Marine Australia

DIRECTIONS FOR MANAGEMENT & FURTHER RESEARCH

building on the findings of the *Climate Change Adaptation – Marine Biodiversity & Fisheries* R&D initiative

FRDC 2014

FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Contents

Executive Summary

Australia's oceans generate considerable economic wealth through fisheries, aquaculture, tourism, oil and natural gas, and transport. Marine ecosystems provide irreplaceable services including defence, oxygen production, nutrient recycling and climate regulation.

Australia's oceans, their physical characteristics, marine biodiversity and fisheries are already experiencing and responding to a changing and more variable climate. This flow-on in climate, ecological and economic change is occurring at a far more rapid rate than that occurring terrestrially. Adapting to our changing climate is essential if Australia is to maintain, build upon and profit from the wealth of goods and services provided by our marine environment.

Chapter 2 summarises the findings of a series of research and development partnerships and a total R&D&E investment of over $9M from 2010 to 2014. This was led by FRDC with the partnership going across Australian and State Governments, CSIRO and universities as the lead co-investors. A more detailed executive summary of each of the 25 projects is provided in Appendix 1. Chapter 2 also identifies some of the key activities underway towards adoption of the findings of the Program.

Chapter 3 provides a climate adaptation checklist. Much of the climate change adaptation science still required to further our knowledge is best undertaken within a total marine systems context. Evaluating science proposals using this checklist will ensure a greater incorporation of climate-related issues within marine biodiversity and fisheries investments.

Chapter 4 details the high priority areas for additional investment so that Australia can increasingly profit from its marine environment and incorporate climate adaptation within management and policy. These areas are:

1. Knowledge to equip marine users & managers to adapt

- Improved marine forecasting and ocean current / eddy forecasting as a key input to a whole host of marine user decisions (e.g. ship movements, defence, fisheries, oil and natural gas extraction)
- Smarter and real-time stock assessment and population predictions (e.g. to foster a more profitable fishing sector)
- Cheaper and more user / outcome-orientated monitoring systems (e.g. to calibrate projections of change, to provide the basis for stock assessment and to inform the effectiveness or otherwise of our management interventions)
- Improved predictive understanding of biological trajectories for our marine environments as they respond to all changes and impacts (e.g. to underpin any changes to marine park reservations and marine biodiversity management)

2. Reinforcing the need to rethink marine management paradigms

- Fostering the transition towards total population management for key target species (e.g. total fisheries stocks rather than jurisdiction by jurisdiction-based management arrangements)
- Encouraging more adaptive and user-friendly management systems (e.g. more flexible conservation and fisheries management)
- Enhancing market and food security opportunities
- Fostering industry development
- Building improved recreational and indigenous futures

3. Equipping inshore fisheries for increased productivity & resilience to more extreme shock events

- Ensuring catchment and estuary health in a more variable climate
- Expediting the transition to sustainable habitat & economic yield-based management

4. Ensuring multi-objective marine resilience

- Working towards all-encompassing governance systems and funding models
- Building the policy framework for 'Blue Carbon' to be part of Climate Mitigation investments
- Fostering more profitable systems across the value chain

5. Fostering climate-informed action through shared knowledge

- Ensuring extension activities apply a diversity of approaches and interaction techniques

6. Contributing to smarter energy use

- Reducing the carbon footprint of marine users
- Improved energy efficient and carbon smart aquaculture

These priorities for action are best undertaken by incorporating climate and climate-related issues within the bigger and more appropriate context of fostering sustainable inshore and marine systems-based management. Australia as a marine nation has much to do to achieve smarter marine management, to ensure sustainable marine uses and to apply eco-engineering to repair to higher levels of productivity and resilience our inshore systems. Adapting to a changing climate is part of this broader all-encompassing goal of a more productive and profitable marine Australia.

1. Introduction

The Fisheries Research and Development Corporation has a dual remit to provide knowledge that will deliver both:

- public benefit marine protection and management; and
- private benefit profitable and sustainable use of marine resources – professional and recreational fisheries, aquaculture and indigenous take.

It took the initiative to coordinate, integrate and lead a range of marine climate adaptation and mitigation-related investments. Table 1 summarises the investment profile.

Table 1. Summary of Cash Investment – Climate Change Adaptation, Marine Biodiversity and Fisheries R&D, including the South East El Nemo initiative

Cash Investors	Approximate (%) contribution
Australian Government	
Department of Climate Change and Energy Efficiency	25%
Department of Agriculture, Fisheries and Forestry	9%
Fisheries Research and Development Corporation	52%
State Governments	
Especially, Victoria, Tasmania, South Australia & NSW	7%
Research Providers	
Especially CSIRO, Universities, State agencies	7%
Total Investment – in excess of $9M over four years	

The FRDC recognises the worth of program management. This includes investing to ensure that priority knowledge gaps are met, that there is close interactions and cross-overs in leanings between the research providers, and that all findings are translated into products to meet the knowledge needs of various user groups in ways that foster adoption. User groups range from policy makers to marine managers to marine users such as fishers.

Table 2 provides a conceptual framework of how the program was designed and projects were selected to deliver to the various needs and hierarchies of marine biodiversity and fisheries management.

All projects were managed under standard contract conditions to agreed sets of milestones. Milestones were required to include research updates. These updates were reviewed for science quality and the findings as the projects progressed were communicated widely. Communication outputs required of all projects included:

- submission of science papers to peer-reviewed journals;
- management and repository of any data generated within the Integrated Marine Observing System (IMOS); and
- preparation of summary findings and presentations such as fact sheets or articles for 'Fish' or other newsletters for broad distribution.

