the dynamics of ocean and coastal processes (such as currents, waves, nutrient cycles, productivity, water quality impacts, noise and pollution impacts) is a fundamental requirement for implementation of this Plan.

Similarly, the incorporation of social and economic elements into marine system models is also essential. Marine scientists, environmental managers, policymakers, industry and the community increasingly recognise the importance of these triple-bottom-line elements for assessing impacts and informing decision-making.

We need to coalesce past efforts into a collaborative, national capability in modelling, re-analysis and forecasting for the entire Australian shelf and coast. This would benefit every marine industry sector, and provide an invaluable foundation for marine science and improved environmental management in perpetuity.

Integration of social, economic and cultural factors

Goal: Develop the national capability and requirement to incorporate social, economic and cultural data into marine estate assessments, and into decision processes for resource allocation and development

Integrating the different forms of knowledge generated by a triple-bottom-line approach is one of the most pressing needs facing marine science.

All the seven challenges involve major social and political influences, and targeted research aimed at understanding these aspects is crucial to addressing the challenges. Across all the marine science fields, there needs to be greater recognition of the crucial role that human dimensions research will play in the future.

Human dimensions research involves building an understanding of human emotions, values, beliefs, worldviews and relationships that influences politics and decision-making—all of which are difficult to quantify. Qualitative methods play an important role in this area.

Science graduates who do not have a basic understanding of the human dimensions of conservation management will struggle to successfully translate biological findings into successful conservation outcomes. And trade-off decisions that do not recognise the full breadth of issues that influence management approaches will ultimately fail.

CASE STUDY

LONG-TERM MONITORING

In 2012 AIMS revealed that the Great Barrier Reef had lost half its cover over 27 years, thanks to its world-first reef monitoring program.

The research was the culmination of 30 years' work monitoring the length and breadth of the Great Barrier Reef World Heritage Area, making it the only coral reef monitoring program in Australia and the world with this geographic footprint and longevity.

Researchers spent more than 2,700 days at sea and $50 million was invested in this monitoring program.

Its high-level analysis of trends and threats to the GBR World Heritage Area have played a fundamental role in understanding critical Reef issues and developing management options for the area.

Furthermore, there is a growing recognition of the role that Indigenous knowledge can play in marine science and research. Indigenous Australians are becoming increasingly involved in aquatic research and monitoring, with ranger programs supporting ground-level management and cross collaboration between Indigenous and western knowledge.

Commitment from state and Commonwealth governments has supported Indigenous involvement in fisheries and aquaculture, and increased the broader recognition of Indigenous Australians as active leaders in marine research.

Emerging smart technologies

Goal: Develop and utilise innovative technology to support marine system understanding and the development of new marine industries

The drive to explore, routinely observe, better understand and exploit our vast marine estate demands that we develop novel and innovative technologies and techniques to reduce the cost, and increase the effectiveness of, our science and marine industries.

Based on experience overseas, Australia needs to bring marine scientists, engineers, and industry together in dedicated innovation hubs to increase smart technology innovation and development.

Australian scientists are well recognised for their innovative application of marine technologies, including in the development of new analytical and technological approaches, such as DNA sequencing, remote sensing applications, environmental sensor networks, aquaculture feed formulation, bioproducts from marine organisms, offshore oil and gas pipeline technologies, and marine ecosystem remediation.

These strengths need to be supported and expanded, while more training is also needed for new capabilities.

Materials science has the potential to become one of the foremost disciplines over the next 50 years, and attracting this burgeoning capability to work on marine science problems will be important.

Restoration ecology and eco-engineering

Goal: Develop solutions for repairing ecosystems and design ecosystem-friendly marine structures

The new fields of restoration ecology and eco-engineering[19] rehabilitate degraded ecosystems and enhance the environmental compatibility of new marine developments and infrastructure.

They require a fundamental understanding of the ecology, oceanography and geomorphology of marine systems, as well as marine and civil engineering, and how these interact and impact on ecosystems.

Knowledge of ecosystem resilience is critical for determining the extent and kind of restoration possible, and can inform the design and construction of infrastructure, from aquaculture farms to major coastal developments.

This research translates directly into best-practice approaches for our use of the marine environment.

Research into new, more sustainable materials for the built marine environment will also require cross-disciplinary efforts among materials scientists, engineers and environmental scientists.

Decision-support science for complex and dynamic systems

Goal: Improve the scientific evidence base and the available decision-support tools for those managing the impacts of multiple and cumulative drivers and pressures on marine systems

We need to develop and refine decision-support tools that translate knowledge and data into useful information for effective decision-making.

This translation is needed for a diverse range of contexts: from adaptation to climate change impacts to assessing and managing cumulative impacts—natural and man-made—on multi-use regions. These tools also need to ensure that social and economic consequences and the social acceptability of impacts are adequately taken into account when making decisions.

Policymakers, regulators and industries, who are involved in stewardship of Australia's marine jurisdiction, face complex challenges.

They have to account for the multiple risks and impacts from agricultural and industrial development, invasive species, climate change, population growth, coastal urban expansion and changing social attitudes. They also need to take into account strong cultural beliefs, such as Indigenous rights.

Moreover, realistic predictions and appropriate long-term policies require the development of research methods that can estimate the cumulative effects of these impacts, both within and across the challenges. Integrated governance frameworks would support the implementation and uptake of such decision-support tools.

RIGHT: **We have mapped less than 30 per cent of Australia's seafloor.**

Mind the gaps | **marine science capability and investment**

Meeting the seven grand challenges and reaching our blue economy potential requires sustained effort and investment in growing and maintaining a national marine science capability.

This capability is the product of three essential, integrated pillars: an appropriately skilled workforce; world-class, fit-for-purpose research infrastructure; and national and international collaborations.

The National Marine Science Committee plays a central role as an adviser and advocate for these three pillars, both within the marine science community and for the community.

To develop the blue economy's cornerstones of knowledge, tools, technology and innovation, this community needs to build on previous government support and address significant gaps in research infrastructure, operational funding and our skills base.

We also need to maximise the coordination and utilisation of this enhanced capability to ensure that we deliver Australia the greatest long-term return on its investment.

Capability recap

From 2009 to 2013, the federal government injected $387.7 million into marine and climate science as part of its Super Science Initiative[22], and in response to a 2008 *Review of the National Innovation System*[23]. The review had concluded that Australia's investment in marine research and maritime industries was underweight.

The Super Science investment included the building of a state-of-the-art research vessel, RV *Investigator*, an extension of the Integrated Marine Observing System; an expansion of Australian Institute of Marine Science infrastructure including a new National Sea Simulator; and the establishment of an online network of marine and coastal data. This has been complemented by federal government investment in the marine science facilities at the Universities of Tasmania and Western Australia through the Education Investment Fund.

These investments provided a major step-up in national marine science capability, and we are already seeing the dividends across a sector that spans publicly funded research agencies, universities, museums, Commonwealth and state government departments and private industry.

