Institute for Marine and Antarctic Studies response to the

Inquiry into the impacts of climate change on marine fisheries and biodiversity

14 November 2016

For more information please contact

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1. Executive Summary

There is widespread acknowledgement of a changing climate. Empirical evidence clearly demonstrates that Australia's oceans are warming, in some regions at a rate significantly above the global average, and that marine biodiversity and fish stocks have changed in response.

Adapting to a changing climate is imperative if we are to manage impacts, maintain healthy marine ecosystems and continue to benefit socially, economically and culturally from sustainable use of our fish stocks and other marine resources.

Marine biodiversity and fisheries are critically important to Australia:

- Australia abuts three major oceans, several climate zones, the world's largest coral reef, and extensive temperate reef systems. Many of our thousands of species are found only in Australia, much of our marine biodiversity is not yet identified, and large sections of our marine territory remains unmapped.

- Australia's exclusive economic zone (EEZ) is the third largest in the world, constituting 70% of our territory. The ocean provides many services; food, energy, commerce, indigenous values, recreation, coastal protection, climate regulation, and nutrient cycling for example.

- Australia's marine sector makes a significant and rapidly growing contribution to the national economy through energy and food production, recreation and tourism, providing at least 4% of gross domestic product (conservatively valued at $48 billion in 2007–08, Department of Environment). By 2020 the value of our marine industries and ecosystem services is projected to be $100 billion (Marine Nation 2020).

- Currently 90% of Australia's population lives within 100km of the coast, and approximately 3.4 million Australians participate in recreational fishing, contributing $2.5 billion to the national economy (Henry and Lyle 2003). Our commercial fisheries employ 22,000 people (ABARE 2000).

In this response we focus on the risks and opportunities associated with climate change for **temperate and Antarctic marine systems**. However, we emphasise that critical climate-driven impacts are also already occurring in tropical regions of Australia (e.g. extensive coral bleaching); we assume that other agencies will respond in detail to these concerns (e.g., Australian Institute of Marine Science, ARC Centre of Excellence for Coral Reef Studies at James Cook University).

Key trends:

- The south east region of Australia is recognised as one of the fastest warming regions globally; direct observations since 1940's indicates that warming is approximately **3.8 times the global average.** Based on sea surface temperatures over a 50-year period, this region is a 'hotspot' **warming faster than 90% of the ocean** (Hobday and Pecl 2014).

- The warming observed off Maria Island, Tasmania, since the 1940s is a function of the increase in strength of the East Australian Current, and represents a shift in the coastal water isotherms such that the water seen off Maria Island today would be equivalent to what was recorded off Eden in the 1940s – **a 350km southern shift in water temperatures***.* Thus those animals adapted to the water temperatures off Eden in the 1940's would now find their preferred niche off Maria

Island. We are seeing a large number of species beginning to make Tasmania their home, or an increase in abundance of species that were previously rare or uncommon in Tasmanian waters.

- Warmer water temperatures **increase likelihood of stress and disease** (e.g., Aquaculture salmon more prone to amoebic gill disease) and some pathogens become more common as the ocean temperature changes (e.g., *Vibrio* spp).

- Marine heat waves in Western Australia have caused **extensive loss of kelp beds** and associated species. Ocean warming has also seen the demise of ~95% of dense forests of giant kelp in eastern Tasmania.

- As waters warm, species are generally **shifting distributions poleward**, although this is occurring at different rates among species. In waters off south-east Australia we have seen extensive changes in distribution of sea urchins, intertidal molluscs, seaweeds and many coastal fish species.

- Temperatures off Tasmania's east coast are now warm enough for long spined sea urchin larvae to survive during their winter spawning period, leading to a climate-driven increase in the distribution and abundance of this species. Urchins have now extensively overgrazed kelp forests to form extensive sea-urchin barrens largely devoid of kelp and other seaweeds. Formation of urchin barrens creates a massive loss of biodiversity and local collapse of abalone and rock lobster stocks.

Significant issues and challenges:

- For species endemic to Tasmania, there are no close coastal regions south of Tasmania for species to shift south into, as waters continue to warm.

- Species that have small geographic ranges are at 'double jeopardy' as they are less likely to be able to shift distribution (Sunday et al 2015) and also more prone to extinction.

- We have a limited understanding of how the climate impacts on many individual species, and the new combinations of species, will collectively change the structure and function of marine ecosystems as a whole.

- We are unprepared for significant range expansions or the increase of marine pest or pathogens causing disease problems in currently poorly monitored areas, thus we need increased vigilance in monitoring programs to protect valuable Australian coastal and fisheries/aquaculture resources. Increases in diseases and pests, such as harmful algal blooms, are having profound effects on commercial species resulting in closures for harvesting of commercial fisheries and aquaculture species. Short-term forecasting techniques are needed for harmful algal blooms for shellfish aquaculture industries.

Critical data and knowledge gaps:

- Marine systems in general, and Australian marine systems in particular, often have a paucity of biological time-series data. This lack of a baseline in many cases can impede detection of changes in the distribution or abundance of species.

- As the composition, structure and function of our marine systems is actively changing, the importance of biological monitoring is increased. Recent trends by many national governments to cut funding for monitoring programs undermines the ability of scientists and managers to document and respond to climate change.

- Although there has been an increase over recent decades in global physical observational capacity, together with improvements in associated modelling capacity, there has been no equivalent innovation leap for cost-effective ecological monitoring on large temporal and spatial scales. This is a major bottleneck for our understanding of climate change implications for natural systems, preventing us from capitalising fully on the enormous amounts of information available on the physical system and its potential changes.

- We currently have a poor understanding of how productivity will change over time in the Southern Ocean. Changes in productivity can have significant impact on structure and function of the ecosystem and associated fisheries.

- In most cases, there is little socio-economic data for the marine sector and associated communities upon which to evaluate the impact and flow on effects of potential management changes and/or adaptation options.

Potential approaches to address challenges:

- **Networking across rapidly changing regions.** As the most rapidly warming region in Australia, eastern Tasmania has the potential to act as an 'early warning laboratory' for the rest of Australia (and the world). The world's natural laboratories for understanding the impact of warming oceans on marine ecosystem goods and services will be those regions that are changing the fastest. These regions can demonstrate impacts earlier and enable predictive models and on-ground adaptations to be tested and validated first. Through networking with researchers and managers from rapidly changing regions there is an opportunity to provide lessons for understanding and future management of marine resources across all scales from individuals to nations.

- **Working in transdisciplinary multi-sector teams.** Understanding impacts associated with climate will need to shift from a sector by sector response to more holistic systems approach that brings industries, communities and government together to monitor and report on changes, to trial and experiment with adaptation scenarios and to develop co-ordinated approaches to support industries to transition through these changes. Research providers will be integral in underpinning experimentation and adaptation including policy development. However, as with the different sectors, research disciplines will need to be brought together into inter-disciplinary teams to provide solutions to the challenge of prospering in a changing environment. Economists, social scientists, biologists, engineers and physical scientists will need to be working alongside each other and with industry and government in a strong culture of innovation and research excellence.

- **Adaptive ecosystem based management**. Given ongoing changes in community composition, regular assessment and adjustment of the management strategies in place will be crucial to prevent major shifts in ecosystem structure and functioning, especially in global hotspots for ocean warming like the east coast of Tasmania where climate-driven changes are extensive and rapid (Creighton et al 2016, Marzloff et al 2016).

- **Long-term changes to aquaculture.** Aquaculture industries may need to consider longer-term changes that include relocation of farming sites, offshore or on-land, to farming warmer water marine species.

- **Efficient adaptation requires baseline data and cost-effective monitoring**. Understanding impacts and developing constructive adaptation responses that are effective and efficient, and appealing to those who need to adapt, requires (i) reliable baseline data, and (ii) consistent monitoring over time. This applies to physical, ecological, social, and economic data and processes.

- **Communication, engagement and knowledge exchange is essential for communities and industries to adapt effectively.** Industries and communities will need to make changes in the way they operate in order to maintain goods and services from the marine environment under a changing climate. For management and policy changes to be acceptable and implemented as required, communication with industries and public is imperative. Communication builds awareness and ensures industries and communities have the opportunity be pre-emptive and plan, rather than just being reactive.

