National Climate Change
Adaptation Research Plan

Marine Biodiversity and Resources

Contents

Image: FRDC.

Executive Summary

Increasing concentrations of greenhouse gases in the atmosphere due to human activities are driving changes in global climate. Climate change will lead to ocean warming, changes in ocean currents, increased intensity of storm events, and changed ocean chemistry associated with increased CO_2 uptake.

Climate change is very likely to affect marine biodiversity and resources, mainly through changes induced in the physical and chemical features of the marine environment such as ocean warming and changed ocean chemistry, which will trigger biological responses in marine organisms. It is also likely to have significant effects on important coastal habitats, including wetland, mangrove, saltmarsh and seagrass ecosystems. Some of these changes have already been observed. The magnitude of the recent physical changes is greater than at any time during human civilization and, importantly, the rate of change is faster.

The effects of climate change may have serious implications for the communities and industries that depend on the resources and services provided by marine ecosystems. Appropriate adaptation to these changes will require that, where possible, the social, economic and environmental consequences are anticipated, impacts minimised, and opportunities realised.

Individuals, institutions and sectors of the community that will need to adapt include those who govern or manage the use of marine resources, those who have responsibilities for conserving marine biodiversity, and those who depend on marine ecosystems for economic or social benefit. High-quality, focused research is required to ensure that these groups are well positioned to adapt to climate change, either in their own interests or on behalf of the Australian community. Some work has been done to improve understanding of the broad impacts on the marine environment, but adaptation research is less well developed.

This National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources identifies research required over the next 5–7 years to inform policy development and help managers of coastal ecosystems and the marine environment and associated industries and communities prepare for the consequences of climate change. It provides a framework to guide research funding decisions and key directions for Australia's marine research community. This Plan, together with Research Plans in other priority thematic areas, will guide researchers generating the information Australia needs to develop an effective portfolio of adaptation strategies.

The Plan takes a sectoral approach to the identification of stakeholders and their priority information needs, focusing on aquaculture, commercial and recreational fisheries, conservation and tourism. It also recognises the high importance of systems-based cross-sectoral research. We note that there are many Indigenous communities around the Australian coast for which climate change impacts on marine biodiversity and resources are likely to have significant implications. This Research Plan does not consider those issues related specifically to Indigenous culture and subsistence use. Those issues will be considered in a National Climate Change Adaptation Research Plan devoted to the Indigenous communities of Australia.

A number of critical information needs and research gaps are identified under each sectoral sub-theme. Ranking research areas into high and low priority is difficult, given that many aspects of research are not directly comparable and time-frames for research vary, but questions were prioritised using five criteria that have also been applied across the Research Plans for other thematic areas:

Essential

- The severity of impact addressed or the degree of benefit from taking action
- Immediacy of required intervention or response
- Need to change current intervention and practicality of intervention

Desirable

- Potential for co-benefits (benefits to other sectors of the community)
- Potential to address multiple, including cross-sectoral, issues.

Image: Graham Edgar.

Priority Research Questions for Climate Change Adaptation and Marine Biodiversity and Resources.

1. Aquaculture

- Which farmed species in which locations are most likely to be impacted by climate change?
- What options are there for businesses to adapt to climate change effects either by minimising adverse impacts or taking advantage of opportunities? What are the barriers to implementing such changes and how might they be overcome?

2. Commercial and recreational fishing

- Which fishery stocks, in which locations, are most likely to change as a result of climate change? What will those changes be (e.g., in distribution, productivity) and when are they likely to appear under alternative climate change scenarios?
- What options or opportunities are there for commercial fishers in identified impacted fisheries to adapt to climate change effects through changing target species, capture methods and management regimes, industry diversification, relocation or disinvestment?

3. Conservation management

- Which ecosystems and species of conservation priority most require adaptation management and supporting research, based on their status, value, vulnerability to climate change and the feasibility of adaptive responses?
- How should conservation managers and planners adapt their practices to ameliorate climate change risks and enhance adaptation options? What intervention strategies will increase system resilience and improve the time within which biological systems can adjust to a future climate?

4. Tourism and recreational uses

- What are the predicted regional impacts of climate change for marine tourism assets (e.g., which tourism sites will be most vulnerable to change and to what degree)?
- What is the adaptive capacity of the marine tourism industry and how can it be enhanced to cope with climate change impacts?

5. Cross-cutting issues

- What are the key interactions across sectors, cumulative impacts and cross-jurisdictional issues that will affect the development of adaptation strategies in each sector and how can these cross- and multi-sectoral issues best be addressed?

Implementation

An Implementation Plan will be prepared following Ministerial approval of this Plan and will include consideration of possible projects, research capacity and resource issues, and funding opportunities. The National Adaptation Research Network for Marine Biodiversity and Resources will play an essential role in implementing the Research Plan, and will contribute greatly to building collaboration, information-sharing and research capacity across the Australian research community.

1. Context and objectives

1.1 Background

The National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources identifies the research required to help managers of the marine environment and associated industries and communities prepare for the consequences of climate change. It provides a framework to guide research funding decisions and key directions for the country's marine research community. It is recognised that climate change will be merely one of several drivers of change in the marine environment. Nevertheless, this Plan focuses on identifying research that is likely to inform adaptation to climate change and to guide funding priorities within that broader context.

There is now widespread acceptance that human activities are contributing significantly to climate change, with serious implications for the broader environment – including the marine environment. Increased atmospheric carbon dioxide (CO2) levels and a more than 2–3°C rise in mean global temperature above pre-industrial levels are very likely to lead to significant changes in the structure and functioning of marine ecosystems (IPCC, 2007). The Natural Resource Management Ministerial Council has recently recognised climate change as one of five key broad-scale threats to marine biodiversity in Australian waters.

It is also accepted that some impacts of climate change have already occurred or are inevitable, and are likely to become more severe if we do nothing to modify our behaviours. Human responses to climate change generally fall into two categories: mitigation, where we reduce the sources of our influence on climate change, generally through reductions of emissions of greenhouse gases; and adaptation, by which we take actions to adjust to, accommodate or attenuate the physical impacts of climate change.

Adaptation research focuses on providing information to reduce the vulnerabilities of societies to risks and increase the capacity to cope with and even benefit from change. In this Plan, the term adaptation refers to deliberate human actions to respond to climate change impacts. This meaning does not include the largely automatic, instinctive or evolutionary responses of non-human biological systems to changing environments, whether forced by climate change or any other driver. Hence, a distinction is drawn between two aspects of climate change impacts on marine biodiversity and resources: the responses of marine ecosystems to climate change, and human social adaptation to changes in marine ecosystems and resources resulting from climate change. Both aspects are considered but, throughout this Plan, the emphasis will be on research that will inform actions that can be taken by society to: (i) minimise the climate change impacts on marine ecosystems and species; and (ii) facilitate social adaptation and aim to minimise the deleterious consequences of ecological responses to climate change.

The aims of this Plan, therefore, are to:

- identify important gaps in the information needed by decision-makers to reduce the vulnerability to climate change impacts of marine ecosystems and the industries and communities that depend on marine resources;
- set adaptation research priorities based on these gaps;
- identify capacity that can be harnessed or needs development in order to carry out priority adaptation research.

Image: FRDC.

The National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources identifies the research required to help managers of the marine environment and associated industries and communities prepare for the consequences of climate change.

1.2 National policy context for this National Climate Change Adaptation Research Plan

The National Climate Change Adaptation Framework (the Framework) was endorsed by the Council of Australian Governments (COAG) in April 2007 as the basis for government action on adaptation over 5–7 years. The Framework identifies possible actions to assist vulnerable sectors and regions, such as biodiversity, fisheries and coasts, to adapt to the impacts of climate change. It also identifies actions to enhance the knowledge base underpinning climate change adaptation and improve national coordination of climate change adaptation research.

The Australian Government in 2007 provided $126 million over 5 years towards implementing the Framework. The Australian Government established the National Climate Change Adaptation Research Facility (NCCARF), hosted by Griffith University, to coordinate and lead the Australian research community to generate the biophysical, social and economic information needed to adapt to climate change. Up to $30 million will be invested in priority research for key sectors as identified in National Climate Change Adaptation Research Plans. A series of Plans are being developed by the Facility, in partnership with relevant government, industry and research stakeholders. The Plans will set national priorities for adaptation research and will be implemented by NCCARF, with assistance from the Adaptation Research Networks (Box 1).

Box 1 – National Adaptation Research Networks and priority themes

Funding of up to $10 million has been provided over 4 years to support the establishment and operation of a number of National Adaptation Research Networks. These research networks will form part of and be coordinated by the National Climate Change Adaptation Research Facility. They will work with NCCARF to advance regional and sectoral knowledge about climate change impacts and vulnerability and adaptation options, and to foster an inclusive and collaborative research environment. The following priority themes form the basis for national adaptation research planning, including National Climate Change Adaptation Research Plans and Adaptation Research Networks:

- Terrestrial biodiversity
- Water resources and freshwater biodiversity
- Human health
- Emergency management
- Primary industries (terrestrial)
- Marine biodiversity and resources (including fisheries and marine aquaculture)
- Settlements and infrastructure
- Social, economic and institutional dimensions

Information about the Adaptation Research Networks is available from http://www.nccarf.edu.au

1.3 Development of the Plan

The development of the National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources was led by the following drafting team: Dr Bruce Mapstone (Chair), Dr Peter Appleford, Dr Kathleen Broderick, Associate Professor Rod Connolly, Dr Alistair Hobday, Dr John Higgins, Professor Terry Hughes, Professor Jan McDonald, Dr Paul Marshall and Ms Marie Waschka.

A national workshop was held in June 2008 to elicit feedback on an Issues Paper from stakeholders and researchers with an interest in marine climate impacts and adaptation. This workshop was attended by over 60 participants representing science, policy, management, and industry groups. The outcomes of this workshop were incorporated into a Consultation Draft of the Plan, which was subject to a further extensive round of public comment. The Draft was sent to all workshop participants and invitees, and posted on the NCCARF website. Follow-up phone calls were made to a range of stakeholders, and the Department of Climate Change sought input from several key agencies during face-to-face meetings. Approximately 40 submissions were received from State, Territory and Commonwealth government agencies, researchers, industry groups and environmental non-governmental organisations and these were carefully considered in the production of this final Plan. The final document was subject to a final round of review by relevant Australian government departments before being submitted to the Minister for approval.

1.4 Related research planning and other activities

A range of other national activities or processes are occurring in the area of marine biodiversity and resources research relevant to adaptation to climate change. These activities are spread between formal government or intergovernmental initiatives and the activities of research organisations and R&D funding programs. The Ocean Policy Scientific Advisory Group (OPSAG) has recognised that Australia needs a coherent, integrated and forward-looking approach to marine R&D and innovation that addresses the economic, environmental and social challenges of the utilisation and preservation of its ocean territories, and in response is developing a Marine Research Strategy. The main activities of relevance are summarised in Figure 1.

Ensuring clear links between these multiple processes and activities will provide for greater efficiency in the allocation of limited research funds. One of the first activities of the Marine

Image: Graham Edgar.

Biodiversity and Resources Network will be a comprehensive review of these disparate but related activities. The Plan will identify critical information and research gaps in order to assist the management of marine biodiversity in a changing climate and will thereby seek to align research priorities relevant to climate change adaptation across the above initiatives. Section 6.2 outlines Australian research capacity relevant to the research priorities identified in this Plan.

1.5 The scope of this National Climate Change Adaptation Research Plan

Some degree of change to marine biodiversity and resources is likely to be unavoidable under a changing climate. These changes may have serious implications for the communities and industries that depend on the resources and services provided by marine ecosystems.

Appropriate adaptation to these changes will mean that the social, economic and, where possible, environmental consequences are anticipated, impacts minimised, and opportunities realised. Individuals, institutions and sectors of the community that will need to adapt include those who govern or manage the use of marine resources, those who have responsibilities for conserving marine biodiversity, and those who depend on marine ecosystems for economic or social benefit. High-quality, focused research is required to ensure that these groups are well positioned to adapt to climate change, either in their own interests or on behalf of the Australian community.

This Plan will support adaptation efforts by identifying research priorities that are most relevant to the needs of these stakeholders. The Plan will provide targeted guidance to research investors and research providers about priority information needs and research that is most likely to address those needs over

Figure 1. Examples of the main processes under way at national level that provide direction for research associated with facilitating adaptation to climate change. The coordinating agency is noted where relevant.

R&D Strategies	Research Initiatives	National Action Plans	Vulnerability Assessments	Response Plans
Marine and Coastal Committee (MACC) Strategic Directions Ocean Policy Scientific Advisory Group (OPSAG) Marine Research Strategy Report on *'A National Climate Change Research Strategy for Primary Industries'* (DAFF) Australian Fisheries Management Forum Research priorities	Plans and Networks (NCCARF) CSIRO Flagships Climate Change Research Strategy for Primary Industries (DAFF) Commonwealth Environment Research Facilities Program (DEWHA) Integrated Marine Observing System (IMOS) Cooperative Research Centres	National Climate Change and Fisheries Action Plan (DAFF) National Biodiversity and Climate Change Action Plan (DEWHA) National Agriculture and Climate Change Action Plan (DAFF) Climate Change Action Plan for the Great Barrier Reef (GBRMPA) Tourism and Climate Change Framework for Action	National Assessment of the Vulnerability of Australia's Biodiversity (DCC/DEWHA) National Coastal Vulnerability Assessment (DCC) Preliminary assessment of the implications of climate change for aquatic ecosystems in Australia Great Barrier Reef Vulnerability Assessment	National Approach to Addressing Marine Biodiversity Decline

the next 5–7 years. If properly funded and delivered, this research is expected to assist stakeholders to adapt to the challenges of climate change.

The Plan focuses primarily on research to inform Australian Governments' and communities' adaptation to climate change impacts on marine biodiversity and resources within the Australian marine environment, including Antarctica and Southern Ocean territories. Research, observations and measurement systems have been given high priority where they will inform the design of adaptation policies or strategies, or help implement adaptation actions by appropriate people and organisations. Research on the nature of climate change impacts *per se* is not emphasised unless such research was considered essential to fill a void in understanding adaptation options.

The Plan focuses on research to inform strategies addressing climate change impacts on:

- marine-dependent species and ecosystems, including those in the ocean, estuaries and coastal saline wetlands and beaches, including production at the base of marine food webs;
- physical features of habitats for the above species, including processes such as increased inundation of wetlands, coastal erosion, nutrient distributions, and warming- and pH-related changes in the ocean as they affect the dependent species;
- physical conditions in the marine environment (e.g., weather and wave climates) that directly affect people's access to marine resources;
- social conditions in marine-dependent or associated communities;
- the economic viability of activities or communities that depend on marine biodiversity and resources;
- the options for governance and management of the marine environment and regulation of its uses.

There are some important aspects of climate change impacts on marine biodiversity and resources that this Plan does not consider. The Plan does not address the implications for non-living resources such as oil, gas, minerals, or access to transport (shipping). Nor does it address freshwater aquaculture and fishing activities, which are covered by the Plan for Primary Industries.

This Plan also does not address adaptation issues or options for Indigenous communities

The Plan focuses primarily on research to inform Australian Governments' and communities' adaptation to climate change impacts on marine biodiversity and resources within the Australian marine environment, including Antarctica and Southern Ocean territories.

around Australia's coast. We recognise that these issues are critical. They will be considered in a National Climate Change Adaptation Research Plan devoted to the Indigenous Communities of Australia.

Adaptation options will apply at different spatial scales. As a *national* plan, this document gives priority to research needs of national significance or that are likely to apply, with different levels of detail, over large geographical areas (e.g., tropical Australia) rather than those that are regionally specific (e.g., the Gulf of Carpentaria), except where local features have unique national significance (e.g., breeding sites of threatened or endangered species). Individual research activities, however, are likely to be regional or local in focus. For example, research is most likely to be focused on fisheries in a particular region or jurisdiction rather than across the nation. The Plan provides a framework within which others can set region-specific research priorities that address local issues similar to those discussed here, either to help local communities *per se* or as case studies for later application elsewhere. For example, research might be done on the implications for industry of a southward extension of a fishery species in Queensland that provides a case study for addressing the economic and social consequences of range extensions of marine species elsewhere. Opportunities to leverage this type of case-study research to inform other planning activities or processes should be recognised wherever possible.

Relating climate impacts to a particular future date depends on the future rate of global warming; when warming is fast, changes will occur sooner than if warming is slowed. Thus, the temporal scales over which this Plan considers climate change impacts and adaptation are relatively unconstrained, potentially extending from issues that are already apparent to those that are expected to become important only several decades from now. The latter are considered because it may be important to start research now to inform actions in the near future that will enable us to accommodate or avert impacts in the more distant future, particularly given the long lag times for some impacts.

Overlaps, synergies or ambiguities between the scope of issues addressed in this Plan and those addressed in other Plans are set out below. Section 2 outlines the projected impacts of climate change that create the need for adaptation, while Section 3 identifies the information needs of key stakeholders. Section 4 formulates research priorities for a number of

Image: Australian Fisheries Management and Authority.

different sectors. Section 5 outlines the process and criteria by which those priorities were ranked, and lists those research priorities ranked as high priority. The full priority assessment matrix for all research questions considered is in Appendix 2. The discussion throughout this Plan is drawn from and supported by a range of sources. To improve readability, references are not included in the text, but are instead included in the Suggested Reading section.

