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Australia's Marine Biodiversity and Resources in a Changing Climate: A Review of Impacts and Adaptation 2009-2012

NATIONAL CLIMATE CHANGE ADAPTATION RESEARCH PLAN

Australia's Marine Biodiversity and Resources in a Changing Climate: A Review of Impacts and Adaptation 2009-2012

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ISBN: 978-1-921609-55-8

NCCARF Publication 18/12

Published by the National Climate Change Adaptation Research Facility
Email nccarf@griffi th.edu.au
Website www.nccarf.edu.au

Please cite this report as:

Holbrook, NJ and Johnson, J. (2012) *Australia's marine biodiversity and resources in a changing climate: a review of impacts and adaptation 2009-2012*, National Climate Change Adaptation Research Facility, Gold Coast, 45pp.

Acknowledgement
The National Climate Change Adaptation Research Facility hosted by Griffith University is an initiative of, and funded by, the Australian Government, with additional funding from the Queensland Government, Griffith University, Macquarie University, Queensland University of Technology, James Cook University, The University of Newcastle, Murdoch University, University of Southern Queensland, and University of The Sunshine Coast.

The role of the National Climate Change Adaptation Research Facility is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government and in vulnerable sectors and communities to manage the risks of climate change impacts.

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1. INTRODUCTION

This document provides a critical review and synthesis of the published literature since December 2008 relevant to climate change adaptation for Australia's marine biodiversity and resources, and identifies relevant funded projects and some key existing knowledge gaps. The literature review is structured in a manner that reports against the research questions identified in Appendix 2 of the National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources (Mapstone *et al* , 2010; hereafter referred to as M-NARP2010) as possible priorities over the subsequent 5–7 years from 2010–2016. Based largely on the published literature since December 2008 and projects underway, we identify some key knowledge gaps that remain, and identify another question area that might be usefully added to the 'cross-cutting issues' theme – consideration of estuaries – not explicitly included in the original M-NARP2010. This document will be used to inform a review of M-NARP2010 in early 2012.

The M-NARP2010 was released in March 2010 following substantial stakeholder consultation in 2008 and a review process in 2009. The document is available for download from the National Climate Change Adaptation Research Facility (NCCARF) website www.nccarf.edu.au. The M-NARP2010 is structured into four marine sector theme areas and a fifth cross-cutting theme. These themes are:

- Aquaculture;
- Commercial and recreational fishing;
- Conservation management;
- Tourism and non-extractive recreational uses; and
- Cross-cutting issues.

This literature review provides a critical synthesis and review of the literature since the original M-NARP2010 was drafted in December 2008 and how recent science addresses the M-NARP2010 research priorities.

2. MARINE AQUACULTURE

2.1 Which farmed species in which locations are most likely to be impacted as a result of climate change?

Recent reviews have considered that although all types of aquaculture – brackish, coastal and marine – are likely to be impacted by climate change, operations in temperate locations are most susceptible to increasing water temperature (Hobday and Poloczanska, 2010), while farms in low-lying coastal areas are likely to be impacted by increased flooding due to storm surge and more extreme rainfall events (De Silva and Soto, 2009). Projections of greater and accelerated ocean warming on Australia's east coast and in the Tasman Sea, and the strengthening of the East Australian Current (EAC), are likely to impact on the growth rates of many species and to change the location of suitable environments for aquaculture (Hobday and Poloczanska, 2010).

Aquaculture operations in temperate zones are expected to be most impacted by increasing water temperature as these increases could exceed the optimal temperature range of species currently cultured in temperate locations (De Silva and Soto, 2009). Aquaculture production in southern cooler waters, particularly around Tasmania, is of particular concern, with the salmon industry most at risk since this species is already farmed near its upper thermal limit during summer months (Battaglene et al., 2008). Southern bluefin tuna are another cool water species farmed in South Australia and likely to be impacted by increasing water temperature.

Banana (*Penaeus merguiensis*) and tiger prawn (*P. monodon*) aquaculture in subtropical and tropical Australia may benefit from climate change with increased pond water temperatures expected to improve growth rates, and extend areas suitable for farming these species further south (Hobday and Poloczanska, 2010). However, cooler water prawn species such as Japanese king prawn (*P. japonicus*) and temperate fish species that have a narrow thermal range for optimal growth are likely to be adversely affected (Barange and Perry, 2009, Hobday and Poloczanska, 2010).

In summary, aquaculture operations in temperate locations (e.g. south eastern Australia) and cool water species (e.g. Japanese king prawn, salmon and southern bluefin tuna) are most likely to be negatively impacted by climate change, particularly from increasing water temperature. The major gap in knowledge for adaptation planning concerns the specifics of changes in aquaculture species that are most likely to be impacted by climate change, that is, the thresholds at which vulnerable species will no longer be viable to farm and the best sites for future operations. More information is needed on the synergistic impacts of climate change stressors – in particular, ocean warming and acidification – on these thresholds and impacts on immune systems and disease resilience. Some of this research is currently underway for key aquaculture species, specifically Atlantic salmon (FRDC 2010/217 and 2010/085), barramundi (FRDC 2010/521) and oysters (FRDC 2010/534), and vulnerable locations (south eastern Australia; FRDC 2009/070 and 2009/055).

2.2 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?

A recent review by Hobday and Poloczanska (2010) identified extreme water temperatures and shifts in temperature regimes likely to affect growth, survival and abundance of various aquaculture commodities, particularly in temperate Australia (e.g. salmon, Battaglene et al., 2008). The review suggested that development of integrated models to predict the socio-economic impacts was a priority to understand the full implications of climate change on aquaculture. Higher pond temperatures may also cause more prevalent disease outbreaks, again with the greatest influence in temperate regions (De Silva and Soto, 2009, Walker and Mohan, 2009).

Projections of increasing storm intensity (and associated storm surge, wind and wave action) will threaten coastal and offshore aquaculture farms, causing structural damage, stock losses and spread of disease (De Silva and Soto, 2009, Hobday and Poloczanska, 2010). Increasing storm activity can also cause flooding and initiate erosion that will affect coastal aquaculture farms (Hobday and Poloczanska, 2010). In addition, sea level rise and salt water intrusion into coastal deltas in the tropics is likely, and will have detrimental effects on brackish ponds in coastal areas, particularly those culturing species that have limited saline tolerance (De Silva and Soto, 2009). Aquaculture commodities in brackish waters are likely to be affected by changes in salinity, and sea level rise that has the potential to affect low-lying coastal areas, impacting pond facilities and their seed stock (Barange and Perry, 2009).

A number of recent studies have looked experimentally at the effects of projected higher sea temperatures and/or ocean acidification on a single species, many of which are farmed in Australia. Elevated pond water temperature enhanced growth of a juvenile tropical sea cucumber (*Holothuria scabra*) (Lavitra et al., 2010), while fertilization of Sydney rock oysters (*Saccostrea glomerata*) decreased at higher pCO_2 and temperatures, and embryonic development decreased with a greater percentage of abnormalities ((Parker et al., 2009, Watson et al., 2009, Parker et al., 2012)). There was no embryonic development at 30°C or more (Parker et al., 2009). Pearl oysters (*Pinctada fucata*) exposed to acidified seawater had weaker shells, with signs of malformation and/or dissolution (Welladsen et al., 2010).

Oyster aquaculture in NSW, South Australia and Tasmania is expected to be impacted by the strengthening EAC, warmer waters, changing rainfall patterns, sea-level rise and storm surges, and ocean acidification. With resultant effects on the timing of oyster growth and spawning, reproduction, shell formation, metabolic capacity, disease outbreaks, higher summer mortality and farm infrastructure (Li et al., 2009, Leith and Haward, 2010, Li et al., 2011).

2.3 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?

Quota reductions in wild capture fisheries are increasing seafood demand that aquaculture may be able to fill, as well as providing available workforce in small coastal towns (Hobday and Poloczanska, 2010). However, fisheries are a major source of inputs for aquaculture, providing feed and some seed stock, and any changes in fisheries caused by quota reductions or climate change induced productivity declines will flow through to aquaculture (De Silva and Soto, 2009, FAO, 2010)

Policy changes aimed at reducing greenhouse gas emissions (e.g. carbon tax) are likely to increase the cost of production, packaging and distribution activities with subsequent effects on aquaculture businesses (Cochrane et al., 2009). To take this one step further, consumers could create a demand for carbon emission labelling, with the result that eco-labelling of some products such as prawns and salmon could result in reduced demand for energy intensive products (De Silva and Soto, 2009).

Policies to promote adaptation by other industries may also affect aquaculture businesses, for example, new water infrastructure and allocations designed to ‘drought-proof’ agricultural industries or urban centres could compromise freshwater availability for freshwater aquaculture operations (Cochrane et al., 2009). For the oyster aquaculture industry in NSW and Tasmania, policies on upstream management of resources and development related to climate change are likely to affect the industry and future adaptation will need to be considered in the broader social context of NRM and landscape planning decisions (Leith and Haward, 2010).

The major gap in knowledge for adaptation policy concerns the implications of coastal and urban planning decisions on the ability of aquaculture operations to relocate to more suitable locations, either landward or to a new site. This information will be particularly important for adaptation planning of coastal aquaculture that often occupies prime real estate.

2.4 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?

Although inferences can be made on which communities or economies will be most vulnerable to climate induced changes in aquaculture, based on the species and locations that are most likely to be impacted and their value, little recent research exists for Australian communities. The two most valuable aquaculture species in Australia are in temperate regions: salmonids (salmon and trout in Tasmania located in the Huon River, Port Esperance and D'Entrecasteaux Channel, Tasman Peninsula in the southeast; Macquarie Harbour on the west coast; and in the Tamar estuary on the north coast), and bluefin tuna (located in Port Lincoln in South Australia) (FRDC, 2010a), making these local communities in Tasmania and South Australia highly dependent on aquaculture. Similarly small communities in Queensland and the Northern Territory that depend on Japanese king prawns will be affected by changes in aquaculture production, as well as the impacts of more intense storms on coastal infrastructure. These communities and businesses are likely to experience spatial contraction of suitable locations, production interruptions, and reduced viability of cool water species with subsequent reductions in productivity, job losses and economic losses both directly for the industry and indirectly for support services (De Silva and Soto, 2009).

Recent studies provide estimates of the economic value of the aquaculture sector to South Australia’s state and regional economies, contributing $194 million (or 49% of the state’s total value of seafood production) in 2009/10 (Econsearch, 2011). Tuna aquaculture is the largest sector, accounting for 53% of the state’s gross value of aquaculture production in 2009/10. In 2009/10, aquaculture’s total contribution to gross state product (GSP) was $278 million, or 0.35% of the total GSP for South Australia. Approximately 66% of the aquaculture contribution to GSP was generated in regional South Australia (Econsearch, 2011). These figures illustrates the importance of aquaculture to regional South Australia in terms of business activity, household income and contribution to state growth and employment, which has both social and economic implications as climate change affects this industry.