- **Long-term investment and strategic planning for research infrastructure and human capacity.** Consideration should be given to the future strategic planning of research infrastructure, both capital and people, to meet the demands of knowledge generation and technologies to undertake the task of management of our marine sector in a changing climate.

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2. The Institute for Marine and Antarctic Studies (IMAS)

a. Background to IMAS

In 2010 the University of Tasmania combined its marine activities into a single research institute called the Institute for Marine and Antarctic Studies (IMAS). IMAS is a national leader in Marine Science in Australia and internationally recognised. It has three centres, Ecology and Biodiversity, Fisheries and Aquaculture, and Oceans and Cryosphere, as well as several cross discipline themes, most importantly about climate change and its impact on marine fisheries and biodiversity. The Institute has grown from $13 million to $43 million of annual turnover in six years.

In the latest Australian Research Council's Excellence in Research for Australia (ERA) assessment, all of IMAS's core research areas were rated as an ERA 5 (research well above international standard), namely in Fisheries Science (the only one in Australia), Ecology, and Oceanography.

IMAS researchers have produced over 3000 publications, 1850 peer-reviewed articles and 63 *Nature* and *Science* papers since 2010 addressing these core areas of expertise.

b. IMAS expertise and research activity relating to impacts of climate change on marine fisheries and biodiversity

IPCC - Intergovernmental Panel on Climate Change
IMAS has several academics that have served as lead and coordinating lead authors for previous and current IPCC assessments. Many of the studies we undertake in science and policy have global scale relevance and frequently contribute to the latest climate change assessments used in the reports of the Inter-Governmental Panel for Climate Change (IPCC).

Coordination of key international workshops & meetings regarding marine climate change
Experts from IMAS have led many key international workshops and meetings addressing issues central to marine climate change and fisheries and biodiversity, including:

- *Moving towards climate-ready fisheries systems: regional comparisons of climate adaptation in marine fisheries* in Santos, Brazil March 2015
- *Climate change and range shifts in the ocean: detection, prediction and adaptation* workshop at the *ICES/PICES Effects of Climate Change on Fish and Fisherie*s Conference, Yeosu, Korea May 2012
- *Marine impacts and adaptation in global marine hotspots* conference session at the World Fisheries Congress in Aberdeen, 2012
- *Networking Across Global Marine Hotspots – rapidly warming ocean regions*, Sendai, Japan 2010

Additionally, IMAS experts serve on the:

- Scientific Steering Committee for the *Fourth Effects of Climate Change on the World's Oceans (ECCWO) Symposium* that will be held in Washington, D.C. June 4-8, 2018. This is hosted by the International Council for Exploration of the Sea (ICES), the

Intergovernmental Oceanographic Commission (IOC), the North Pacific Marine Science Organization (PICES).
- Research Advisory Board of the €5.58 million project '*Climate change and European Aquatic Resources*', one of the first Horizon 2020 Blue Growth Projects
- The Steering Committee of the *Scientific Committee for Antarctic Research (SCAR) Special Research Programme: State of the Antarctic Environment and the SCAR Expert Group on Birds and Marine Mammals.*

IMAS also hosted recent key international meetings relevant to marine climate change:
- The *Ocean in a High CO2 World* was held in Hobart in May 2016 and was attended by more than 350 scientists and representatives from marine industries.
- *Species on the Move* in February 2016, attended by 277 international experts from 21 countries. This interdisciplinary conference assessed species responses to climate from all systems and regions across the world.

FRDC-DCCEE Climate Change Adaptation, Marine Biodiversity and Fisheries R&D program
IMAS was a major research provider under the FRDC-DCCEE Climate Change Adaptation, Marine Biodiversity and Fisheries R&D program of investment, including the South East 'El Nemo initiative'. IMAS led or was involved in 40% of the projects under this program.

NCCARF Adaptation Network for Marine Biodiversity and Resources
IMAS was the host of the 2008-2013 NCCARF Adaptation Network for Marine Biodiversity and Resources, led by Associate Professor Neil Holbrook. The Adaptation network was an interdisciplinary network that built adaptive capacity and adaptive response strategies for the effective management of marine biodiversity and natural marine resources under climate change.

Marine National Climate Change Adaptation Research Plan
IMAS played a key role in the drafting of the 2010 National Climate Change Adaptation Research Plan (NARP) for the marine ecosystems and biodiversity theme of climate change adaptation (Marine NARP 2010), the update in 2012 (Marine NARP 2012), and the 2016 current revision (Marine NARP 2016).

National Environmental Science Program Marine Biodiversity Hub
The National Environmental Science Program Marine Biodiversity Hub, which provides research for understanding and managing Australia's oceans and temperate marine environments, is hosted by the University of Tasmania with Professor Nic Bax from CSIRO and IMAS as the Director of the Hub.

Citizen science, climate change and marine biodiversity
IMAS hosts two citizen science monitoring projects that are relevant to marine biodiversity and climate change.
- *Reef Life Survey* is an international programme with highly trained volunteer divers gathering high-quality data at scales impossible for researchers to cover, but without sacrificing the detail needed for direct relevance to management. The Reef Life Survey dataset provides one of the most comprehensive databases of inshore reef life in the world.

- *Redmap Australia* (the Range Extension Database and Mapping project) is an Australia-wide citizen science website where fishers and divers submit photographic records of species they observe outside their expected distributions, i.e., species that may be shifting where they live as a function of warming waters. This project plays a key role in communicating with Australia's marine community on the issue of marine climate change, in addition to providing an early indication of how our marine systems may be changing.

c. Links between IMAS and other research providers and groups in relation to climate change and marine systems

IMAS has strong collaborations with CSIRO, the Australian Antarctic Division (AAD), government and industry as evidenced by our success at obtaining funding for large collaborative projects such as the Sustainable Marine Research Collaboration Agreement (SMRCA) with the Tasmanian Government; the ARC Rock Lobster Industrial Transformation Hub; the Antarctic Climate and Ecosystems Cooperative Research Centre; the ARC Special Research Initiative for Antarctic Gateway Partnership; a node of the ARC Centre of Excellence for Climate System Science and the recent successful bid as a node of the ARC Centre of Excellence for Climate Extremes.

IMAS is strongly linked to other key marine activities at the University, including the Integrated Marine Observing System, the electronic Marine Information Infrastructure, the Australian Ocean Data Network development office, and the Tasmanian Partnership for Advanced Computing.

IMAS is the home of the flagship joint UTAS–CSIRO PhD Program in Quantitative Marine Science program and the recently created joint UTAS–AAD PhD program in Quantitative Antarctic Science.

IMAS is also a key component of the Centre for Marine Socio-ecology, a collaboration between the University of Tasmania, the CSIRO and the AAD. This Centre is led by Professor Stewart Frusher from IMAS.

d. *Contributors to this document*

Prepared by:
Professor Richard Coleman, IMAS Executive Director
Associate Professor Gretta Pecl, Deputy Associate Dean of Research & ARC Future Fellow
Professor Stewart Frusher, Director, Centre for Marine Socio-ecology & IMAS Climate Change Theme Leader

With contributions from:

Dr Louise Adams
Dr Neville Barrett
Dr Chris Bolch
Professor Nathan Bindoff
Professor Philip Boyd
Professor Chris Carter
Professor Graham Edgar
Professor Caleb Gardner
Professor Gustaaf Hallegraeff
Dr Klaas Hartmann
Professor Marcus Haward
Professor Mark Hindell
Associate Professor Neil Holbrook
Professor Craig Johnson
Dr Mary-Anne Lea
Dr Scott Ling
Dr Jeremy Lyle
Associate Professor Catriona Macleod
Dr Craig Mundy
Professor Barbara Nowak
Dr Emily Ogier
Dr Eric Oliver
Dr John Purser
Dr Jeff Ross
Dr Rick Stuart-Smith
Dr Sean Tracey
Dr Jeff Wright

3. Response to the terms of reference

(a) The current and future impacts of climate change on marine fisheries and biodiversity, including recent and projected changes in ocean temperatures, currents and chemistry associated with climate change.