Blue economy bang for our buck

Over the past decade, Australian investment in marine research and development has helped achieve a blue economy worth $47.2 billion per annum in 2011–12, double the 2001–02 value of $23.8 billion.[8]

At an estimated $450 million[12], the annual marine science spend across the nation represents just under 1 per cent of our known blue economy's value. Over the coming decade, we will continue to enjoy the benefits of this investment due to the strategic nature of much research and development.

But with the blue economy projected to grow at 7.5 per cent per annum by 2025[13], Australia has a greater goal in sight, challenges to overcome and some remaining significant gaps in marine science capability.

Closing these gaps will require focused and strategic planning, and further investment. The prize for doing this well will extend further than the projected doubling of the ocean's economic contributions, most of which will come from existing industries.

Further investment and planning will generate marine-science-enabled technology and product innovation in sectors such as renewable energy and bioproducts, providing potential for continued growth of our blue economy well after 2025.

Benchmarking with the best of them

Countries throughout the world are recognising the importance

RIGHT: **Autonomous ocean gliders are transforming our understanding of ocean currents.** Image: IMOS and potential of their own blue economies—many of them our major trading partners and others our smaller regional neighbours. Investment in marine science capability, research and development, and innovation is an integral part of their international strategies:

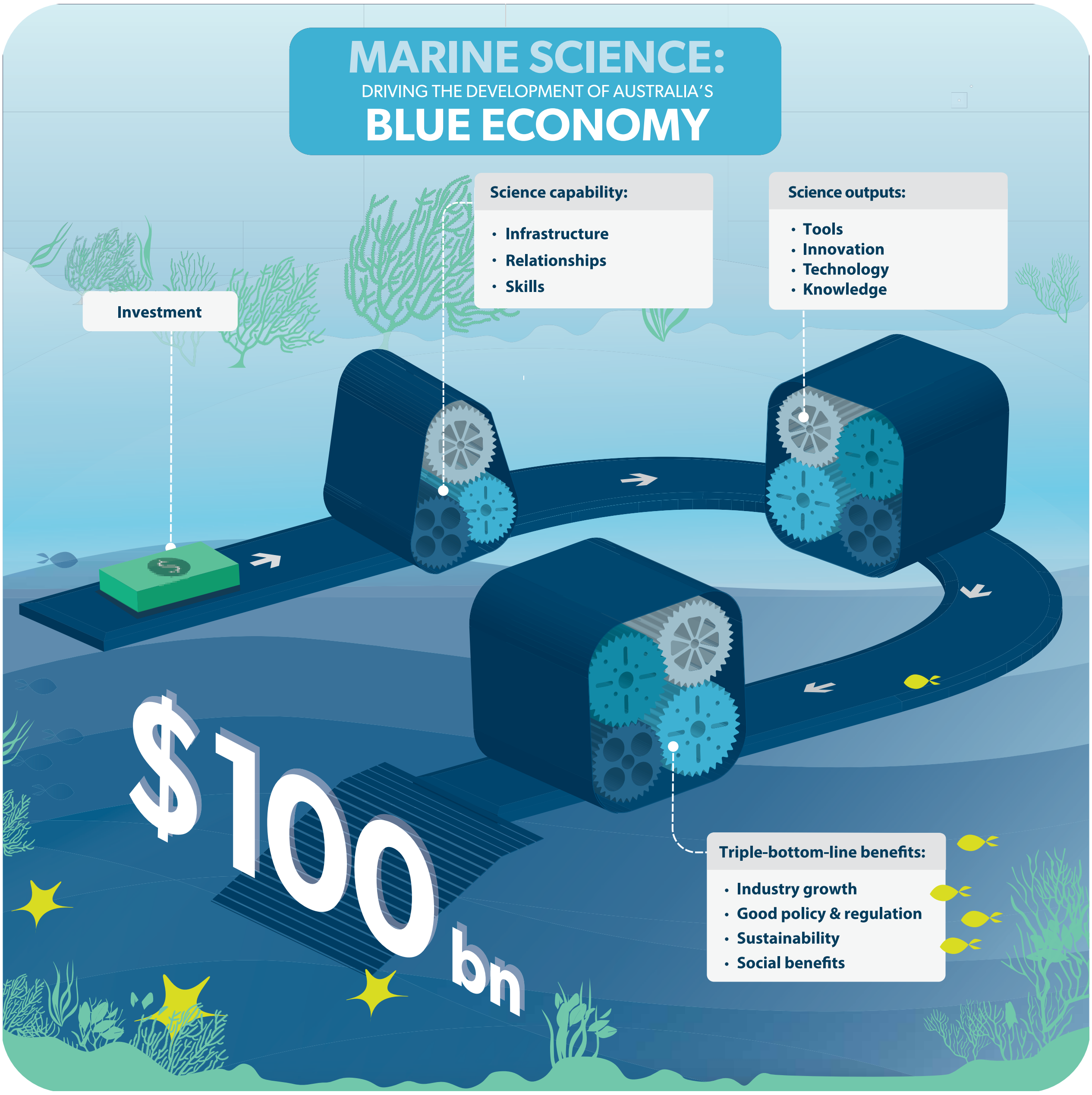
- The European Commission has developed a Blue Growth Strategy for the development of key marine industries.[24]
- China has included the marine economy in its National Economic Development Strategy and set their marine R&D investment at 2 per cent of the total marine economy value,[25] which is close to 10 per cent of their national GDP.
- The US National Oceans Policy implementation plan has been developed to promote the nation's multi-trillion dollar ocean economy and maintain the resilience of marine ecosystems.[26]

Taking it national

Over the last decade, initiatives such as Super Science and the National Collaborative Research Infrastructure Scheme (NCRIS) have emphasised the benefits of taking 'collaborative and national facility' versus 'institution-specific' approaches.

The National Marine Science Committee, on behalf of the marine community, embraces this principle. So throughout this Plan, we identify mechanisms that will help ensure that investments in science capability and research will provide long-term benefits to government and industry partners.

We also advocate the development of national and regional collaborative mechanisms required to make the whole greater than the sum of the parts. We have models of best practice already in marine science, and propose to expand and extend these across the full reach of Australia's marine science.



National facilities, strongly backed by the marine science community, can make collaboration an advantage and give us an edge internationally.

Skills

Australia's world-class marine scientists are the driving force behind this Plan's implementation, with both existing and emerging skills critical to Australia's greater understanding of our marine estate and to meeting the complex challenges ahead.

Across Australia, over 2300 marine scientists work across a wide range of disciplines and research issues.[27] Many are world leaders in their fields, including physical and chemical oceanography, marine geology, ocean climate, coral reefs, marine ecology, fisheries, marine engineering, microbial ecology and genomics.

But while these existing skills are critical to our success, there is also a growing awareness that we need to attract, train and retain the next generation of marine scientists. In particular, we need to ensure that these graduates have skills in the emerging marine science fields, as well as the ability to work in multidisciplinary and interdisciplinary teams and focal areas.