1.6 Links to and synergies with other National Climate Change Adaptation Research Plans

There are clear overlaps between this Research Plan and research priorities in other National Climate Change Adaptation Research Plan thematic areas. Some potential areas of synergy and common interest or conflict are set out below. The Implementation Plans for these Plans will ensure that these priorities are complementary and mutually supportive and seek to avoid duplication of research effort.

Terrestrial Biodiversity

There is a strong overlap between terrestrial and marine biodiversity research in the coastal zone. Both sea-level rise and increased storm activity are likely to have significant impacts on the marine–terrestrial interface and coastal ecosystems, including the condition and distribution of salt marshes, mangroves, estuaries, beaches and dunes. Higher sea levels will cause coastal erosion and the landward migration of marine ecosystems, potentially at the cost of other coastal ecosystems. Coastal ecosystems are covered by the issues and priorities set out in this Plan. The priorities identified in the Terrestrial Biodiversity Plan are also likely to address these issues. The Implementation Plans for these Plans will ensure that these priorities are complementary and mutually supportive and will seek to avoid duplication of research effort.

Water Resources and Freshwater Biodiversity

There is a significant link between this Plan and the Plan for Water Resources and Freshwater Biodiversity. Reduced water quality in river systems will have a major impact on estuarine and coastal ecosystem health, and may exacerbate climate-related stressors on the marine environment. Research into the effects of climate change on coastal systems will therefore also need to consider the impacts of climate change on the quality and quantity of riverine flows.

Primary Industries

Fisheries issues are typically administered along with land-based primary industries, such as agriculture and forestry. However, it is considered more appropriate that marine fisheries and aquaculture be dealt with as part of this Plan, while freshwater fisheries and aquaculture are discussed as part of the Plan for Primary Industries. Adaptation strategies for marine fisheries and aquaculture will be heavily dependent on the impacts of climate change on overall marine ecosystem health. Management strategies in the marine environment will be likely to involve integrated responses across fisheries, aquaculture, conservation management and tourism. The principal links between this Plan and the Primary Industries Plan, therefore, relate to the minimisation of non-climate stressors on the marine environment, including land-based marine pollution such as agricultural runoff.

Emergency Management

Emergency management organisations will need to prepare for the possibility of increased maritime risks arising from extreme weather events. The Emergency Management Plan has research priorities in the areas of identifying where the greatest risks lie, enhancing community and organisational resilience to such risks, and developing targeted emergency management adaptation strategies.

Settlements and Infrastructure

Coastal communities interact with the marine environment in a variety of ways. Pressures for new urban development along the coast will place further stress on coastal and estuarine ecosystems. Adaptation strategies for marine ecosystem health that seek to reduce land-based pressures will therefore include controlling such coastal development. The potential for relocation of aquaculture activities and fishing infrastructure in response to climate change impacts will be affected by how coastal communities respond to climate change impacts and how future planning and development is regulated.

The location, design and construction of infrastructure to protect coastal assets such as sea walls, groynes and artificial reefs will need to minimise unintended impacts on marine biodiversity. Such works have the potential to impact on marine biodiversity and resources, but these impacts can be reduced by careful planning and sympathetic design.

Social, Economic and Institutional Dimensions of Adaptation

Developing and implementing adaptation strategies for marine biodiversity and marine-dependent industries and communities will require a strong understanding of the social, economic and institutional barriers to adaptation and sources of resilience. Many of these barriers are unique to the marine context but others cut across the Australian society, economy and legal system. These cross-cutting issues will be considered under the Plan for Social, Economic and Institutional Dimensions of Adaptation (SEI Plan). They include how best to integrate economic models into decision-making tools for evaluating adaptation actions and strategies and cross-cutting issues relating to how communities impacted by multiple stressors will adapt.

Human Health

The decline or loss of marine resources may impact negatively on the livelihood, and hence the mental and physical health, of communities dependent on these resources for a living, or with specific cultural relationships with marine biodiversity and resources; and thus may have potentially negative health outcomes.

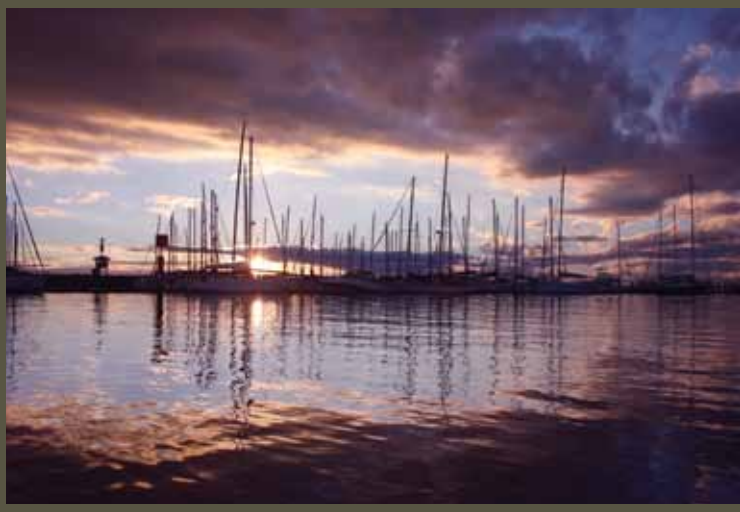

Image: Timo Balk.

2. The need for adaptation

Climate change is happening in the broader context of a range of other pressures on, and uses of, the marine system that will cause changes in the short and longer term. These pressures and uses include coastal development, fisheries, tourism, marine pollution, increased terrestrial pollutant runoff, and issues affecting marine-based industries such as 'peak oil', labour costs and macro-economic factors. Climate change will exacerbate the effects of many of these uses, and society will need to adjust conventional management and governance practices to accommodate those greater effects.

Natural resource management in Australia is moving towards an ecosystem-based approach, requiring joint consideration of the biological systems and all their uses in order to provide a holistic management response. It is important, therefore, to see climate change as another driver of change in the marine environment that will need to be considered in ecosystem-based management. Adaptation strategies within an ecosystem approach will have to be location-, user group-, and time-specific. Impacts of climate change will occur over different temporal scales. Gradual changes can be identified and monitored, and adaptation can be proactive, progressive or reactive. In contrast, step or threshold changes may not be foreseen and, in the absence of any prediction, adaptation in these cases will often be reactive. One of the key challenges in developing climate change adaptation strategies is how to deal with the uncertainty over the precise nature, scope, and timing of impacts. Climate change projections and associated ecological impacts are inherently uncertain, and policy-makers, resource managers and users will have to learn to make adaptation decisions in the face of such uncertainty. Information is therefore needed to assist this decision-making *in the face of unavoidable uncertainty.*

2.1 Expected marine impacts of climate change

Increasing concentrations of greenhouse gases in the atmosphere due to human activities are driving changes in global climate. Climate change is expressed as, among other things, a general increase in global temperature, including overall warming of the Earth's oceans. Climate change is very likely to affect marine biodiversity and resources, mainly via changes induced in the physical and chemical features of the marine environment that will trigger biological responses in marine organisms.

The change in the Earth's climate and oceans over the past 200 years is very different from the 'natural' climate variability seen over millions of years in the past. The magnitude of the recent physical changes is greater than at any time during human civilization and, importantly, the *rate* of many changes is higher in relation to previous changes. Further, unlike previous periods in the Earth's history, contemporary climate change is occurring in conjunction with other human impacts, unlike any in previous periods. The magnitude and rate of these changes present major challenges to marine biological systems that have evolved over millennia. It remains unclear exactly how these systems will be affected by the current rapid changes in their environment.

To help researchers and stakeholders understand the research priorities, we first summarise the key relevant changes in the marine environment likely to be caused by climate change, and then discuss the likely biological responses to those changes that will impact on marine biodiversity, productivity and resources.

2.1.1 Climate change effects on the ocean

Climate change is leading to overall ocean warming and changes in ocean currents and ocean chemistry associated with CO_2 uptake. These changes are the major drivers of direct and indirect effects of climate change on marine biota, and each has various consequences that will impact on marine biodiversity and resources.

Warming and the ocean

The global oceans have warmed over the last 100 years by an average of ~0.6°C as a consequence of anthropogenic emission of greenhouse gases. The rate of warming accelerated in the last decades of the 20th century and is expected to accelerate further during the 21st century. Ocean temperatures are not increasing at the same rate everywhere and the rate of change varies regionally around Australia: tropical oceans are warming at close to the global average rate; west-coast waters are warming around twice as fast as the global average; while warming off south-east Australia is greatest, at around four times the global average. Within smaller regions, however, minor cooling may also occur, perhaps due to increased wind-driven upwelling.

Ocean warming causes expansion of the water, and is one cause of rising sea levels. Ocean warming, significant inputs of fresh water from melting ice and enhanced high-latitude precipitation, and changes in the dynamics of polar sea ice are likely to cause reductions in the horizontal and vertical circulation of the oceans, leading to increased vertical stratification in the short to medium term, and even greater warming of the oceans' surface layer. Changes in the strength and direction of ocean currents at both regional and global scales will have wide-ranging impacts. Slowing ocean circulation is likely to affect upwelling and nutrient supply to coastal and shelf waters. The convergence location of the eastern, southern and western currents in south-east Australia may also be altered.

Ocean temperature affects regional meteorology, especially the formation of intense low-pressure systems or tropical cyclones. It remains unclear whether the frequency of such events will increase under climate change, but warmer oceans are expected to contribute to increased intensity of such storms, meaning rougher seas, larger and more frequent severe waves, and greater physical disturbance of shallow water and coastal environments.

Carbon dioxide and the ocean

Increased concentrations of carbon dioxide (CO_2) in the atmosphere ultimately drive increased uptake by the ocean. The ocean has absorbed approximately half of the human CO_2 emissions into the atmosphere since around the year 1750. Increased ocean uptake of CO_2 is leading to the acidification of ocean waters. This is a direct chemical effect of anthropogenic emissions and occurs largely independently of anthropogenic global warming.

The chemical properties of the ocean are changing as a result of increased CO_2 concentrations. The ocean is becoming less alkaline and more acidic because when CO_2 dissolves in sea water it reacts to form weak carbonic acid. Modern acidification of the ocean has been occurring since the industrial revolution, when anthropogenic emission of CO_2 began increasing, and the oceans are now considered more acidic than at any time during at least the last 650,000 years.

A second effect of increasing ocean uptake of CO_2 is reduced availability of dissolved carbonate, which is necessary for many marine plants and animals to build shells or skeletons. Two forms of carbonate – aragonite and calcite – are important for shell formation, with different organisms using each of the forms. The ocean has been supersaturated in both aragonite and calcite for millennia, with the greatest concentrations in warmer tropical waters. This supersaturation provides an environment that favours the formation of shells and skeletons and the persistence of carbonate sands in marine waters. Increasing the uptake of CO_2 into the ocean reduces the level of supersaturation of carbonate, making the environment increasingly hostile to shell- and skeleton-forming organisms. Continued anthropogenic emissions of CO_2 to the atmosphere are likely to drive sufficient gas into the oceans to cause under-saturation of aragonite in polar oceans this century, meaning that the environment will increasingly favour dissolution rather than formation of carbonate shells, skeletons and sediments.

The capacity of the ocean to absorb CO_2 varies with ocean temperature. More CO_2 is absorbed and stored in the high-latitude, cold temperate and polar oceans than in lower-latitude, warm temperate and tropical waters. This pattern has existed for millennia, but the greater capacity of the colder polar oceans to absorb CO_2 means that those regions take up most of the anthropogenic CO_2 emissions that end up in the ocean. Hence, changes in ocean chemistry and effects on marine organisms are likely to be seen first in the Southern Ocean and in the North Atlantic and North Pacific.

2.1.2 Impacts on marine biodiversity and resources

Recent reviews of climate impacts on marine biodiversity and resources and aquaculture have consolidated the knowledge of historical and predicted changes for Australian marine systems. Biological changes occur in several categories, including changes in (i) distribution and abundance, (ii) physiology (e.g., growth) and phenology (timing of life-history events such as breeding), and (iii) community structure and function (including general productivity). Some species will be advantaged and others disadvantaged by these changes.

Effects of warming water

Many marine species survive and reproduce only within specific ranges of water temperature, and become physiologically stressed or die when water temperatures extend outside that tolerable range. Sessile organisms such as corals and benthic algae are those most likely to suffer such stress in the short term, because individuals cannot escape waters that become warmer or colder than they can tolerate.

For example, coral bleaching is a symptom of the inability of most corals to tolerate unusually high water temperatures. Bleaching, or the breakdown in the symbiosis between the coral animal and single-celled algae, can occur because of many environmental stresses. However, widespread, mass coral bleaching events affecting whole reef tracts are caused by warming taking the corals closer to their upper limit of thermal tolerance. Many fish and other mobile organisms can move to avoid warmer or colder waters, and some species move extensively to remain within favourable water masses. Other species, however, are sedentary and either cannot or will not move even relatively short distances to escape periodic doses of warm or cool water.

Ocean warming is likely to result in more frequent and/or widespread physiological stress for many organisms (e.g., coral bleaching), possibly resulting in significantly increased rates of mortality or failure to reproduce. Such effects may lead to substantial changes in the species composition of marine communities, as species intolerant of warmer water are replaced by more warm-temperature tolerant species. These effects are likely across wide geographical ranges, from tropical coral reefs to cold

Image: James Dunn.

temperate macroalgae, seagrasses and kelp communities, and may affect important fishery or aquaculture species that are currently near the limits of their thermal tolerance.

Both sessile and mobile species might respond to ocean warming over longer intergenerational time-scales in either or both of two ways. First, species might physiologically adapt to warming water as successive generations are born into warmer environments, provided that their thermal tolerance is not genetically 'hard-wired'. Such evolution would mean that species could maintain their historical geographical ranges as water temperatures increase locally. Second, species may experience changed or extended geographical ranges as, for example, planktonic larvae in successive generations survive dispersal and settlement into new habitats as water in those habitats warms. This effect might mean progressively southerly range extensions for various warm-water species around Australia, but might lead to local population extinctions of cold-water species already at the southerly limits of their available habitat (e.g., along the Southern Australian margins). Southerly range extensions have been documented already for fish, invertebrate, zooplankton and phytoplankton species off south-eastern Australia.

Seasonal variation in water temperature is also important in triggering reproduction in some species, with reproduction triggered when water temperatures exceed a specific level. Ocean warming is likely to change the timing and duration of these seasonal transitions, triggering spawning at different times. While this change might not directly threaten reproductive success, it may affect the efficacy of harvest management strategies based on seasonal closures designed to prevent harvest during spawning, unless those closure periods are changed to keep pace with changes in seasonal temperature cycles.

Ocean warming is also likely to affect the extent and thickness of sea ice around Antarctica, and this will affect the productivity of the Southern Ocean at all trophic levels, with flow-on effects for species such as baleen whales.

Effects of changing ocean and atmospheric circulation

Changes in ocean circulation or wind patterns that may alter the upwelling of nutrient-rich waters or change the distribution of plankton, including the larvae of benthic and pelagic species, would affect the general productivity of continental-shelf ecosystems, possibly also changing the productivity of associated fisheries. Such effects have been hypothesised but not yet documented and model projections indicate that they may not become apparent in Australian waters for several decades.

Effects of sea-level rise

Rising sea level has been documented and rates are following the most severe trajectory projected by global climate models. Rising mean sea level will have three main impacts on coastal marine biodiversity. First, increased areas of low-lying

A second effect of increasing ocean uptake of CO_2 is reduced availability of dissolved carbonate, which is necessary for many marine plants and animals to build shells or skeletons.

Recent evidence from the Southern Ocean indicates that some organisms may already be having difficulty in forming shells.

habitat will become inundated, including many coastal tidal wetlands and mangroves. In some instances, inundation might simply result in the retreat of coastal habitats to slightly higher ground adjacent to their current location. However, such natural adjustments will not be possible where the coastal habitats are adjoined by either steep terrain or built environments that preclude the shoreward migration of coastal wetlands. In such cases, these habitats and the species dependent on them will be reduced or lost. Changes in wave height and wave energy may amplify these effects.

Second, a rising mean sea level will cause erosion of coastal sediments, changes in coastlines and redistribution of sediments in estuaries, possibly causing infilling of some estuaries or deepening of others. A rule of thumb (the Bruun Rule) says that for every one unit rise in mean sea level, sandy shorelines will recede by 100 units. That is, if sea level rises by 1 metre, we can expect many sandy shorelines to recede by about 100 metres. The 100-to-1 ratio, however, applies to very specific circumstances on calm sandy coasts with little or no longshore transport. The ratio is considered to be much higher, perhaps as high as 800-to-1, for high-energy coasts with strong alongshore currents, such as exist around most of the southern half of Australia. Conversely, the ratio is likely to be smaller for embayed coasts with generally calm waters and low wave exposure, such as in many tropical locations. Again, habitats on receding shores might simply 'retreat' shoreward in some areas but might be prevented from doing so elsewhere because of human development or unaccommodating coastal topography.

Third, rising mean sea levels will lead to more frequent periodic inundation of low-lying coastal environments by extreme sea levels. Extreme sea levels are the highest (or lowest) sea levels experienced locally because of periodic or intermittent variations in, for example, tides, storm surges, waves, the effects of high- or low-pressure systems, or any combination of these. Even a moderate rise of 0.5 metres in mean sea level this century will mean that extreme sea-level inundation events currently expected annually will recur at least monthly by 2050, and will probably be daily events by 2100. These increases in frequency are likely to change the exposure of local terrestrial or freshwater habitats to saline inundations, potentially leading to significant shifts or losses of species composition and habitat characteristics.