Documented trends

- Sea-surface temperatures trends for the period 1901 to 2012 are rising everywhere except in the northern Atlantic. The global average temperature change is 0.075 to 0.083 (+-0.013) degrees C per decade and since 1901 is approximately 0.89 [0.69 to 1.08] degrees C (Stocker et al 2013).

- The ocean is the dominant store of excess energy in the climate system with 93% of the total energy imbalance. The largest temperature changes occur in the surface ocean with smaller changes extending deeper in the oceans. The top 75m of the ocean has warmed at a rate of 0.11 [0.09 to 0.13] degrees C per decade since 1971. This rate of warming of the upper ocean is the same, within errors, as the global average surface temperature of 0.124 degrees C per decade (+-0.03).

- There is good evidence that the deep ocean below 3000 metres has warmed, and that the mid-depth ocean (between 2000 to 3000 metres) has not warmed, consistent with our understanding of global ocean circulation.

- Rising greenhouse gases and other anthropogenic forcings caused by human activities are the dominant source of the observed ocean surface temperature changes since the 1951 and it is 90% certain that anthropogenic forcings have warmed the upper 700m of the ocean since the 1970's (Bindoff and Stott et. al. 2013).

- Rising carbon dioxide in the atmosphere has led to gradual acidification of the ocean. The pH of surface waters of the ocean has decreased by about 0.1 since the pre-industrial era, an increase of 26% in hydrogen ion concentrations (Rhein et al 2013). The oceanic uptake of anthropogenic carbon by the ocean has increased from 1994 to 2010 by 155 Peta grams of carbon (+-20%).

- The pH of surface waters around Australia have also decreased everywhere with smaller decreases towards the equator and larger decreases in the Southern waters (Lenton 2016, State of Climate 2016).

- The concentration of oxygen in the oceans is changing, in the main thermocline it has decreased and the tropical oxygen minimum zones have expanded, and these changes have also been attributed to human influence.

- Around Australia there are also marked long term trends in surface temperatures. The Tasman Sea is warming and has long term trend patterns (e.g., Holbrook and Bindoff 1997). This long-term warming is also reflected in the long-term time series of surface temperatures measured at the Maria Island monitoring station (Ridgway 2007). These changes extend into the water column down to at least 400 metres. The NOAA Extended Reconstructed Sea Surface Temperature Version 4 (ERSST v4) data set shows trends from 1950 to present of sea-surface temperatures increasing at or above the average global rate, and for most Australian coastal regions rising at greater than 0.12 degrees C per decade (Bureau of Meteorology, 2016).

- Marine heat waves, is a new term, coined in response to new observations of regions of the ocean exhibiting extreme temperatures.
  - Marine heat waves have been observed around Western Australia (Wernberg et al., 2013 and Ming et al. 2011, Pearce and Ming, 2013) and have led to significant impacts on ecosystems.
  - In 2015-2016 the southern Tasman Sea also experienced a marine heat wave. Mean heat waves are already 2-5 time more likely than the 1911 to 1940 base period climate.

Projected changes

Projected changes depend very strongly on the emissions pathway taken by society. In the case of a low emissions pathway (RCP2.6) used by IPCC, the projected changes are much smaller than in the case of high emissions pathway (RCP8.5) where projected changes are much higher. The low emissions pathway implies strong mitigation, and the high emissions pathway no mitigation.

- For the lowest emissions pathway Australian marine temperatures are projected to rise by a further 0.5 to 1.0 degrees C from the 1986 to 2005 base period by the end of this century. For the high emissions pathway Australian marine temperatures are projected to rise by 2 to 4 degrees C.
- The incidence of marine heat waves will also increase given the projected changes in ocean temperatures. One potential outcome off Tasmania's east coast, found in high resolution model projections for mid-21st century, is increased eddy activity, with eddies lasting longer, and consequently an increased frequency of sudden warming events off Tasmania's east coast (Oliver et al. 2015).

It is crucial that investment in IMOS, sensor arrays, and modelling capacity at the regional scale is maintained to provide us with the physical basis for assessing and understanding changes on ecosystems and fisheries.

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(b) The current and future impacts of climate change on marine fisheries and biodiversity, including recent and projected changes in fish stocks, marine biodiversity and marine ecosystems associated with climate change.

Documented trends

The anticipated rate of change over the next century will be at least 10 times quicker than any climate shift in the past 65 million years (Diffenbaugh & Field 2013). If species are to persist in the face of such rapid environmental change, they must adjust in-situ or, where able, shift their geographic distribution. Consequently, one of the most widely documented impacts of climate change is a **shift in species distributions** – effectively a redistribution of the planet's species, fundamentally transforming the biological ecosystems we depend on for a range of services.

- Warming mediated species **changes in distribution (or 'range shifts')** are largely a function of the strong and systematic effects of environmental temperature on biological processes at all levels of organization, from cells to ecosystems (Dell et al 2011).
- **Species are 'tracking' environmental warming**, on land and in the sea, by moving towards the poles, resulting in range extensions at poleward boundaries of their distribution (i.e., distributions extending south in the southern hemisphere) and range contractions at equatorward boundaries (i.e., analogous to local species extinctions at the northern end of species distributions).
- There are substantial differences among species in the magnitude of responses to warming (Sunday et al 2012), and we have little knowledge about the processes responsible for this vast variation in species responses.
- Changes in distribution in the ocean appear to be much faster (on **average 72 km decade**) than those documented for terrestrial species (17km decade, Poloczanska et al 2013).
- Species redistribution is now pervasive, with **25-85% of species** from a wide range of marine and terrestrial ecosystems shifting at least part of their geographic range (Bates et al. 2014).
- **Range shifts are evident in waters around all continents**, including Antarctica, and in diverse marine fauna and flora, e.g., seaweeds, invertebrates, and fish (Last et al 2011, Robinson et al 2015).

Key issues

- Range shifts are already significantly impacting ecosystem structure and function (Johnson et al 2011). Shifts of individual species **change our access** to commercially or culturally important species (Arnason 2012), present risks to **human health** (e.g. toxic algal blooms, disease or harmful jellyfish) (Madin et al 2012), and directly affect the distributions of other dependent species if they provide **structure or habitat** for other species (Johnson et al 2011). Eg:
    - Movement of Ciguatera fish poisoning into NSW and Victoria, and possibly North East Tasmania.
    - *Vibrio* parahaemolyticus outbreak (clinical cases) from Tasmanian shellfish, previously unheard of in Tasmania and coinciding with very high summer temperatures in 2016.
- Not all species shift at the same time and rate, and so community reorganization occurs in both the old and new ranges, creating **novel ecosystems** (Van der Putten 2012).
- Species redistribution, and in particular the creation of novel assemblages of species, brings with it significant challenges for governments, resource users and coastal communities, particularly when dependence on natural resources is high or where species cross jurisdictional boundaries (Pecl et al 2014).
- Species distribution models have been widely used to predict future ranges of marine species. However, these models are openly naïve to the effects of food web changes and do not assess how species interactions will affect the final novel communities.
- We need to better assess the consequences of climate change for ecosystems and fisheries and wider policy at the nexus of **food security, biodiversity and climate change**.

Potential approaches to address key issues

- It is of critical importance that we identify the mechanisms and processes driving species responses so we can improve our capacity to predict future ecological change, to manage proactively the effect of these changes on resource-based human livelihoods and ensure we address conservation objectives (Pinsky & Fogarty 2012), Although generalities of poleward movement are evident, as with many large-scale patterns and processes in ecology, the devil is in the detail.
- To assess the full consequences of climate change on fisheries, food security and marine biodiversity we need to be able to develop models that can predict changes in species composition *and* abundance simultaneously. This step-change in understanding is not only necessary for understanding the interacting impacts of fisheries and climate change on ecosystems; it is urgently needed to make integrated ecosystem assessment of climate change a reality.
- Extensive change in the distribution of our species will result in extensive change in the structure, and therefore function, of our ecosystems. The management implications of extensive ecosystem change are significant (Marzloff et al 2016). Developing effective adaptive response strategies to **minimize negative impacts** and to **seize any opportunities**, e.g., 'new' species, is vital. Close scrutiny of high-exposure,

fast-changing regions, e.g., SE Australia and SW Australia, may highlight metrics or approaches appropriate for monitoring climate change impacts in this and other marine ecosystems.