BELOW: **We need to attract, train and retain the next generation of marine scientists.**
Image: Rob Harcourt, Macquarie University

Pipelines and planning

As with all workforce planning, a viable pipeline of these next-generation skills will require concerted and coordinated action and investment.

The Chief Scientist of Australia sets out the requirements for, and approaches to, increasing our science, technology, engineering and mathematical (STEM) skills base In *Science, Technology, Engineering and Mathematics: Australia's Future*.[28] When implemented, this national strategy will provide some of the core disciplinary skills required by marine science over the coming decade.

However, social sciences and economics are also increasingly required in the translational elements of marine science, including the evaluation of triple-bottom-line risk and the development of decision-support science for complex and dynamic systems.

Regardless of whether marine science graduates go into research and development roles, or work for industry or government, these translational skills and the ability to communicate science to a wide range of audiences and stakeholders will be critical.

Universities and research agencies therefore face the dual challenge of building the required strong disciplinary skills, as well as an appreciation of, and competency in, working across disciplines.

Our current skills training base

The majority of Australia's current marine scientists have undergraduate qualifications in one of the core biological, physical or mathematical disciplines, undertaking their marine science training at the postgraduate level and beyond.

Less than 3 per cent of Australia's higher-degree research completions between 2009 and 2013 had an explicit marine science focus[29], with biological and ecological sciences dominating these completions at 49 to 53 per cent. Unsurprisingly, the dominance of marine biology and ecology graduates mirrors the skill and disciplinary bases of supervisors across Australian universities and research agencies.

It is not clear what percentage of marine science graduates find employment in marine research or marine industries—universities do not consistently collect these data. However, there has been a consistent call from research agencies over the last decade for graduates to have enhanced quantitative and multidisciplinary skills.

Without a targeted change to training and the disciplinary profile of supervisors, it seems unlikely that we will change this mismatch between what we are producing and what we need. And without incentives, targeted initiatives to address the marine science workforce planning issues are unlikely to happen.

We suggest that universities with a marine science priority should form a coalition and develop a coordinated national strategy for undergraduate and graduate marine science training. This would be useful first step in addressing the above issues.

Mixing it up: multidisciplinary and emerging skills

Through this Plan's white paper process, the National Marine Science Committee collected the views of more than 500 scientists and end users on the skills base required by marine science to address the complexity of the grand challenges.

The following represents a summary of these views. More details are provided in the white papers.

- Australia desperately needs to increase the participation rate and quality of students in a number of disciplines fundamental to marine science: mathematics, statistics, physics, chemistry and ICT. All of these areas have suffered significant declines since 1992. Marine science can, and should, play an important role in raising the profile and attractiveness of these areas by engaging in the implementation of the Australian Government's STEM Strategy, and communicating the importance of these subjects to marine science and to the future of our country and globe.
- We need greater skills in multidisciplinary areas and emerging fields, such as integrated assessment modelling and earth system science, that integrate inputs from a wide range of disciplines.
- Computational science, bioinformatics and the use of the new 'omics disciplines (for example, metagenomics, proteomics and metabolomics) in systems biology will be essential for creating innovative approaches. These skills need to be fully integrated into marine science institutions and university departments.
- Greater involvement of social scientists and economists in marine science will become increasingly important as the integration of quantitative biophysical data with quantitative and qualitative social and economic data becomes central to decisions on resource allocation, climate adaptation and industry development. These integrative approaches will require greater interdisciplinary training and more sophisticated modelling skills.

LEFT: **Antarctic diving: marine science requires a multidisciplinary workforce.**
Image: Emma Johnston, SIMS

"By 2025, Australia's marine industries will contribute around $100 billion each year to our economy."

- While Australian marine science training is world-class in specific discipline areas (such as oceanography and marine ecology), few Australian universities currently offer multidisciplinary doctoral programs that encompass the spectrum of marine science disciplines: biology, chemistry, earth science, mathematics, analytical statistics and modelling, engineering and physics. Such programs exist elsewhere in the world (Germany, Japan, UK and USA) and constitute the global benchmarks. Australian universities should consider developing programs based on these models to ensure we remain globally competitive, and produce students of the highest calibre that can become the future generations of world-leading, innovative researchers.

This vision for multidisciplinary training should equally be applied to enhance skills in early-career researchers. We encourage those involved in funding and supervising postdoctoral programs to embrace this over the next decade.

Connecting with community

For science and scientists to remain credible and capable of providing appropriate advice, it is critical that they learn to engage and communicate more effectively with a broad spectrum of society, which includes those in industry, policy, regulation and the community at large.

It is also essential that this communication is both taught and undertaken as a two-way activity, with a focus on sharing knowledge, rather than delivering wisdom.

To build this capability, we need to formally integrate engagement and communication training into university undergraduate and graduate programs. And there are some universities already doing this with great results, including the Sydney Institute of Marine Science and James Cook University.

The Australian Academy of Science also runs science communication programs, and our National Science Week provides marine science with the opportunity to showcase the work we do, and the contributions we make, to our broad stakeholder base. The National Marine Science Committee will provide a focal and coordinating point for this outreach over the next decade.

Infrastructure

National research infrastructure is critical for delivering the science and outcomes of this Plan. This infrastructure is needed to support the observation, study and routine monitoring of our oceans' health, and must be accessible to multiple institutions.

This infrastructure includes:

- vessels—bluewater, polar and shelf-scale, which allow exploration of the open oceans, Antarctic regions and our continental shelf and coastal waters
- observing systems—both in situ monitoring devices and satellites that provide Earth observation from space
- experimental facilities—research aquaria, research stations and analytical systems
- e-research—data, high-performance computing and modelling.

Despite having the third-largest ocean territory on Earth, Australia has a modest research vessel fleet, a very small marine technology industry and no domestic satellite capability. This highlights the importance of coordination in these areas.

Access all areas—a national effort.

In recognising the critical role of infrastructure in marine science, *Marine Nation 2025* recommended that the concept of widely accessible national facilities be expanded to include all significant marine research infrastructures.

National facilities, strongly backed by the marine science community, can make collaboration an advantage and give us an edge internationally. This means that the Australian marine science community needs to do two difficult but important things:

- We need to rise above institutional and disciplinary perspectives and get behind the concept of national facilities that can be used by the whole community through appropriate management and access arrangements.
- We need to prioritise future infrastructure investments to maximise our chances of success in what is likely to remain a competitive environment for publicly funded marine science.

Global ocean economic activity is estimated to be in the realm of US$3 to 5 trillion. The economic potential of the world's oceans is significant; countries and businesses are increasingly thinking about how to tap ocean resources for economic growth and investment.[7]

A lifecycle approach is also required to build, operate, maintain, decommission and refresh national marine research infrastructure over the life of this Plan and beyond.

Beyond our borders

Marine scientists also benefit from access to national infrastructure that serves a broader science base. These include Earth observations from space, data storage, high-performance computing and some analytical ('omics) facilities.

For example, dedicated geostationary satellites with optical visible imagery would have a profound impact on Australian marine science. A feasibility study to examine the scope and cost of this capability would be a useful first step.