Effects of changing ocean chemistry and acidification

Changing ocean chemistry is likely to mean that many marine species, including molluscs, echinoderms, corals, coralline macroalgae and many planktonic organisms, will have difficulty in forming skeletal material. Recent evidence from the Southern Ocean indicates that some organisms may already be having difficulty in forming shells. The consequences of reduced

Substantial changes to marine biodiversity and resources are unavoidable in a changing climate. Natural systems are likely to have limited capacity to adjust to the *rate* of climate change and its consequences.

shell mass or thickness are not yet known for planktonic organisms but it is likely that loss of skeletal mass in sessile organisms (e.g., corals) will increase their vulnerability to physical storm damage and biological erosion. Such effects will be particularly important in coral reef systems where the reef matrix is composed of biogenic carbonate. Reduced skeletal formation will be likely to diminish the rates of reef growth, weakening reef structures and perhaps reducing the capacity of reef growth to keep pace with rising sea levels.

Physiological stress from difficulty in skeleton or shell formation may be most pronounced in very small organisms, such as planktonic organisms and larval animals, including larval fish. The consequences of such stress for individual survival and population productivity is not known and neither is it clear what will be the consequences of effects on organisms at the base of food chains for higher-order consumers, including fishery species. Recent laboratory experiments, however, suggest that both the fertilisation of eggs and the survival of larvae of many marine species are likely to suffer considerably as a result of changed ocean chemistry and ocean acidification.

Acidification of the ocean is also expected to affect the availability of some micronutrients for biological use. If these effects decrease the availability of micronutrients such as iron or silica, we might expect to see significant reductions in primary production in areas where these micronutrients are currently limiting production – such as throughout the Southern Ocean. It is not yet clear whether such effects are evident in natural (as opposed to laboratory) conditions or what consequences might be propagated up the food chains that depend on oceanic primary production. It is clear, however, that more information is needed in order to understand how acidification may affect adaptation options, given the considerable uncertainty surrounding these impacts.

2.2 Adaptation strategies relevant to impacts on marine biodiversity and resources

Substantial changes to marine biodiversity and resources are unavoidable in a changing climate. Natural systems are likely to have limited capacity to adjust to the *rate* of climate change and its consequences. These changes may have implications for the industries and other stakeholders that depend on the services provided by marine ecosystems, even though most commercial fisheries, for example, have developed over several decades to manage the variability in stock abundance and distribution driven by natural variability in the marine system. The capacity of these stakeholders to adapt to increasingly rapid changes in marine ecosystems will influence the extent to which they are

Image: Jan-Olaf Meynecke.

affected by climate change and will influence their ability to realise the opportunities that may arise from climate change.

Response to climate change within the marine ecosystem may occur autonomously through natural physical and biological processes, or it may be engineered by human intervention. Both autonomous and planned adaptation can be facilitated publicly or privately, by individuals or groups. Autonomous responses include movement, acclimatisation, genetic changes through selective mortality (biological evolution), and shifts in species distribution or composition of communities. Autonomous responses can also be facilitated by human actions at various levels. For example, networks of protected areas facilitate species redistribution, protecting and restoring habitats essential for important life stages (e.g., nursery grounds), and might preserve biological robustness to climate variability and change. More direct action may take the form of translocation of mature (breeding) animals, or human-engineered strategies designed to increase the ability of species or other ecosystem components to cope with or be resilient to climate change. Examples of these might include genetic engineering for heat-tolerant fish and assisted dispersal of larvae or seeds (e.g., mangroves and seagrasses). There is considerable uncertainty about the effectiveness of such direct interventions and experience shows that they come with a significant risk of unintended or unanticipated consequences. We must learn to incorporate risk and change into management strategies, preferably using a formal adaptive management approach that is informed by a proper evaluation of risks.

We can anticipate some of the likely climate change impacts and design specific strategies to adapt to them.

For example, we anticipate that some fisheries species distributions will extend southward as waters warm, and so one adaptive strategy might be that fishing vessels relocate to more southerly ports. Projections of climate change become increasingly uncertain, however, as the spatial scale becomes finer, and hence it is likely that there will be direct and indirect effects in unexpected places. It is difficult to prepare specifically for unexpected or unknown effects. Rather than contemplating all possibilities and attempting to design a myriad of targeted adaptation strategies, a more effective action may be to enhance the resilience and flexibility of social and ecological systems, providing them with the capacity to autonomously adapt or respond as likely changes become more clearly understood. Building general resilience by promoting diversity, flexibility and responsiveness within human systems is usually advocated in preference to individual, prescribed adaptation measures targeting specific impacts of unknown likelihood.

Reducing society's vulnerability to the challenges of climate change requires proactive management and rapid institutional learning. Governance and management strategies and practices need to be regularly tested and adjusted. Adaptive management uses information derived from targeted interventions to revise successive interventions and improve policy. Adaptive management has been advocated for several decades as an approach to natural resource management that maximises the rate of learning and progressive improvement in management responses to problems. 'Whole of system' strategies such as catchment-scale management and ecosystem-based management are likely to increase the prospect that marine systems will build increased resilience to unexpected 'shocks' or unforeseen cumulative impacts of multiple stresses.

3. Key stakeholders

Here we provide brief descriptions of the primary stakeholders in the implementation of the research agenda set out in this Plan. We have deliberately focused on the groups likely to be most directly affected by climate change impacts, and have not attempted to provide an exhaustive list of all stakeholders slightly or tangentially affected.

The primary stakeholders are grouped here into three broad categories.

3.1 Policy-makers and regulatory decision-makers

These are people who design policy, draft legislation or formulate regulations, and who oversee management that directs or constrains activities within Commonwealth, State and Territory and local jurisdictions. They are likely to play very important roles in adaptation to climate change by shaping the institutions (regulations and incentive systems) that limit or facilitate adaptation responses by others. They generally act through government, on behalf of the community, and their decisions are expected to reflect community values.

Policy and regulatory decision-makers require information about the changing ecological conditions of the resource, levels of resource use, interactions between existing ecological status and regulatory environments, and the public values of resources (whether economic, cultural, material or aesthetic), including the desired outcomes for resource management. These values may change over time, including in response to real or perceived impacts from climate change, and agile policy development and implementation will be required for effective climate change adaptation. A thorough understanding of the changes in public values attached to marine biodiversity and resources because of climate change will be essential to good policy development and a key information requirement from adaptation research. The ability to estimate likely future resource status and opportunities for uses will also be important. Policy- and decision-makers will benefit greatly from knowledge of the environmental, social and economic impact of regulatory decisions that adjust access to resources because of climate change impacts.

3.2 Direct and dependent users of marine biodiversity and resources

These are people who use marine biodiversity and resources directly and tangibly for sustenance and culture (e.g., Indigenous peoples), recreation and amenity (e.g., recreational fishers and divers), and/or commercial benefit (e.g., commercial fishers, aquaculturists, and tourism operators). Support industries depend on, but are not directly involved in, these activities (e.g., chandlers, seafood processors and exporters, tackle retailers). These users also include representative industry bodies and groups.

Direct and dependent users arguably have the biggest direct stake in effective adaptation to climate change. They are most likely to suffer real social or economic impacts if they are limited in their ability to adapt to climate change. Users will face increasing pressure to accommodate or compensate for changes in the availability of ecosystem resources and services on which they depend. They can reduce the impact of climate change on marine biodiversity and resources by modifying their activities.

Researchers might also be considered direct users of marine biodiversity and resources. Scientists study the marine environment: to provide basic knowledge to underpin resource extraction and management; to provide monitoring information to inform management; and to provide a broad knowledge base that improves understanding. Changes in the marine environment will affect all of these activities.

3.3 Representatives of interests in marine biodiversity and resources

These are people who claim a 'stewardship' role for marine biodiversity conservation (e.g., non-governmental organisations). They seek to influence policy to meet the values of their constituencies but do not themselves depend on or directly use marine biodiversity or resources.

It is recognised that the broader population has a strong interest in the ongoing health and good management of marine biodiversity and resources. In addition to the commercial, recreational and cultural values of marine biodiversity, the conservation, existence and intrinsic values of that biodiversity will be essential considerations when analysing adaptation and management issues.

This Plan groups primary stakeholders around the sectoral activities or interests they have in Australia's marine biodiversity and resources (e.g., fisheries, tourism) rather than by the different functional categories described above. A sectoral grouping recognises that it is likely that the adaptation issues faced within a sector (e.g., commercial fishing) will require the coordination of actions by stakeholders within that sector, from policy-makers and regulators to lobbyists, fishers and those in support industries. Hence, actions by each group will interact with those of other groups with interests or responsibilities in the same sector, and similar research is likely to be required to inform actions by multiple groups. It should be noted, however, that climate change adaptation issues for Indigenous communities around Australia's coasts and islands are not addressed in this Plan even though there may be significant implications for people in those communities from climate change impacts on marine biodiversity and resources. Adaptation issues specific to Indigenous issues will be considered in a National Climate Change Adaptation Research Plan devoted to the Indigenous communities of Australia.

Therefore, the sectors addressed in this Plan are:

1. Marine aquaculture
2. Commercial and recreational fishing
3. Conservation management
4. Tourism and non-extractive recreational uses.

Image: Ned Pankhurst.

4. Sectoral information needs and key research questions

This section outlines the adaptation challenges for the aquaculture, commercial and recreational fishing, conservation management, and tourism and non-extractive recreational use sectors. The treatment of each sector is organised under seven headings:

1. Primary stakeholders and their interests in the sector and its relationship to marine biodiversity and resources
2. Climate change impacts and issues of specific importance to the sector
3. Resilience features of the sector likely to provide capacity to cope with climate change impacts on marine biodiversity and resources
4. Adaptation options for that sector to adjust to climate change effects on marine biodiversity and resources
5. Existing knowledge likely to help devise adaptation strategies
6. Information requirements to improve the design of adaptation strategies
7. Priority research to meet the most important information needs.

While the Research Plan adopts a sectoral approach, it is critical also to acknowledge cross-cutting research needs that cover more than one sector associated with the marine environment. Such work might address multi-sectoral or systems-based adaptation responses, examination of cumulative impacts, cross-jurisdictional issues, questions of how communities that are affected by multiple impacts of climate change can adapt, and how economic models and techniques can be integrated into decision-making tools or frameworks for the evaluation of adaptation actions and strategies. Some of these questions raise broader issues for adaptation research that transcend the marine biodiversity and resources adaptation research agenda. These are addressed in the Plan for Social, Economic and Institutional Dimensions of Adaptation. The importance of research that addresses cross-cutting issues specifically related to marine biodiversity and resources is recognised as a separate high research priority in Section 5.

4.1 Aquaculture

4.1.1 Primary stakeholders

Aquaculture, defined as the production of aquatic species for commercial gain where there is intervention in the production cycle, occurs in most coastal waters around Australia. Salmonids (salmon and trout), southern bluefin tuna, pearl oysters, edible oysters and prawns are the most valuable aquaculture species, accounting for 86% of the industry gross value, but barramundi, kingfish and abalone aquaculture industries are expanding rapidly. Barramundi, prawns and pearl oysters are grown mainly in Australian tropical and subtropical waters, while salmon, trout, edible oysters and tuna are cultivated in the cooler southern waters. The valuable salmon aquaculture industry is based almost entirely in Tasmania, and the southern bluefin tuna industry in South Australia.

Aquaculture businesses depend on a range of support industries, including boat builders and chandlers, port facilities, gear and feed suppliers, maintenance and service providers and wholesalers. Some businesses are vertically integrated, while others sell to wholesalers or direct to consumers via on-site marketing or through speciality retail outlets. Primary stakeholders include the direct employees, support industry participants, and seafood consumers.

Costs of business relate to gear, feed, consumables and infrastructure requirements, proximity to ports and markets, and the time required to grow a product. These costs are influenced by various factors, including economic externalities such as fuel, labour and other operating costs, and service industry charges, operating days, species survival, growth, disease and quality issues, regulatory constraints on operations, and environmental conditions, that will all determine profitability.

4.1.2 Climate change impacts and issues

Marine aquaculture operations are location-specific, often with substantial land-based

Image: Ned Pankhurst.

infrastructure. Some land-based hatchery facilities may be climate-controlled but the majority of grow-out facilities are exposed to ambient conditions in that location. Businesses may not be able to move due to availability of labour or infrastructure, financial limitations or planning restrictions, so adaptation may be limited to the present location.

Growth, survival and the abundance of various life stages for most marine aquaculture species are sensitive to extreme temperatures and to shifts in temperature regimes. Some aquaculture operations may benefit from these changes while others will be adversely affected. It is expected that climate change will have adverse impacts on the production of species such as salmonids in Australia's cooler southern waters. Climate change will also influence aquaculture ventures in tropical and subtropical regions, either reducing or increasing production efficiency for different species. The availability of wild marine species which are used as feed may also be affected.

Projected increases in the intensity of storms and cyclones may cause physical damage and stock losses, and increase the risk of flooding, which threatens stock through overflows or damage to pond or dam walls. Many coastal processes, such as sediment transport, happen mostly during high-energy events (storms). An increase in storm activity may therefore initiate erosion even for facilities protected from direct exposure to increased wind and wave activity. These and other effects may influence the technical requirements of aquaculture infrastructure and the accessibility of sea-farms.

Climate change may also affect the introduction or establishment of new, and the spread of existing, pests and/or diseases, although this risk can be reduced through sound operational management of the facility and contingency planning. Other events, such as the growth of harmful algae (including algal biotoxins) or jellyfish blooms, may limit market access by affecting aquaculture outputs. Changes to rainfall could impact on coastal aquaculture through changes in salinity, nutrients and suspended sediment in and around culture facilities.

4.1.3 Resilience features

Climate variability is a fact of life for many operators in the aquaculture sector and this has allowed them to develop some natural resilience to climate change. The growing environment is often regulated for some of the earlier stages of a species' life history (e.g., through indoor hatcheries for salmon and abalone) but the adults are usually exposed to a more natural environment. Even here, however, attempts are made to reduce the effects of climate variability via feeding, cleaning or removal of competitors, and stock thinning. The ability to control and plan the time of harvest, and hence delivery of product, also provides some measure of resilience to aquaculture businesses.

Image: Graham Edgar.

The aquaculture industry has a range of options for adapting to climate change. Selectively breeding for tolerance to altered temperature regimes or the use of alternative species that are pre-adapted to the expected temperature regimes may be feasible.

The existence of established national and international markets, diverse consumption habits and well-established seafood distribution and marketing facilities across Australia and internationally are likely to enhance resilience to change and the capacity to seize new opportunities in aquaculture. The established, high-demand markets for seafood are likely to be accommodating to changes in the species composition of supply and more tolerant of increased consumer costs than would be the case if existing markets were under-developed or narrowly focused.

4.1.4 Adaptation options

The aquaculture industry has a range of options for adapting to climate change. Selectively breeding for tolerance to altered temperature regimes or the use of alternative species that are pre-adapted to the expected temperature regimes may be feasible. Relocation of production facilities may be feasible for businesses, depending on costs, infrastructure requirements and planning limitations. Impacts can be mitigated to some extent by foresight in planning and selection of sites and of species. Rapid response to the projected warming can be achieved in the farming of caged fish, such as salmon, by moving cages offshore to deeper, cooler waters, albeit with increased exposure to harsher open-ocean operating conditions. Ameliorating the impacts of climate change, particularly for species at the limits of their thermal tolerance, may provide an additional incentive to develop offshore aquaculture technology, although there are considerable challenges involved.

Selective breeding is already a major focus area for aquaculture research. There is considerable effort towards developing strains with increased biological performance (e.g., more robust stocks with fast growth). The predicted temperature change in waters around Australia over the coming century is relatively slow compared with the generation times of the aquaculture species that are currently considered amenable to selective breeding in Australia (which range from 1 year or less for prawns to 2 years for oysters and 3 years for Atlantic salmon and temperate abalone). Whether it is possible to adapt these aquaculture species to changes in temperature within appropriate time-frames for adaptation to climate change will depend largely on the genetic diversity of the breeding population. The development of new aquaculture species to meet the growing demand for seafood products will also increase the adaptability of aquaculture industries to climate change, but the choice of new species is not independent of markets, competitors, biological limitations and husbandry challenges.

4.1.5 Existing knowledge

Most of the aquaculture species are sufficiently well understood with regard to biological performance, including reproduction, growth and survival, and interaction with environmental variables, to inform adaptation strategies. The likely environmental conditions around aquaculture operations are also known, and many operators actively monitor the state of the environment and routinely respond to their observations. Business planning cycles are well established and the costs and profits of each stage of production are well defined.

There is a solid capacity base for ongoing aquaculture-related research under established funding mechanisms (e.g., through State and Commonwealth agencies and the Fisheries Research and Development Corporation). Research and industry development in recent years has also developed considerable knowledge of and improvement in aquaculture technologies, product marketing and value-adding strategies, all of which will provide some industry resilience to the effects of climate change on aquaculture resources.

4.1.6 Information needs

Knowledge regarding the potential impacts of climate change is limited, particularly regarding the time-scales of change. The expected rate of climate change in relation to the speed at which biological adaptation can occur is particularly important information with regard to planning selective breeding.

There is considerable potential for many aquaculture operators to use improved information, regardless of the impact of climate change. Predictions of environmental

variables at several time-scales will be relevant, including the harvest time-scale (next few months), life-cycle time-scale (next few years), and business infrastructure time-scale (next few decades). These predictions will also need to be at a finer spatial scale than is currently available from most climate projection models.