While the FRDC has clearly identified the social and economic implications of production declines as inevitable, with flow-on effects to dependent societies particularly in regional Australia, there is little evidence from Australia (FRDC, 2010b). One FRDC project currently underway (2009/073) is assessing the social and economic risk for the fishing and aquaculture sectors in south eastern Australia. More science is needed in this arena to better understand the relationship between vulnerable aquaculture operations and the communities and economies that depend on them, and to detail how these communities will be affected socially and economically by declines in aquaculture activity.

2.5 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?

Adapting vulnerable aquaculture businesses to climate change effects and optimising opportunities are essential responses to inevitable future change. Hobday and Poloczanska (2010) identified a range of options such as selective breeding programs to adapt some aquaculture species to warmer conditions by developing more robust stocks with faster growth rates (e.g. prawns, oysters, temperate abalone and salmon), growing different species that are pre-adapted to higher temperatures, or new commodities such as microalgae biomass, biofuels, feeds and pharmaceuticals. Alternatively, genetic selection of disease-resistant stock (e.g. oysters: Leith and Haward, 2010) may improve the viability of some commodities in warmer waters. Some current research focuses on the potential for genetic adaptation in oysters that can protect them from the harmful effects of ocean acidification and increasing ocean temperature (Amaral et al., 2012, Parker et al., 2012).

Diversification of farmed species, an ecosystem approach to aquaculture management, improved water and energy efficiency, and promotion of aquaculture crop insurance are other adaptation options that have been proposed in the international context (De Silva and Soto, 2009, FAO, 2010). Relocation of production facilities will be necessary at a range of scales, including moving cage systems into deeper cooler waters or moving entire farms away from flood-prone coastal areas where saltwater intrusion may be a problem (De Silva and Soto, 2009), or where increasing water temperatures are expected to increase mortality or inhibit optimal growth (Hobday and Poloczanska, 2010). Greater regulation of earlier life stages (e.g. indoor hatcheries), supplementary feeding, and more frequent disease treatment (e.g. bathing salmon in freshwater to combat gill disease) may also be necessary.

One low-cost strategy for mitigating the effects of sea level rise on low-lying coastal prawn ponds is to raise the level of the bottom of ponds. This was trialled in New Caledonia in 2010 using agricultural soil and results show unexpectedly better prawn production and improved ability to discharge pond water, empty ponds for harvest and dry ponds before re-stocking, providing a viable mechanism for minimising the impacts of future sea level rise for this commodity (Della Patrona et al., 2011).

In the face of more extreme weather events, aquaculture operations can minimise adverse impacts by using improved weather forecasting, early warning systems, and stronger infrastructure (Cochrane et al., 2009). In marine cage culture, the introduction of improved technologies to withstand extreme weather events will be an important adaptation measure (De Silva and Soto, 2009). Improved access to and use of information on climate variability and risk will be important to inform production decisions and increase overall economic performance in a changing climate (Hobday and Poloczanska, 2010).

Opportunities to expand aquaculture of tropical and subtropical species south (Hobday and Poloczanska, 2010) or landward as saltwater intrudes (De Silva and Soto, 2009) will depend on the availability of suitable sites and the production input costs. An FRDC project to investigate the potential to develop aquaculture in Jervis Bay, NSW (e.g. shellfish) made recommendations on how future plans can be environmentally and economically sustainable (Joyce et al., 2010), and may facilitate climate change adaptation through relocation or expansion of some aquaculture commodities. Increased food supplies will be needed to facilitate expansion and realise benefits from faster growth rates, increased growing seasons and range expansions (Barange and Perry, 2009). Aquaculture operations that are less or not reliant on fishmeal and fish oil inputs (e.g. bivalves and macroalgae) have better scope to adapt and expand. Feed replacement using high energy density feeds may be one measure to combat this issue (De Silva and Soto, 2009).

More recently in Australia, aquaculture businesses are considering the implications of climate change on their future plans. Industries in the south east farming salmon, abalone and rock lobster are aware that they are going to be affected by rising water temperatures and in response, the Tasmanian Atlantic Salmon industry has initiated a research program to examine how to farm fish in warmer waters, including investigation of selective breeding of heat tolerant fish and options for farming fish in cooler offshore waters (FRDC, 2010b). Similarly, northern fisheries reliant on barramundi and prawns understand they will need to deal with the effects of more variable climate on populations and are involved in studies to determine thermal tolerances and adaptation strategies (FRDC 2010/521).

Workshops with the oyster industry in Australia identified a range of social (e.g. relationship between growers and government, retention of skilled staff) and natural capital (e.g. ability to access suitable water and land resources) issues as potential barriers to future climate adaptation (Leith and Haward, 2010). More generally, barriers to adaptation of the aquaculture industry have been identified as mainly economic (e.g. the cost of relocating farms or developing more tolerant strains: De Silva and Soto, 2009). However, there is a dearth of studies that detail the specifics of these economic or other barriers and further work is required.

2.6 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?

Recent examples of changes in aquaculture due to external factors that can inform adaptation planning are mostly from an international context. For example, in 2009, extreme climate events in southern China – unusually cold temperatures and snow storms – impacted on finfish aquaculture farms damaging infrastructure and causing significant stock losses. Preliminary estimates are of losses of nearly 0.5 million tonnes of cultured finfish stocks, mostly warm water alien species (e.g. tilapia), of which a considerable proportion was broodstock (De Silva and Soto, 2009).

Fishmeal production shortages (e.g. Peruvian sardines and anchovies) and subsequent farmed tuna mortalities have already been experienced globally due to climate fluctuations and growing demand. They are an indication of the ongoing impacts climate change may have on aquaculture in Australia, particularly for those commodities dependent on fishmeal such as prawns and finfish (Hobday and Poloczanska, 2010).

There are opportunities to draw lessons on climate-proofing infrastructure, undertaking risk assessments of stock losses due to changing conditions, reducing reliance on fishmeal or other feed inputs and adapting to increasing water temperatures that can be taken from these examples. Unfortunately, few reviews exist in Australia of recent changes in aquaculture, or studies that interpret how these externally influenced changes (in Australia or overseas) can inform future risk assessment and adaptation planning in Australia.

3. COMMERCIAL AND RECREATIONAL FISHING

3.1 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?

Fisheries climate change hotspots have been identified off south eastern and south western Australia – with southeast Australian sea surface temperatures increasing at a rate of approximately four times the global average (Ling et al., 2009a). These represent locations where significant changes for marine and estuarine species are likely (Booth et al., 2011, Stuart-Smith et al., 2010). Mechanistically, fisheries in the southeast are expected to be impacted by the strengthening East Australian Current and in the southwest by the weakening Leeuwin Current (Ridgway and Hill, 2009, e.g. Feng et al., 2009, Holbrook et al., 2009, Hobday and Lough, 2011).

Temperate fishery stocks in south eastern Australia are likely to change as a result of climate change –particularly through increasing ocean temperature, due to the direct effects on species with limited thermal ranges and the indirect effects from movement of warm temperate species (Hobday and Poloczanska, 2010) and increasing disease outbreaks (Danovaro et al., 2010). This has been documented in Tasmania with the expansion of the long-spined sea urchin (*Centrostephanous rodgersii*) from NSW that is altering benthic habitats critical for the valuable rock lobster and abalone fisheries (Ling et al., 2009b). Dang et al. (2012) noted correlations between water temperature and immune response in commercial abalone stock in South Australia (Dang et al., 2012). Pecl et al. (2009) also concluded that climate change (particularly expressed through ocean warming) is expected to have a significant impact on the Tasmanian rock lobster fishery, causing declines in rock lobster biomass and recruitment in northern and north eastern regions by 2030 under the A1B ('business-as-usual') emissions scenario, and then in southern regions by 2070 under both the A1B and A1FI (A1 fossil intensive) scenarios. This was supported by current catch rate monitoring that shows a long-term trend of decline, which is expected to continue.

Community and ecosystem effects of climate change will have impacts on fishery stocks (Pörtner and Peck, 2010). However, recent studies have primarily focused on the implications for individual stocks or populations, or the indirect effects of habitat loss or degradation. Distributional shifts attributed to warming temperate oceans were documented by: Last et al. (2010), with 45 fish species showing distributional shifts south since the late 1800s; Stuart-Smith et al. (2010) who noted that although Tasmanian rocky reef community structure remained unchanged, there were southern range shifts (e.g. whiting and luderick) and new records (e.g. rock cale); Pitt et al. (2010) who documented range shifts in 16 species of Tasmanian invertebrates; and Johnson et al. (2011) who showed that there are cascading effects of ecological change in benthic (rocky reef) and pelagic systems. Madin et al. (2012) discuss the socio-economic and management implications of range-shifting marine species.

A study of metabolic rate of banded morwong (*Cheilodactylus spectabilis*) in the Tasman Sea showed increased growth in the middle of their range but reduced growth at the northern edge of their distribution that coincided with warmer ocean temperatures potentially leading to declining productivity and range contraction (Neuheimer et al., 2011). Community monitoring in Tasmania has also recorded marine species that have extended or shifted their usual habitat ranges, and include eastern blue groper, eastern rock lobster, mahi mahi and grey morwong[1]. An important habitat component of temperate rocky reefs – seaweeds – have been shown to bleach as a result of temperature-mediated disease (Campbell et al., 2011) and southern distributional shifts of seaweeds have been documented over the last 40 years

[1] http://www.redmap.org.au/species/browse/ accessed 15 November 2011

(Wernberg et al., 2011), both of which are likely to have implications for habitat-dependent fish species.

Tropical fisheries that target species dependent on habitats such as coral reefs, mangroves and seagrass meadows (e.g. prawns, mud crabs, coral trout and aquarium species), are likely to change as a result of climate related impacts on these habitats (Pratchett et al., 2009, Badjeck et al., 2010, Bell et al., 2011, Donnelly, 2011, MacNeil et al., 2010, Pratchett et al., 2011b). For example, barramundi (*Lates calcarifer*) landings have been correlated to an index of climate variability (Balston, 2009a), and nursery habitat productivity (Balston, 2009b). Long-term studies in the Indian Ocean detected declines in reef fishery catches consistent with lagged impacts of habitat disturbance (Pistorius and Taylor, 2009). Coral reef fisheries are also likely to be affected by predicted reductions in population connectivity due to the effects of climate change on reproduction, larval dispersal and habitat fragmentation, potentially affecting catch rates and species availability as reef fish community composition changes (Munday et al., 2009). These habitat associations and community dynamics have been identified by 33 scientists as high priority research questions in relation to coral reefs and climate change (Wilson et al., 2010).