We must therefore ensure that marine science does not try to duplicate this infrastructure. Instead, we must provide a clear and coherent articulation of infrastructure requirements that is influential within the national innovation system.

In some instances, Australian scientists should access international infrastructure. Ongoing access to the International Ocean Discovery Program (IODP) through the Australia–New Zealand (ANZIC) consortium is one example.

Vessels

The recent commissioning of RV *Investigator* as Australia's Marine National Facility allows the nation's marine scientists to work throughout our marine jurisdiction and the high seas, down to the ice edge in the Southern Ocean. This is an essential capability for addressing the grand challenges outlined in this Plan.

To map our marine jurisdiction and to develop **national marine baselines,** we need an increase in the *Investigator's* operating level, from its current 180-day allocation to 300 days.

Building and commissioning Australia's next-generation polar vessel has also begun. However, we need to ensure that there is adequate funding for Southern Ocean and Antarctic marine science on an annual basis. This has been run down to unsustainably low levels in recent years.

Australia's shelf-scale research vessel capability is modest relative to the size of our marine jurisdiction and length of our coastline. Moving from institutional management and access arrangements towards a national alliance of shelf-scale vessels operators is seen as a necessary first step in strengthening this capability.

Observing systems

The Great Barrier Reef Long-term Monitoring Program, established and maintained by the Australian Institute of Marine Science for over 30 years, illustrates how time series data can elucidate the extent and drivers of ecosystem change, and help guide resource and conservation management decisions.

Australia's oceanographic national reference stations further highlight the benefits of a national approach. These stations have recorded key physical, chemical and biological oceanographic variables and processes for up to 70 years.

But despite these two examples, Australia has very few long-term monitoring programs. This limits our ability to assess the impacts of climate change, resource extraction and decision-making by regulators, policymakers and industry on high-value ecosystems. It also limits our ability to sustainably manage our impacts on these systems, and to adapt to the likely pressures associated with ocean warming and acidification.

LEFT: **RV *Investigator*: We need to fund Australia's new research facility to operate 300 days a year.** Image: CSIRO

Integrated Marine Observing System

Australia has benefited immensely from the development of an Integrated Marine Observing System (IMOS), and its success provides the impetus and opportunity to bring a range of disparate monitoring efforts into a coordinated, long-term **national marine system monitoring program.**

Begun in 2006 under the Australian Government National Collaborative Research Infrastructure Scheme, IMOS has supported the expansion of the national reference station network and the development of physical, biogeochemical and biological observational time series, across oceanic and coastal waters.

These series are contributing valuable data to assessments and models of ocean state and health, from the Great Barrier Reef to Antarctica. We now need to extend IMOS observation networks, data and information systems into inshore coastal waters including embayments, harbours, ports and estuaries.

With the health of Australia's coastal ecosystems intimately linked to the management of water quality from farming land and urban systems, we also need to integrate an extended IMOS with terrestrial observation systems (surface and groundwater, vegetation and soils). This integration would be in line with the Soil and Water element of the National Science and Research Priorities.

The recent commitment by the Department of Environment to develop a national marine monitoring program in the Commonwealth Marine Reserves is a good first step towards establishing such a coordinated, national long-term ecosystem monitoring program.

Experimental facilities

Australian marine scientists have access to an impressive range of experimental facilities, including marine research aquaria, specialist research and analytical laboratories, and research stations in Antarctica, across the Great Barrier Reef, and in temperate coastal locations.

These facilities are engine rooms for research, education and training, providing many young scientists with formative experiences working in and with the marine environment.

Collectively, the level of experimental marine science undertaken in Australia is significant, but we currently lack mechanisms to make its 'whole' more than the sum of its parts. This is particularly important if we are to create a **national focus on understanding the adaptive capacity of marine systems.**

National marine modelling and forecast centre

This Plan highlights the need for a coordinated **national marine environment and socioeconomic modelling system**. A National Collaborative Research Facility akin to IMOS, and dedicated to developing and using a suite of national marine system models, would provide the next important step in managing our marine estate.

RIGHT: **The nationally funded series of buoys monitoring the oceans should be extended into inshore waters.**
Image: Paul Rigby, AIMS

Over the past decade, collaborations involving CSIRO, the Bureau of Meteorology, the Royal Australian Navy, universities, the Queensland Government and the Australian Institute of Marine Science have developed a suite of world-leading global and regional oceanographic models (such as Bluelink) for use in Australian waters.

These have increased our ability to understand past and present ocean states and predict ocean dynamics.

More recently, the establishment of regional observing systems under IMOS has helped facilitate collaborative development of hydrodynamic and biogeochemical models for Australia's continental shelf. This has involved universities, state and Commonwealth research agencies, and the Bureau of Meteorology.

The eReefs modelling suite, developed for the Great Barrier Reef region through a partnership between industry, Queensland and Australian Governments, is also making advances in our ability to link terrestrial and coastal marine systems.

The next step is to coalesce these developments into a national modelling approach, which would unify the national programs on baselines, experimental science and ecosystem monitoring into a coordinated, predictive and coherent whole.

Linking coastal research stations and infrastructure

Marine and estuarine research stations encircle Australia's coasts, from Darwin to Hobart and Perth to Sydney, but are poorly integrated.

These stations provide core support for much of Australia's coastal marine science and hundreds of marine scientists. They represent a significant investment in infrastructure.

Enhanced integration of research stations would provide a national network for estuarine and coastal research, reduce redundancy in infrastructure expenditure and use, and provide a coordinated approach to marine science, particularly for state and local governments.

E-research

National data

Over the last five years, the Integrated Marine Observing System has begun to bring to life the vision of an interoperable, online network of marine and coastal data resources supporting science, education and management needs.

Some progress has been made in using this infrastructure to provide access to other marine and coastal data resources, in line with the vision of having an Australian Ocean Data Network (AODN).

However, this development could be significantly accelerated. Current efforts in marine data management are highly regarded nationally and internationally, and fully embracing a federated, standards-based AODN will give Australian marine science a competitive edge.

Ensuring that valuable environmental, economic and social data are placed into the public domain and made available on national databases would be a major advance in building **national marine baselines.**

Transitioning from project-specific collection of proprietary data to government–industry collaboration is also essential to building these national baselines, understanding cumulative impacts and driving down costs.

Relationships

Greater coordination and collaboration among scientists and research institutions, and between scientists and end users, are paramount to the successful implementation of this Plan.

The complexity of the national grand challenges, the geographic scale and connectedness of marine systems, and the multidisciplinary nature of marine science, means that no one institute can do it alone. Nor can we do it without working together with government and industry, at national, regional and global scales.

With Australia's marine scientists spread across all states and territories, we have developed a wide range of mechanisms to stay connected and, in some focal areas, work closely together. These include professional societies and associations (such as the Australian Marine Science Association), formal and informal links between institutions, and a number of very successful centres supported by the Cooperative Research Centres Programme and the Australian Research Council's Centres of Excellence funding.