System specific comments

Temperate Reefs

Shallow rocky reef systems

Warming in eastern Australia has facilitated significant southward range extensions of many species (Poloczanska 2007, 2013), including fishes (Last et al. 2010) and sea urchins (Johnson et al. 2005, 2011; Ling & Johnson 2009). With climate-induced incursion of the long-spined sea urchin (*Centrostephanus rodgersii*) into Tasmania and the added stressor of ecological overfishing of large lobsters as their key predator in Tasmania (Ling et al. 2009), urchins have extensively overgrazed kelp forests (mostly *Ecklonia radiata* forests) to form extensive sea-urchin barrens largely devoid of kelp and other seaweeds (Johnson et al. 2005, 2011, 2013). Winter temperatures off the east coast of Tasmania now reach the 12°C threshold required for urchin larvae to survive in greater numbers. **Formation of urchin barrens creates a massive loss of biodiversity** (Ling 2008) **and local collapse of abalone and rock lobster stocks** which are the key inshore fisheries in eastern Tasmania (Johnson et al 2011).

The abalone fishery is Tasmania's most valuable wild fishery, with 25% of the global wild harvest coming from the state. Ocean warming has negatively affected abalone through direct and indirect mechanisms.

- The direct effect has been to **reduce the maximum size to which abalone grow**, reflecting that abalone reach sexual maturity more quickly in warmer water and stop growing when they attain maturity (Johnson et al. 2011).
- The indirect effect is through the establishment of the long-spined sea urchin (*Centrostephanus rodgersii*) in eastern Tasmania, and here there are two quite distinct effects. The first is the **reduction of abalone populations on urchin barrens**, most likely reflecting lack of macoalgal food (Johnson et al. 2011). The second is the impact of the urchins on abalone behaviour within intact kelp beds before any destructive grazing of seaweeds occurs. Occurrence of the urchins in seaweed beds causes abalone to seek and remain for longer times in cryptic habitat (Strain et al. 2013), leading to reduced growth and gonad size and thus reduced production in the fishery (Strain & Johnson 2009), and reduced visibility and accessibility to fishers.

Ocean warming has also seen the **demise of ~95% of dense forests of giant kelp** (*Macrocystis pyrifera*) in eastern Tasmania (Johnson et al. 2011; Steneck & Johnson 2014), leading to listing of giant kelp forests as an endangered marine community type under the EPBC Act in August 2012. This is the first marine community to be listed in this way in Australia.

Kelp beds are among the most productive ecosystems on earth, often surpassing even the most intensely managed agricultural systems (Mann 1973), and across southern Australia kelp forests dominated by *Ecklonia radiata* supply important ecosystem services including supporting valuable fisheries (Bennett et al. 2016). However, ocean acidification associated with climate change is likely to lead to reduced production in *E. radiata* in Australia. Kelps live in a fluctuating pH environment as a result of their photosynthesis (being a net user of CO_2 during the day and a net producer at night), and their rates of photosynthesis and growth are elevated in the fluctuating pH environment. However, this effect is lost under more acidic conditions expected over the nest 50-80 years (Britton et al. 2016).

Ocean warming increases the likelihood that temperature anomalies will precipitate as heat wave events (see Hobday et al. 2016). **Heat waves in Western Australia have caused extensive loss of kelp beds and associated species** (Wernberg et al. 2012, 2016).

Deep sponge-dominated reef systems

Photo sampling using the IMOS AUV (autonomous underwater vehicle) show that deep reefs on the continental shelf (30-100 m) are extensive and highly biodiverse (e.g., James et al., submitted manuscript). Distribution modelling suggests that different functional groups are likely to respond to environmental change in different ways, so that by 2060 there will be a marked shift in community assembly, yielding community patterns with no counterpart in the present day and thus leading to a shift in both the biodiversity and functioning of these reefs (Marzloff et al., submitted manuscript).

On-shelf planktonic systems

Ocean warming in eastern Tasmania is correlated with a **shift in the species composition of zooplankton in coastal waters** on the continental shelf in which there has been a distinct shift from assemblages dominated by species characteristic of sub-Antarctic water masses to domination by zooplankton characteristic of the East Australian Current (Johnson et al. 2011).

Antarctica and Southern Ocean

Fish

There are few data on the current responses of Southern Ocean fish species to climate change, due largely to the difficulty in collecting time series of fish survey data in remote waters. However enough is known regarding the habitat requirements of the more common and ecologically important fish groups, such as myctophids (laternfishes), to make some predictions about how they may be affected by future climate change. Southern Ocean marine habitats are likely to experience overall warming and freshening, strengthening of westerly winds, with a potential pole-ward movement of those winds and the frontal systems, and an increase in ocean eddy activity (Constable et al. 2014).

The southward movement of Southern Ocean frontal systems will result in **southward shifts in the distributions of pelagic species** including the ecologically important myctophids (Collins et al. 2012). This is one of the most abundant fish groups in the Southern Ocean and is an important prey source for squid and penguins. A southerly shift of this group could lead to some populations of demersal fish with restricted distributions (such as island shelves) becoming locally extinct if they are unable to adapt to warmer ocean temperatures. Similarly, icefish could be vulnerable to ocean warming around currently productive sub-Antarctic islands because of their limited distribution and reliance on highly oxygenated cold water as they lack haemoglobin (Near et al. 2012). Projected changes for Southern Ocean fish under the impacts of climate change need to considered with respect to the potential confounding effects of fisheries.

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(c) The current and future impacts of climate change on marine fisheries and biodiversity, including recent and projected changes in marine pest and diseases associated with climate change.

Marine pests, and fisheries and aquaculture pathogens, can either be native to Australia but newly stimulated by environmental stressors such as eutrophication, climate change or high aquaculture stocking densities; or they can be newly introduced into previously uncontaminated areas via shipping, translocation of aquaculture products, or climate-driven range expansions.

- These two categories of mechanisms (native and introduced) interact so that ecosystems disturbed by pollution or climate change are more prone to non-indigenous species invasions (Stachowicz et al. 2002).
- Aquaculture salmon stressed by **increased water temperatures** are thus more prone to **amoebic gill disease** (AGD) by the parasite *Neoparamoeba perurans* (Johnson-Mackinnon et al. 2016, Oldham et al. 2016) and other diseases (Battaglene et al. 2008). AGD is potentially fatal and can cost millions a year in treatments and/or lost productivity.
- Some pathogens become more common as the sea water temperature changes. For example, changes in the surface seawater temperature increased the spread of **pathogenic bacteria *Vibrio* spp**, including those pathogenic to humans (Baker-Austin et al. 2012, Vezzulli et al. 2013). Cholera (which is also a *Vibrio* species) oubreaks in Bangladesh often occur in warm El Nino years (Pascual et al. 2002).
- Through the past efforts of CSIRO's Centre for Research on Introduced Marine Pests and the continuing National System for the Prevention and Management of Marine Pest Incursions (NIMPIS) we have a good overview in Australia of macroscopic marine pest problems. These include starfish, screwshells, clams, mussels, crabs, fan worms, seaweeds etc. Monitoring of Australian ports for new shipboard arrivals is continuing.

Increased water temperatures act as a stressor potentially impacting all marine life including commercial species such as abalone, pacific oysters, Atlantic salmon and southern rock lobster by increasing susceptibility to disease and pathogens.

For the vast majority of marine microbial pathogens, Australia has very limited R&D skills, and overseas knowledge is unlikely to be fully applicable to emerging Australian disease outbreaks. This is well-evidenced by chaotic government responses to:

(1) The arrival in 2016 in Tasmania of the ostreid herpesvirus 1 causative organism of **Pacific oyster mortality syndrome** (POMS) which put the entire $53M Australian oyster industry at risk by triggering devastating oyster mortalities in Tasmania but also bans on stock movement and sale of oyster spat to NSW. It is unresolved as to the cause - the role of ship ballast water, **climate driven range expansion or stimulation**

of resident cryptic virus populations by unusually high summer temperatures - remains unclear (Whittington et al. 2016).