Recent studies correlating fisheries catch rates with climate by Ives et al. (2009) showed that growth and movement of school prawns (*Metapenaeus macleayi*) in northern NSW were affected by river discharge rates, with higher river discharge usually resulting in increased commercial catches. Meynecke and Lee (2011) showed positive correlations between commercial catches of barramundi (*Lates calcarifer*), mud crabs (*Scylla serrata*), mullet (e.g. *Mugil cephalus*), flathead (e.g. *Platycephalus fuscus*), whiting (*Sillago spp.*), tiger prawns (*Penaeus monodon, P. semisulcatus*) and endeavour prawns (*Metapenaeus endeavouri, M. ensis*) with sea surface temperature and rainfall on the Queensland coast. Examination of NSW commercial fisheries data has shown that catch-per-unit-effort (CPUE) increased in proportion to freshwater flow for four commercial estuary species (dusky flathead, luderick, sand whiting and sea mullet) and decreased during drought (Gillson et al., 2009). Booth et al. (2011) found similar correlations, with increases in overall CPUE of the northern mud crab fishery interpreted as a response to sea surface temperature increases. Estuarine species may be more exposed to reduced pH as these environments are shallower, less saline and have lower alkalinity than marine waters (Miller et al., 2009). However, little work has been done in this field.

Modelling has also provided a range of recent predictions for fishery species and catch rates, however, it should be noted that representing complex ecological interactions and model design choices can influence model outputs and uncertainty, and these results are likely to be revised with future model improvements. Nevertheless, model results can provide insight into the direction of change and likely responses. For example, in response to warmer oceans in the Torres Strait tropical rock lobster fishery (by 2030 under the SRES A1B emissions scenario) it was predicted that there would be physiological effects with flow-on impacts on productivity, fisheries catch, fisher income and employment, intermediary and final demand sectors, and the local economy (Plaganyi et al., 2011b).

Brown et al. (2010) simulated future climate change effects on 12 marine food webs in Australia under the A2 emissions scenario over the next 50 years, and predicted (i) increases in primary production in tropical Australia (north and east), (ii) only minor increases (or declines) in primary production in the south east and west, (iii) benefits to fisheries catch and value proportional to the predicted change in productivity with the Gulf of Carpentaria and the Eastern Tuna and Billfish Fishery expected to show the largest increases, and (iv) small changes in community composition for all regions. More recent ecosystem modelling by Fulton (2011) projected an ecosystem regime shift in south eastern Australia (by 2060 under the A2 emissions scenario) with primary producers and pelagic systems likely to benefit from climate change, while demersal systems would most likely decline. However, pelagic fisheries will still experience change, with Hobday (2010) projecting distributional shifts of 14 large pelagic species captured by longline fisheries in Australian waters as their core habitats move south and contract.

Projections by Cheung et al. (2010) of global catch potential from 2005 to 2055 (under the A1B scenario) show an average of 30-70% increase in high latitude regions and a ~40% decline in the tropics. However, more recent modelling by Cheung et al. (2011) showed that these projected fishery catch potentials may be reduced by a further ~10% with the inclusion of biogeochemical factors (under A1B by 2050). Although some doubt has been raised as to whether this work can be transferred to the Australian context (Fulton, 2011), there are implications for fisheries targeting species at the edge of their range, particularly in tropical regions where Australia may become a last refuge for Indo-West Pacific species as the oceans warm (Hobday and Poloczanska, 2010).

Although there is limited empirical evidence that demonstrates direct changes to fisheries in Australia due to climate change, correlations of historic fisheries with climate data and modelling have predicted changes in distribution and productivity of many important fishery stocks, as well as locations that are most likely to experience changes. In summary, the greatest impacts of climate change on fishery stocks are likely to manifest in south eastern and south western Australia (Hobday and Poloczanska, 2010), and for some fisheries in tropical regions (Pratchett et al., 2009, Pratchett et al., 2011b). The nexus between tropical and temperate systems, the subtropics, is an important zone that is likely to experience changes to species abundances and community compositions. The fisheries stocks most at risk are those dependent on vulnerable habitats (Koehn et al., 2011), cool temperate endemic species (Hobday and Poloczanska, 2010), and coastal and demersal species (Barange and Perry, 2009, Pratchett et al., 2011a), with some shifts in distribution already observed and others possible as early as 2030.

Current FRDC projects are investigating the implications of climate change for fisheries in vulnerable locations: tropical Australia (2010/565), south western Australia (2010/535) and south eastern Australia (2009/070); and key fisheries species: coral trout (2010/554), barramundi (2010/521), and western rock lobster (2009/018); as well as the recreational fishing sector (2010/524). Preliminary results from 2009/070 identified temperature as the most common driver of current or potential climate change impacts on south eastern Australian fisheries species, with the fishery stocks considered at highest risk also supporting the region's highest value fisheries – blacklip and greenlip abalone and southern rock lobster (Pecl et al., 2011a, Pecl et al., 2011b). A new project (2011/039), focusing on the southeast region, will work to identify climate change adaptation options for four key fisheries species.

3.2 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?

Coastal areas in tropical Australia are projected to experience more intense storms and severe weather events that can reduce fishery access, as well as destroy or severely damage fisheries assets and infrastructure such as landing sites, boats and gear (Daw et al., 2009, Badjeck et al., 2010). Increased storm and wave activity may reduce (i) the number of days recreational fishers can fish, (ii) access to some locations for both boat and shore-based fishers, and (iii) the seasonal availability of fish (Hobday and Poloczanska, 2010).

A study by Tobin et al. (2010) investigated the effects of two severe tropical cyclones (Tropical Cyclone (TC) Hamish and TC Justin) on fish abundance, catch composition and catch rates of the coral reef finfish fishery on the Great Barrier Reef (GBR) (FRDC project 2008/103). The project also explored the socio-economic effects of these cyclones on the commercial and charter fishing sectors (described in section 3.3). An assessment immediately following TC Hamish showed that 66% of the coral reef structure had been damaged but there was no measurable change in the associated fish community and abundance. However, depressed fisheries catch rates of target species (coral trout and red throat emperor) of >30% occurred and lagged as much as nine months post-cyclone. This reduced 'catchability' of fish could not be correlated with any abiotic data such as reef structural damage or sea temperature. TC Justin on the other hand, resulted in depressed catch rates of up to 50% for coral trout, accompanied by an ~200% increase in red throat emperor catch that was related to a cool-water event that followed the cyclone. These results demonstrate how extreme weather events can significantly alter access to fisheries during the event and catch rates up to 12 months later. However, the unique nature of each cyclone makes it difficult to predict the magnitude or direction of impacts.

Access to fisheries is expected to be influenced not only by extreme climate but also distributional shifts of key commercial species away from the major ports/landing sites and economic zones (Booth et al., 2011). Diminished access and property rights as distributions shift may become a significant issue for some regions, while other fishers may gain access to fish as they move (Hobday and Poloczanska, 2010). Research on predicting these changes needs to be targeted in locations most likely to experience these shifts (e.g. south eastern and south western Australia), and species most likely to expand or contract their ranges (e.g. warm temperate species). Some range-shifters may become 'locally invasive' as they move south (e.g. the long-spined sea urchin that has overgrazed Tasmanian kelp, (Ling et al., 2009b)) being natural predators of important fishery species. Research is needed on the impacts of these distributional shifts on important fisheries as they are likely to occur sooner than the direct impacts of warming or other climate-related changes.

3.3 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?

Grafton (2010) identified communities with a high proportion of members employed in a particular capture fishery, low employment, low geographic mobility, and specialised skills as being most likely to be affected by changes to their fisheries due to climate change (i.e. less resilient). Such communities are likely to be small remote towns that focus on a single fishery resource. As fisheries resources change, small-scale fisheries are less able to adapt due to their limited resources (Daw et al., 2009). Based on examples worldwide, fishing communities that are dependent on local resources of a limited number of species are more vulnerable to fluctuations in stocks, whether due to overfishing, climate or other causes (Brander, 2010).

In Australia, the socio-economic impacts of reduced access to fisheries resources and depressed catch rates after tropical cyclones were investigated by Tobin et al. (2010). This study found that the gradual reliance of the coral reef finfish fishery on high-value live coral trout has limited their ability to adapt to change. This reliance on a single species destined for a single market makes the coral reef finfish fishery highly vulnerable to declines in catch rates of target species. Sustained reductions in catch rates, as were observed after two tropical cyclones in the GBR, resulting in reduced CPUE, increased operating costs and reduced profit. In contrast, the recreational and charter fishing sectors employed more adaptation options (e.g. species diversification and fishing location shifts) and were not significantly impacted by the cyclones.

Economic studies in South Australia have valued wild capture fisheries at $202 million in 2009/10 (Econsearch, 2011). Similar economic valuations for other states in Australia can provide a guide to the local, regional and state economies that are most dependent of fisheries and therefore most likely to be affected by climate-related changes to their fisheries. However, further work is required in Australia to identify these dependent communities most at risk from climate-related changes to their fisheries, and the likely social and economic impacts.

3.4 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?

Management policies aimed at protecting marine biodiversity in the face of climate change through zoning that excludes commercial fishing may cause future user conflicts. As stocks move to new areas without adequate management, that are designated for recreational or no fishing activity, and stocks diminish in commercial fishing areas, commercial fishers will have diminished access to these resources (Hobday and Poloczanska, 2010).

Policy changes that focus on adaptation of agriculture, heavy industry or urban centres to changing rainfall patterns, for example, the construction of more flood control, drainage and irrigation schemes, are likely to exacerbate the direct impacts of climate change on fisheries that target species reliant on river flow and estuarine habitats (e.g. barramundi, prawns) (Badjeck et al., 2010, Koehn et al., 2011).

Policy changes aimed at reducing greenhouse gas emissions (e.g. carbon tax) are likely to increase the costs of fuel, and the storage and distribution for capture fisheries (OECD, 2010), particularly affecting fisheries that may have to travel greater distances to access moving fish stocks. These additional costs associated with anticipated carbon mitigation policy have been identified as contributing to future business risk and uncertainty for the tropical marine aquarium industry (Donnelly, 2011).

The effectiveness of current and possible future fisheries management (e.g. single-species assessment models, management strategy evaluation approaches, multi-species assessment models) to cope with climate change implications for fisheries will affect future fisheries sustainability, with adaptive management frameworks identified as the best tools (Plaganyi et al., 2011b). A current FRDC project 2009/073 includes a new component that aims to identify management objectives and weightings for four key fisheries in south eastern Australia, that will evaluate alternative management arrangements.

3.5 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?

In response to projected greater spatial and temporal variability in landings, fishers are likely to have to become more mobile and responsive to fishing opportunities (Badjeck et al., 2010). This will require more flexible management and policy with an adaptive management paradigm that can manage for uncertainty (Brander, 2010, Grafton, 2010, Johnson and Welch, 2010, OECD, 2010). An example in Australia of fisheries management that incorporates climate variability into an adaptive management approach is the east coast pelagic longline fishery that targets southern bluefin tuna. A near-real-time ocean model identifies tuna habitat and as this changes throughout the season, management adjusts the location of restricted access areas (Hobday et al., 2009).

In Australia, a couple of recent studies have explored the adaptation of commercial fisheries to climate impacts; the response of the coral reef finfish fishery after tropical cyclones in the GBR was to shift effort, the only adaptation response employed with larger operators moving more than smaller ones (Tobin et al., 2010). A secondary effect of this effort shift was the impact on nearby operators who believed more fishers in their ‘patch’ impacted on their catches. No operators employed long-term adaptations, or diversified their target species due to lack of appropriate gear and the price differential between export live coral trout and domestic markets. Fisher surveys identified government support to (i) provide access to locations closed to fishing, (ii) remove other management controls, (iii) provide low interest loans, or (iv) relief funds as the best ways to mitigate the impacts of cyclones on their fishery.