The efforts of individual scientists working on fundamental science questions will continue to play an important and valued role in implementing this Plan. However, science investors across public and private sectors expect the community to produce much more than the sum of our parts.

So, like astronomers must do with their 'big science', marine science will increasingly seek to answer the complex and large-scale questions ahead through national collaborations and programs.

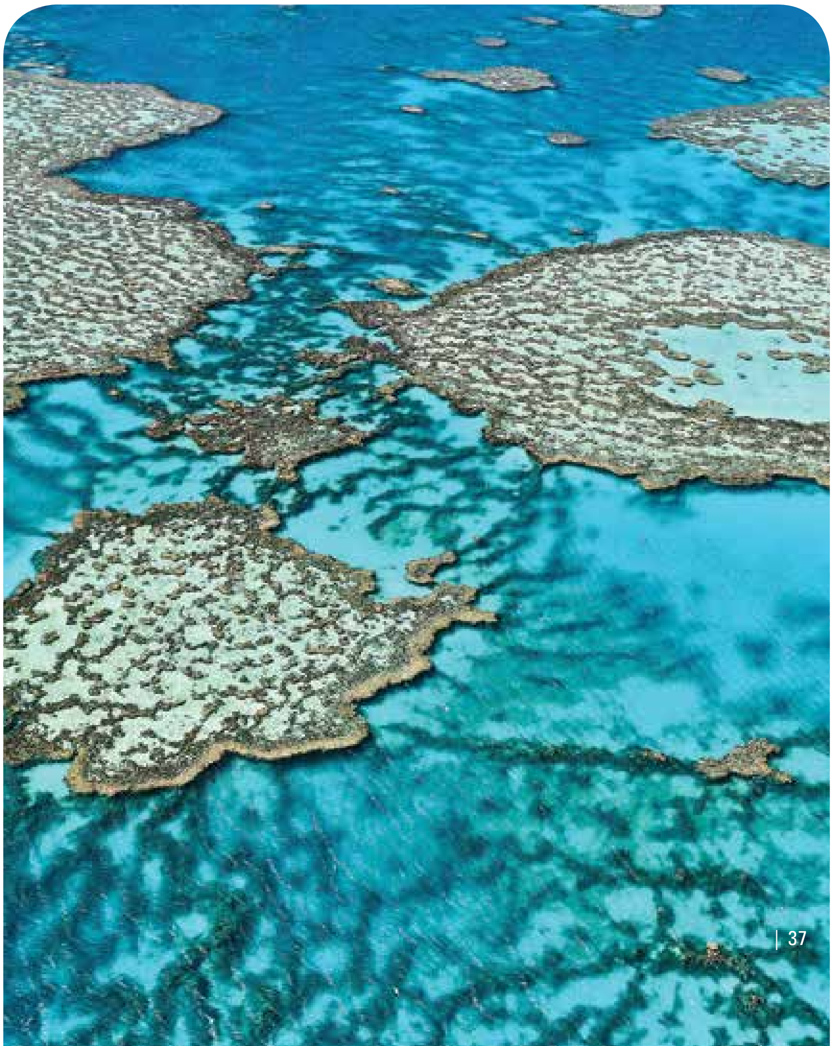
Similarly, the Australian marine science community will maintain and expand its connections to regional and international marine science programs.

National collaboration

Over the last decade, national, state and institutional initiatives have created a number of very effective collaboration mechanisms. These need to be sustained as they are fundamental to the implementation of this Plan and the support of our blue economy.

These initiatives use a variety of collaborative models, which provide excellent guidance as we seek to develop the national programs recommended in this Plan:

- The Integrated Marine Observing System is part of the National Collaborative Research Infrastructure Strategy and is built on partnerships. Internationally peer-reviewed science plans guide investment focus; eight operational partners maintain and deploy the observing infrastructure; the collected data is used by 20 national and 13 international science partners; and all data is publicly available through a world-leading data and information management system. The NCRIS investment and the IMOS collaborative model have provided a quantum leap in the availability of ocean data in Australia, and in the collaborative partnerships between data users across the university, government and industry sectors.
- The National Research, Development and Extension Strategy for Fisheries and Aquaculture guides a very mature collaboration model that works across industry, research, policy, management and nongovernment organisations, with the sector-specific Fisheries Research and Development Corporation playing a central role. In this marine science sector, researchers are strongly encouraged to link with end users, data is publicly available, and there is major investment in the communication and extension of research findings.



RIGHT: **EReefs: Extending the EReef modelling framework to cover all Australian coastal waters would provide a step change in our oceanographic capacity.**

- The National Environmental Science Programme (NESP) and its predecessors have been instrumental in bringing together consortia of universities, research agencies and user communities to undertake public-good marine science targeted at key policy and end user questions and geographic areas of strategic interest. The sustained investment by the Commonwealth Department of the Environment in marine research hubs has facilitated strategic, and in some cases long-term and large-scale, research that is linked closely to the management of assets such as the Great Barrier Reef and the National Marine Reserve System. Once again, NESP data and information are all publicly available.
- The Western Australian Marine Science Institute is a partnership between the WA Government, universities, publicly funded research agencies and industry. For over a decade, it has provided a collaborative framework for marine research and training on key marine environmental assets in Western Australia. The Marine Innovation Southern Australia partnership has also enhanced collaboration, innovation and marine science capability across government, university and industry in South Australia.
- Cooperative Research Centres, focusing on aquaculture development, Antarctic climate and ecosystems, and reefs and rainforests, and Australian Research Council Centres of Excellence (Coral Reef Studies, Climate Systems Science, Mathematical and Statistical Frontiers of Big Data, Big Models, New Insights) continue to be engine rooms for science excellence and collaboration across the marine science community.

There are a number of common features to these success stories. They all:

- seek to address major national and regional science priorities, and provide significant societal benefits
- have strong and effective collaborative governance mechanisms
- have managed to gain sustained core funding from a government source and, through the security of funding, they have all leveraged significant and sustained co-investment by research institutions and, in many cases, by industry and other public funding sources
- bring universities and publicly funded research agencies together, and have provided exceptional opportunities to train the next generation of marine scientists
- make their data openly available
- are internationally recognised as world-leading research programs.

International and regional collaboration

At an international level, the Australian Government is party to a number of intergovernmental frameworks. These include the United Nations Framework Convention on Climate Change/ Intergovernmental Panel on Climate Change, UNESCO's Intergovernmental Oceanographic Commission, the Convention on Biological Diversity, the World Meteorological Organization, and the International Maritime Organization.

Extra-governmental arrangements, such as Group on Earth Observations, Committee on Earth Observation Satellites, also set the context for global and regional collaboration in marine matters, as well as global science leadership.

The Australian marine research community maintains strong and enduring international connections as part of these global programs, with many of our scientists holding leadership positions on these bodies. We are therefore well positioned to leverage our own investment in marine science, and ensure that Australia is at the forefront of global efforts.