(2) Unprecedented *Alexandrium tamarense* **toxic dinoflagellate blooms** in 2012, 2015, 2016 in a previously considered low biotoxin risk area of Tasmania's East Coast led to $24M worth of product recall and lengthy closures of mussel, oyster, scallop and rock lobster fisheries. Four human hospitalisations (Paralytic Shellfish Poisoning) also occurred, leading to new warnings being sign-posted along public jetties to protect seafood reputation, tourism and public health. **Early genetic evidence suggests that a previously cryptic resident species has been newly stimulated by changing behavior of the East Australian Current** (Hallegraeff & Bolch 2016). Exceptional harmful algal blooms in Chile in 2016 associated with an extreme El Nino event killed US$800M of fish and triggered massive social unrest.

One of the greatest problems for human society from climate change will be caused by being unprepared for significant range expansions or the increase of marine pest or pathogens causing disease problems in currently poorly monitored areas, thus calling for increased vigilance in monitoring programs to protect valuable Australian coastal and fisheries/aquaculture resources.

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(d) The current and future impacts of climate change on marine fisheries and biodiversity, including the impact of these changes on commercial fishing and aquaculture, including associated business activity and employment.

Thriving in a changing environment requires that the rate of adaptation exceeds the rate of change; consequently, there is an urgent need to understand the impacts of climate change on marine resources and the people and communities they support. Identifying opportunities and threats, and developing adaptation options is essential to optimising the benefits that society can continue to derive from the goods and services provided by marine resources.

Some of the challenges we face include:

- Rapid shifts of large commercial stocks causing resource conflicts across borders or between sectors, and challenging traditional fisheries management approaches (Madin et al 2012). For example, as waters warmed, mackerel has expanded rapidly into Iceland since 1996 and now supports a commercial fishery (1700 t in 2006 to 120,000 t in 2009). This climate-driven change in distribution underpinned the 'mackerel wars' between EU and Iceland (Astthorsson et al 2012).
- Conservation species moving out of protected areas making them vulnerable to over-exploitation or accidental by-catch. Spatial or temporal overlap between conservation/commercial species changing, e.g., Threatened, Endangered and Protected Species (TEPS) moving into regions where they are newly susceptible to fishing gear.

Australia's blue economy was estimated to exceed $42 billion annually in 2010 and this economic activity is expected to grow at a faster rate than terrestrial economic activity, more than doubling in value over the present decade. Meeting the challenges that climate change will have on commercial fishing and aquaculture needs to be undertaken within a portfolio of transdisciplinary research - research involving the different disciplines and stakeholders that seeks opportunities and delivers positive outcomes in developing Australia's blue economy.

Opportunities for research, development and commercial investment include development of offshore structures that utilize more of Australia's marine domain for food production; on-land facilities using recirculation aquaculture system (RAS) technology; hatchery technology to support habitat restoration; new aquaculture and transfer of existing aquaculture southwards; broad scale research innovation and IP generation to address specific and large challenges (e.g., vaccines, selective breeding and new varieties, rearing animals).

Commercial Fishing

With improved technology and modernisation of fishing vessels and gear, there has been a change in the distribution of fishing fleets with larger more powerful vessels working out of larger ports. However, decline in fishing vessels in rural ports in Northern and Eastern Tasmania represents a multitude of factors, among them a decline in the productivity of fish stock (e.g. lobsters) in addition to modernisation. For example, Flinders Island once supported a thriving lobster fishing community yet now only one part-time lobster fisher is based on the island. St Helen's was considered one of Tasmania's major fishing ports and over the last 30 years has seen over 60% of the fishing fleet disappear (van Putten et al.,2014).

In the Tasmanian rock lobster fishery, decreased recruitment and management changes driven by bio-economic goals, has led to a reduction in the fishery by almost a third. In addition to a reduction in the Tasmanian commercial quota, special management actions have been put in place to further limit exploitation on the Eastern seaboard. This is due to both the reduced recruitment as well as the **climate-driven range expansion of the long spined sea urchin** that modifies the shallow water (<40m) habitat by denuding the coastal reefs of algae. Recreational catch limits have also been reduced in line with these changes to the commercial fishery.

The East Coast Tasmanian abalone fishery has also seen declines in productivity that have resulted in changes in allocated quota. Flow on impacts on local employment and levels and types of business activity in allied marine industries and post-harvest sectors are expected however have long lead times, causing delays in detection. They include livelihood diversification and a shift away from commercial fishing towards aquaculture, tourism and mining (Fleming et al., 2014, Van Putten et al., 2014). Some reduction in fleet size and associated businesses were part of the planned outcomes of ITQ management and other changes to increase fleet efficiency. However, the effects of climate change may have compounded the reduction in fleet size.

Climate change risk has been extensively studied in abalone and rock lobster fisheries. Modelling of southern rock lobster has shown that economic yield from the fishery is increased by conservative catch settings and high levels of residual biomass (as occurs when fisheries have an objective of maximizing economic yield, rather than catch). This also has the benefit of providing greater resilience to changes in recruitment, as is expected with climate change (see Section f). However, this resilience is obviously limited if recruitment consistently trends downwards.

In the 1980's Tasmania supported the largest single species by volume fishery in Australia – the jack mackerel fishery. The fishery operated out of the town of Triabunna on eastern Tasmania. The jack mackerel concentrated in this region by feeding off large schools of krill "that turned the waters pink". By the mid-1990's these krill schools and jack mackerel had disappeared leaving the Triabunna processing plant and associated jobs defunct. In a study of the plankton in Storm Bay by CSIRO in the late 1980's they observed that during periods of warm waters caused by the East Australian Current, the plankton switched from being dominated by larger zooplankton such as krill, mysids and smaller copepods and the phytoplankton from diatoms to dinoflagellates (Clementson et al., 1989). These changes represented a 10 fold decrease in productivity and provide anecdotal evidence that the ***warming east coast waters play an important role in the disappearance of this fishery.***

Aquaculture

Atlantic salmon, Australia's largest aquaculture marine food production by value species, is confined to Tasmania due to the cooler waters of Tasmania being those suited to its survival. The industry is worth $0.5 billion and seeking to expand to $1 billion over the next 20 years. IMAS has previously provided comment on the potential impacts of climate change on salmon aquaculture (see Macleod et al 2015; Battaglene et al. 2008).

In summary, these reports identified that without strategic research and specific changes in farming practice climate change would negatively impact on salmon aquaculture production through temperature related increases in physiological stress and diseases and decreased feeding, growth and growth efficiency.

There is likely to be a period of transition, with an unknown timeframe that could be many decades, whereby the existing industry substantially change practices. Changes may include relocation of salmon farming sites, offshore or on-land, to farming warmer water marine fish.

IMAS and the State Government via the SMRCA (Sustainable Marine Research Collaboration Agreement) has been engaged in the development of new aquaculture for several decades. Planning for the aquaculture industry should consider how to incorporate continued **investigation and introduction of warmer-water alternative species (e.g., eastern rock lobster and yellowtail kingfish)**.

Diseases and pests that may impact on fisheries and aquaculture

Pacific Oyster Mortality Syndrome (POMS) was first observed in Tasmania in 2016 and caused widespread mortality in regions of Tasmania. POMS required development of an IMAS facility with the oyster industry to produce seed from disease resistant varieties and potentially stock into disease-free regions.

Increases in diseases and pests such as harmful algal blooms are having profound effects on commercial species resulting in closures for harvesting of commercial fisheries and aquaculture species. For example the period that *Gymnodinium catenatum*, a toxic dinoflagellate, impacts oysters has increased resulting in longer periods of closure for harvesting; the arrival of the toxic form of *Alexandrium tamarensis* that has resulted in closures of mollusc and crustacean fisheries, the increased prevalence of amoebic gill disease in salmon resulting in increased mortality and management costs for treatment, the expansion of *Noctiluca* blooming dinoflagellate and the recent decimation of parts of the pacific oyster stocks with the arrival of POMS are examples of diseases and pests which now find the ***warmer waters off eastern Tasmania conducive to their life histories***.

While the specific mechanism that can be attributed to the arrival and expansion of some of these species is unknown, the rapid change in the biological and physical characteristics of the eastern seaboard due to the observed warming is a most likely driver.