The identification of suitable alternative aquaculture sites will help to inform business choices and allow marine planning to adjust to potential changes in the location of aquaculture activities. Re-zoning of some waters will be necessary before aquaculture businesses can relocate or expand operations, and the conservation implications of such re-zoning will also need to be assessed. The availability of a suitably trained workforce is also an issue for some aquaculture industries, and the development of training programs in coastal communities is one way to improve workforce access and capability.

Marine aquaculturists are also interested in changes that will increase the cost of production or product value. Aquaculture operators need information on what changes are likely to occur, both through direct impacts on the cultured species (e.g., rising temperatures, changes in disease and pest occurrence) and through indirect effects on the conduct of their business (e.g., changes in markets, pest species and feed supplies).

4.1.7 Priority research

Standard aquaculture research that is likely to be required or sought irrespective of the prospect of climate change will be low priority (or absent) in this Plan, although clearly such research might be sought for other reasons. Research questions inferred from the above information needs for climate change adaptation include the following:

- Which farmed species in which locations are most likely to be impacted – positively or negatively – as a result of climate change? What will change (e.g., growth, survival, disease levels, quality of product)? When are changes likely to be observed?
- What are the most likely effects of climate change on key environmental variables affecting aquaculture operations, including ocean temperature, stratification and oxygenation, freshwater runoff or availability, algal biomass, and extreme wind and wave events? Which regions are most vulnerable to such changes?
- What are the likely policy changes driven by climate change that will affect aquaculture businesses, including either directly through changes in access to suitable locations and natural resources such as freshwater or marine-based feeds, or indirectly because of changes in harvest marine policies affecting feed supplies or non-marine climate adaptation and mitigation policies?

Image: FRDC.

- Which local or regional communities or economies are most dependent on aquaculture businesses and how will changes in aquaculture production (especially a decline in activity) affect those vulnerable communities socially and economically?
- What options are there for businesses to adapt to climate change effects either by minimising adverse impacts or by taking advantage of opportunities, including through selective breeding, changing or diversifying farmed species, relocating, expanding or contracting business sites, or improving environmental control through infrastructure development? What are the barriers to implementing such changes and how might they be overcome?
- What significant changes in aquaculture have already occurred because of extrinsic factors, and what can be learned from those changes that will inform adaptation to climate change?

Section 5 outlines the process and criteria by which the identified research questions were prioritised, and lists those research questions evaluated as having the highest priority. The full assessment matrix is in Appendix 2.

4.2 Commercial and recreational fishing

There are a range of stakeholders involved in commercial and recreational fishing of marine resources. While many of their concerns, regulatory regimes and interests differ, many of their information needs and resulting research priorities are the same. Accordingly, for the purposes of identifying national research priorities, this section deals with commercial and recreational fishers together, highlighting important differences where appropriate.

4.2.1 Primary stakeholders

Commercial fishers

Commercial fishing comprises the harvesting of wild living marine resources for commercial gain, as distinct from aquaculture where there is some intervention in the life-cycle prior to harvest. Commercial fishing is an extractive marine activity that directly affects the status of the targeted species and often also affects other non-target species or the marine environment, through incidental harvest or impacts caused by the gear being used, or through ecosystem imbalances created by the removal of one species.

Commercial fishing is perhaps the most actively and directly regulated marine activity. Policies and laws apply in Commonwealth and all State and Territory jurisdictions, underpinned by the expectation that fisheries resources are exploited in a way that is ecologically, economically and socially sustainable. A trend in fisheries management has been towards increased specialisation with regard to target species, rather than towards diversification. Risk-based and spatially-explicit approaches are also being implemented in several jurisdictions.

Commercial fishing depends on diverse support industries, including ship builders, port and processing facilities, chandlers, gear and bait suppliers, maintenance and service providers, wholesalers and marketers. Commercial fishing also has direct links to local and international consumers through the provision of seafood, as well as bait and fishmeal. Primary stakeholders in commercial fishing therefore include the fishers and their families, including vessel crews, fishery and conservation managers, support industry participants, and seafood consumers.

Commercial fishers harvest diverse species, including finfish (e.g., coral trout, tuna), molluscs (e.g., abalone), cephalopods (squid and octopus), crustaceans (e.g., prawns, rock lobsters) and holothurians (sea cucumber) using diverse gear including hook and line, traps, trawls, nets and by hand. Fishers generally make decisions based on the ability to 'make a living' or to deliver the required 'return on investment', although there are also lifestyle reasons for

continuing to fish. Costs of harvest relate to gear and infrastructure requirements, distances to fishing grounds and markets, management costs such as cost recovery, licence and quota fees, and the time required for harvest. These costs will be influenced by various factors including economic externalities such as fuel and labour costs, service industry and marketing charges, species abundance and distribution, regulatory constraints on operations, and at-sea conditions, that will all determine access and fishing efficiency.

Recreational fishers

Recreational anglers go fishing for many reasons, including catching fish for sport and food, enjoying the relaxation that outdoor pursuits provide and the company of friends. Surveys indicate that satisfaction with the experience is determined by the number and species of fish caught relative to cost, effort and expectations, and other amenity experiences associated with the trip, such as sighting marine mammals. Some anglers target particular species with specialist equipment, while others use a range of techniques to attract and catch the fish in the area. Recreational anglers make several types of decisions including the species they wish to target, the type of techniques they wish to use, and other associated amenity values. They invest in equipment (such as boats and rods) and supporting services (including charters, accommodation and travel) in pursuit of a satisfying experience.

Recreational fishing depends on diverse support industries, including boat suppliers and servicing businesses, charter operators, launching facilities, tackle and bait suppliers, and tourism operators such as accommodation suppliers. Primary stakeholders in recreational fishing therefore include the fishers, fishery and conservation managers, and support industry participants.

4.2.2 Climate change impacts and issues

The direct climate change effects most relevant to commercial and recreational fishing will include:

- changes in the distribution of target (or potential target) species because of changing ocean temperatures or changes in the distribution of key habitats or food or prey species;
- changing abundances of target species, or species on which they depend or interact with, because of a change or loss of key habitats or processes, such as spawning or nursery habitats. Such changes may be caused by the effects of sea-level rise or ocean warming on coastal environments or changing productivity of estuaries associated with changed freshwater flushing regimes because of changed rainfall patterns;
- changes in general productivity of target species, either locally or generally, because of changes in ocean circulation and nutrient upwelling or thermal or biochemical effects on key life-history events (e.g., egg fertilisation), life-history stages (e.g., larvae) and subsequent settlement patterns, or growth, because of ocean warming or acidification;
- changes in target species due to displacement of existing fishery species by new species whose distribution or ecological competitiveness is enhanced by changing ocean conditions;
- reductions in sustainable levels of harvest of some species already under fishing pressure because of any of the above effects, or due to external responses to climate change by society.

Primary issues for commercial fishers may include declining asset values (e.g., quotas) and harvest, and diminished economic viability of some traditional fishing grounds, although other areas may experience increases in these variables. Primary issues for fishery managers will include the need to change harvest regulations, and perhaps policy and legislation, to satisfy expectations that fisheries will be regulated to optimise the ecological, economic and social sustainability associated with fisheries and reduce the barriers to adaptation. Climate change may mean greater uncertainty with regard to population status, and management strategies that are robust and flexible may enhance the adaptive capacity of the industry. Commercial fishers and industry peak bodies will be interested in industry changes if changing regulations diminish access to stocks.

Image: FRDC.

Secondary issues if fishery activity or profitability falls will include economic impacts for support industries and local communities with significant fishery participation. The reduced supply or increased cost of seafood to consumers may also be a secondary impact of climate change.

Primary issues for recreational fishers may include the declining value of their recreational fishing experience, the need to change target species or preferred fishing method, and increased costs of 'successful' fishing trips. Recreational fishing experiences may improve in some areas as a result of climate change impacts on the marine environment. Fishers will be interested in what alternative options are available in regard to pursuing their favoured species or returning to their preferred fishing location, and the associated cost implications. Recreational fishing tends to have a marked impact on selected stocks over a relatively small spatial scale due to more limited accessibility than for commercial fisheries. Fishery managers may need to facilitate equitable access to resources between and within user groups (commercial, recreational, traditional fishers). This will involve a combination of resource and social regulation.

Direct climate change effects on the marine environment or weather may include:

- changes in storm, wind and wave conditions that change access to fisheries or alter the cost or availability of operation at sea;
- changes in coastal morphology or sediment distribution that affect access to and from estuaries or ports or change access to or costs of required coastal infrastructure.

Indirect consequences of climate change effects on the marine environment or weather may include:

- changed access to fisheries because of policy, legislative or regulatory actions for non-fishery agendas, such as environmental protection and biodiversity conservation measures;
- loss of support infrastructure, especially in coastal environments subject to significant impacts from sea-level rise, including infrastructure damage, coastal erosion or inundation;
- possible increased costs of operation because of climate change mitigation strategies and associated increases in fuel costs and potential alterations to market access.

Adaptation strategies will need to take these factors into account even where they might not all be direct impacts of climate change *per se.*

4.2.3 Resilience features

Commercial and recreational fishers will be the principal groups required to evolve with adaptive actions or adjustments. Agile governance and management arrangements, as well as adaptive capacity in support industries, will facilitate resilience in commercial fishery systems. Stressed fisheries may fail and new opportunities will be missed unless the fishers can adapt.

Research into the resilience of commercial fishers has identified four key factors that typify the response to generic change:

1. perception and management of risk and uncertainty;
2. capacity to plan, learn and reorganise;

3. emotional and financial capacity to cope with change;
4. level of interest in change.

Larger fishing enterprises with higher capitalisation, a larger number of employees, larger vessel capacity and a strategic approach to business (including good business planning) are likely to be more resilient, especially if they target multiple species or move among different fisheries either seasonally, inter-annually or regionally. They generally have a larger buffer with which to trial options for the future, and can better absorb the costs of change. The diversified or mobile fishers will be most readily able to change their fishing targets, locations or practices in the face of changing species distributions or availability or shifts in access to stocks or support for their operations, irrespective of whether these changes are direct or indirect. Economically diversified fishers are also likely to have more options to adapt to climate change, including the option to disinvest in some or all of their fisheries.

More species-specific fishers, operating only in local waters, are likely to face considerable social, economic and operational challenges if they need to relocate or restructure. Such fishers are also likely to be at a disadvantage if entry to new or alternative fisheries is limited by licensing or quota management, since these would be subject to market availability and the costs of buying licences or quotas, if available. The least resilient commercial fishing enterprises are lifestyle fishers, characterised by low profitability, few or no crew, a high level of attachment to the activity, and possibly low employability or opportunities for employment in other industries as defined by age, education and attitude to working elsewhere. Other characteristics important to resilience are the level of involvement that key individuals within an enterprise have in decision-making processes relating to the management of their industry, and the linked issue of their interpretation of policies for protecting the marine ecosystems and resources. Interpretation of policies is a function of the quality of involvement in the decision-making process. Fishers who are financially strong are generally also better able to adapt than those whose operations are marginal or financially unstable. The costs of adjustment may mean that more 'industrialised' fishers (with multiple vessels and commercially diverse operations) will be more resilient than lifestyle fishers, although the costs of relocation or replacement of large-scale commercial infrastructure may offset this advantage, especially where individuals or companies are already over-capitalised.

Recreational fishers who are generalists in their fishing experience, targeting a range of species, using a variety of fishing methods, or fishing a variety of locations are likely to be more resilient to climate change effects than fishers whose preferred experience is limited to a single species or method. The generalist fisher will be more readily able to change his or her fishing targets, locations or practices in the face of changing species distributions or availability, irrespective of whether these changes are direct or indirect (as described above).

Recreational fishers who have a higher level of disposable income are better placed to purchase additional equipment (boat or gear) and pursue stocks either locally or by travelling to other regional locations. Changes in the cost of fishing may result in changes to fishing behaviour. There may be fewer trips and trips may last longer. There may be greater expectations for return (catch) for each trip.

More locally focused fishers may be faced with considerable increases in the cost of their fishing experience or may be unable to undertake their desired experience. Such fishers may have to consider whether recreational fishing of another type is a pastime they wish to continue or whether they wish to change the type of experience they are pursuing.

There are some features of relevant support industries that will contribute to the resilience of commercial and recreational fishing to the effects of climate change. Most of the infrastructure, support and marketing needs of fisheries are already established in areas where it is economically advantageous to operate. In many cases, these existing facilities may be readily responsive to changes in harvest species or fishing activity. On the other hand, fishing cooperatives that require fish

to be landed at a specific location may have difficulty in adapting to changed commercial fishing practices. Support industry viability, such as accommodation, may also be diminished. In these cases, relocation due to changed fisher requirements, or overcoming the loss of recreational fisher income, may not be possible.

The existence of support infrastructure and facilities such as boat access or fishing platforms in many places potentially provides for resilience in the recreational fishing sector. Some of these facilities may themselves be vulnerable to change and are already restricted and under pressure from high demand. There may be further pressure placed on them where those facilities are themselves directly affected by climate change, such as through impacts of rising sea levels. Thus, support facilities might not always underpin resilience for recreational fisheries in highly sought locations.

Fishery regulatory regimes in all Australian jurisdictions can promote resilience. Supportive fishery policies and regulations provide the governance and regulatory machinery to implement climate change adaptation strategies and enable fishers and support industries to understand their options under the existing rules. However, regulatory inflexibility might undermine resilience where increasing reliance on ecosystem-based management and integration of fishery management with other management agendas (e.g., environment protection and biodiversity management) constrains the administrative responses possible in the particular interests of commercial or recreational fisheries alone. These broader management agendas may give effect to broader community values and can ultimately be designed to improve long-term fisheries sustainability, but they may also reduce administrative flexibility in adapting to climate change impacts on commercial fishing in the short term. The risk of increased conflicts between commercial and recreational fishers will also drive the need for clearer resource-sharing policies.

The existence of established national and international markets, diverse consumption habits and well-established seafood distribution and marketing facilities are likely to enhance resilience to change in commercial fisheries.

The established, high-demand markets for a great variety of seafood are likely to be more accommodating to changes in the species composition of supply and more tolerant of increased consumer costs than would be the case if markets were under-developed or narrowly focused. The reasonably well-organised and sophisticated marketing organisation, infrastructure and capacity will also identify market constraints and develop corrective strategies, and will help facilitate the transfer of changes in supply and demand in consumer markets.

4.2.4 Adaptation options

The most directly relevant and effective adaptation options for commercial and recreational fisheries will comprise actions by fishers and fisheries managers. Adaptation by support and dependent industries are likely to rely on adaptation strategies exercised by fishers, managers and policy-makers. It seems likely that the support and dependent industries are generally well placed to be responsive to changes in fisheries.

Commercial fishers have a history of adaptation to natural- and human-induced changes in the marine resource upon which their activities are based. Several types of adaptation options are likely to be available to commercial fishers, whether motivated by changes in resource status or availability or by changes in the regulatory regime, although some options will be more practicable than others. Options will include:

1. refocus fishing to alternative target species or move to alternative fisheries locally;
2. relocate to locations where commercial fishing is feasible or has become more feasible, either within the same type of fishery or in an alternative fishery;
3. diversify to alternative non-extractive marine activities;
4. disinvest from commercial fishing;
5. change markets or adopt value-adding strategies to assist with adaptation strategies, although such market adjustments would be expected irrespective of whether climate change impacts have occurred if they confer economic benefits on the fishers.

Recreational fishers may also refocus fishing to alternative target species, as well as taking fishing trips to locations where preferred species or fishing methods can be enjoyed, or may modify their expectations of what constitutes an enjoyable fishing experience.

Changing target species within an existing multi-species fishery may be a relatively low-cost option economically and socially but may require alteration to existing harvest rules. Changes in target species might be driven either by fishers responding directly to altered availability or productivity of a species or indirectly because of management responses to such changes, including seasonal or permanent closure of fisheries, or bag or size limits for recreational fishers. Hence, this option is likely to require continued active engagement between fishers, fishery managers and fishing industry peak bodies and other stakeholders in fisheries management. Changing target species might require additional research and development expenditure where the new target species are poorly understood, have not been assessed for appropriate harvest rates, or require gear developments (e.g., shifting from shallow-water to deep-water line fishery). Refitting of fishing operations to target these species might also be required, which would be a cost to fishers.

Changing fisheries locally could incur additional costs of refitting and, perhaps, retraining or lost income whilst fishers gain the necessary skills and experience for efficient participation. In some cases, such refitting and re-skilling may be a sufficient disincentive to preclude a change in fishery. Administrative or regulatory adjustments may be required in some cases to facilitate restructuring or changed access to fisheries. Alternatively, in the same or other cases, changing access to fisheries may be left to market forces (e.g., licence and quota trading).

Relocation of fishing in response to shifts in the status or distribution of harvestable stocks or fishery closures will probably incur the greatest economic cost and social dislocation. The social, skill and economic barriers involved may prompt some fishers to opt to leave the industry. Relocation may require administrative and regulatory flexibility across jurisdictions, although here it is also likely that market processes within existing fishery regulations might be allowed to moderate such adaptation strategies. In either case, it is likely that fishers, and perhaps support industries, will lobby for financial relief or for government-funded structural adjustment.

Travelling to follow the preferred fishing experience would incur the greatest economic cost for recreational fishers. This would either

Agile governance and management arrangements, as well as adaptive capacity in support industries, will facilitate resilience in commercial fishery systems. Stressed fisheries may fail and new opportunities will be missed unless the fishers can adapt.

impact on the overall cost of maintaining the fishing activity or result in reduced fishing activity or changes in the timing and intensity of fishing from a regular activity to intermittent, dedicated fishing trips (perhaps lasting longer than previous daily outings). There may be an associated social change in the expectations of what constitutes an acceptable experience due to the increased cost, or there may be increased fishing pressure on the most accessible locations or at times when dedicated fishing trips can be made (e.g., holiday periods).