Similarly, a review of fisheries policy for the commercial rock lobster fishery in Tasmania found that management is beginning to actively integrate the longer-term issues associated with climate change with shorter-term responses to current stock trends (Pecl et al., 2009). Current proactive management suggests the industry has the capacity to respond to longer climate trends even if it's not explicitly managed. Adaptation measures identified included: incorporate changes in lobster recruitment into catch modelling, establish a long-term lobster monitoring program, develop regional management tools, redefine standard risk management, develop longer-term priorities, and make no-regrets adaptation a priority.

On a more general level, a number of recent reviews have identified long-term adaptation options for fisheries management to minimise the impacts of climate change. These include: preserving age and geographic structure of fished populations; protecting key functional groups; co- and multi-jurisdictional management of stocks; integrated management systems that include social, economic and ecological values; reducing overcapacity in the fishery; incorporating a climate change catch quota into stock assessments; and reducing barriers to adaption such as resource depletion and resource reliance through diversification (Badjeck et al., 2010, Johnson and Welch, 2010, MacNeil et al., 2010). Diversification can be achieved through occupational multiplicity (several income generating activities), occupational mobility (i.e. diversification outside fisheries), geographic mobility (migration) and diversification within fisheries (i.e. multi-species, multiple gears). Diverse and flexible livelihoods require diverse and adaptable institutions and policies (Badjeck et al., 2010).

Brander (2010) identified focused fisheries management as being particularly important for populations at the edge of a species range that are likely to have adaptations to extreme conditions. These adaptations make them valuable sources of genetic material but also reduce their surplus production, thus increasing their vulnerability to (previously tolerable) levels of fishing. Special protection should therefore be afforded to populations at the edges of ranges that are also expected to experience the first adverse impacts of climate change (e.g. increasing temperature).

It has been suggested that climate change and overfishing can have significant synergistic impacts on fisheries (e.g. North Sea cod fishery) (Kirby et al., 2009). Therefore, improved fisheries and ecosystem management will be important for proactive adaptation to the impacts of climate change by minimising other stressors (e.g. overfishing and pollution) that will promote more resilient fish stocks (Allison et al., 2009, Perry et al., 2010, Koehn et al., 2011). Many of the management improvements that are needed do not require new science or understanding; they require development of acceptable, effective, responsive institutions and tools for achieving adaptive management (Brander, 2010) and an ecosystem approach to management (OECD, 2010, Hobday et al., 2011).

Other proactive adaptation options identified include improved long-term planning by incorporating climate change responses into fishery management plans (Cooley and Doney, 2009), reducing physical exposure to extreme climate events through improved access to climate information to inform fisheries decisions (Hobday and Poloczanska, 2010), disaster risk-reduction/early warning systems (Daw et al., 2009, Badjeck et al., 2010), conservation of mangroves to create natural barriers against sea level rise and storms, and changes to resource property rights allowing more flexible access (Badjeck et al., 2010). Bell et al. (2011) also identified conservation of key coastal habitats (e.g. coral reefs, mangroves and seagrass) as important to protect important fish species, create natural barriers against sea level rise and storms, and effective catchment management to minimise impacts from terrestrial runoff on coastal habitats that support coastal fisheries species (e.g. barramundi, prawns).

Climate change is expected to favour some fisheries species in Australia, such as warm temperate species, changing their distribution and relative abundance. For example, southern fisheries may have increased opportunities where tropical species move south but lost opportunities where southern species decline (Hobday and Poloczanska, 2010). If commercial fishers can change their harvest strategies and processing without incurring significant additional costs, travel time or associated fuel consumption, they can take advantage of these opportunities. Diverting effort to target new or different fisheries species will be an important adaptation strategy as distributions shift (MacNeil et al., 2010). The capacity to quickly adapt to changing fisheries resources using new harvest techniques and gear will be a significant factor determining the future success of commercial fisheries (Badjeck et al., 2010). For example, if the southern bluefin tuna distribution contracted south, as predicted, longline fishers would experience fewer seasonal area restrictions and be able to target other species (Hobday and Poloczanska, 2010).

3.6 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?

Recreational fishers will have some inherent flexibility to adapt to changes in fish distribution and seasonality, with options to target alternative species, fish at different times, or move to new fishing locations in the vicinity (Hobday and Poloczanska, 2010). For example, the responses of recreational and charter fishers after TC Hamish in 2009 on the GBR included moving locations and habitats they fished, targeting different species, and reduced expectations of catch (Tobin et al., 2010).

A study in the Indian Ocean of gear-based adaptive management in response to climate change by Cinner et al. (2009) identified gear types commonly used in coral reef fisheries and their role as adaptive management tools on reefs impacted by climate change. Gear types that target a high proportion of species likely to be affected by habitat loss and are important for coral recovery (e.g. traps and spear guns) are candidates for management restrictions post disturbance. In contrast, line fishing catches the lowest proportion of susceptible and recovery-enabling species and is not likely to affect recovery of reefs after climate-related impacts such as coral bleaching or cyclone damage. Given that full fisheries closures are not always practical, temporarily banning or restricting certain fishing gears is a potential adaptation tool for recreational fisheries that allows habitat recovery. This strategy may also have utility for commercial coral reef fisheries.

Recreational and charter fisheries may also have opportunities for businesses in new areas as fish stocks move, or for longer seasons where species respond to warmer ocean temperatures. For example, the southward movement of game fishing targets (warm water species) is likely to lengthen the season and provide opportunities further south that previously didn't exist (Hobday, 2010).

3.7 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/constraints; market drivers and constraints?

For fishers to be able to adapt to future change or capitalise on future benefits to some fisheries species, there will be barriers they need to overcome. Two recent reviews (Brander, 2010, Johnson and Welch, 2010) identified factors that will limit the ability of fisheries to adapt to climate change: the projected rapid rate of change; the compromised resilience of fisheries already under pressure from fishing, loss of biodiversity, habitat destruction, pollution, introduced and invasive species and pathogens; weak social and economic structures; a high dependence on fisheries; and inflexible management regimes.

Uncertainty about future climate change encourages the use of short planning horizons that focus on immediate problems while delaying mitigation actions until more information becomes available (McIlgorm et al., 2010). To avoid this, Miller et al. (2010) proposed a focus on integrated science that supports timely and appropriate institutional responses, a broader planning perspective, and development of resilience-building strategies, while Johnson and Welch (2010) proposed a rapid assessment approach that can identify highly vulnerable fisheries and targets for action. Perry and Ommer (2010) concluded that good progress is being made towards studying marine social and ecological systems as coupled systems, but that many issues still challenge full integration.

Economic constraints were also identified by McIlgorm (2010) as a significant barrier to fisheries adaptation, particularly in the context of oceanic fishers (e.g. tuna) that have made long-term investments in fishing vessels, fish storage and processing. Future changes in the distribution and abundance of stocks due to climate change and the expected increases in fuel prices are likely to be barriers to operators being able to travel greater distances to access moving stocks, or change gear or practices to target different species. This was observed in the GBR after TC Hamish, where operators in the coral reef finfish fishery did not target different species or markets due to their existing vessel and gear set-up (Tobin et al., 2010).

Changes in fish stock distribution and the abundance of target and non-target (but potentially "new") species are likely to disrupt existing access and allocation arrangements (Daw et al., 2009, OECD, 2010). In Australia, where fisheries are managed by a range of jurisdictions, climatic variations that lead to shifts in resource distribution may raise issues with regards to who manages the fishery or limit flexibility to access cooperatively manage resources that are shared among multiple jurisdictions. This was experienced in the North Pacific with the wild salmon fishery (Badjeck et al., 2010), and is predicted to occur as Australia's east coast tuna stock move south, necessitating changes to the jurisdiction of the Federal fishery in consultation with the Tasmanian Government, or between northern and southern state governments (McIlgorm et al., 2010).

Recent modelling by Fulton (2011) showed that from an economic perspective, larger fisheries operators had an adaptive advantage that enabled them to change their operation in response to fish redistributions, with the converse being true for small and/or family-based fishing operations that are less likely to be able to move to access shifting fisheries stocks. Family-based fishing operations also face a barrier associated with their long-term association with fishing, connecting their identity with fishing and potentially limiting willingness to adopt adaptations that involve occupational diversification (i.e. starting new income generating activities or leaving fisheries: Coulthard, 2009).

If adaptation options that involve further reductions of fishing pressure are to be adopted, it must be acknowledged that there is likely to be political opposition, as many of those same fisheries have already undergone extensive effort reductions over the past 10 years (Worm et al., 2009). This barrier to fisheries management is not new, and mechanisms have been identified to overcome community opposition, in particular, involving fishers and the broader public in decision-making in order to facilitate the necessary support for policy changes (OECD, 2010).

Commercial fisheries have a range of adaptation options available in the face of climate change, at the individual operator, community and government level. However, identifying and selecting the most appropriate measure is not straight-forward and requires further research to inform decisions and develop tools that ensure mal-adaptation doesn't occur.

3.8 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?

Fishers live with and already adapt to climate variation (see review of El Niño – Southern Oscillation (ENSO) in the context of marine biodiversity and resources and climate change impacts and adaptation by Holbrook et al., 2009), by moving the location and time where they fish, and the species they target. For example, fishers in the east coast longline fishery use a range of ports on the east coast to land their catch, and change where they fish as fish distribution and availability changes (Hobday et al., 2009). Similarly, the tsunami that impacted India in 2004 has resulted in a revision of fisheries management in the south with an increased focus on livelihood diversification, coastal rather than offshore fisheries, and post-harvest employment opportunities (FAO, 2010). Adaptation of fisheries to external impacts is possible for even small sectors, and examination of examples of successful adaptations provides lessons on ways to manage fisheries in an uncertain future, and how to overcome barriers to adaptation (OECD, 2010).

In cases where species managed under a quota system move to locations fishers do not hold quota, designing a flexible framework and developing markets for trading quotas (OECD, 2010) or an Individual Transferable Quota system (McIlgorm et al., 2010) may be options for overcoming the issue of access to a moving resource. The OECD (2010) report also identified governments as having an important role in identifying and removing institutional barriers to change, periodically reviewing protection measures to ensure they are still applicable and ensuring that they do not dilute incentives for fishers to adapt to future climate change. Government may also have a role to play in providing innovative incentive structures, including payments to fishing communities that offset reductions in their fish catches; payments to use new technology; creating and accessing new domestic or international markets or introducing new products; and, increased flexibility to deal with supply changes in relation to market demand (OECD, 2010).

Significantly, overcoming barriers to change within the fishing industry will require ongoing involvement of the fishing industry in co-management and self-governance initiatives to assist governments in meeting the new management paradigm required due to climate change (McIlgorm et al., 2010). Incorporating multi-stakeholder participation, a long-term perspective, and flexible livelihood and governance strategies into future fisheries management, will be key to effective adaptation to climate change (Plaganyi et al., 2011a).