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(e) The current and future impacts of climate change on marine fisheries and biodiversity, including the impact of these changes on recreational fishing.

Australia has a high recreational fishing participation rate (over 20% in Tasmania for example) and climate change range induced changes in the distribution of several coastal and game fishing species is considered a positive outcome for several coastal towns.

- Recreational fishing is of great economic and social importance in Australia. Given this, there is a need for strategies and adaptation activities and management systems that respond wisely to climate change.
- Ensuring accurate information on climate change is available and is considered with other direct and indirect aspects effecting fish populations such as habitat loss, water quality, endemic range, thermal tolerance and biological impacts is essential to understanding the effects of climate change on recreational fisheries.
- The need for monitoring to focus on data that can be used to better predict the future, especially in the areas of recruitment and recording species outside their normal range is critical. These are areas where recreational fishers can play a role in data collection through citizen science initiatives.
- Climate change was identified as a key issue in "Recreational fishing in Australia - 2011 and beyond: a national industry development strategy". This strategy was initiated by the Minister for Agriculture, Fisheries and Forestry and was developed by the Recreational Fishing Advisory Committee from 2008-11.
- The effects of climate change will act at the social, ecological and economic levels. At the social level this will translate into changes in recreational fisher behaviour in response to changes at the ecological level. In general, individual fishers have greater capacity to adapt based on the flexibility in their decisions about fishing activities and these will be influenced by how much they value particular species (e.g., eating qualities, catchability, fighting qualities, iconic status), in contrast to the commercial sector who are more influenced by economic factors and catch legislation. However, the regional impacts of altered recreational fisher behaviour should not be underestimated. Many regional areas in Australia are highly reliant on the economic benefits of recreational fishing.
- Recreational fishers will need to adapt to shifts in the range of species and fluctuations in populations of species important to recreational fishers. In some cases, climate change may produce new fishing opportunities, particularly in southern waters, but may also produce reduced opportunities for species or ecosystems negatively affected.
- With the onset of increasing climate variability fish populations and their appeal to the recreational sector will also fluctuate, especially in response to wet and dry periods, variable ocean currents, water temperatures and ecological impacts (such as:

habitat loss, biological invasions, toxic algal blooms). The impacts of climate change will be highly species specific and will be related to the vulnerability of each target species and also to different life stages of the species. Adequate monitoring and scientific research can ensure managers have predictive knowledge on population fluctuations and changes in range for specific species. Decision rules for management changes will be needed so that management arrangements can implement agreed harvesting strategies and rapidly respond to these fluctuations.

- Climate change will likely provide added pressure on fishing organisations and government to develop approaches and policies that provide a greater level of flexibility and responsiveness in fisheries management. For example, in some years the increased abundance will allow for a loosening of bag limits. In other years, limits might need to be tightened. It is recommended that climate and its impact on abundance of recreational species populations be incorporated within an approach towards more flexible and population responsive bag limits.
- Management within State jurisdiction boundaries is likely to become ineffective for species that straddle these borders and are likely to change their distribution under climate change impacts. Consideration of a whole of stock management approach as climate change alters the dynamics and distribution of fish stocks may be required. Increased cooperation between fisheries management agencies across State boundaries and across State–Commonwealth waters is essential.

This section was based largely on the report:

Creighton, C., Sawynok, B., Sutton, S., D'Silva, D., Stagles, I., Pam, C., Saunders, R., Welch, D., Grixti, D., Spooner, D. (2013) Climate change and recreational fishing: Implications of climate change for recreational fishers and the recreational fishing industry. Fisheries Research and Development Corporation report 2011/037. P125.

(f) The current and future impacts of climate change on marine fisheries and biodiversity, including the adequacy of current quota-setting and access rights provisions and processes given current and projected climate change impacts.

Australian fisheries are managed under a range of different management tools. Most of Australia's more valuable fisheries are managed under output controls often referred to as quota management. In these fisheries, the total allowable commercial catch (TACC) is determined and allocated to fishers based on their ownership in the fishery. In setting the quota, managers use pre-defined reference and target points to ensure that the quota is set at a level that is sustainable. Over the last decade there has been a move towards harvest strategies that set limits below which a fishery should not operate and targets to where a fishery needs to operate to meet economic, social and ecosystem objectives. These are based on the magnitude of the resource (often called biomass) and where the estimated biomass is between the limit and the target, catches (quotas) are determined that should raise the biomass to the target level.

The information to determine these reference points for fisheries operating under quota comes from assessment models that bring together the available data to determine the magnitude of the quota. In general, for fisheries that have a lot of relevant data, the confidence around the quota determination is greater and the quota can be set close to the target estimate. In contrast, for fisheries with limited data, the confidence in the quota determination is lower and thus a more precautionary approach is taken. This can be achieved by building a buffer between the target point and the allocated quota.

The impacts of climate change in setting the quota are associated with **how climate change impacts the key assessment parameters**.

- One of the key assessment parameters that defines the amount of fish available for harvest is the **recruitment to the fishery**. This is also one area that we are seeing major climate change impacts.
- Unfortunately, future recruitment cannot be determined and thus estimates of past recruitment events are used to determine future catches. For some fisheries, such as Australia's lobster fisheries, there are methods to create an index of recruitment by sampling juveniles on specialised measuring systems. In such fisheries, the use of the recent recruitment as examples of future recruitments tends to be more reliable than using the entire past set of recruitment data. For finfish stocks this is not possible and recruitment can only be estimated from the past by sampling the catch and using scientific methods for determining the age of the fish.
- Until recently, most of the recruitment values used in the models were randomly selected from the historical data. Future catch advice based on these assessments tended to **overestimate the suitable quota** and we are now beginning to see some fisheries change their recruitment values to reflect changes due to climate change.
- For example, scientists assessing jackass morwong generated a recruitment trend that incorporates a climate-induced recruitment shift and this is also being investigated for other species globally (Wayte 2013, Castillo-Jordon, pers. comm).

- However, there are other key parameters in assessment models where there is **limited knowledge of the impacts of climate change** (e.g., selectivity, growth, reproduction).
- Due to natural variability in many of these key parameters, long term data sets are required to determine trends.
- For key fisheries in SE Australia, their vulnerability to climate change has been estimated and many of the areas of priority research have been identified (Pecl et al 2014).

Recommendation: To incorporate climate change impacts on key assessment parameters into routine fishery stock assessments and development of harvest strategies that account for a changing environment.

The adequacy of access rights provisions

Management of most fisheries in Australia has resulted in the allocation of catch-share access rights (ITQs - individual transferable quotas). In most cases, this has resulted in a move away from owner –operators that personally harvest the resource, to investors who own the access rights and lease it to harvesters. Owner-operators are considered to have greater concerns over the resource than investors as they have greater connections to the sea and its resources (Gibbs 2009; Pinkerton and Edwards 2009). Although Nursey-Bray et al., 2012 found that **fishers were reluctant to acknowledge climate change**, their observations of biological and physical changes in their operating area were substantial. In contrast, investors often have limited connection to the operating area and tend to be less accepting of negative impacts that reduce quota. For example, analyses of ITQ systems in Australia and New Zealand showed that access right holders generally resisted lower TACCs when cuts were required during periods of low recruitment consistent with climate change (Emery et al., 2014 and 2016; Leon 2015).

To-date, the use of access rights in fisheries has had a very narrow focus with limited innovation. As access rights are unlikely to be changed, Governments should look at ways that they can be used for improved socio-economic benefits that can enhance benefits to society and **be more flexible to adapt and respond to climate change**. An example of more innovative use of rights based systems is the Community Development Quota Program in Alaska (https://alaskafisheries.noaa.gov/fisheries/cdq).

Recommendation: Fisheries should aim to retain flexibility to adapt and respond to climate change.

Management systems that promote stewardship and flexibility should be promoted. Greater innovation in the development of rights-based systems needs to considered.

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WAYTE, S. E. 2013. Management implications of including a climate-induced recruitment shift in the stock assessment for jackass morwong (*Nemadactylus macropterus*) in south-eastern Australia. Fisheries Research, 142, 47-55.