4.2.5 Existing knowledge

Fishery systems are perhaps the best researched and most well-understood Australian marine systems that are vulnerable to climate change effects. There is reasonably sound knowledge of the biology of most target species, good commercial catch and effort information and formal harvest strategy assessments for the commercially valuable target species. There are also well-established and understood administrative and regulatory processes for most commercial fisheries. Knowledge of the biology and assessment of by-product species is less well understood and there is limited knowledge on by-catch species.

There is a solid capacity base for ongoing fishery-related research under established research funding mechanisms (e.g., through State and Commonwealth fishery agencies and the Fisheries Research and Development Corporation). Growing emphasis on ecosystem-based management of fisheries is also driving research investment into understanding the ecological relationships and dependencies of harvest species, and formal management strategy evaluations are increasingly assessing both the trade-offs between alternative fishery management options and the interactions between fishery and other management agendas. Research and industry development in recent years has also amassed considerable knowledge of and improvements in fishery technologies, product marketing and value-adding strategies, all of which will provide some industry resilience to the effects of climate change on fishery resources. Some research has been done in recent years on the motivations and social drivers for some fishery sectors (recreational, charter) and there have been occasional analyses of the economic characteristics of commercial fisheries, although both these areas lag somewhat behind research on harvest sustainability.

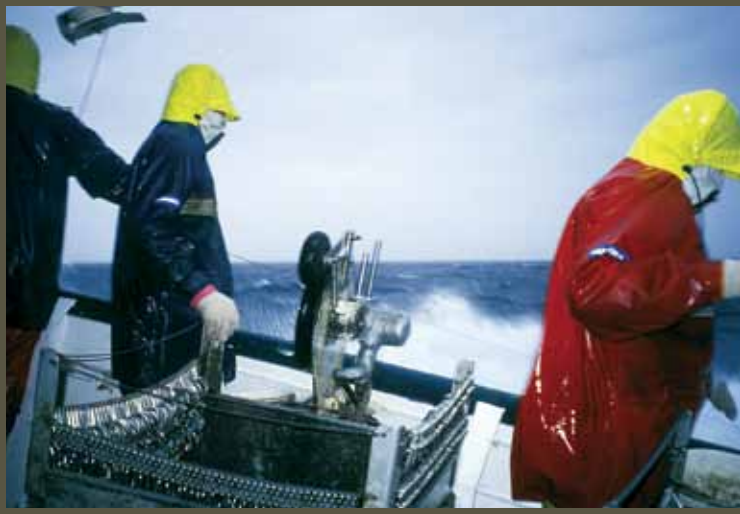

Image: Australian Fisheries Management Authority.

Research into recreational fishing is increasing for a variety of reasons, including its popularity and social and economic importance, the need to satisfy the requirements of resource allocation processes, and the growing emphasis on ecosystem-based management of fisheries. The capacity base for ongoing fishery-related research under established funding mechanisms such as State and Commonwealth fishery agencies and the Fisheries Research and Development Corporation, is generally directed towards commercial fisheries. Some jurisdictions have revenue from the sale of recreational licences to support recreational fishing research, but funding for many aspects of recreational fishing is generally specific and short-term in nature.

The way in which recreational fishers interact with marine resources is well understood but the size of the take is poorly documented and the ecological impacts are poorly understood. Thus, the development of methods that are cost-effective with acceptable levels of certainty to quantify and monitor this interaction across the range of recreational fisheries still requires further investment. This is an area of developing fisheries science but is not necessarily central to climate change adaptation.

A variety of methods to determine the economic value of the recreational fisheries, including socio-economic value, and to determine valuation of the resource by recreational fishers are well established, but are not standardised. These methods have been used in regard to some recreational fisheries but most economic analysis has focused on commercial fisheries. A major constraint in this knowledge base is the limited investment in detailed economic and social assessments across many of the recreational fisheries and limited implementation of performance measurement programs to determine whether previous assessments are still valid.

There is a need for additional information on fishers' motivations, skills, resources and networks in order to ensure that decision-makers have the relevant information to encourage adaptation, including effectively targeting information and training. In addition, coordinated research is required to establish information on capacity, knowledge, skills, and attitudes and beliefs related to climate change at a range of scales and fisheries sector vulnerabilities. Social assessment and understanding of recreational fishers generally remains in a developmental phase. Social science methods are well established, but an understanding of the sociology of recreational fishers in general is lacking because of the relatively few studies targeted at the sector.

Image: Daniel T Yara.

4.2.6 Information needs

Improved basic fishery information will be required irrespective of climate change effects and is not the focus of this Plan. Such information should improve the capacity to respond to climate change effects on fisheries, but such benefit will be serendipitous rather than planned. The focus here is on the additional information needed specifically to anticipate and adapt to climate change.

Commercial fishers will need information that helps them to identify options and opportunities to adapt to the potential effects of climate change. Fishery managers are likely to need information that allows them to anticipate likely climate change drivers for changed fishery administrative or regulatory regimes. Support industries will benefit from alerts regarding potential shifts in fishing activity, but it is more likely that support industries will follow rather than lead changes in primary fishery activities. Hence, the primary information needs are likely to include information about:

- the most likely climate change-driven changes in the status (abundance, productivity, availability) or distribution of fishery resources;
- likely changes to the at-sea operating environment, including storm frequency and intensity, wave conditions and access changes that might affect future operating costs, access to fisheries and market supply;
- the dependency on marine biodiversity and resources by fishing and support industries and local communities and their capacity for incremental or transformational change;
- likely options for restructuring or relocating to adjust to climate change effects;
- likely policy directions that will drive fishery administrative and regulatory responses to climate change;
- potential shifts in marine policy for non-fishery activities because of climate change that might affect fishery policies or regulations (e.g., increased introduction of no-take reserves);
- likely consequences for commercial fishing from other (non-marine) policy decisions driven by climate change (e.g., carbon pollution reduction schemes);
- the nature and timing of impacts on marine ecosystems from climate change;
- the social and economic implications of ecosystem impacts under different scenarios.

Recreational anglers may need information relating to what changes could occur regarding their preferred experience. These will generally relate to the distribution and abundance of particular species or fish generally in an

Commercial fishers will need information that helps them to identify options and opportunities to adapt to the potential effects of climate change.

area(s); and likely changes in access to the species, including bag and size limits, fishing techniques, or spatial and temporal closures. Such information will allow fishers to determine the likelihood of having a satisfying experience or whether they might be better off pursuing alternative activities, either fishing or non-fishing in nature. These decisions may drive changes in participation, fishing preferences and or expectations.

The biological, economic and social aspects of recreational fishing are poorly understood. There is a need to improve the information base for recreational fishing catch and effort, the economics of recreational fishing, and understanding the social drivers of this user group. There is a requirement to undertake a qualitative social assessment of recreational fishers more broadly, followed by a fit-for-purpose quantitative assessment of the sector and its vulnerability to the expected effects of climate change on marine biodiversity and resources. This information is important for developing effective ways of engaging recreational fishers on issues such as climate change adaptation and in building the social capital to accommodate adaptation.

In general there is a need to invest more in determining the biological and economic impacts of recreational fishing and to better understand the underlying economics and sociology of this sector, all of which will be required to inform decisions relating to industry adaptation to effects of climate change on fishery resources.

4.2.7 Priority research

Research priorities for climate adaptation research will be driven by the need for information not likely to be available from the existing knowledge base or captured under existing research directions. Hence, standard fishery research that is likely to be required or sought irrespective of the prospect of climate change is given low priority in this Plan.

Research questions inferred from the above information needs for climate change adaptation include the following:

- Which fishery stocks, in which locations, are most likely to change as a result of climate change? What will those changes be (e.g., in distribution, productivity) and when are they likely to appear under alternative climate change scenarios?

Research priorities for climate adaptation research will be driven by the need for information not likely to be available from the existing knowledge base or captured under existing research directions.

- What and where are the most likely effects of climate change on oceanographic conditions affecting fishery access (e.g., wind and wave effects for boating access)?
- Which local or regional communities or economies, if any, are dependent on commercial and/or recreational fishing? How will changes in fisheries (especially declines in activity) affect those vulnerable communities socially and economically?
- What are the likely policy changes that may be driven by climate change that could affect commercial and recreational fisheries either directly, for example through changes in harvest policies, or indirectly because of changes in non-harvest marine policies or changes in non-marine climate adaptation or mitigation policies?
- What options or opportunities are there for *commercial fishers* in identified impacted fisheries to adapt to climate change effects through changing target species, capture methods and management regimes, industry diversification, relocation or disinvestment?
- What options or opportunities exist or might become available for *recreational fishers* in identified vulnerable fisheries to adapt to climate change effects through changing target species or preferred fishing methods or through travelling to pursue their preferred target species or methods?
- What are the barriers to fishers implementing such options, including existing fishery management arrangements and fisher motivations that impede autonomous adjustment; reliability of information about species changes; cost–benefit analyses of different options; current or prospective availability of support industries and services in new locations; jurisdictional, legal, administrative or regulatory uncertainties or constraints; and market drivers or constraints?
- How might barriers to adaptation be overcome? What significant changes in fisheries have occurred before because of extrinsic factors and what can be learned from those changes that will inform adaptation to climate change?

Section 5 outlines the process and criteria by which the identified research questions were prioritised, and lists those research questions evaluated as having the highest priority. The full assessment matrix is in Appendix 2.

Image: Graham Edgar.

4.3 Conservation management

4.3.1 Primary stakeholders

Conservation management is aimed at the preservation or restoration of marine species, ecosystems and habitats for their intrinsic values and social and economic importance. Conservation management is typically species- or habitat-focused, but there is increased recognition that humans are an integral component of dynamic ecosystems, and that people depend on ecosystem resources and services for societal and economic development. The concept of ecosystem-based management has highlighted the need for conservation to manage functional groups of species that play key roles in maintaining ecological processes, rather than the traditional focus on single species or habitats. Successful management of ecosystems requires governance structures and institutions that are flexible, with the capacity to respond and adapt to change.

The primary stakeholders engaged in conservation management or whose activities are affected include:

- policy-makers and management agencies;
- industries based on ecosystem resources and services (e.g., commercial fishing, tourism);
- Indigenous[1] communities and subsistence users;
- non-extractive recreational users;
- recreational fishers (including both catch-and-release and retained elements);
- people engaged in coastal and catchment activities in multiple sectors (e.g., agriculture, urban development, ports) that influence nutrient runoff, pollution and sediment;
- non-governmental conservation organisations that seek to influence public opinion and political process in the interests of conservation of marine biodiversity and resources.

4.3.2 Climate change impacts and issues

Human activities have resulted in significant alterations to marine ecosystems over the past 200 years, including significant declines in species such as whales, seals, dugongs, turtles and sharks, and many currently fished species (e.g., the orange roughy). It is often unclear what effects these known changes have had, or will have, on broader ecosystem function, but many near-shore and coastal marine ecosystems already suffer multiple anthropogenic stresses. Further changes in the marine environment, because of climate change, are likely to exacerbate ecosystem stress and provide a conservation challenge. Contemporary conservation management has been based on maintaining the *status quo* or reducing threats, especially to species and habitats that have experienced severe decline in abundance, range or health due to anthropogenic activities. These goals may be unachievable in the face of climate change, so determining appropriate conservation goals will be a major challenge in adaptation planning.

The biodiversity of coastal habitats is likely to be particularly vulnerable to climate change effects because of their existence at the land–sea interface and exposure effects from land, ocean and atmospheric disturbances. Coastal wetland, saltmarsh, mudflat, mangrove, seagrass and beach habitats are particularly exposed to multiple climate change effects (e.g., from sea-level rise, changing ocean chemistry, storm impacts and changes in runoff). Degradation or loss of these systems may have significant effects for other ecosystems or species, especially where these coastal systems provide key services (e.g., nursery habitats) for species from elsewhere. There is also the likelihood of significant loss of amenity and, in some communities, sustenance, if these coastal systems are diminished or lost.

Some ecological effects of climate change are already apparent (e.g., changes in species' geographical ranges, reduced carbonate shell weights as a result of ocean acidification, increased mortality from events such as coral bleaching). Biological changes such as coral

1. As noted in other sections of this Plan, adaptation issues specific to Indigenous issues will be considered in a National Climate Change Adaptation Research Plan devoted to the Indigenous communities of Australia.

bleaching, reduced fecundity, and the spread of invasive species are generally negative. The capacity of natural systems to respond to and cope with rapid climate change is poorly understood and is an area of growing research activity. Human intervention to 'manage' the process of biological system responses to climate change is not well understood and may prove ineffective or counter-productive. The major issues for human and biological adaptation research to address the ecological effects of climate change are therefore likely to relate to: (i) broad actions to protect ecosystems from known stressors and to enhance system resilience to climate change impacts; and (ii) social and economic adjustments required to either cope with changing availability of ecosystem services or to facilitate the protection of ecosystems from human stressors.

4.3.3 Resilience features

Two sets of factors are likely to affect the success of conservation strategies for marine biodiversity and resources under a changing climate: (i) the current status and health of marine ecosystems and the non-climate change pressures on those resources; and (ii) the attitudinal and regulatory environment within which conservation management is effected.

Australia has a very large marine estate relative to its population. Human pressures on marine resources tend to be concentrated near the coast and over a relatively small proportion of the marine estate. Large-scale industrialised fishing methods used in many other national and international waters have been less common in Australian waters. There are few, if any, known examples of widespread ecosystem collapse or regime shift. While there are some stocks and species in serious decline, these features mean that there is more potential for successful conservation management of Australia's marine biodiversity under climate change than in many other parts of the world.

The existence of various large marine management regimes that include no-take provisions (e.g., the Great Barrier Reef Marine Park, Ningaloo, coastal marine reserves and no-take areas, and the South-east

Image: Jan-Olaf Meynecke.

Commonwealth Marine Reserve Network) means that reasonable amounts of the marine biodiversity and resources in some areas are already protected from exploitation. All governments (Commonwealth, State and the Northern Territory) have committed to the National Representative System of Marine Protected Areas (NRSMPAs) and participated in development of the Interim Integrated Marine and Coastal Regional Assessment, marine protected areas strategies and guidelines that underpin the national system. The NRSMPA will extend such conservation-oriented measures across Commonwealth waters to establish a comprehensive, adequate and representative system of marine protected areas and provide an important platform for strong cross-jurisdictional collaboration, as will marine protected areas proposed in State waters.

Australia also has a reasonably well-established legislative base of conservation instruments and underlying principles that provide a sound platform from which to build conservation adaptations to climate change. Federal and State conservation legislation provides a policy platform for biodiversity conservation of Australia's marine resources, in many cases underpinned by international legal regimes and instruments. Ecosystem-based management objectives are recognised in fisheries legislation in some jurisdictions, and all jurisdictions have ecosystem-based fishing polices. There has also been increased recognition in recent decades that conservation management of marine biodiversity and resources should involve management of threatening activities beyond the marine environment (e.g., rural or urban activities that produce significant runoff into marine waters) and 'whole of system' considerations to complement single-species harvest management. The growth in integrated catchment management practices, ecosystem-based management of fisheries, and multi-user, multi-species ecosystem evaluations of interactions between human activities and marine systems all are likely to facilitate climate change adaptation in the marine conservation space. The marine bioregional planning framework also provides an overarching reference for the implementation of marine conservation measures in Commonwealth waters that may facilitate conservation management adaptations to climate change threats.

Australia has substantial adaptive capacity that is likely to facilitate conservation actions to cope with climate change, due to well developed economic, scientific and technological capabilities, and well-developed and relatively progressive conservation legislative, planning and regulatory environments. Alternative livelihoods in a relatively affluent country also offer societal support when conservation actions displace people or activities.

4.3.4 Adaptation options

Adaptation options are highly dependent on specific geographical, biological and climatic risk factors, and are subject to institutional, political and financial constraints. Some adaptation is occurring now to observed and projected future change, but on a limited basis. Flexible and adaptive governance will be central to achieving conservation goals in the future.

Improvement of coastal development and planning regimes with specific attention to likely climate change impacts on marine biodiversity is likely to help with conservation of coastal wetland habitats under a changing climate. The provision of buffer zones between development and coastal habitats and set-back provisions to allow for the retreat and re-establishment of coastal habitats as sea level rises are two options for revision of planning guidelines. However, there is little evidence that such measures are being implemented except to protect built infrastructure or to diminish the legal liability of local governments for damage to built environments. Recognition of the need for more consistent, integrated and ecologically sensitive coastal planning and development rules may result in protection of coastal habitats or accommodation of their retreat as sea level rises. Nonetheless, there remain considerable constraints to implementation of adaptation responses, especially over relatively short time-frames and across multiple jurisdictions. The development of more consistent and proactive development and planning instruments is at an early stage, and many surviving coastal ecosystems are already either compromised or constrained by surrounding development.

Research is in its infancy with respect to enhancing biological responses to climate change. Potential strategies that have been proposed seek to reduce stress and enhance resilience. These approaches are expected to increase the period of time over which biological responses (e.g., evolution for increased temperature tolerance) can occur. Examples include habitat restoration, provision of shade for turtle-nesting beaches, assisted translocation of heat-tolerant coral genotypes from warmer waters, inoculation of bleached corals following bleaching, disease suppression, stocking of genetically modified animals, and establishment of new populations or habitat structure. Many concepts and ideas have been borrowed from the terrestrial sphere, but the scale at which these intervention strategies can be applied in the oceans is limited. The application is likely to be limited to high conservation value species and locations. The ethical issues around so-called ecosystem engineering have yet to be considered.