4. CONSERVATION MANAGEMENT

4.1 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?

Climate change impacts on marine biodiversity are projected to be greatest in high latitudes (specifically south eastern Australia) and the tropics (Cheung et al., 2010), particularly coral reefs and coastal habitats including wetlands (Steffen et al., 2009, Hughes, 2011). Tropical reef ecosystems are valuable biodiversity 'hotspots' that are vulnerable to a range of future climate change impacts. In addition, tropical marine habitats that are subject to local pressures are likely to be more vulnerable to increasing climate change impacts in the future (Veron et al., 2009, Waycott et al., 2009, Anthony et al., 2011, Bell et al., 2011), as are subtropical rocky habitats (Russell et al., 2009). Intertidal habitats that experience peaks of warming daytime temperatures coinciding with exposure at low spring tides are expected to be impacted by die-offs despite the high stress-tolerance of some intertidal organisms (Brierley and Kingsford, 2009). These ecosystems and many of the species that live in them are likely to require adaptation management and supporting research.

In tropical marine ecosystems of Australia there is growing evidence of ecosystem and species vulnerability to climate change that has conservation implications to protect future adaptive capacity. For example, responses to increasing sea surface temperatures (e.g. coral bleaching and mortality, Veron et al. (2009); seabird foraging and breeding success, Alter et al. (2010)), ocean acidification (e.g. coral calcification, De'ath et al. (2009); reef community structure, Fabricius et al. (2011); impaired ability of larval fish to detect predators, Dixson et al. (2010); fish aerobic capacity, Munday et al (2009); invertebrate growth, Byrne et al. (2010)) and indirect climate effects (e.g. cetaceans, Alter et al. (2010)) provide support for prioritising adaptation management and research effort. Modelling has also predicted future biomass changes for species of conservation interest in the tropics (Brown et al., 2010) and local extinctions and species invasions in south eastern Australia (Cheung et al., 2009).

A decline in coral calcification on the GBR was documented by De'ath et al. (2009) and postulated to be due to increasing temperature stress and a declining saturation state of seawater aragonite, with a tipping point reached in the late 20th century. Further, studies in shallow CO_2 seeps in Papua New Guinea (Fabricius et al., 2011) have observed reductions in coral diversity, recruitment and abundance of framework building corals, and shifts in competitive interactions between taxa as pH declines from 8.1 to 7.8 (the change expected if atmospheric CO_2 concentrations increase from 390 to 750 ppm). However, coral cover remained constant between pH 8.1 and ~7.8, as massive *Porites* corals dominated, despite low rates of calcification, and reef development ceased below pH 7.7.

Evidence from Michaelmas Cay in the GBR – an important tropical seabird nesting site – suggests that climate variation may be driving foraging success and breeding-population dynamics in the sooty tern (*Sterna fuscata*) and the common noddy (*Anous stolidus*) but not the inshore crested tern (*S. bergii*), implying that a precautionary approach is warranted for the management of any potential stressors to birds in this ecosystem (Devney et al., 2009). A study by Alter et al. (2010) suggests that tropical coastal and riverine cetaceans such as the Irawaddy dolphin, Indo-Pacific humpback dolphin, and finless porpoise are particularly vulnerable to climate-driven shifts in human behaviour and economic activities.

Australian temperate marine regions have a higher rate of species endemism (e.g., Benkendorff and Przeslawski (2008): for molluscs) and typically temperate species have a narrow distributional range. With the predicted accelerated warming of Australia's southeast coast and Tasman Sea, endemic coastal temperate species in southern mainland Australia and Tasmania are less likely to shift their distribution further south as available habitat is limiting, and are therefore good candidates for research focus. Acidification coupled with local stressors is expected to impact on coralline algae, an important component of temperate and subtropical near shore communities (Russell et al., 2009), with consequences for habitat structure. The subtropics will be an important adaptation zone for both tropical and temperature species and warrant further research focus. Reduced calcification will also likely affect temperate invertebrates, such as sea urchins, many of which are ‘keystone species’ and therefore result in ecosystem wide consequences (Byrne, 2011).

Modelling by Brown et al. (2010) for 12 Australian marine food webs under the A2 emissions scenario over the next 50 years predicted that the biomass of functional groups of conservation interest (marine turtles, marine mammals, seabirds and sharks) generally increased due to increases in primary production. The few simulations that predicted some species declines (e.g. turtles in Jurien Bay and dugongs on the Burdekin coast) were due to local influences, such as declines in food resources (e.g. seagrass) or strong competition. These results show that changes in primary productivity will cause predictable changes in the biomass of most marine species that can be used to inform future adaptation of threatened species. Primary production declines may challenge management by requiring reductions in other impacts on marine ecosystems to conserve biodiversity, while primary production increases will provide opportunities to conserve threatened biodiversity.

Modelling by Cheung et al. (2009) predicted that climate change may lead to local extinctions in sub-polar regions (e.g. Tasmania) and the tropics, and species invasions in the Southern Ocean. Together, they are expected to result in dramatic species turnovers worldwide of > 60% of present biodiversity, implying ecological disturbances that may disrupt ecosystem services and future adaptation.

A current FRDC/DCCEE project (2010/564) is aiming to investigate the potential for translocating fish as an adaptation measure to pre-adapt coastal ecosystems in Tasmania using highly valued locally extinct species. Further research to understand the long-term consequences of ocean acidification, particularly for acclimatisation or adaptation are needed (Hofman et al., 2011), and will in part be addressed by FRDC/DCCEE project 2010/510 that is developing a model to predict the effects of ocean acidification and climate change on the distribution of deep reef corals and biota. In addition, many species of conservation priority have not been studied in detail, in terms of their responses to climate drivers and adaptive capacity, and another current FRDC/DCCEE project (2010/533) is investigating adaptation options to increase resilience of conservation-dependent seabirds and marine mammals impacted by climate change, filling an important knowledge gap.

4.2 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?

Most of the recent work on critical thresholds for ecosystem change and ‘tipping points’ has focused on the impacts of single parameters rather than multiple stressors, particularly temperature. For example, an examination of historical climate data and coral reef ecosystem responses worldwide has shown that mass coral bleaching causing mortality in geographically extensive locations started when atmospheric CO_2 concentrations exceeded 320 ppm, and bleaching became sporadic but highly destructive in most reefs at ~340 ppm. Coral reefs are projected to be in rapid and terminal decline at 450 ppm (2030–2040 at current rates) from multiple synergies of mass bleaching, ocean acidification, and local environmental impacts (Veron et al., 2009).

Warming of tropical oceans has raised the baseline sea surface temperature where coral reefs live closer to the thermal threshold for bleaching, so that natural variability is more likely to exceed this threshold (Eakin et al., 2009). In addition, a recent study proposed that elevated nutrients can lower coral bleaching thresholds (Wooldridge and Done, 2009). Thresholds for bleaching in subtropical Australian coral reefs have been predicted to be 26.5–26.8°C, lower than the threshold for tropical corals, indicating that subtropical reefs may be more susceptible to thermal stress (Dalton and Carroll, 2011) in a region of eastern Australia that is projected to experience accelerated ocean warming. The results of a current FRDC project (2010/506) to develop effective approaches for ecological monitoring and predictive modelling of temperate reefs should provide useful adaptation options to minimise climate change impacts.

A recent study in the southern GBR documented mechanisms of ecological recovery after a coral bleaching event that included rapid regeneration of remnant coral tissue, very high competitive ability of corals allowing them to out-compete macroalgae, a natural seasonal decline in the dominant species of macroalgae, and an effective marine protected area (Diaz-Pulido et al., 2009). A study by Bruno et al. (2009) supports this, finding that coral-algal phase shifts are far less common than expected, even in reefs subject to overfishing and nutrient enrichment, with only 4% of 1851 reefs surveyed dominated by macroalgae. These examples demonstrate the dynamic nature of resilient reefs, and the need to measure ecosystem processes to inform management.

Modelling of coral reef ecosystem resilience under the SRES A1FI scenario by Anthony et al (2011) projected that severe acidification and ocean warming lower reef resilience (by impairing coral growth and increasing mortality), even when herbivore grazing is high and nutrients low. Further, acidification and warming lowered the threshold at which reduced grazing leads to a coral–algal phase shift. At CO_2 levels above ~600 ppm the model predicted a regime shift to alternate coral–algal states, leading to macroalgal dominance at the highest CO_2 level. Specifically, increasing CO_2 lowers the threshold at which local and regional processes drive the community from coral-dominated to algal-dominated. Interestingly however, results of recent experiments indicate that although the rate of macroalgal growth is enhanced by 20–40% under intermediate CO_2 levels (560–700 ppm) it declines under higher CO_2 concentrations (Diaz-Pulido et al., 2011), meaning that these phase shifts may in fact be less likely if CO_2 becomes very high.

Studies on the interactive effects of warming and acidification on abalone (*Haliotis coccoradiata*) and sea urchin (*Heliocidaris erythrogramma*) found deleterious effects on development (e.g. number of spines produced, skeleton formation) with increasing acidification (pH 7.6–7.8). An interactive effect between stressors was also documented for sea urchins, with +2°C warming reducing the negative effects of low pH but the developmental thermal threshold was exceeded at +4°C (Byrne et al., 2010). A review of marine invertebrate thresholds more broadly shows that all development stages are highly sensitive to warming, and larvae are particularly sensitive to acidification (Byrne, 2011).

Recent modelling of increasing air and sea temperature impacts on marine turtle nesting in northern Australia project that hatchling production will be primarily all females at three Queensland nesting sites by 2070 (Moulter Cay, Milman Island and Bramble Cay) and by as early as 2030 at Ashmore Island (WA) and Bare Sand Island (Northern Territory), while these latter two sites are projected to regularly exceed the upper thermal incubating threshold (33°C) by 2070, resulting in deformed hatchlings and severe mortality (Fuentes et al., 2009).

An assessment of the implications of sea-level rise for coral reefs using historic reef records found that coral reef development was inhibited on the reef crest (+3 m) with a 2-3 m sea-level rise during the last interglacial period (Blanchon et al., 2009), which is a threshold that may be exceeded if rapid ice loss occurs in the Antarctic and Greenland ice sheets. Mangroves, on the other hand, are expected to benefit from projected sea level rise, potentially expanding landward and increasing in productivity, particularly in areas that experience higher rainfall (Steffen et al., 2009, Waycott et al., 2011).

There is still limited knowledge on the interactive effects of climate change stressors for many marine species, and critical thresholds could be underestimates if these synergistic effects are not considered. Similarly, climate change stressors that cause immuno-suppression could facilitate the establishment and spread of disease thus greatly shifting the ‘tipping point’ of marine populations and communities. Further research on critical thresholds for marine ecosystems and species, and methods for measuring ecosystem dynamics and processes, such as phase shifts, is required for a range of marine ecosystems in Australia to identify species and ecosystems that require immediate assistance, and to inform future adaptation management.

4.3 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?