(g) The current and future impacts of climate change on marine fisheries and biodiversity, including the adequacy of current and proposed marine biodiversity protections given current and projected climate change impacts.

As described in the Australian 2016 State of the Environment Report (currently in press), the status of marine biodiversity in our nation is mixed, with improved management in some areas over the past five years, but also with the condition of many habitats declining. The short- and long-term outlook for groups such as estuarine invertebrates is poor, as growing coastal human populations continue to lower the quality of bay and estuarine habitats, invasive species increasingly dominate communities, and with the severity of climate change impacts potentially overriding all other threats. This poor outlook is particularly acute for Threatened, Endangered and Protected Species (TEPS) that may be unable to track favourable conditions (e.g., climate-driven changes in temperature) due to lack of dispersal capability or suitable alternative habitats.

Current protections applied to safeguard marine biodiversity are generally inadequate, including numerous large gaps in the current network of marine protected areas, small size and paucity of most no-take zones, and sparse and disconnected monitoring programmes for tracking ecological and socio-economic values, as needed for adaptive management.

An adequate safeguard for marine biodiversity in Australia, as elsewhere, requires appropriate sectorial management strategies (e.g. fisheries, transport, defence), plus the safety net of marine protected areas (MPAs,) and also a focus on protection of threatened species. Such strategies need to be integrated and accommodate the massive potential impacts of climate change (Dawson et al. 2011), including the application of an increased level of precaution during an era of high uncertainty when the environmental domain exceeds historical bounds (Davidson et al. 2013, Melnychuk et al. 2014).

Effective MPAs comprise one key tool for reducing future climate-related changes in biodiversity:

- They can potentially reduce anthropogenic stressors on populations of thousands of species, whereas conservation strategies aimed at single species are rarely feasible due to prohibitive cost.
- Monitoring of no-fishing MPAs and adjacent fished sites allows influences of warming to be distinguished from effects of fishing, thereby assisting management decision-making.
- MPAs can increase the resilience of marine communities by reducing the influence of local anthropogenic stressors, and thus overall stress on a system. One long-running Tasmanian study, for example, found that rocky reef communities within long established no-take MPAs resist the arrival of climate immigrants (i.e. warm-water species with populations expanding poleward due to increasing water temperature) relative to communities in fished locations (Bates et al. 2014).

- Queensland studies indicate that effective MPAs can increase resistance of communities to impacts from flood events (Olds et al. 2014), and destructive outbreaks of the crown-of-thorns seastar (McCook et al. 2010).
- Inadequate protection of range-restricted fish species on Lord Howe Island (e.g. bluefish and double-header wrasse), has likely contributed to observed population declines (Stuart-Smith et al 2015). Many range-restricted species such as these are unlikely able to shift distribution with warming, and may become threatened by the combined impacts of exploitation and warming.

Nevertheless, the Australian MPA network is poorly-designed for resisting impacts of climate change. Most MPA zones allow some forms of fishing and are small in size. As a consequence, they have little if any conservation value (Edgar et al. 2014). The distribution of MPAs is also far from comprehensive, with pronounced biases, particularly in the case of the Commonwealth Marine Reserve network, away from locations where threats most acute and they are most useful (Edgar et al. 2008). Habitats distributed on the Australian outer continental shelf and upper slope have negligible protection with effective no-take MPAs (Devillers et al. 2015).

To the present, no thought has been given in any State or Commonwealth jurisdiction to designing an MPA network that best maintains biodiversity in a changing climate.

Features needed include: (i) no-take zones with large north-south dimensions, allowing species to shift internally with warming climate, (ii) such zones to be distributed without major (>200 km) gaps as a north-south network, facilitating poleward range shifts, (iii) all major marine habitat types and biodiversity features to be protected from exploitation within at least one MPA, (iv) the MPA network to include considerations of connectivity with deeper water and adjacent habitats (Olds et al. 2012). The first need is to undertake a comprehensive gap analysis to identify the most important additions needed for the current MPA network, then coordinated planning to fill these gaps. *Ad hoc* ecological and socio-economic monitoring, as presently undertaken in most jurisdictions, needs to be expanded and coordinated within an adaptive ecosystem based management framework.

Biodiversity values are also managed via range of other tools in addition to MPAs. The most widespread of these is the listing of Threatened, Endangered and Protected Species (TEPS) via the Commonwealth EPBC Act 1999, or similar state or international structures (e.g., IUCN Red List).

- By their very definition, TEPS are currently under significant pressure, which will only be worsened by climate change.
- Many listed TEP species are listed partly on the basis of restricted geographical extent, that usually reflects an inability to disperse, and/or a close-coupled dependence on particular (and often rare) environmental conditions that may not be found outside their current range. Such species will not be able to track optimal thermal

requirements, and will need active management such as translocations, new habitat creation (where old habitats are not present further south or due to sea level rise for intertidal species), maintenance in aquarium systems (arcs), and spatial management to protect against threats.

- Despite listing of such species, there is currently little capacity to respond to climate mediated threats.

At a recent FRDC workshop examining potential adaptive management of climate impacts on temperate reef biodiversity in SE Australia (Barrett et al. 2015), the message from conservation managers was clear, that given the large number of terrestrial TEPS in a similar situation (680 in Tasmania alone), there would be no capacity to protect such species in a meaningful way, so no current or proposed protections are envisaged with respect to climate responses. At best, a triage process may be undertaken, with actions proportional to the risk assessment undertaken. At this stage (for non-commercial species) no formal risk assessment for marine species has been undertaken in Australia to inform future responses, and this is clearly an important next step in planning and prioritising future actions.

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(h) The current and future impacts of climate change on marine fisheries and biodiversity, including the adequacy of biosecurity measures and monitoring systems given current and projected climate change impacts.

"Marine Biosecurity is a significant risk which is poorly recognized …. there is a mismatch between perceptions and the resources allocated". "The resources applied to managing marine biosecurity in Australia do not appear to match the magnitude of the risk and are fragmented between government agencies and authorities, commercial entities, environmental interests and research organisations."

CSIRO Biosecurity Flagship - Marine Biosecurity Workshop, Hobart, July 2013: Summary Report.

While there are some notable achievements in the biosecurity area such as the forthcoming ratification in Sept 2017 of the International Maritime Organisation's (IMO) *International Convention for the Control and Management of Ship's Ballast Water and Sediments* (www.imo.org), comparable *Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species* are less advanced. The 2005 *ICES Code of Practice on the Introductions and Transfer of Marine Organisms* warns about the inadvertent consequences of introduction of new (or genetically modified) aquaculture species, but also warns against the impacts of translocation of unwanted contaminants such as pathogens. A global consensus is emerging, however the option of doing nothing to curb harmful aquatic pathogen and pests translocations is no longer acceptable.

Australia's ocean territory is the third largest on Earth and more than 85% of Australia's population live within 50 km of the coast. Given the demonstrable value of fisheries and marine industries at state and national level ($42 billion in 2010) it is surprising that invasive marine species research amounts to less than 1% of current R & D investment.

AQUAPLAN is Australia's National Strategic Plan for Aquatic Animal Health 2014–2019 which was formally endorsed by the Commonwealth and State/Territory governments and the private sector, and the implementation of its projects are overseen by the ministerially appointed Fish Health Management Committee. While Australia has strong diagnostic capabilities for seven aquatic diseases determined as priority (Animal Health Australia 2015), early detection of emerging pathogens and strategic research remain an issue.

The limited R&D capabilities and investment in fish health in Australia are inadequate to support ever increasing aquaculture growth, which at the same time faces largely unpredictable threats from climate change.

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(i) Other related matters.

Monitoring *(in addition to biosecurity monitoring above at point h.*)

To best adjust to marine climate change impacts, we need to address some of the fundamental gaps in our ecological understanding and fill these through hypothesis testing using all available data. Our understanding is weakest in poorly surveyed regions such as the tropics and Antarctica.

As climate change continues to unfold, we have the opportunity to refine our understanding of the processes and implications, and our capacity to project futures changes. However, taking advantage of this opportunity requires access to consistent, high quality data on a series of environmental, biological and socio-economic parameters.