4.3.5 Existing knowledge

Marine ecosystem science in Australia is highly advanced by world standards. Recent marine bioregional planning activities, directed in part towards development of the National Representative System of Marine Protected Areas, have highlighted the fact that knowledge of marine biodiversity and resources is highly variable, with considerable detailed knowledge for some regions (e.g., the Great Barrier Reef near-shore coastal systems) but generally very poor knowledge of what biodiversity exists or its ecological status over most of the marine environment. Knowledge of the location and extent of coastal wetlands, beaches and estuaries is far more detailed and comprehensive than knowledge of off-shore marine biodiversity and resources, largely because of their proximity to coastal communities, aesthetic importance, and ease of observation. The Department of Climate Change has initiated a coastal biodiversity vulnerability assessment that should provide valuable information on where conservation actions are most important. This is part of an overarching coastal vulnerability assessment.

There is growing awareness that the scientific basis of resource management is not sufficient for sustainable biodiversity conservation outcomes; a better understanding of social, political and economic aspects of our dependence on marine biodiversity and resources is needed.

4.3.6 Information needs

Conservation management that is adaptive to climate change will require five categories of information:

- Knowledge of which ecosystems and species of conservation priority most require adaptation management and supporting research. This requires understanding a range of factors, including the status and value of the species or ecosystem, its vulnerability to climate change, and the feasibility of adaptive responses.
- A sound understanding of ecosystem responses to climate change in the context of other drivers of change. This will require a better understanding of ecosystem dynamics, since conventional biophysical measurements merely describe the current state or past trajectory of ecosystems. Future performance measurement programs need to be designed to gain a clearer understanding of the thresholds beyond which regime shifts are likely. They also need to understand the

There is growing awareness that the scientific basis of resource management is not sufficient for sustainable biodiversity conservation outcomes; a better understanding of social, political and economic aspects of our dependence on marine biodiversity and resources is needed.

capacity of ecosystems to sustain ecological services that support fisheries or tourism, in the context of globally and locally induced disturbances brought about by climate change.

- Determination of which adverse ecological responses to climate change can be reduced by biodiversity conservation management interventions, and to what extent. The marine bioregional planning framework, and the further development of marine conservation reserve systems around Australia, will play a central role in the climate change adaptation strategies for marine biodiversity: for example, analyses of how design criteria for protected area networks might require adjustment to address climate change adaptation considerations.
- Evaluation of the range of management options available to governments, and other stakeholders, for helping marine biodiversity and resources adapt to the range of potential climate change impacts. For example, analysis of options to guide land-use planning and development for safeguarding vulnerable coastal habitats in response to rising sea level.
- Cross-cutting social and economic assessments of the vulnerability of Australian communities and industries to conservation management actions that might be required to protect marine biodiversity and resources.

In addition, conservation stakeholders must consider what balance they will strike between attempting to preserve present conditions and allowing new ecosystems to develop. The combination of future environmental variables means that novel ecosystems are likely, comprising species combinations and possibly even ecological processes that do not currently exist. Many conservation agencies will be challenged to establish new goals that are not based on 'preserve and maintain'. They will need tools to use and interpret models and trade-offs, and associated information storage systems and infrastructure and sharing protocols, to facilitate the management and sharing of data.

4.3.7 Priority research

The research areas below focus on existing research gaps and on bridging research that crosses disciplines, spanning physical, chemical, ecological and human systems.

- Which ecosystems and species of conservation priority most require adaptation management and supporting research, based on their status, value, vulnerability to climate change, and the feasibility of adaptive responses?
- What are the critical thresholds to ecosystem change and how close is the ecosystem to such 'tipping points'? How can we improve our measurement of marine ecosystems

Image: Griffith University.

6 See http://www.accessimulator.org.au/.

to account for ecosystem dynamics and processes?

- How will goals and governance for the conservation of Australia's marine biodiversity need to change to adapt to climate change impacts? What are the barriers, limits and costs to implementing adaptation and effective policy responses to climate change?
- How should conservation managers and planners adapt their practices to ameliorate climate change risks and enhance adaptation options? What intervention strategies will increase system resilience and improve the time within which biological systems can adjust to a future climate?
- What are the major sources of social resilience, and the processes by which stakeholders and organisations interact, negotiate and build alliances? What role do varying perceptions among stakeholders play in adaptive management and how do they change over time?

Section 5 outlines the process and criteria by which the identified research questions were prioritised, and lists those research questions evaluated as having the highest priority. The full assessment matrix is in Appendix 2.

4.4 Tourism and non-extractive recreational uses

4.4.1 Primary stakeholders

Tourism is one of Australia's most important industries and a substantial proportion of tourism revenue is derived from marine biodiversity and resources ($5.1 billion annually and 54,000 jobs in the Great Barrier Reef catchment alone). Tourism is also among the most sustainable uses of the marine ecosystem. Marine tourism is, however, highly vulnerable to the impacts of climate change, because of its strong dependency on ecosystem quality, aesthetics and access under favourable weather conditions. The viability of tourism enterprises and the sustainability of their contribution to the national economy will be highly dependent on their ability to adapt to climate change.

Marine tourism activities take a diversity of forms, including sea kayak tours and wildlife viewing, water sports (e.g., jet ski and catamaran hire), water taxis, diving and snorkelling tours, fishing charters, sail boat rentals, cruise boats and island resorts. Tourism businesses are similarly varied, ranging from small-scale, single-person operations to very large, multi-million-dollar enterprises that employ thousands of staff. Marine tourism also provides business to an extensive network of support industries, including many of those used by commercial fishing operations (ship building, port facilities, fuel suppliers, chandlers etc) as well as those specific to tourism, such as accommodation, restaurants, retailers and land-based transport (buses, taxis).

The principal stakeholders in marine tourism are the numerous enterprises that provide people with access to the marine environment on a commercial basis and the businesses that support those operators. Marine tourism operators provide the only contact many people have with the marine environment, facilitating unique and important opportunities for them to experience, understand and relate to marine biodiversity.

Social users are non-extractive users who benefit from the amenity value of the resource. This may be realised through direct visitation (direct users) or the knowledge that healthy marine biodiversity and resources exist (indirect users). These users want to know that the resource is available to support their well-being. This group may include tourists, but is broader because it covers a far wider range of marine-based recreational activities, especially those that do not involve commercial enterprises. The range and number of social users of the marine environment is growing, as is their potential to cause increased pressure. Examples include recreational divers, sailors, surfers, jet skiers, bird-watchers and beachgoers. Indirect stakeholders also include businesses that support such activities, such as dive shops, kayak and surf retailers, and food outlets.

4.4.2 Climate change impacts and issues

Marine tourism is highly sensitive to the impacts of climate change on marine biodiversity and resources. The majority of tourism enterprises are founded on aesthetic experiences (wildlife viewing, seascape experiences, diving/snorkelling) that in turn are extremely dependent on habitats and populations being in a relatively intact and natural state. Perception of the ecosystem state is often as critical to the visitor as the actual state. Climate change is expected to effect widespread (and often profound) changes in marine ecosystems, with potentially far-reaching implications for tourism. In effect, the attributes that give ecologically based tourism the potential to be inherently sustainable (non-extractive) are the same ones that render it highly vulnerable to climate change.

There are many factors that affect tourism operations aside from the state of marine biodiversity and resources. Projected changes in weather patterns and sea states, for example, are likely to negatively impact on the accessibility of many tourism resources and the appeal of tourism products, or on the types of vessel and infrastructure required by operators. Other factors are not directly linked to climate, but are also subject to changes that can substantially affect tourism businesses. These include fuel prices, labour costs, and competition within the global tourism market.

Potential direct effects of climate change on marine biodiversity and resources that are most relevant to tourism include:

- changes in the quality of ecosystems, such as diversity of fish and invertebrate species, that are the aesthetic focus of tourism experiences (e.g., the Great Barrier Reef and Ningaloo);
- changes in the abundance, behaviour or accessibility of key species for tourism (e.g., whales, dolphins, sharks and seals), especially migratory species;
- changing quality or suitability of physical attributes important to marine tourism, such as beaches, islands and water quality, for example through erosion and algal blooms;
- changes, especially decreases, in general productivity of species important to extractive tourism (tourist fishing);
- displacement of species important to the tourism appeal of a destination (e.g., kelp forests or staghorn coral thickets) by range-changing species whose distribution or ecological competitiveness is enhanced by changing ocean conditions;
- reduction in productive vegetative habitat for shorebirds (e.g., seagrasses providing habitat for small prey organisms) which results in decreased populations and a reduction in the value of the area for recreational bird-watching;
- a southern range shift of undesirable species such as crocodiles and stinging jellyfish may reduce the amenity of coastal aquatic activities, although shifts in species with popular appeal to tourists might also create new tourism opportunities.

Any of these effects are likely to present issues primarily for tourism operators and institutions responsible for permitting or regulating tourism (such as the Great Barrier Reef Marine Park Authority) but also for non-commercial recreational users. Important secondary consequences can be expected also for support industries and the users of tourism services. Primary issues for operators may include declining ecosystem quality and changing

weather and sea conditions that increasingly limit access to the marine environment or diminish the satisfaction of clients. Primary issues for policy managers may include the need to be responsive to changes in resource condition or accessibility, either through flexible regulation and legislation or processes for adaptation of policy. Secondary issues may include economic hardship for related industries (airlines, accommodation), support businesses, and local communities with significant dependence on tourism enterprises.

The potential direct effects of climate change on the sea state and weather most relevant to tourism operations are similar to those that will affect commercial fishing:

- changes in storm, wind and wave climates that alter access to fisheries or reefs, or increase the costs of operation at sea;
- changes in coastal morphology or sediment distribution that affect access to and from estuaries or ports or change access to, or costs of, the required coastal infrastructure;
- reduction in the amenity value of the boating opportunities due to more frequent unfavourable weather events such as storms, high seas and winds;
- increased frequency of windy days may provide opportunities for wind-based recreation activities;
- increased turbidity of waters due to greater rainfall and subsequent runoff in some places, reducing the recreational value of waterways by reducing water clarity;
- reduced visibility due to algal and plankton blooms;
- increased amounts of large debris (e.g., trees and logs) in coastal waterways due to greater rainfall intensity and subsequent runoff, thereby increasing, for example, the danger to jet ski users and reducing recreational value;
- a reduction in the aesthetics of beaches and waterways because of increased erosion, sea-level rise and hard engineering coastal defences may reduce the value of activities.

These effects may impact primarily on the tourism operators and consequentially on support industries and consumers, as above.

The potential indirect effects of climate change most relevant to tourism have some commonality with those affecting commercial fishing, and include:

- changed access to tourism resources because of policy, legislative or regulatory actions for non-tourism agendas, such as environmental protection and biodiversity conservation measures (although there would be expected to be less conflict with conservation from the tourism agendas than from commercial fishing);
- loss of support infrastructure, especially in coastal environments subject to significant impacts from sea-level rise, including infrastructure damage, coastal erosion or inundation;
- increased costs of operation because of climate change mitigation strategies, such as emissions trading or tax regimes and potential associated increases in operating costs;
- changes in the market appeal of Australian marine tourism destinations *relative* to alternative ecosystems (such as terrestrial) or competing marine tourism destinations in other countries.

These effects would impact primarily on the tourism operators and consequentially on support industries, local communities and consumers, as above.

4.4.3 Resilience features

Tourism businesses regularly deal with fluctuating visitor numbers driven by externalities (e.g., currency exchange rates, disease, international conditions) while having to contend with changes in the quality of tourism assets due to acute disturbance events, chronic environmental stressors and natural variability. Their direct experience with changes in resource quality, coupled with the strong dependence of many sectors of the tourism industry on high ecosystem quality, render tourism operators especially aware of their sensitivity and exposure to climate change impacts. As a result, at least some segments of marine tourism in Australia (such as the Great Barrier Reef tourism industry) are actively concerned about the impacts

of climate change on their businesses and livelihoods and have indicated a willingness to prepare for any potential climate change impacts. These factors in combination suggest that tourism businesses have greater potential for resilience than most other stakeholders.

Some of the key issues for marine tourism and non-extractive recreational uses associated with climate change include degradation of natural assets (marine biodiversity and resources) and deteriorating ocean-going conditions due to increased storm activity. The ability of tourism enterprises to cope well with these changes is likely to be linked to a range of social and economic characteristics. There has not been any work published on the factors that determine the resilience of marine tourism, but there are likely to be many parallels with findings on resilience in commercial fishers, as outlined in Section 4.2. Applying these criteria to tourism enterprises is likely to give a useful starting point for understanding what types of tourism enterprises are more likely to be resilient to climate change impacts.

One of the other major concerns for tourism operators is the potential for Australia to lose its marketing advantage as a high-quality tourism destination as a result of climate change. The profile given to climate change impacts in Australia could pose additional business risk through its potential impacts on destination appeal, and therefore on market share, even though many other tourism destinations around the world are likely to have similar or even greater vulnerability. This is one risk that the tourism industry can hope to have the most success in reducing, as it is amenable to influence through marketing and public relations efforts. In this respect, the marine tourism industry has the potential to be highly resilient. Managing perceptions, however, can be an adaptation strategy that can be maladaptive, and must be carefully considered.

Overall, the potential impacts from climate change can be expected to be offset somewhat by the high adaptive capacity of the tourism industry and recreational users. The industry's strong awareness of the risks and early indications of an ability to identify and pursue strategies of mitigation and adaptation suggests a high level of resilience. Recreational users will find other activities and attractions, possibly not associated with the marine environment, for their entertainment. The businesses which

A substantial proportion of tourism revenue is derived from marine biodiversity and resources ($5.1 billion annually and 54,000 jobs in the Great Barrier Reef catchment alone).

Marine tourism is, however, highly vulnerable to the impacts of climate change, because of its strong dependency on ecosystem quality, aesthetics and access under favourable weather conditions.

serve specific recreational activities may be less resilient, but general skills developed in these businesses will be transferable. Businesses accustomed to changing markets or catering to diverse recreational activities are likely to be more resilient to climate change effects than single-focus businesses. Businesses and lifestyles associated with beach activities are most at risk because rising sea levels may require hard engineering defences along our beaches to defend properties which, more often than not, results in the loss of the beach. These businesses have no option but to alter their strategy and move away from depending on beach activities.

4.4.4 Adaptation options

The implications of climate change for marine biodiversity, resources and weather may have diverse and often far-reaching ramifications for tourism. Operators will need to consider both the short- and long-term implications of climate change for their businesses. The quality of the marine ecosystem is a key asset to marine tourism, and this is potentially at risk from climate change. Visitor perceptions of Australia's marine environments will be negatively affected if climate change causes significant deterioration of ecosystem quality, leading to reduced visitor interest and numbers. The declining quality of the environment due to climate change has a number of other possible implications for tourism businesses, including increased uncertainty in market forecasts, and potentially increased difficulties in obtaining finance and insurance. Climate change may also have positive implications for the marine tourism industry. For example, key Australian destinations such as the Great Barrier Reef may remain one of the better-quality ecosystems worldwide in a relative sense, despite deterioration due to climate change. This may provide a marketing advantage that could partially offset declines in resource condition.

Adaptation options for marine tourism can be divided into three categories: (i) increasing the resilience of natural tourism assets (marine ecosystems) to climate change; (ii) increasing the adaptive capacity of tourism enterprises in response to climate-induced changes in marine ecosystems; and (ii) offsetting the potential impacts of ecosystem decline or poor adaptive capacity through maintaining or enhancing market share.

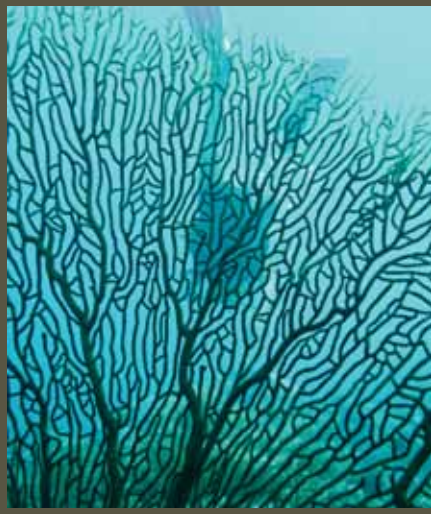

Image: James Dunn.

Tourism operators often have a close, two-way relationship with marine biodiversity. Tourism enterprises are strongly dependent on the condition of the marine environment, but they can also have a strong influence on its condition. The resilience of ecosystems is expected to be a major determinant of how they cope with climate change, and conservation efforts are becoming increasingly important as the threat of climate change grows. Strategies for raising awareness and motivating behavioural change among their customers are an important contribution that tourism operators can make to the resilience of tourism assets and, therefore, to their own resilience to climate change.

Tourism enterprises have the potential to be highly adaptive, by changing their tourism product or diversifying their tourism venture (to decrease dependence on particularly sensitive parts of the marine environment). Marine tourism businesses could change their activity, destination or focal habitats or species to those that are less vulnerable to climate change. A risk-spreading approach could also be taken to accommodate the uncertainty about climate change impacts, with businesses diversifying their tourism ventures to decrease dependence on any single, potentially sensitive, part of the marine environment. There may also be the potential in some situations for tourism operators to actively restore or maintain the condition of tourism assets to compensate for the damage caused by climate change.