Management of Australia's marine biodiversity under future climate change will need to take an ecosystem approach to conservation (Brierley and Kingsford, 2009), explicitly considering the cumulative effects of multiple pressures (Russell et al., 2009), impacts on linkages between species and ecosystems, dynamic ecosystem interactions (Walther, 2010) and ecosystem function (Willis et al., 2010) as they interact to reduce resilience. For example, the effects of fishing and climate interact, because fishing reduces the biodiversity of marine ecosystems, making them more sensitive to additional stresses, such as ocean warming (Brander, 2009). New generation ecosystem models (e.g. multi-species coupled biophysical and end-to-end) can provide valuable ecosystem response and multi-pressure predictions - however, they are not currently used by management due to their accuracy and precision not being sufficient for defensible management decisions (Ito et al., 2010). This barrier requires further work to be addressed and provide conservation governance with a practical tool in the face of climate change.

Climate-aware conservation will need to develop objectives that are not underpinned by a return to historical baselines (Hobday, 2011), but rather acknowledge the inherent dynamic nature of ecosystems. Hughes et al. (2010) suggested that learning how to avoid undesirable phase-shifts in marine ecosystems, and how to reverse them, requires a reform of scientific approaches, policies, governance structures and management goals. A resilience-based approach that builds on an improved understanding of ecosystem dynamics, thresholds and system feedbacks may provide a future management paradigm (Obura and Grimsditch, 2009, Hughes et al., 2010). Progress is being made in this arena, with a recent trial in the southern GBR using a series of indicators to identify resilient reefs and regions to inform management (Maynard et al., 2010) and operationalise a range of local resilience strategies, providing a possible framework for future conservation.

An alternative hypothesis put forward by Cote and Darling (2010), however, is that chronic disturbances gradually degrade the ecosystem and remove disturbance-sensitive individuals and/or species, shifting the tipping point in response to climate change and ultimately making the ecosystem more resilient to future disturbances. Therefore, management of local anthropogenic pressures will inadvertently lower the resilience of the system (Cote and Darling, 2010). This poses an interesting challenge for resilience-based management and further work is needed on the most effective strategies to enhance and/or protect resilience to climate change in marine ecosystems.

Marine managers may also need to change the ecosystem components that they manage and the measures they use. For example, results of modelling ecosystem responses to climate-driven primary production changes by Brown et al. (2010) led to the recommendation that marine managers need to consider primary production in future governance arrangements. Attention to ecosystem processes in management goals was also advocated by Casini et al. (2009) who identified ecosystem impacts due to trophic cascades, and by Veron et al. (2009) who advocated maintaining an effective trophic pyramid by protecting top predators. Reductions in marine biodiversity (due to local and regional drivers) will likely lead to compromise resilience of ecosystems to climate change, and future management will need to consider ecosystem structure and function to maximise adaptation (Planque et al., 2010).

Recent work by Iwamura et al. (2010) used a resource allocation algorithm to prioritise conservation investment that incorporates the ecological stability of ecoregions under future climate change. Although this work focused on terrestrial ecosystems, the governance approach of accounting for ecological stability of ecoregions and focusing funding in stable regions provides a realistic way of incorporating climate change into conservation planning that may have utility for marine systems.

In addition, climate change acts at a range of scales – cellular, genetic, species, population and ecosystem – and managers will need to respond to this by acting over different spatial and temporal scales than traditionally have been used. The focus of conservation will need to shift from historic species assemblages to potential future ecosystem structure and function, and active adaptive management based on potential future climate impact scenarios (Lawler, 2009).

The Convention on Biological Diversity identified that *"…biodiversity, through the ecosystem services it supports, also makes an important contribution to both climate-change mitigation and adaptation. Consequently, conserving and sustainably managing biodiversity is critical to addressing climate change"* (CBD, 2010). However, Rice and Garcia (2011) suggest that actions being proposed to address pressures on marine biodiversity are incompatible with the actions considered necessary to meet future sustainable use and development. This poses a significant challenge to biodiversity conservation as a strategy to combat climate change that requires further consideration.

An FRDC/DCCEE project (2010/532) currently underway aims to identify adaptive governance and management arrangements for conserving marine biodiversity in the context of climate change.

4.4 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?

Prioritising conservation of marine ecosystems in the face of climate change will be important, and decisions need to be made whether areas of high biodiversity (Trebilco et al., 2011), high genetic diversity (Sanford and Kelly, 2011, Willis et al., 2010, Reed et al., 2011), high stability (Iwamura et al., 2010), high resilience (Hughes et al., 2010), or novel ecosystems (Willis et al., 2010) should be protected. Veron et al. (2009) argue that the speed at which climate change is impacting marine ecosystems leaves little opportunity for evolutionary processes and survival will be highly dependent upon the natural resistance already existing in gene pools and the management interventions that can increase resilience.

Modelling by Anthony et al. (2011) supports this assertion, projecting that under a low CO_2 scenario (e.g. below 540 ppm) local management that maintains or restores resilience (e.g. healthy herbivore populations for grazing and low nutrients) increases the chance that reefs remain coral-dominated. However, under high CO_2 (A1FI scenario), acidification effects on coral calcification and increased coral mortality from thermal bleaching may potentially reduce branching coral abundance even if grazing and nutrients are well-managed. This indicates that management efforts to control local pressures will become increasingly critical as atmospheric CO_2 levels rise above 450–500 ppm (Anthony et al., 2011).

Some phenotypic adaptation to thermal stress has been indicated in southeast Asia after the 2010 coral bleaching event (Guest et al., 2012). However, long-lived species are unlikely to have the phenotypic plasticity to 'keep pace' with project climate change rates (Reed et al., 2011). Baskett et al. (2010) modelled different management priorities to address thermal stress on corals and found that protecting diverse coral communities is critical to maintaining coral cover in the long-term, as is reducing other anthropogenic impacts. Addressing local scale impacts on tropical marine ecosystems is considered critical for maintaining healthy ecosystems in order to build resilience to future climate change, and secure future adaptation options (Hoegh-Guldberg et al., 2009, Waycott et al., 2009, Anthony and Maynard, 2011, Wilkinson and Brodie, 2011). Management will need to be coordinated and collaborative across sectors to reduce current stressors from deteriorating water quality, overexploitation of marine resources, pollution and shipping (Hoegh-Guldberg et al., 2009, Veron et al., 2009, Wilkinson and Brodie, 2011).

Another management strategy that is considered in a number of recent studies to have potential for ameliorating climate change risks and enhancing adaptation options is the use of marine reserves or marine protected areas (MPAs). Marine reserves (or no-take areas) can have great benefits for mobile species (Graham et al., 2011), benthic communities (e.g. increasing coral cover), biodiversity conservation (McCook et al., 2010), and protection of genetic diversity for future adaptation (Sanford and Kelly, 2011). However, Graham et al. (2011) suggest that they offer only limited resilience to climate impacts. For example, Myers and Ambrose (2009) documented that bleached reefs on the GBR showed no difference in recovery rate between protected and general-use areas over a 6- to 10-year period. Similarly, no differences in recovery in the 7 years following the 1998 bleaching event were found as a function of protection status (Selig and Bruno, 2010).

The utility of MPAs may lie in their ability to protect ecosystem connectivity and recovery after climate disturbance. Simulations by Munday et al. (2009) showed that climate change is expected to reduce population connectivity in coral reef ecosystems by reducing average larval dispersal distance, with naturally fragmented habitats likely to be at higher risk. The study suggests that future conservation consider habitat fragmentation and connectivity when designing MPAs, placing reserves closer together to retain connectivity patterns. As populations become smaller and more isolated due to climate-related habitat loss and fragmentation, it may also be necessary to increase the size of reserves to ensure viable populations are maintained within their boundaries (Munday et al., 2009). In addition, modelling showed that protection of, and connectivity to, areas expected to have lower exposure to climate drivers was identified as important for enhancing the adaptive capacity of corals (Baskett et al., 2010) and promoting ecosystem recovery post-disturbance (Cote and Darling, 2010).

Further consideration of MPAs as tools for addressing climate impacts on marine systems is required including optimum design. Flexibility in MPA design (both spatial and temporal) has been identified as critical to allow for climate-related changes in marine environments, with mobile MPAs proposed as an option for protecting species as they change their distribution (Hobday, 2011). Guidelines for incorporating connectivity into MPAs have been developed by McCook et al. (2009), and McLeod et al. (2009) provided guidance on the size, spacing, shape, risk spreading (representation and replication), critical areas, connectivity, and maintenance of ecosystem function for designing MPA networks that are more robust in the face of climate change.

Effective implementation of MPAs as a resilience strategy will depend on local and/or regional influences on connectivity and marine habitats, and further work is required to better understand the spatial and temporal drivers at specific locations. Current FRDC projects, to assist marine biodiversity governance and management respond to climate change by identifying the critical influences of climate change on habitats and species (2010/532) and provide information for adapting deep sea reserves to climate change (2010/510), will provide support for adaptation and MPA management. In addition, as international initiatives work towards improving networks of MPAs that connect source and sink reefs to promote recovery after climate-related impacts, investigations of whether these are effective in reducing long-term climate change risks are required.

4.5 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?

Although there are a number of recent publications seeking to detail social resilience and ways to measure and/or enhance it, many still provide general concepts rather than practical examples. For example, high livelihood diversity, policy perceptions, and resource dependency are well-documented social concepts known to significantly influence social resilience (Obura and Grimsditch, 2009, Marshall et al., 2010). Resource dependency is particularly explored in detail, and defined as comprising of social components (occupational attachment, attachment to place, employability, family circumstances) economic components (business size, strategic approach, financial situation), and environmental components (level of specialisation, local skills and knowledge and environmental attitudes) (Obura and Grimsditch, 2009). While conceptual frameworks and operational tools define social resilience as comprising of: (i) the perception and management of risk, (ii) the proximity to financial and emotional thresholds, (iii) the capacity to plan, learn and reorganise, and (iv) the level of flexibility (Marshall, 2009).

Most recent work to assess the social resilience of communities has been done at the international level (Obura and Grimsditch, 2009, Marshall et al., 2009, Wongbusarakum and Loper, 2011). For example, McClanahan et al. (2009) used socioeconomic household surveys as measures of social resilience to determine the adaptive capacity of coastal communities reliant on adjacent coral reefs in the Indian Ocean. Social organisation and networks were found to affect the adaptive capacity of communities and were recommended as a target for management support.

Wongbusarakum and Loper (2011) identified the relationship of communities to environments and ecosystems likely to be impacted (i.e. their resource dependence) and their capacity to cope with and adjust to new circumstances as being fundamental in social resilience to climate events and impacts.

The interaction between management and stakeholders has also been shown to be critical to social adaptation, with meaningful involvement in the decision-making process essential to fostering feelings of satisfaction, understanding, trust and confidence in the future (Marshall et al., 2010). Similarly, designing co-management arrangements that include social integration and allow for self-organisation and autonomous control by stakeholders was identified as critical for building the adaptive capacity of social systems (Kalikoski and Allison, 2010). Organisations in the UK that are successfully adapting to climate change have particular features, including: visionary leadership, setting objective, risk and vulnerability assessment, guidance for practitioners, organisational learning, low-regret adaptive management, multi-partner working, monitoring and reporting progress and effective communication (Wilby and Vaughan, 2011).