The current absence of long-term funding for comprehensive, coordinated biodiversity monitoring systems is a major bottleneck for our understanding of climate change implications for natural systems. Thus far we have seen extensive national cooperation in terms of coordinating the collection and the distribution of physical and chemical environmental monitoring data (e.g., IMOS). However, biological data collection has been more limited (e.g., zooplankton and animal tracking) and a comparable level of coordination for biological data is required. A national, robust biodiversity monitoring system that successfully integrates field and remote sensing data could significantly improve our ability to manage the changes to come, while potentially driving faster mitigation measures.

Likewise, social and economic data, which is necessary to evaluate the impact of potential management and policy changes in response to climate change, is also currently limited in scale and scope.

Flow on effects to communities (in addition to employment and business activity above at point d.)

The flow on effects to communities from climate change varies according to the marine sector impacted. In general, while there have been substantial reductions in commercial fishing fleets from a number of causes, including climate change, fishing is only a minor industry in most rural and regional towns.

In Australia, over the last three decades, fishing fleets in coastal towns have declined by between 30 and 60% (Van Putten et al., 2014). Most of the restructuring of fleets within small coastal towns has been through planned adaptation such as industry buybacks or autonomous adaptation in response to localized declines in marine resources and has seen larger and more technologically efficient vessels move to larger centres for their fishing and related activities.

Although declining participation in fishing in small coastal towns can affect population size and thus the demand for other services (e.g., school teachers, medical staff, banks), limited planned adaptation by coastal communities to consider either the consequences of such declines or the adaptation options available appears to have occurred (Metcalf et al., 2014; Bradley et al., 2015).

Aquaculture is an expanding marine industry in Tasmania and many rural coastal towns are supportive of its development as it brings new employment opportunities. However, community concerns over aquaculture's environmental impacts is causing conflict within communities and regions that favour the economic benefits that new industries bring or weigh environmental concerns higher than economic benefits.

In contrast to declining commercial fishing activity, recreational fishing can have major economic benefits for coastal communities. Over summer periods, the population in coastal communities can increase 10-fold and many of these holiday makers are also recreational fishers.

Changes in the abundance and distribution of species from climate change will impact communities to varying degrees. Other impacts will be from the public concern over the safety of seafood as increased incidences of harmful algal blooms occur and there are closures of species and regions.

Metcalf, S.J., van Putten, E.I., Frusher, S.D., Tull, M. and Marshall, N. (2014) Adaptation options for marine industries and coastal communities using community structure and dynamic. Sustain. Sci. 9:247–261. doi:10.1007/s11625-013-0239-z.

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Bradley, M., van Putten, I. and Sheaves, M. (2015) The pace and progress of adaptation: marine climate change preparedness in Australia's coastal communities. Mar. Policy 53:13–20.

Communication and engagement regarding marine climate change

As with other impacts of climate change, impacts of climate change on marine species will create "winners" (i.e., a new commercial species in an area) and "losers" (i.e., loss of an important species, or introduction of a new pest), re-shaping the pattern of human well-being between regions and different sectors and potentially leading to substantial conflict (i.e., Who accesses a new resource? Who pays to remove a new damaging pest?). Successful management changes will therefore involve trade-offs and complex decisions around who pays for adaptation and how could/should resource allocation change – communication on climate change thus becomes very important.

The scientific community needs to engage effectively with the marine industry sector, the public and resource managers on the issue of climate change impacts on marine biodiversity, fisheries and aquaculture. Part of the answer could be citizen science and participatory observing approaches, in which community members are **directly involved** in data collection and interpretation (e.g., Redmap and Reef Life Survey). These are tools that can help address both **data gaps and communication gaps**. When properly designed and carefully tailored to local issues, such participatory observing approaches can provide quality data, cost-effectively and sustainably, while simultaneously building capacity among local constituents and prompting practical and effective management interventions (Pecl et al 2015).

Pecl GT, Gillies C, Sbrocchi C, Roetman P (2015). Building Australia through citizen science. Occasional Paper Series for the Office of Chief Scientist. Issue 11 http://www.chiefscientist.gov.au/wp-content/uploads/Citizen-science-OP_web.pdf

Governance

Climate variability and change is likely to have a range of impacts on marine fisheries and biodiversity. Governance of fisheries has received increasing prominence at national, regional and international levels from the mid-1980s. This increased attention is in part due to concerns on "pressures being exerted on the ocean ecosystems through over-fishing, pollution, and environmental and climate change" (Costanza et al 1998). Climate change is likely to have a range of impacts on species and fishing communities, and influence the approaches and tools used to manage such impact including effects on distribution and abundance such as "range shifting". While climate variability and change is one driver, it has the potential to significantly affect productivity of marine fisheries. This directly links to questions of governance.

The UNDP defines governance as "the system of values, policies and institutions by which a society manages its economic, political and social affairs through interactions within and among the state, civil society and the private sector" (UNDP 2007, p.1). The reporting framework for the application of Ecologically Sustainable Development (ESD) in Australian Fisheries sees governance relating to the question: "does the fishery have sufficient management processes and arrangements in place to enable the other elements [ecological and human wellbeing] to achieve an adequate level of performance?" (Fletcher et al. 2002, p. 30).

This centres attention on governance processes that are adaptive and responsive, where legislation, regulation, institutional arrangements and administrative processes recognise the different scales of climate change impacts.

Adaptive management can be applied in a variety of contexts; from single-species fisheries management to management of multi-species assemblages; from centralized fishery management systems to community and stakeholder led co-management approaches; from small scale to large scale fisheries. A range of instruments (i.e., state-based, market-oriented or a community-driven) can be used to support such approaches. As Ogier et al. note, it is "important that fisheries governance regimes incorporate institutional arrangements that do not exclude the potential for management approaches to integrate additional adaptive requirements" (Ogier et al. 2016: 91).

Costanza, R., F. Andrade, P. Antunes, M. van den Belt, D. Boersma, D. F. Boesch, F. Catarino, S. Hanna, K. Limburg, B. Low, M. Moliror, J. G. Pereira, S. Rayner, R. Santos, J. Wilson, and M. Young. 1998. “Principles for Sustainable Governance of the Oceans” *Science,* 281: 198-199.

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4. Additional resource material

Articles by IMAS staff and others written for *The Conversation*

Was Tasmania's summer of fires and floods a glimpse of its climate future?
http://theconversation.com/was-tasmanias-summer-of-fires-and-floods-a-glimpse-of-its-climate-future-58055

A marine heatwave has wiped out a swathe of WA's undersea kelp forest
http://theconversation.com/a-marine-heatwave-has-wiped-out-a-swathe-of-was-undersea-kelp-forest-62042

Marine heatwaves threaten the future of underwater forests
http://theconversation.com/marine-heatwaves-threaten-the-future-of-underwater-forests-37154

How you can help scientists track how marine life reacts to climate change
https://theconversation.com/how-you-can-help-scientists-track-how-marine-life-reacts-to-climate-change-33370

Can you surf the East Australian Current, Finding Nemo-style?
https://theconversation.com/can-you-surf-the-east-australian-current-finding-nemo-style-27392

Tipping point: how we predict when Antarctica's melting ice sheets will flood the seas
https://theconversation.com/tipping-point-how-we-predict-when-antarcticas-melting-ice-sheets-will-flood-the-seas-56125

Six burning questions for climate science to answer post-Paris
https://theconversation.com/six-burning-questions-for-climate-science-to-answer-post-paris-55390

Australia's 'other' reef is worth more than $10 billion a year - but have you heard of it?
https://theconversation.com/australias-other-reef-is-worth-more-than-10-billion-a-year-but-have-you-heard-of-it-45600

Your coastal town's climate score? There's a website for that
https://theconversation.com/your-coastal-towns-climate-score-theres-a-website-for-that-33306

Websites

National citizen science website where fishers and divers submit photographic records of species observed 'out-of-range', i.e. species that may be shifting where they occur.
www.redmap.org.au

International project using highly-trained SCUBA divers to assess inshore reef biodiversity.
www.reeflifesurvey.com

Online climate change blueprint tool to assess if Australian coastal communities are prepared for the effects of climate change in the marine environment.
http://coastalclimateblueprint.org.au/