However, in this complex and sometimes crowded international environment, there is one area that Australia could do better: the coordination and communication of efforts and opportunities across the marine science community. Engagement in these international bodies is often driven at the level of institutions, or even individuals, restricting the two-way benefits to the community and nation.

The National Marine Science Committee provides a mechanism to improve coordination of contributions to international engagement and the extension of its benefits. We encourage the departments and institutions that currently lead Australia's participation to engage with the Committee to achieve these.

Recommendations |

In this *National Marine Science Plan 2015–2025*, Australia's marine science community has addressed a set of grand challenges that need to be solved if we are to fulfil our blue economy potential and prosper as a marine nation.

To achieve this, the marine science community, government and industry must undertake a coordinated, collaborative and dedicated national effort. We need to build and share critical marine data, undertake multidisciplinary research, and create the technology, tools and innovations that will drive economic development, environmental management and cultural stewardship of our marine estate for the next decade.

The following high-level recommendations are directed at Commonwealth and state governments and their research agencies; Australian universities with a strong interest in marine research and in the education of the next generation of marine scientists; and the significant number of industry sectors who stand to benefit if we get it right. We also encourage the broad number of community groups that support and use marine science to engage with us and help shape and support the future.

1. Create an explicit focus on the blue economy throughout the marine science system.

The aspirations of this decadal plan will not be realised with 'business as usual' marine science.

It will require some fundamental and generational shifts in the way we teach and learn marine science, the platforms and technologies we use at sea and in the laboratory, and the processes through which we plan and deliver marine science.

Creating an explicit focus on the blue economy throughout the marine science system will be key to our success.

To do this, we will need to:

- increase the collection and analysis of social and economic data, and develop the methods to allow the full integration of social, economic, biological and physical data on marine systems into decision-making by governments and industry as part of a fully integrated approach
- accelerate the innovation cycle by increasing government investment in developing and applying diverse, non-traditional science to marine problems and spawning new technological solutions, services and products, such as bio-prospectivity and bioproducts, eco-engineering and geoengineering, and eco-restoration
- facilitate placements of scientists in business, and managers in research, as part of their education and training
- plan large, long-term research, with end users involved from concept to delivery
- focus marine science effort at the front end of regional development cycles, like those we are about to see in northern Australia.

This blue economy focus is already done well in some research areas, but we must build on these strengths, and make marine science indispensable to our nation's growing economy.

2. Establish and support a National Marine Baselines and Long-term Monitoring Program, to develop a comprehensive assessment of our estate, and to help manage Commonwealth and State Marine Reserves.

We recommend that a National Marine Baselines and Long-term Monitoring Program be established and supported as a partnership between the Commonwealth and states.

BELOW: **Long-term monitoring will enhance policy making**
Image: AIMS

This would provide the basis for systematic exploration, mapping and characterisation of our marine estate, and for monitoring the condition of key assets. For example, the Great Barrier Reef, the Commonwealth marine reserve system, state marine protected areas, major ports and urban embayments.

This would also:

- bring together existing data sets held by governments and government agencies, universities and industry
- establish methods and data standards for developing environmental baselines and long-term monitoring, and ideally also environmental impact assessments conducted by industry
- provide a basis for reporting the state of the national marine environment and the impact of cumulative pressures on high-value systems.

Environmental baselines and long-term monitoring will require the collection of a suite of essential biophysical and ecosystem variables, but will also need to incorporate key social and economic data.

Marine conservation measures should routinely include provision for performance (outcome) monitoring.

This will help facilitate the establishment and ongoing support for a National Marine Baselines and Long-term Monitoring Program.

3. Facilitate coordinated national studies on marine system processes and resilience to enable understanding of development and climate change impacts on our marine estate.

To make good decisions on sustainable development and adaptation to climate change, we need to take into account all the components of the marine system: biological, physical, social and economic. We also need to understand and quantify the cumulative and compounding impacts on our marine estate of:

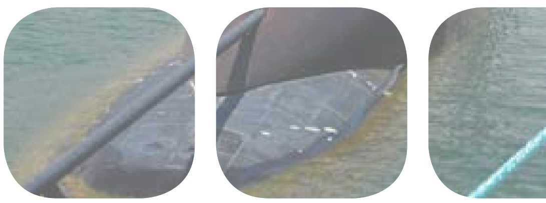
- population growth
- industrial, agricultural and urban development
- fisheries
- climate change, including ocean acidification.

We urgently need to improve knowledge of the key processes that underpin system function to understand the limits to resilience and adaptation in our diverse range of marine ecosystems. We also need to better understand the cultural, political, social and economic drivers, which will be critical to developing policy and management responses by government and industry.

Given the scale and complexity of this challenge, the community must focus its efforts and take a more collaborative approach.

Therefore, we recommend that the Australian marine science community establish an agreed set of ecosystems and regional foci

LEFT: **A national oceanographic modelling system will make our oceans safer and more secure.**



The aspirations of this decadal plan will not be realised with 'business as usual' marine science.

where coordinated and intensive studies of ecosystem processes and resilience would be concentrated.

It is also recommended that we enhance the capability of the marine science community to investigate the key elements of marine systems in each of the chosen focal areas. We need to do this by establishing strategic collaborative partnerships between universities, research agencies, citizen scientists and end users in the private and public sectors to fund and conduct the research.

4. Create a National Oceanographic Modelling System to supply the accurate, detailed knowledge and predictions of ocean state that defence, industry and government need.

This modelling system would serve the broad range of Australian Government regulators and operational agencies, marine industry sectors (offshore oil and gas, shipping, fisheries, aquaculture and tourism) and public users that require accurate, detailed knowledge and predictions of ocean state, including currents, waves, temperature, salinity, pH and productivity.

It would use and assimilate data collected by a sustained and expanded IMOS and our national research vessel fleet, and also draw in the significant observational data collected by industry as part of their core business.

Given the scale of this challenge, and the depth of capability across academic institutions and publicly funded research agencies, we recommend that a national research focus on operational oceanography be established to ensure timely delivery of this significant national capability.

5. Develop a dedicated and coordinated science program to support decision-making by policymakers and marine industry.

Over the last two decades, the development and governance of marine and coastal assets has increasingly been a contested space for industries, governments and communities. These contested values and aspirations have often led politicians and regulators to make inherently difficult choices, at times without conclusive information on the risks and benefits associated with their decisions.

As we continue to develop our blue economy and urban coastal fringe, advances in decision science, and risk and systems modelling methods offer great promise. This promise is also driven by the growing awareness that better decisions and outcomes are based on integrating biophysical, economic and social data. Industries, insurance companies, regulators and local government authorities all stand to benefit from this enhanced capability.

It is recommended that the marine science community work with planners and managers from government, industry and nongovernment organisations to develop and refine decision-support tools that will translate knowledge and data into useful information for effective decision-making.

In particular, it is recommended that these efforts focus on better decision-support for cumulative impacts and conflict resolutions in multi-use systems, and for the integration of social and economic consequences and social acceptability of impacts. Integrated governance frameworks would support the implementation and uptake of such decision-support tools.