A number of recent studies have identified stakeholder perception of resource condition and future impacts of climate change as significant contributors to their willingness to participate in adaptation measures (Obura and Grimsditch, 2009, Marshall et al., 2010, Wongbusarakum and Loper, 2011). However, significant work remains to understand the nuances of negotiating and alliance building, and how perceptions change over time.

5. TOURISM

5.1 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)?

Recent reviews have identified a number of Australia's tourism regions that are at risk from climate change impacts, notably the Great Barrier Reef, Ningaloo Reef, and coastal wetlands in the Northern Territory (DCC, 2009, Turton et al., 2009). Marine tourism destinations such as the Great Barrier Reef, Ningaloo Reef, coastal islands and beaches are in regions that are likely to be affected by sea-level rise, increased cyclone intensity and storm surge (DCC, 2009, Moreno and Becken, 2009). Tropical north Queensland is probably the most threatened tourism region in Australia (in terms of absolute numbers of holiday visitors) exposed to the effects of climate change -- primarily from the risks of increased sea surface temperatures (leading to coral bleaching), ocean acidification (compromising coral calcification), and increased tropical cyclone intensity (DCC, 2009). In addition, marine tourism assets in popular island and beach destinations (e.g. the Gold Coast, Sunshine Coast and Fraser Island) are vulnerable to sea-level rise, storm surge and erosion, likely to impact on regional communities and economies that depend on tourism (DCC, 2009).

Sea-level rise and storm surge are projected to pose problems for many coastal tourist destinations, such as beaches, estuaries, coral reefs, wetlands and low-lying islands. A vulnerability assessment undertaken for the Department of Climate Change in 2009 examined the cumulative effect of a 0.5 m sea-level rise on climatic extreme events that impact coastal environments (e.g. severe storms) and projected that events that now occur every 10 years could occur every ~10 days, and current 1-in-100 year events could occur several times a year by 2100 (DCC, 2009).

Coral reefs are particularly important for tourism (Harding et al., 2010) and expected to be highly vulnerable to climate change. A recent study of the socio-economic implications of climate change impacts on the GBR ecosystem concluded that the Cairns region will be the most susceptible, followed by the Mackay-Whitsundays and then Townsville (Miles et al., 2009). This is particularly concerning for the tourism industry because the Cairns and Mackay-Whitsunday regions receive the majority of tourist visitation to the GBR (GBRMPA, 2009). Miles et al. (2009) also found that the visitor experience is highly linked to reef condition, with most tourists who were asked to rank the key features influencing their reef experience choosing characteristics that are either directly or indirectly expected to be affected by climate change due to coral bleaching and the consequent decline in reef habitat and biological complexity.

Climate-related increases in incidences of algal blooms and poor weather are also expected to impact on reef tourism. Coghlan and Prideaux (2009) investigated the effects of poor weather on GBR marine tourism experiences, finding that the increased likelihood of seasickness, cold and wet conditions, reduced water visibility, and difficult snorkelling/diving conditions, reduced overall visitor satisfaction. Poor weather was found to have a direct and immediate effect on tourist experience and satisfaction, and lowered perceived value for money.

More generally, climate change is expected to influence tourists' preferred destinations due to its perceived effect on the appeal of natural attractions, since tourist attractions are usually based near attractive or unique natural features (Dwyer et al., 2009), and the conditions of these plus the climate are important determinants of industry viability (Dwyer and Kim, 2003). Climate change will also potentially affect the profitability of the tourism industry through indirect impacts on the cost of transport and accommodation (Dwyer et al., 2009).

5.2 How can the impacts on tourism, if any, of public perceptions of climate impacts on Australia's marine biodiversity and resources be minimised?

Recent studies have identified a negative public perception of climate change impacts on terrestrial tourist destinations such as Kakadu and the Blue Mountains (Turton et al., 2009), and the lessons from these areas can be potentially applied to tourism that is dependent on marine biodiversity and resources. For example, a consistent and coordinated public campaign to address negative public views and to highlight positive destination aspects can be applied to marine tourism. This has been proposed for GBR marine tourism, where the impression that north Queensland and the GBR may be 'buffered' from extreme climate impacts, relative to other regions (Turton et al., 2009), can be used as a marketing advantage.

However, there are few recent studies that fully examine the public perception of climate change impacts on Australia's marine tourism destinations, and how any negative views can be minimised. This will be particularly important for regions that rely on domestic beach recreation where alternative destinations may be available and easily accessible.

5.3 How can the links between resource condition and marine-dependent tourism business vitality be modelled and evaluated?

Although few models exist that can link marine resource condition and tourism viability, two recent projects have developed novel approaches to examine the influence of resource condition on the tourism industry. Bohensky et al. (2011) developed four scenarios that considered global development and Australian development to link the condition of marine ecosystem goods and services to regional communities and industries. Narratives were used to describe each scenario and the modelling results showed that under the scenarios 'trashing the commons' and 'free riders' the international marine tourism industry essentially collapses shifting from biodiversity to beaches, casinos, theme parks and shopping. While under the scenario 'treading water' the international tourism industry adapts by shifting away from reefs and focusing on more undamaged locations and species (e.g. whale-watching), and reduces its ecological footprint. With the 'best of both worlds' scenario, the international reef tourism industry declines by mid-century but recovers and remains the primary regional industry in 2100.

Pham et al. (2010) developed an approach to examine the potential economic impacts of climate change on tourism in five Australian tourism destinations. The study found that although the economic impacts were small nationally, at a regional level they were considerable, with communities that had a larger tourism share predicted to experience a greater economic effect. This confirms the notion that regional destinations that depend on tourism are likely to be adversely impacted economically due to climate change effects on natural systems. Although the study focused on only one region that depends on marine tourism – the Cairns region – the findings may be broadly applicable to marine tourism destinations around Australia.

Further work is required to fully understand the links between resource condition and vitality of marine-dependent tourism businesses in Australia, to inform future adaptation to climate change.

5.4 What is the adaptive capacity of the marine tourism industry and how can it be enhanced to cope with climate change impacts?

While some recent studies have suggested that coastal tourism as a whole may have considerable resilience to climate change impacts, small to medium sized operators are likely to have less capability to adapt (Burns and Bibblings, 2009, DCC, 2009, Turton et al., 2009). A large part of the tourism industry in Australia consists of small to medium enterprises that are more constrained in terms of mobility and flexibility to adapt to the impacts of climate change and are therefore likely to be more vulnerable to significant economic effects (DCC, 2009). These smaller operators are unable to plan for time frames longer than 2-5 years and, as a result, making costly changes now to address threats that may or may not occur in 10, 40 or 60 years is not something that they are willing (or able) to do (Turton et al., 2009). Therefore adaptation and mitigation strategies for the majority of tourism businesses in Australia need to have clear benefits and be simple, cheap and effective (Turton et al., 2009).

A recent survey of businesses in the GBR region by Miles et al. (2009) asked operators about what level of demand downturn would impact negatively on their enterprise. Survey results show that only 40% of businesses would be likely to close in response to a 50% downturn with the most likely response to a 25-50% demand downturn being to reduce staff and diversify by seeking alternative markets and/or products. These results indicate that north Queensland businesses have reasonable adaptive capacity to respond to changed conditions. However, they need to know what those changed conditions are. In addition, 50% of business operators believed they would have opportunities as a result of climate change, indicating a general optimism about their ability to adapt to the challenges of climate change (Miles et al., 2009).

A workshop with Australian tourism stakeholders reached consensus that the tourism sector must help mitigate and adapt to climate change, and develop more climate-friendly and climate-proof alternatives (Dwyer et al., 2009). Participants agreed that the economic benefits of timely action by the industry to invest in mitigation and adaptation far outweigh the costs, and acknowledged that investing in 'healthy' environments may come at the expense of higher priced transport and accommodation with consequent impacts on visitor numbers (Dwyer et al., 2009, Gössling et al., 2010). Adaptation options identified by stakeholders included sustainable operations, destination management, targeted marketing, education, risk management, innovation in product development and long-term strategic planning (Dwyer et al., 2009).

A CRC Sustainable Tourism project (Turton et al., 2009) examined the potential impacts of climate change in five Australian tourist destinations over the next 10, 40 and 60 years (with the Cairns region being the only marine-dependent area) and identified seven adaptation themes including: green, data and knowledge, disaster management, marketing, planning, community-based, and resources. Further to this work, Turton et al. (2010) surveyed tourism stakeholders in four Australian destinations to examine tourism stakeholders' knowledge of climate change impacts, existing adaptation approaches, and the potential to develop a self-assessment toolkit to assess tourism vulnerability. The study found that the responsibility for leadership on climate change related issues was seen to be with the public sector (especially local authorities) and not with the industry or tourists. Secondly, the tourism sector was hesitant to invest in climate change adaptation due to perceived uncertainties in the magnitude of climate change impacts. This view was supported by the adaptation themes stakeholders identified, which were actually adaptations to climate policy (e.g. reducing emissions or marketing the destination as "green"). This limited understanding of climate change adaptation by tourism stakeholders represents an important barrier to mainstreaming climate change in tourism decision-making.

At an international level, the *Climate Justice and Tourism* side event at the Copenhagen Climate Conference in December 2009 focused on emissions reductions, adaptation requirements for tourist destinations and questions around equity, justice and the role of tourism in developing countries. The session concluded that "*technological measures alone won't solve the problems without accompanying structural and behavioural changes*" (Scott and Becken, 2010). This provides some guidance for enhancing and supporting tourism businesses to adapt to climate change.

A recent review by Burns and Bibbings (2009) suggested that the tourism industry has a number of adaptation options in the face of climate change, including working with governments in the short-term to identify supply/value links, and working with tourists to develop business models that minimise carbon footprints. In the longer-term, operators can examine their practices to develop new ways of satisfying the experiences tourists want, and communicating with government, industry, the media, and consumers to develop socially beneficial behaviour and new ways of marketing.

Mitigation that complements adaptation has been identified as a necessary response by the tourism industry, with Gössling et al. (2010) advising operators to assess their dependency on and vulnerability to energy-intense tourism, and to restructure their tourism products to favour low-carbon, high value tourism. Similarly, Weaver (2010) suggests that only focussing on adaptation without the tourism industry also tackling mitigation is disingenuous, and supports strategies that yield practical and tangible benefits and/or simultaneously address local as well as global issues, such as habitat restoration that can enhance local biodiversity and store carbon.

Ultimately, enhancing the adaptive capacity of the Australian marine tourism industry to climate change will require confidence in future climate projections, motivation to avoid risk or take up opportunities, demonstration of the viability of new technologies, transitional and legislative support from government, resources from public and private sectors, and effective monitoring and evaluation (Turton et al., 2009). Tourism operators in the GBR have taken up this challenge, developing the *GBR Climate Change Action Strategy 2009 – 2012* to address climate change impacts on their industry and implement effective adaptation options (TCCAG, 2009).