Adaptation of marine operations to climate impacts on ocean conditions may also be necessary. Adaptation options could include increasing vessel size or design to maintain passenger comfort, restricting operations to certain seasons or times of day, or increasing the number of alternative sites to allow weather-based choices. Other options (some of which could be in conflict with those just listed) include changes in vessel size or design (e.g., sail vessels) to minimise operational costs associated with fuel, modularising the vessel fleet (e.g., more smaller vessels) to cope with variable demand, or relocating port operations.

One of the most cost-effective adaptation options for the tourism industry is likely to be changing marketing strategies to reflect the altered conditions of tourism destinations and

The quality of the marine ecosystem is a key asset to marine tourism, and this is potentially at risk from climate change. Visitor perceptions of Australia's marine environments will be negatively affected if climate change causes significant deterioration of ecosystem quality, leading to reduced visitor interest and numbers.

experiences. Tourism operations that reduce their carbon footprint through use of biodiesel fuels, sail or solar power can not only reduce operational costs, but also increase their market appeal in an increasingly climate-aware public. This strategy could be extended to related infrastructure, creating 'climate-friendly' destinations. The potential negative impact of effective expectation management might be offset through marketing campaigns highlighting the good condition of the Australian marine environment in comparison with major competing destinations.

Businesses that are dependent on recreational users of the marine environment can adapt by using transferable skills and targeting different markets (e.g., boat salespeople and mechanics can switch to selling and maintaining land-based recreational equipment). Individual recreational users may respond to a decreasing perception of the recreational value of marine environments by seeking recreation elsewhere, including land-based activities. It is also worth noting that changing weather conditions may enhance the popularity of different activities and people may adapt by taking advantage of these changes (e.g., where wind speeds increase, wind-associated sports such as sailing, sailboarding, and kite surfing may become more popular).

4.4.5 Existing knowledge

Basic information on tourism numbers, and tourist destinations and characteristics, is collected under various national survey programs. These provide useful inputs to large-scale models but they are not adequate for necessary assessments of social and economic resilience to climate change impacts at regional and sectoral scales. There have been few studies of the implications of climate change for marine tourism in Australia. One earlier report used a scenario approach to estimate the potential impacts of climate change on users of the Great Barrier Reef. A more recent overview of the vulnerability of social and economic systems dependent on the Great Barrier Reef can be found in Fenton et al. (2007). Few other marine tourism sectors in Australia have been specifically analysed for their resilience to climate change.

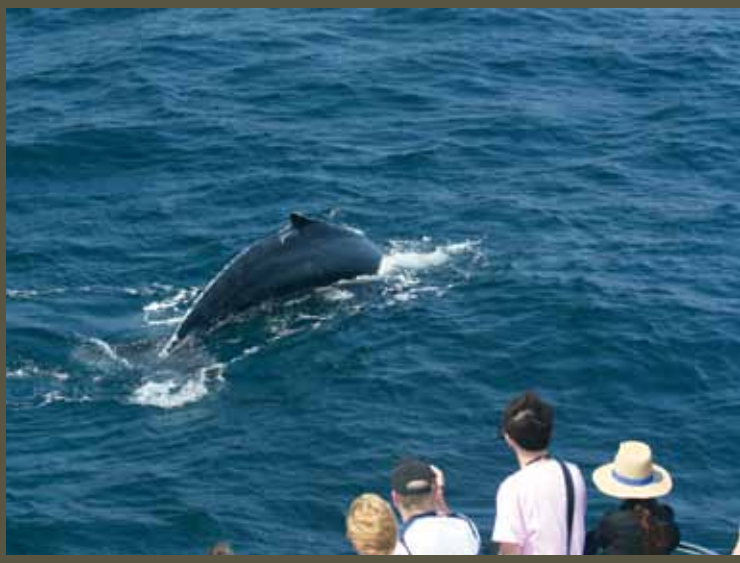

Image: Jan-Olaf Meynecke.

4.4.6 Information needs

Successful adaptation of Australia's marine tourism industry will require information that helps operators predict and prepare for changes in tourism markets, operational conditions (weather etc), condition of the tourism assets (ecosystems), and rules and regulations.

Fishing charter operators have many of the same information requirements as commercial and recreational fishers, with the addition of a need to know about changes in tourism activity or expectations related to climate change.

Information to assist tourism enterprises adapt to climate change includes:

- downscaled predictions of impacts of climate change for marine tourism assets (i.e., which tourism sites will be most vulnerable to change and to what degree);
- the implications of climate change for the business environment (including finance, investment and insurance);
- the impact on the tourism industry of media coverage of climate impacts on natural assets;
- knowledge of resource dependency and its implications for adaptation;
- assessment of the adaptive capacity to climate change impacts;
- adaptation strategies that are relevant and scaled to each sector and region;
- communication methods and messages for raising awareness in the tourism industry and among its customers;
- the feasibility of adaptation options;
- the identification of laws, regulations, accreditation schemes and practices that are both flexible and appropriate for adaptation;
- impacts and responses of marine tourism businesses from other regions affected by climate change;
- engineering and technical solutions to infrastructure risk from increased weather severity.

Non-extractive users may need information that helps them to make decisions on the ability to have a recreational experience that meets their wants or needs, changes to the nature of that experience, and any cost changes associated with travel, assets and operations (including charters). They may need information that alerts them to the changes that are predicted to occur to the resources and their associated amenity values, the cause of these changes, and the management response, if any.

In summary, the types of information required by non-extractive and indirect users include:

- businesses servicing this recreational use will want to know the projected changes to the perceived utility of recreational areas under different climate scenarios and the predicted response of people using it (e.g., will Fraser Island beach camping be closed for three years out of five in the future?);
- resource managers may need to know what user activities reduce the resilience or limit the coping capacity of the ecosystem of value to these users;
- safety authorities such as search and rescue will need to know if risk profiles of activities in certain areas and during particular seasons are likely to change (e.g., activities such as ocean yacht races may be more dangerous in areas or seasons of increased wind);
- assessments of potential actions that managers can take to increase the resilience of the ecosystem (e.g., restricting the amount of camping in beach dunes in an attempt to reduce erosion);
- thresholds for coping and transformation of highly dependent user groups, although this may be insignificant since the effect is shared among many small businesses and the general public;
- adaptation strategies for minimising negative impacts and capitalising on any opportunities arising from changes to ecosystems;
- alternative recreational activities being made available to users.

4.4.7 Priority research

Research priorities for climate adaptation by marine tourism will be driven by the need for information not likely to be available from the existing knowledge base or captured under existing research initiatives. Hence, standard information on business characteristics and tourism patterns collected under current national tourism survey programs will have low priority in this Plan.

Research questions inferred from the above information needs for climate change adaptation include the following.

- What are the predicted regional impacts of climate change for marine tourism assets (e.g., which tourism sites will be most vulnerable to change and to what degree)?
- How can any negative impacts on tourism of public perceptions of climate impacts on Australia's marine biodiversity and resources be minimised?
- How can the links between resource condition and marine-dependent tourism business vitality be modelled and evaluated?
- What is the adaptive capacity of the marine tourism industry and how can it be enhanced to cope with climate change impacts?
- What engineering and technical solutions might reduce risks to marine tourism infrastructure from increased weather severity?
- Are current safety standards and protocols for marine activities adequate to deal with future conditions under climate change?
- What are the most appropriate techniques for preserving beaches in the face of rising sea levels?
- How can water clarity be maintained by controlling runoff during periods of increased rainfall?

Section 5 outlines the process and criteria by which the identified research questions were prioritised, and lists those research questions evaluated as having the highest priority. The full assessment matrix is in Appendix 2.

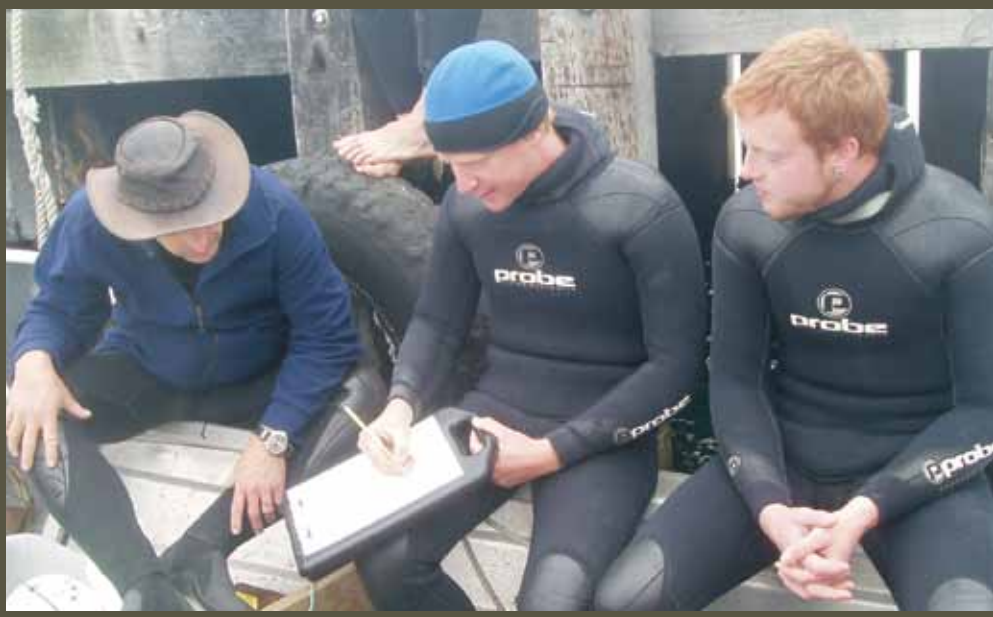

Image: Alistair Hobday.

5. Research prioritisation

5.1 Criteria and considerations for prioritising research activities

Actions aimed at addressing the likely impacts of climate change span a wide spectrum of sectors. The COAG National Climate Change Adaptation Framework 2007 identifies eight sectoral areas, including biodiversity, for implementing adaptation actions. Since the resources and capacity currently available in Australia for adaptation research are limited, the National Climate Change Adaptation Research Facility has developed a set of five criteria to be used for prioritising research topics within each theme area (see Appendix 1 for details). These criteria are being used in all the Research Plans being developed by the Facility. The criteria are:

1. Severity of potential impact or degree of potential benefit (essential)
2. Immediacy of required intervention or response (essential)
3. Need to change current intervention and practicality of intervention (essential)
4. Potential for co-benefits (desirable)
5. Cross-sectoral relevance (desirable).

A number of issues need to be considered when assessing priorities for climate change and marine biodiversity and resources adaptation research, in order to achieve the 'best' outcomes. An essential front-end need is for information about the (likely) magnitude of adverse impacts due to climate change, in order to guide decisions about the choice of adaptive interventions. It is relevant to seek evidence of actual impacts of climate change, particularly in vulnerable sectors, species or locations; although other factors will affect the amount of evidence required to guide decision-making. For example, less evidence may be needed to justify a relatively low-cost undertaking that will be useful in both current and future situations in any event. Research into adaptation and adaptive strategies must also address both short- and long-term time horizons.

A crucial task is to determine who is at the greatest risk of adverse effects of climate change on marine biodiversity and resources. Groups and communities at highest risk include industries and groups whose livelihood is heavily dependent on a fished species that is projected to become less abundant. In general, adaptive strategies should pay particular attention to the needs of these subgroups.

5.2 Prioritising research activities related to marine biodiversity and resources adaptation to climate change

Ranking areas for research into high and low priority is difficult, given that many aspects of research are not directly comparable and time-frames for research vary. Nonetheless, an attempt has been made to apply the five prioritisation criteria to the lists of research questions identified under each of the four sub-themes in Section 4. A fifth group containing a high research priority question is listed here to reflect the importance of cross-cutting research needs that cover more than one sector associated with the marine environment. An important early step might be to develop frameworks and approaches for identifying and dealing with cross-cutting issues arising out of interactions across sectors.

Applying the prioritisation criteria, research priorities were ranked from low to high. The full assessment matrix is in Appendix 2. From this, the following list of high-priority topics emerged.

High priority research questions

1. Aquaculture

- Which farmed species in which locations are most likely to be impacted as a result of climate change?
- What options are there for businesses to adapt to climate change effects either by minimising adverse impacts or taking advantage of opportunities? What are the barriers to implementing such changes and how might they be overcome?

2. Commercial and recreational fishing

- Which fishery stocks, in which locations, are most likely to change as a result of climate change? What will those changes be (e.g., in distribution, productivity) and when are they likely to appear under alternative climate change scenarios?
- What options or opportunities are there for commercial fishers in identified impacted fisheries to adapt to climate change effects through changing target species, capture methods and management regimes, industry diversification, relocation or disinvestment?

3. Conservation management

- Which ecosystems and species of conservation priority most require adaptation management and supporting research, based on their status, value, vulnerability to climate change and the feasibility of adaptive responses?
- How should conservation managers and planners adapt their practices to ameliorate climate change risks and enhance adaptation options? What intervention strategies will increase system resilience and improve the time within which biological systems are given the opportunity to adjust to a future climate?

4. Tourism and recreational uses

- What are the predicted regional impacts of climate change for marine tourism assets (e.g., what tourism sites will be most vulnerable to change and to what degree)?
- What is the adaptive capacity of the marine tourism industry and how can it be enhanced to cope with climate change impacts?

5. Cross-cutting issues

- What are the key interactions across sectors, cumulative impacts and cross-jurisdictional issues that will affect the development of adaptation strategies in each sector and how can these cross- and multi-sectoral issues best be addressed?

6. Implementation issues

6.1 Funding and supporting priority research

There are two principal pathways through which the NCCARF will work to support implementation of this PLAN for Marine Biodiversity and Resources:

- through the Adaptation Research Grants Program administered by the Department of Climate Change with support from the NCCARF, which will provide seed funding for the key research priorities identified in the preceding sections;
- with support from the Marine Biodiversity and Resources National Adaptation Research Network, hosted by the University of Tasmania.

An Implementation Plan will be prepared following Ministerial approval of this Plan and will include consideration of possible projects, research capacity and resource issues, and funding opportunities.

6.2 Research capacity

Australian marine physical, biological and chemical scientists are global leaders in climate impacts research. Maintaining international links to the underpinning climate science (models and observations from the physical and chemical areas) will be crucial. Links with biogeochemical, ecosystem and human system modellers will also be necessary in the coming years.

Research institutions and programs across Australia are also responding to the widespread, high-risk impacts that climate change will bring and are focusing on targeted research which is of relevance to this Research Plan. Government research agencies such as CSIRO and AIMS are undertaking relevant research to address significant questions relating to climate change impacts and adaptation. This research is often undertaken in collaboration with agencies such as the Bureau of Meteorology. The Commonwealth Environment Research Facilities (CERF) Program co-funds multi-institutional environmental research across environmental, economic and social disciplines to support environmental policy development and decision-making, including in response to effects of climate change. For example, the Marine and Tropical Sciences Research Facility is developing tools to map climate change scenarios on the Great Barrier Reef.

Cooperative Research Centres are also doing research on climate change impacts and adaptation. Many university-led projects are funded through the State, Territory and Commonwealth governments, the Australian Research Council (ARC), and various Research and Development Corporations that are targeting either the impacts of, or responses to, climate change. Government agencies are working together to develop targeted outcome-based research programs to address climate change in fisheries and aquaculture.

The biological sciences research community has only recently engaged in this area, suggesting that there is considerable scope to develop capacity in this area. The national and international profile of the biological impacts work is increasing through the recent publication of a number of government-commissioned and peer-reviewed publications. Specifically, there are reviews of climate impacts on fisheries and aquaculture (Hobday et al., 2008), general marine life (Hobday et al., 2006; Poloczanska et al., 2007) and the Great Barrier Reef (Johnson and Marshall, 2007), the Southern Ocean (ACE-CRC, 2008), and globally on important marine groups such as plankton (Richardson, 2008 a, b) and rocky shore organisms (Poloczanska et al., 2008). It seems, from this experience, that maintaining the capacity to respond to short time-scales for delivery and working on short-term projects is likely to continue for at least the next two years. A focus on adaptation that ignores detection and attribution, however, may lead to setbacks in the future, when the effectiveness of adaptation measures needs to be demonstrated and assessed.

All these activities signal increasing capacity and focus in Australia on research to support climate change adaptation, either directly or indirectly. However, the vast majority of this work is biophysical, with relatively little focus

on social science or adaptation by people, although there has been some recent work on adaptation frameworks using resilience models (Marshall and Marshall, 2007). Socio-economic research is in its infancy within climate adaptation science. There is a strong need to engage with social scientists and economic resource modellers, many of whom will be researchers or practitioners not currently involved in marine issues. At the same time, investment in training the next generation of interdisciplinary scientists is needed.

The marine climate impacts space is dispersed, reactive, and fast moving. A consequence of this rapid expansion in research effort is the potential for duplication of both research effort and capability development. The National Adaptation Research Network and the implementation of the Primary Industries Ministerial Council National Research Development and Extension Framework can help coordinate research effort and capacity building, but all research providers need to consider their structures and governance arrangements to support these outcomes.

6.3 Engagement

It is essential that the needs of end-users be taken into account early in the design of priority research in order to ensure that research outputs are capable of easy and prompt uptake. The questions identified in the preceding section are driven by those needs. Participatory forms of research have been shown to be most effective in assessing and supporting change processes through adaptive learning and effective combining of local and expert knowledge. Therefore, close partnership and collaboration in research activities will also be critical.