6. Sustain and expand the Integrated Marine Observing System to support critical climate change and coastal systems research, including coverage of key estuarine systems.

We recommend that Australia's Integrated Marine Observing System be sustained as a national provider of open ocean and continental shelf observations, and expanded to serve as the national provider for estuarine and coastal observations.

Improved and sustained observations of these systems are essential for many of the key research foci identified in this Plan.

Additionally, we recommend that a guaranteed proportion of time on the RV *Investigator* and coastal marine research vessels be allocated to IMOS to ensure that the national observing system networks can be deployed and serviced at required intervals.

7. Develop marine science research training that is more quantitative, cross-disciplinary and congruent with the needs of industry and government.

Marine science research training is weighted towards specific disciplines that do not always match the future needs of industry or government employers. We also need to ensure that the training produces graduates that have highly developed numeracy skills and the ability to engage effectively with stakeholders.

Australian training of PhD students focuses on the research topic of the candidate's thesis. This often limits opportunities for cross-disciplinary training and provides little formal structure for training in basic science technology, engineering and mathematics skills.

It also does not facilitate training in a mixture of natural and social sciences, which is increasingly critical for environmental scientists.

These issues are partly a consequence of historical trends in training demands for different disciplines, but they are also a consequence of the formal structure of research training.

To make training more quantitative and cross-disciplinary, we may need to introduce formal teaching components into PhD programs. We may also need to change the current duration and basic structure of postgraduate programs, which are built around three-year PhD scholarships.

Similarly, to ensure that the marine science graduates are job-ready for careers in marine industries, more formal connections between industry and universities are needed.

Cadetships, internships, industry-sponsored postgraduate and postdoctoral scholarships provide an opportunity for students and early-career researchers to understand how their skills can be applied, and learn the very different drivers of research and development in the commercial world.

8. Fund national research vessels for full use.

To achieve the goals of this plan, we need the funds to operate Australia's new world-class, marine national facility, RV *Investigator*, for 300 days per year.

Given our Antarctic territorial claim, we also need to fund the national icebreaker, Research/Supply Vessel (RSV) *Aurora Australis*, to support a significant increase in marine science throughout the eastern Antarctic sector of the Southern Ocean.

Over the next decade, we will need to replace our ageing coastal research fleet, which is operated by government agencies and universities.

To ensure that the nation gets the most from existing vessel capacity, we recommend that operators of coastal research vessels increase the opportunities for collaborative use across the Australian marine science community, particularly for areas identified in this Plan as a high priority.

Models for sharing international research vessel capacity should also be explored.

Investing in our future

This Plan is designed to prioritise and coordinate marine science over the next decade, and we have identified a number of high-priority areas for future investment. This will allow us to build and operate essential research infrastructure, form collaborative science and research centres for priority interdisciplinary science, and support the next generation of marine science graduates.

Given the breadth of the challenges and the large number of blue economy beneficiaries, we stress that future investment must come from a broad base, including different levels of government, private industry and the community.

Future investments would prioritise:

- a National Blue Economy Innovation Fund to promote and commercialise innovation in new ocean technology, bioprospecting, bioproducts, ocean renewable energy, aquaculture and offshore oil and gas production
- National Marine Research Infrastructure to extend the Integrated Marine Observing System, and to fully utilise the RV *Investigator*
- a National Marine Baselines and Long-term Monitoring Program to systematically map, explore (mineral, hydrocarbons and biological resources and key ecological features), and describe the marine estate, and monitor areas designated for their high conservation value
- a National Integrated Marine Experimental Facility to link and enhance existing coastal marine research facilities across Australia for an integrated experimental program on the key natural and anthropogenic drivers affecting marine coastal communities and their resources
- a National Ocean Modelling Program to improve operational oceanographic and ocean climate modelling
- a Marine Science Capability Development Fund to support postdoctoral and early-career researchers in high-priority skill areas.

CASE STUDY

IS IT TIME TO REVISIT AUSTRALIA'S OCEAN POLICY?

Australia's Oceans Policy was released in 1998, the International Year of the Oceans. It was a globally ground-breaking initiative, setting a framework for integrated and ecosystem-based planning and management of Australia's marine jurisdictions. In the 17 years since the policy's release, marine bioregional plans have been developed for Australia's marine jurisdiction and an expanded Commonwealth marine reserve system has been declared. During this time our marine industries have also grown rapidly, the challenges of balancing development with environmental health have amplified, and the rest of the world has woken up to the growth potential in their blue economies.

Given the increasing national and global focus on blue economic growth, the grand challenges that our marine nation faces, and the sustainable benefits to unlock from our marine estate, it seems timely that we revisit the scope and intent of Australia's Oceans Policy.

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Endnotes |

1 Oceans Policy Science Advisory Group (2013), *Marine Nation 2025: Marine Science to Support Australia's Blue Economy*, Australian Government, Canberra.

2 For the purpose of this Plan 'marine estate' is defined as Australia's oceans, seas, seabed, coasts, close catchments, traditional sea country, and the living and non-living resources they contain within Australia's marine jurisdiction (i.e. water column and seabed beyond the territorial sea baseline) and is 13.86 million km^2 (from Inspiring Australia Expert Working Group (2012) *Marine science: a story for Australia*, Australian Government, Canberra and Symonds P, Alcock, M & French, C (2009). *Setting Australia's limits: understanding Australia's marine jurisdiction*. AusGeo News 93:1–8, <www.ga.gov.au/ausgeonews/ausgeonews200903/index.jsp> (accessed 14 July 2015)). Australia's full confirmed marine jurisdiction includes Australia's territorial Sea (TS) of 0.85 million km^2, exclusive economic zone of 10.19 million km^2, extended continental shelf of 2.56 million km^2, and marine areas landward of the territorial seabed baseline to coast (approx. 0.26 million km^2).

3 The White House Council on Environmental Quality—*Obama Administration Releases Plan to Promote Ocean Economy and Resilience* 13 April 2013, accessed 1 August 2015, <https://www.whitehouse.gov/administration/eop/ceq/Press_Releases/April_16_2013>.

4 The eight white papers (including infrastructure) and subtheme papers underpinning this Plan can be found at www.marinescience.net.au

5 Commonwealth Science Council, *Strategic science and research priorities* <www.science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx>

6 See the UK's *Setting Course* marine science statement; <noc.ac.uk/f/news/downloads/2011/Setting%20Course%20document%2013-12-11.pdf> the report *Ocean Science in Canada: meeting the challenge, seizing the opportunity*; and the US policy document *An Ocean Blueprint for the 21st century*.