Two current FRDC projects are examining adaptation options for tourism destinations and communities in Australia: one project looking at coastal regional communities (2010/542) and another investigating beach and surf tourism and recreation including infrastructure (2010/536). These will provide valuable insights into the adaptive capacity of Australian tourism and ways to enhance it in the future.

5.5 What engineering and technical solutions might reduce risks to marine tourism infrastructure from increased weather severity?

The recent coastal vulnerability assessment undertaken for the Department of Climate Change (DCC, 2009) identified issues in relation to engineering solutions to reduce the risk posed by increasing climate events to coastal infrastructure. Of key importance was the development of engineering standards and benchmarks that incorporate climate projections and include specifications for the resilience and life of buildings and building materials. In addition, providing more detailed information for engineering design, auditing existing infrastructure that may be at risk, using risk allocation frameworks, providing on-ground demonstrations of adaptation options, and building local capacity, were identified as important.

The type of technical solutions available for protecting coastal infrastructure include barrages, seawalls, groynes and other 'hard' engineering defences that can maintain coastal assets in their current location (DCC, 2009). 'Soft' protective works such as nourishment of beaches were also put forward as a viable solution to help reduce beach erosion and the effects from greater storm surges in the short- to medium-term, but require repeated access to sand resources and are therefore not always a viable long-term prospect. Coastal ecosystems (e.g. mangroves and coral reefs) can also provide coastal protection, buffering many of the risks associated with severe weather events in the coastal zone and planning is needed to maximise ecosystem resilience and allow for natural movement (DCC, 2009).

Other technological solutions include the modification of existing structures to meet future climate change impacts, provision of setbacks and buffers for future coastal developments, and preparation of emergency management plans that can all allow the continued or extended use of high risk areas. Alternatively, coastal infrastructure can be relocated from a high risk to a lower risk site (DCC, 2009). Although all these measures have been identified in relation to any built environment on the Australian coast, the engineering and technical solutions suggested can equally be applied to marine tourism infrastructure.

The importance of this adaptation response is highlighted in the *GBR Tourism Climate Change Action Strategy* (TCCAG, 2009) that has identified the development of environmental management and engineering strategies to address climate change impacts on marine tourism infrastructure, such as ports, marinas, pontoons, roads, seaside buildings, and boats as a key action for the industry in north Queensland (Strategy 5.4). The focus is on reducing damage to infrastructure and insurance costs by retrofitting existing assets and implementing climate smart planning, zoning and development for future assets (TCCAG, 2009).

5.6 Are current safety standards and protocols for marine activities adequate to deal with future conditions under climate change?

Although increasing threats to maritime safety have been identified as an issue for fisheries operations (Daw et al., 2009, Hobday and Poloczanska, 2010, Bell et al., 2011), tourism (TCCAG, 2009) and other shipping activities, an extensive review of the literature and relevant websites (e.g. Australian Maritime Safety Authority, Maritime Safety Queensland) revealed no recent studies that investigate whether current safety standards and protocols are sufficient to deal with future climate conditions. This is an important knowledge gap that needs to be addressed for a range of maritime sectors.

5.7 What are the most appropriate techniques for preserving beaches in the face of rising sea levels?

In Australia, the switch from accreting beaches to receding beaches is a coastal management threshold that is not well understood but is likely for some locations due to future climate change impacts from rising sea level and storm surge (DCC, 2009). Fortunately, Australian beaches are currently not receding on a large scale, except in some localised places, such as 90 Mile Beach in Victoria (Sharples et al., 2009). In other locations, revegetation and better coastal management have reversed erosion where vegetation removal had made dunes unstable (DCC, 2009), and hard engineering and development on fore-dunes coupled with rising sea level have resulted in erosion hotspots (Sharples, 2009). For example, the erosion of Redcliffe beaches (near Brisbane) is consistent with the present day increase in sea level, and modelling for Manly Beach has identified sea-level rise as the main driver of erosion, and predicts a 50% probability of a further 50 m of erosion by 2100. Modelling for Bundjalung Beach (New South Wales north coast) shows that the beach is sensitive to sediment loss and sea-level rise, and has a 50% probability of 150 m of erosion by 2100 (DCC, 2009, Sharples, 2009).

Responses to climate-induced erosion include beach replenishment, dune protection and hardening, and progressive retreat, which have been proposed for Roches Beach near Hobart in Tasmania (DCC, 2009). However, experience shows that beach replenishment is a costly exercise in some locations that will be ongoing if the source of erosion is not addressed, and ultimately longer-term solutions will be required. Parkinson (2009) has suggested that scientists need to model future coastal landscape changes and develop sustainable plans to address long-term planning and management issues associated with rising sea-level impacts on beach systems.

6. CROSS-CUTTING ISSUES

6.1 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?

A significant and important interaction that will affect adaptation of aquaculture (De Silva and Soto, 2009, Leith and Haward, 2010), fisheries (De Silva and Soto, 2009, Hobday and Poloczanska, 2010), marine conservation (Veron et al., 2009, Hughes, 2011) and to some degree marine tourism, is land-based management decisions (e.g. dam construction or removal, deforestation, green infrastructure to limit runoff, shoreline hardening, urban development). This will be particularly evident as decisions aimed at climate change adaptation for agriculture, urban centres and coastal planning are implemented (DCC, 2009) to address changes in water quantity and quality, coastal inundation and storm damage. Scientific information that informs effective marine climate adaptation must take a holistic approach that considers interactions between multiple stressors, cumulative pressures of co-occurring factors, and the flow-on effects for industries and ecosystem health (Johnson and Martin, 2011).

In addition, the increased incidence of marine pathogens and disease has implications that cut across all marine sectors and is currently a major knowledge gap in Australia. Information is needed on which pathogens are most likely to increase in distribution and abundance due to climate change; which pathogens will become more virulent and how can they be monitored; how the host pathogen relationship will be affected by climate change; which marine species and ecosystems are likely to be most vulnerable to disease outbreaks under future climate change scenarios; and how current policies can help minimise disease transmission and manage outbreaks.

7. KNOWLEDGE GAPS

Based largely on the afore-discussed literature since December 2008, together with our knowledge of the funded projects that are currently underway, we summarise the knowledge gaps identified from this review and that would benefit from further research, and note a key research theme not included in the original National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources (NARP-MBR 2010). Further research is needed on:

- The specifics of changes in aquaculture species most likely to be impacted by climate change – that is, the thresholds at which vulnerable species will no longer be viable to farm, and the best sites for future operations. Some of this research is currently underway for key aquaculture species, specifically Atlantic salmon (FRDC 2010/217 and 2010/085), barramundi (FRDC 2010/521) and oysters (FRDC 2010/534), and vulnerable locations (south eastern Australia; FRDC 2009/070 and 2009/055).
- The social and economic risk associated with aquaculture production declines in a changing climate – in particular, the relationship between vulnerable aquaculture operations and the communities and economies that depend on them, and to detail how these communities will be affected socially and economically by declines in aquaculture activity.
- The specific detail of economic or other barriers to adaptation for the aquaculture industry.
- Recent changes in Australian aquaculture, and studies to interpret how externally influenced changes (in Australia or overseas) – for example, opportunities to draw lessons on climate-proofing infrastructure, undertaking risk assessments of stock losses due to changing conditions, reducing reliance on fishmeal or other feed inputs, and adapting to increasing water temperatures – can inform future risk assessment and adaptation planning in Australia.
- Predictions of distribution shifts of key commercial fisheries species in targeted locations likely to experience these shifts (e.g. south eastern and south western Australia), species most likely to expand or contract their ranges (e.g. warm temperate species), and species that may become 'locally invasive' as they move south.
- Identifying dependent communities in Australia most at risk from climate-related changes to their fisheries, and the likely social and economic impacts.
- Adaptation options for commercial fishers that inform the most appropriate measures available to aid decision-making and avoid mal-adaptations.
- Species in Australia of conservation priority and clear metrics and goals for prioritising species under future climate change.
- Critical thresholds for marine ecosystems and species, and methods for measuring ecosystem dynamics and processes, such as phase shifts - required for a range of marine ecosystems in Australia to identify species and ecosystems that require immediate assistance, and to inform future adaptation management.
- Changes to marine pathogens and disease under future climate change scenarios and the implications for marine ecosystems, marine industries and human health.
- Consideration of marine protected areas (MPAs) as tools for addressing climate change impacts on marine systems is required including optimum design.
- Better understanding the spatial and temporal drivers affecting connectivity and marine habitats.
- Whether improving networks of MPAs that connect source and sink reefs, to promote recovery after climate-related impacts, are effective in reducing long-term climate change risks.
- Understanding the nuances of negotiating and alliance building, and how perceptions change over time in relation to building social resilience.
- The public perception of climate change impacts on Australia's marine tourism destinations, and how any negative views can be minimised. This will be particularly

important for regions that rely on domestic beach recreation, where many alternative destinations are available and easily accessible.

- Understanding the links between resource condition and vitality of marine-dependent tourism businesses in Australia, to inform future adaptation to climate change.
- Whether current marine safety standards and protocols are sufficient to deal with future climate change conditions, particularly changes in storm and cyclone intensity, storm surges and sea-level rise.

Finally, we consider here another question – in the area of estuaries in a changing climate - that might be usefully considered under the ‘cross-cutting issues’ theme, not included in the original National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources (Mapstone *et al*, 2010). Estuaries have arguably ‘fallen through the cracks’ since they represent the *system* at the interface between the marine environment, the freshwater environment, the terrestrial environment, and the built (settlements and infrastructure) environment. As such, they contain elements that characterise all four environments for adaptation and that have been considered discretely and/or in isolation in a non-comprehensive, disconnected and/or non-integrated treatment in the past. Here, we suggest a possible question for estuaries.

7.1 What are the most appropriate approaches for preserving estuarine systems in the face of climate change?

There has been recognition within NCCARF for the need to better understand estuarine systems, and their vulnerability in the face of climate change risks. This recognition has resulted in a few projects being supported. These include: (1) a synthesis and integration project entitled “Coastal Ecosystems Responses to Climate Change Synthesis Project” led by Dr Wade Hadwen; (2) an NCCARF cross-network workshop and activity led by Dr Melanie Bishop between the Adaptation Research Networks for Marine Biodiversity and Resources, Freshwater Biodiversity, Terrestrial Biodiversity, and Settlements and Infrastructure; and (3) an FRDC/DCCEE funded Adaptation Research Grant project (2011/040) on estuaries entitled “Estuarine and nearshore ecosystems – assessing alternative adaptive management strategies for the management of estuarine and coastal ecosystems” led by Dr Marcus Sheaves.

Recent work has investigated the response of estuarine habitats to species declines (Bishop et al., 2010), the resistance of invertebrates to recurrent estuarine acidification (Amaral et al., 2011), and changes in estuarine species, particularly oysters, in NSW due to a range of influences (Summerhayes et al., 2009b, Summerhayes et al., 2009a, Bishop et al., 2010), which could provide the foundation for more climate change specific research in the future.

8. ACKNOWLEDGEMENTS

The authors want to sincerely thank Clare Brooker for her diligence in installing the cited references in the Endnote library for this review.

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