Understanding the context and manner in which research will be used will help determine what modes of dissemination and uptake are most appropriate. The route to market for research outputs must be considered at the start and not the end of the work. Very few end-users will access research through traditional academic publications, preferring instead toolkits, guidance manuals, presentations and workshops, on-site training, interactive web-based material, summary-style report cards, and so on. Partnerships throughout the research process will be crucial in developing the best uptake mechanisms.

A critical starting point in deciding how best to disseminate information and promote uptake will be to identify relevant primary and secondary end-users for particular research priorities. Some work, for example, may directly inform the operational decisions of management agencies or industry groups. Other research, however, may speak directly to policy-makers, informing their choice of policy intervention. There are already a number of key industry groups and peak bodies supporting the work of the stakeholders who will need to use the research outputs of this Plan. Development of engagement practices as part of the networks will be a critical step in ensuring that end-users are included in adaptation efforts. These practices will need to be mindful of the capacity and resource constraints of some stakeholders, such as community and conservation groups. The NCCARF will work with these groups as well as the other research networks to ensure that existing mechanisms are used as much as possible.

6.4 Additional funding sources

It will be necessary to look for funding sources additional to those made available through the Adaptation Research Grants Program to fully address the key research objectives outlined in the Plan and to undertake essential research programs. Key government organisations such as the Great Barrier Reef Marine Park Authority, Commonwealth, State and Territory agencies entrusted with primary industries and fisheries and with marine protected areas and biodiversity conservation are particularly relevant to the Marine Biodiversity and Resources Plan. The fishing, aquaculture, tourism and boat-building industries also have a strong interest in this research and may contribute to the research effort both financially and through in-kind support such as knowledge exchange.

Funding and resources may be accessed through the Fisheries Research and Development Corporation, which is establishing a National Climate Change and Fisheries Investment and Coordination program. Several Cooperative Research Centres also have research agendas relevant to climate change adaptation research in line with this Plan.

The Australian Research Council grants program is likely to be the first port of call for many researchers and research institutions that seek additional support. Relevant grants offered by the ARC include:

- *Discovery Projects*. A variety of fellowships are offered under the scheme to nurture the talents of Australia's most promising early-career researchers and to support established researchers.
- *Discovery Future Fellowships.* Future Fellowships are offered to promote research in areas of critical national importance by giving world-class researchers incentives to conduct their research in Australia.
- *Linkage Infrastructure, Equipment and Facilities*. The scheme fosters collaboration through its support of the cooperative use of national and international research facilities. Essentially, the scheme provides funding for large-scale cooperative initiatives, so that expensive infrastructure, equipment and facilities can be shared by researchers in partnered organisations. However, the ARC may fund single-organisation proposals in some circumstances.
- *Linkage Projects*. The scheme supports collaborative research and development projects between higher education organisations and other organisations, including within industry, to enable the application of advanced knowledge to problems. In recommending funding for proposals under Linkage Projects, the ARC may take into consideration the likely benefit of the research to Australian regional and rural communities.
- *Linkage International Projects*. The scheme encourages networks and collaborations between researchers, research teams and research centres of excellence in Australia and overseas. Researchers awarded Linkage International funding may participate in national and international exchanges between research organisations.

Image: Michael Birt.

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Appendix 1

Criteria for setting research priorities

The criteria listed below will guide the research planning process to set research priorities.

1. Severity of potential impact or degree of potential benefit

What is the severity of the potential impact to be addressed or benefit to be gained by the research? Potentially irreversible impacts and those that have a greater severity (in social, economic or environmental terms) will be awarded higher priority.

2. Immediacy of required intervention or response

Research will be prioritised according to the timeliness of the response needed. How immediate is the intervention or response needed to address the potential impact or create the benefit? Research that must begin now in order to inform timely responses will receive a higher priority than research that could be conducted at a later date and still enable a timely response.

3. Need to change current intervention and practicality of intervention

Is there a need to change the intervention used currently to address the potential impact being considered. If yes, what are the alternatives and how practical are these alternative interventions? Research that will contribute to practicable interventions or responses will be prioritised. Does research into the potential impact of the intervention being considered contribute to the knowledge base required to support decisions about these interventions?

Desirable

4. Potential for co-benefits

Will the research being considered produce any benefits beyond informing climate adaptation strategies?

5. Potential to address multiple, including cross-sectoral, issues

Will the research being considered address more than one issue, including cross-sectoral issues?

Appendix 2

Prioritising research needs

The prioritisation set out below focuses on research needed over the next 5–7 years to support adaptation planning. Ranking is guided by the time-frame of these information needs. Some research questions that are ranked as low or medium priority are more fundamental and prospective and may therefore be higher priorities in other research funding contexts, for example discovery science. An overall high priority is achieved by two or more 'high' scores for individual criteria, and a medium priority by two or more 'medium' scores for individual criteria.

Research question	Essential	
	Severity of harm or level of benefit	**Immediacy of research need**
1. Aquaculture		
1.1 Which farmed species in which locations are most likely to be impacted as a result of climate change?	**High** Significant scope to ameliorate adverse impacts and seize new opportunities	**High** Some research needed to commence now in order to inform staged interventions
1.2 What are the most likely effects of climate change on key environmental variables affecting aquaculture operations, including ocean temperature, stratification and oxygenation, freshwater runoff or availability, and extreme wind and wave events and which regions are most vulnerable to such changes?	**Medium** Significant scope to ameliorate adverse impacts and seize new opportunities	**High** Some research needed to commence now in order to inform staged interventions
1.3 What are likely policy changes driven by climate change that will affect aquaculture businesses either directly through changes in access to suitable locations, and natural resources such as freshwater or marine-based feeds or indirectly because of changes in harvest marine policies, affecting feed supplies or non-marine climate adaptation and mitigation policies?	**Medium** Important to understanding of broad socio-economic context if industry adaptation is to be designed most effectively	**Medium** Medium/longer-term need
1.4 Which local or regional communities or economies are most dependent on aquaculture businesses and how will changes in aquaculture production (especially decline in activity) affect those vulnerable communities socially and economically?	**Medium** Adaptation options need to be location/community-specific	**Medium** Medium/longer-term need
1.5 What options are there for businesses to adapt to climate change effects either by minimising adverse impacts or taking advantage of opportunities, including through selective breeding, changing or diversifying farmed species, relocating, expanding or contracting business sites or improving environmental control through infrastructure development? What are the barriers to implementing such changes and how might they be overcome?	**High** Significant social and economic disruption if industries threatened by climate change impacts: high benefit to identifying alternatives	**High** Some research needed to commence now in order to inform staged interventions
1.6 What significant changes in aquaculture have already occurred because of extrinsic factors and what can be learned from those changes that will inform adaptation to climate change?	**Medium** Useful to inform adaptation options	**Medium** Evaluation of past experience will provide helpful guidance on future options

	Desirable		Overall
Need to change current intervention/ practicality of new intervention	**Potential co-benefits**	**Cross-sectoral relevance**	
			Medium
High Interventions to be evaluated for practicality			**Medium**
Medium Interventions to be evaluated for practicality: engineering solutions possible to ameliorate impacts			**Medium**
Medium Full information about range of variables affecting marine policy is likely to improve intervention	Understanding of policy context should assist industry, regardless of climate change	Policy context likely to have similar impacts on commercial fishing and tourism operations	**High**
Low Considerable inertia in transforming communities	Should contribute to broader resilience	Findings will inform similar work in the recreational and commercial fishing areas	**Medium**
Medium Reason to believe that some practicable adaptation options will be available			
Medium Lessons learned from past efforts will contribute to practicability of new interventions			

Research question	Essential	
	Severity of harm or level of benefit	**Immediacy of research need**
2. Commercial and recreational fishing		
2.1 Which fishery stocks, in which locations, are most likely to change as a result of climate change? What will those changes be (e.g., in distribution, productivity) and when are they likely to appear under alternative climate change scenarios?	**High** Understanding adverse impacts critical to informing fisheries policy and fishing operations, including to seize new opportunities	**High** Some research needed to commence now in order to inform staged interventions
2.2 What and where are the most likely effects of climate change on key variables affecting fishery access, including wind and wave climatologies and boating access?	**High** Understanding adverse impacts critical to informing fisheries operations, infrastructure and policy, including to seize new opportunities. Less critical than biological change.	**Medium** Some research needed to commence now in order to inform staged interventions
2.3 Which local or regional communities or economies, if any, are dependent on commercial or recreational fishing? How will changes in fisheries (especially decline in activity) affect those vulnerable communities socially and economically?	**High** Adaptation options need to be location/community-specific	**Medium** Medium/longer-term need
2.4 What are the likely policy changes driven by climate change that will affect commercial fisheries either directly through changes in harvest policies or indirectly because of changes in non-harvest marine policies or changes in non-marine climate adaptation or mitigation policies?	**High** Important to understanding of broad socio-economic context if industry adaptation is to be designed most effectively	**Medium** Medium/longer-term need
2.5 What options or opportunities are there for commercial fishers in identified impacted fisheries to adapt to climate change effects through changing target species, capture methods and management regimes, industry diversification, relocation or disinvestment?	**High** Significant social and economic disruption if industries threatened by climate change impacts: high benefit to identifying alternatives	**High** Some research needed to commence now in order to inform staged interventions or prepare for possible adjustment
2.6 What options or opportunities exist or might become available for recreational fishers in identified vulnerable fisheries to adapt to climate change effects through changing target species or preferred fishing method or travelling to pursue their preferred target species or method?	**Low** Social disruption to recreational fishing may have indirect economic consequences	**Medium** Significant scope for autonomous adaptation in the short term
2.7 What are the barriers to fishers implementing such options, including reliability of information about species changes; cost–benefit analyses of different options; current or prospective availability of support industries and services in new locations; prospects of adjustment and flexibility; jurisdictional, legal, administrative or regulatory uncertainties or constraints; and market drivers and constraints?	**High** Understanding barriers to adaptation is critical precondition to evaluation of adaptation options	**Medium** Some research needed to commence now in order to inform staged interventions
2.8 How might barriers to adaptation be overcome? What significant changes in fisheries have occurred before because of extrinsic factors and what can be learned from those changes that will inform adaptation to climate change?	**Medium** Useful to inform adaptation options	**Medium** Stocktake of past experience will provide helpful guidance on future options

	Desirable		Overall
Need to change current intervention/ practicality of new intervention	**Potential co-benefits**	**Cross-sectoral relevance**	
High Interventions to be evaluated for practicality	Better knowledge should also enhance conservation efforts	Findings will inform tourism sector adaptation	**High**
Medium Interventions to be evaluated for practicality: change of fishery or practices likely to be practicable in some areas	Better knowledge should also enhance conservation efforts	Findings will inform other coastal infrastructure and tourism requirements	**Medium**
Medium Interventions to be evaluated for practicality	Should contribute to broader resilience	Findings will inform tourism and aquaculture sector adaptation	**Medium**
Medium	Understanding of policy context should assist industry, regardless of climate change	Policy context likely to have similar impacts on aquaculture and tourism operations	**Medium**
High Reason to believe some adaptation options will be effective for some fishers/ locations			**High**
Medium Significant scope for autonomous adaptation		Shifts in recreational fishing practices may have effects elsewhere	**Medium**
Medium Reason to believe some barriers to adaptation can be removed	Identifying adaptation barriers will assist in fisheries and natural resource management industries adaptation for non-climate change drivers of change		**Medium**
Low Lessons learned from past efforts have made limited contribution to practicability of new interventions	Removal of barriers will assist in fisheries and natural resource management adaptation for non-climate change drivers of change		**Medium**

Research question	Essential	
	Severity of harm or level of benefit	**Immediacy of research need**
3. Conservation management		
3.1 Which ecosystems and species of conservation priority most require adaptation management and supporting research, based on their status, value, vulnerability to climate change and the feasibility of adaptive responses?	**High** Significant threats to some regions/ecosystems/ species	**High** Information needed to underpin further work
3.2 What are the critical thresholds to ecosystem change and how close is the ecosystem to such 'tipping points'? How can we improve our measurement of marine ecosystems to account for ecosystem dynamics and processes?	**High** Significant threats to some regions/ecosystems/ species that support users: high benefit to enhance understanding of ecosystem dynamics	**High** Information needed to inform conservation management immediately
3.3 How will goals and governance for conservation of Australia's marine biodiversity need to change to adapt to climate change impacts? What are the barriers, limits and costs to implementing adaptation and effective policy responses to climate change?	**High** Significant need to review agility of conservation governance and management to ensure responsiveness to conservation needs. High benefit in responding to impacts and ensuring effective and efficient investment.	**Medium** Research needed in order to inform development and testing of management options
3.4 How should conservation managers and planners adapt their practices to ameliorate climate change risks and enhance adaptation options? What intervention strategies will increase system resilience and improve the time within which biological systems can adjust to a future climate?	**High** Effective design and delivery of information and tools critical for success of conservation management interventions	**High** Research needed now in order to inform research design and delivery strategies
3.5 What are the major sources of social resilience, and the processes by which stakeholders and organisations interact, negotiate, and build alliances? What roles do varying perceptions among stakeholders play in adaptive management and how do they change over time?	**High** Changes in the use and management of marine biodiversity and resources will need to be driven by government, industry etc, so understanding social factors will be critical to success	**Medium** Useful to understand best mechanisms for implementing adaptation options; needed before such options are implemented

	Desirable		Overall
Need to change current intervention/ practicality of new intervention	**Potential co-benefits**	**Cross-sectoral relevance**	
High Targeted actions will maximise research and policy effort and outcomes	Potential to inform broader conservation strategies	May affect planning processes in other sectors, especially for areas of high conservation value	**High**
Low Unclear whether greater certainty or identification of thresholds is possible or will change management interventions	Identifying critical thresholds will inform fishing and tourism impact assessments. Measurement will inform tourism and fishing adaptation timing.		**Medium**
Medium Practicality of interventions to be evaluated. Reason to believe some targeted management can assist. Stakeholders may resist change in policy direction.	Improved policy direction will create more effective and efficient conservation management beyond climate change impacts	Identifying more effective conservation policy in line with directional change will support efforts to effectively manage other marine resource developments such as fishing. Where management requires land-based intervention, potential for both positive and negative impacts on primary industries and coastal development.	**Medium**
High Reason to believe interventions will be practicable	Developing information, guidelines and tools will support better delivery beyond climate change		**High**
Medium Practicality of interventions to be evaluated. Reason to believe some targeted management can assist	Determining the major sources of social resilience, and the processes by which stakeholders and organisations interact, negotiate, and build alliances will support adaptation beyond climate change		**Medium**

Research question	Essential	
	Severity of harm or level of benefit	**Immediacy of research need**
4. Tourism and recreational uses		
4.1 What are the predicted regional impacts of climate change for marine tourism assets (e.g., what tourism sites will be most vulnerable to change and to what degree)?	**High** Understanding adverse impacts critical to informing tourism, fisheries and conservation policy with respect to the marine environment, including to seize new opportunities	**Medium** Some research needed to commence now in order to inform staged interventions
4.2 How can the impacts on tourism, if any, of public perceptions of climate impacts on Australia's marine biodiversity and resources be minimised?	**Medium** Secondary factor contributing to economic impacts	**Low** Useful to understand best strategies in order to be prepared for negative media coverage of major events as they occur
4.3 How can the links between resource condition and marine-dependent tourism business vitality be modelled and evaluated?	**Low** Important contribution to understanding vulnerability	**Low** Medium-term
4.4 What is the adaptive capacity of the marine tourism industry and how can it be enhanced to cope with climate change impacts?	**High** Significant social and economic disruption if industries threatened by climate change impacts: high benefit to identifying alternatives	**Medium** Some research needed to commence now in order to inform staged interventions or prepare for industry shifts
4.5 What engineering and technical solutions might reduce risks to marine tourism infrastructure from increased weather severity?	**Medium** Risks to infrastructure require assessment	**Medium** Some research needed to commence now
4.6 Are current safety standards and protocols for marine activities adequate to deal with future conditions under climate change?	**Low** Safety standards already designed to consider range of weather variability	**Low** Medium-term: issues already arise in severe weather conditions unrelated to climate change
4.7 What are the most appropriate techniques for preserving beaches in the face of rising sea levels?	**Medium** Major issue but likely to be addressed under Settlements and Infrastructure theme	**High** Research needed immediately to identify and refine best techniques for specific locations
5. Cross-cutting issues		
5.1 What are the key interactions across sectors, cumulative impacts and cross-jurisdictional issues that will affect the development of adaptation strategies in each sector and how can these cross- and multi-sectoral issues best be addressed?	**High** need for integrated, systems approach well recognised	**High** Research needed immediately to inform adaptation policy

	Desirable		Overall
Need to change current intervention/ practicality of new intervention	**Potential co-benefits**	**Cross-sectoral relevance**	
High Change of tourism location or practices likely to be practicable in some areas		Findings will inform fishing adaptation	**High**
Low Practicability requires further assessment			**Low**
Medium Reason to believe that better understanding of links can assist in refining adaptation options			**Low**
High Reason to believe that some adaptation options will be effective for some locations	Understanding and enhancing marine tourism industry ability to cope with climate change impacts will support adaptation to other drivers of change		**High**
Medium Some interventions may be practicable; but closely aligned with broader adaptation options	Technical solutions can be applied beyond climate change		**Medium**
Medium Higher standards likely to improve safety			**Low** Safety standards are designed to deal with a range of conditions and tourism operators need to amend their safety plans.
Medium Reason to believe that some interventions will be practicable		Significant cross-sectoral benefits for settlements and infrastructure	**Medium**
Medium Reason to believe that some interventions will be practicable		**High** Significant scope for contributing to systems-based analysis of adaptation options in other themes	**High**

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Image: Alistair Hobday.