7 The European Commission has developed a *Blue Growth Strategy*, while China has also developed a 12th Five-Year Development Plan for National Marine Economy <www.china-briefing.com/news/2013/02/01/china-releases-12th-five-year-plan-for-the-marine-economy.html>. The United Nation recognised its importance in its *2014 Blue Economy Summit*, <sustainabledevelopment.un.org/?page=view&nr=603&type=13&menu=203> while industry, science and government leaders gathered at the *World Ocean Summit 2015 <www.economistinsights.com/sustainability-resources/event/world-ocean-summit-2015>* to focus on blue growth. The OECD is conducting a forward-looking assessment of the ocean economy to 2030 and beyond, with particular emphasis on the development potential of emerging ocean-based industries—see *OECD: The Future of the Ocean Economy: Exploring the Prospects for Emerging Ocean Industries to 2030* <www.oecd.org/futures/oceaneconomy.htm>.

8 Australian Institute of Marine Science, *The AIMS Index of Marine Industry* <www.aims.gov.au/publications.html> (from 2011/12 data).

9 State of the Environment 2011 Committee. *Australia state of the environment 2011*. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. Canberra: DSEWPaC, 2011.

10 Blue economy definition: 'Global ocean economic activity is estimated to be in the realm of USD $3–5 trillion … A blue economy is one which strikes the right balance between reaping the economic potential of our oceans with the need to safeguard their longer term health. A blue economy is one in which our ocean ecosystems bring economic and social benefits that are efficient, equitable and sustainable, from the Department of Foreign Affairs and Trade. *What is a blue economy?* <https://innovationxchange.dfat.gov.au/project/innovating-blue-economy>.

11 Exploration of Australia's marine estate: according to 2015 calculations by Geoscience Australia, the total physical mapping of Australia's ocean floor by multibeam sonar has covered approximately 25 per cent of Australia's 13.86 million km^2 marine jurisdiction.

12 There are no official data on the total amount Australia spends on marine science. This estimate derived from a census of all major funding agencies and more than 90 per cent of the established research institutions, universities and government laboratories. Some of the figures are likely to be underestimates as they did not include institutional overheads. No attempt was made to value the educational income from undergraduate and postgraduate marine science programs. Nor were we able to determine the amount industry spent on R&D, although some of this will have been captured in the budgets of key R&D providers to industry, for whom industry contributions are included.

13 The 7.5 per cent blue economy growth rate is calculated based on our goal to increase from $47.2 billion of current Australian marine economy to $125 billion by 2025. The 2.5 per cent GDP growth rate is taken from 2013/14 ABS data <www.abs.gov.au/AusStats/ABS@.nsf/MF/5220.0>.

14 Australia's marine jurisdiction is 13.86 million km^2 (from Inspiring Australia Expert Working Group (2012) *Marine science: a story for Australia*, Australian Government, Canberra and Symonds P, Alcock, M & French, C (2009) *Setting Australia's limits: understanding Australia's marine jurisdiction*. AusGeo News 93:1–8, <www.ga.gov.au/ausgeonews/ausgeonews200903/index.jsp)>. Australia's Search and Rescue Region covers 52.8 million km^2—over one-tenth of the Earth's surface <https://www.amsa.gov.au/search-and-rescue/sar-in-australia/arrangements-in-australia/>.

15 Ecosystem services are the benefits people obtain from ecosystems. These include 'provisioning services' such as food, water, timber, and fibre; 'regulating services' that affect climate, floods, disease, wastes, and water quality; 'cultural services' that provide recreational, aesthetic, and spiritual benefits; and 'supporting services' such as soil formation, photosynthesis, and nutrient cycling. *Millennium Ecosystem Assessment (2005). Ecosystems and human wellbeing: synthesis*. Washington, DC: Island Press.

16 Department of Industry and Science's March 2015 Resources and Energy Quarterly forecasts <www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-quarterly.aspx#>.

17 Ruello N.V. (2011). *A study of the composition, value and utilisation of imported seafood in Australia*. Fisheries Research and Development Corporation Final Report 2010/222. Ruello & Associates Pty Ltd. <www.frdc.com.au/research/Documents/Final_reports/2010-222-DLD.pdf>.

18 The *National Fishing and Aquaculture RD&E Strategy 2015–20* incorporates research priorities and themes from the *National Marine Science Plan*. The governance and implementation of the RD&E Strategy is overseen by a Governance Committee and the Research Provider Network, both of which also drive collaboration. In turn, the Fisheries Research and Development Corporations' RD&E Plan aligns with the research priorities and themes of the fishing and aquaculture strategy.

19 Eco-engineering: Ecological engineering is an emerging study of integrating ecology and engineering, concerned with the design, monitoring, and construction of

ecosystems <https://en.wikipedia.org/wiki/Ecological_engineering>.

20 Will Steffen, John Hunter and Lesley Hughes (2014), *Counting the Costs: Climate Change and Coastal Flooding* by Climate Council of Australia accessed on 14 July 2015, <www.climatecouncil.org.au/uploads/56812f1261b168e02032126342619dad.pdf>.

21 Deloitte Access Economics (2013), *Economic contribution of the Great Barrier Reef*, Great Barrier Reef Marine Park Authority, Townsville.

22 Super Science Initiative, Marine and Climate, <https://www.education.gov.au/super-science-initiative>.

23 *Venturous Australia—building strength in innovation: 2008* Report on the Review of the National Innovation System <www.industry.gov.au/innovation/InnovationPolicy/Pages/ReviewoftheNationalInnovationSystem.aspx>

24 European Commission's *Blue Growth Strategy* <http://ec.europa.eu/maritimeaffairs/policy/blue_growth/index_en.htm>.

25 China has developed a 12th Five-Year Development Plan for National Marine Economy <www.china-briefing.com/news/2013/02/01/china-releases-12th-five-year-plan-for-the-marine-economy.html>.

26 US National Ocean Policy Implementation Plan <https://www.whitehouse.gov/administration/eop/oceans/implementationplan>.

27 Allen Consulting Group (2011), *Girt By Sea—A Draft Decadal Strategy for Marine Research and Innovation: 2012 to 2022*, Prepared for the Oceans Policy Science Advisory Group

28 Office of the Chief Scientist (2014), *Science, Technology, Engineering and Mathematics: Australia's Future*. Australian Government, Canberra. <www.chiefscientist.gov.au/2014/09/professor-chubb-releases-science-technology-engineering-and-mathematics-australias-future/>.

29 Six-digit Australian Standard Classification of Education (ASCED) Field of Education Code 010907

FRONT COVER IMAGES: Cephalopod, subantarctic emperor penguins, industrial port, mangroves, school of fish, scientist diving on reef – Courtesy Tethys-Images.com

Ship in fog – Courtesy Meredith Banhidi

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Australian Government

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Department of the Environment

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Department of Industry and Science

Department of Defence
Defence Science and Technology Organisation

Geoscience Australia

Great Barrier Reef Marine Park Authority

Australian Institute of Marine Science

FRDC Fisheries Research & Development Corporation

AMSA Australian Marine Sciences Association Inc

CSIRO

IMAS Institute for Marine and Antarctic Studies | UTAS

IMOS Integrated Marine Observing System

UNESCO IOC Perth

Government of Western Australia | Department of Fisheries Western Australia

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State and Territory Governments

Australian Academy of Science

The National Marine Science Plan has been endorsed by the Australian Academy of Science