Final reports for all projects are progressively quality assured, and uploaded on to the FRDC website, provided to libraries, workshopped through with specific end user groups and presented to peer groups at various conferences. This summary report is part of the task to ensure all key across-Program findings are made readily available to policy makers, managers and other end users.

Appendix 1 provides Executive Summaries of all the projects – summary methods, key findings, recommendations and lists of peer-reviewed papers.

Table 2. Conceptual Framework for Marine Biodiversity and Fisheries Climate Adaptation R&D

<table>
<tr><th colspan="2">Sentinel Biodiversity & Tourism Species & Communities</th><th></th><th colspan="2">Sentinel Indigenous, Recreation/Tourism & Commercial Species</th></tr>
<tr><td colspan="2">Key species/ communities that are of high conservation significance, probably have management plans in place across much of their range or perhaps are subject to international agreements and for which if we think through climate adaptation we will be contributing to their and broader ecosystem conservation (eg migratory birds, dugongs, coral reefs, whale sharks, turtles).</td><td></td><td colspan="2" rowspan="3">Key species that are high value for indigenous, recreational, tourism and commercial fisheries and for which if we understand climate adaptation needs we will be contributing to both their sustainable use and the broader issues of ecosystem conservation across their habitat range.</td></tr>
<tr><th>Marine Biodiversity Planning & Management</th><th>Marine Fisheries Management</th><td rowspan="4">⇔</td></tr>
<tr><td>Regional to national projects that build on conservation theory to analyse the management shifts that are likely to be needed to ensure marine habitat / ecosystem conservation – well linked to Australia's bioregions.</td><td>Regional projects that reflect spatially high value often multiple species fisheries and think through sustainable harvest and management arrangements.</td></tr>
<tr><th colspan="2">Marine Systems and Populations – Shifts and Management Implications</th><th>Inshore & Estuary Based Wild Fisheries Shifts, Populations & Adaptation Implications</th><th>Inshore & Estuary Based Aquaculture Shifts, Practice & Adaptation Implications</th></tr>
<tr><td colspan="2">Selected high value species that are already subject to management planning for sustainability and best represent examples of the types of shifts in population and management implications that is essential for adaptation.</td><td>Selected high value species / fisheries that best represent examples of the types of shifts in population and management implications that is essential for adaptation.</td><td>Selected high value industries that best represent examples of the types of shifts in practice and management implications that is essential for adaptation.</td></tr>
<tr><th colspan="2">Marine Biophysical Understanding</th><td>⇔</td><th colspan="2">East Coast and Tropical Estuary Biophysical Understanding, (incl Wetlands as Biodiversity + Habitat Surrogate)</th></tr>
<tr><td colspan="2">National, part collation – data management – synthesis that defines in an IPCC type set of scenarios biophysical shifts + Net Primary Productivity and implications for marine management. Provides foundation for all marine projects</td><td></td><td colspan="2">Build on Geosciences Australia sea level and DEM work for Australian coasts, estuaries and wetlands with ecological implications so that biophysical shifts – temp, pH, wetlands, nutrient fluxes, population shifts can be predicted. Provides foundation for all estuary projects.</td></tr>
</table>

2. Key Findings

Following are a selected set of key findings from this research program of the changes occurring across marine Australia and the implications for marine management. These findings build on the Marine Report Card, www.oceanclimatechange.org.au (Poloczanska et al. 2012) which is cited at the start of each section.

2.1 Temperature

Ocean temperatures around Australia have warmed by 0.68^{o}C since 1910–1929 with south-west and south-eastern waters warming fastest. The rate of temperature rise in Australian waters has accelerated since the mid 20th century from 0.08^{o}C/decade in 1910 – 1950 to 0.11^{o}C/decade from 1950 – 2011.

Caputi et al. [2010/535 p.81] detail the marine heat wave event in the Gascoyne and mid-west region of Western Australia during the summer of 2010/11 as an example of an extreme event that resulted in water temperatures of 4–5^{o}C above average. The heat wave had a short-term effect of fish kills and temporary range extension of some tropical species moving south as well as a longer-term negative effect during the spawning and larval phase of some invertebrate species. There has also been a continuation of above-average temperatures in the following two summers with the south coast of WA having record sea surface temperatures in 2012/13.

2.2 East Australian Current and fish southwards movement

The intensification of flow and accelerated warming observed in the EAC is also seen in other Southern Hemisphere western boundary current systems, driven by the strengthening and contraction south of Southern Hemisphere westerly winds although regional responses mean rates of warming differ among systems. A range of species, including plankton, fish and invertebrates are now found further south because of enhanced transport of larvae and juveniles in the stronger Eastern Australian Current and the high rate of regional warming. Redmap (www.redmap.org.au) provides detail of range expansion southwards for many commercial and recreational fishing target species.

Gledhill et al. [2010/524 p.64] in reviewing spear fisher's records found the 50 most common species from NSW catches underwent a statistically significant shift toward a more tropical community, and this effect was robust across 'summer' and 'winter' periods. Examining the top 25 and top 26–50 species as separate units demonstrated the complexity of change occurring, with varying responses over different seasonal periods. Victorian records demonstrated no discernible change in the tropicalisation index for the 50 most common species, possibly resulting from the scoring criteria used.

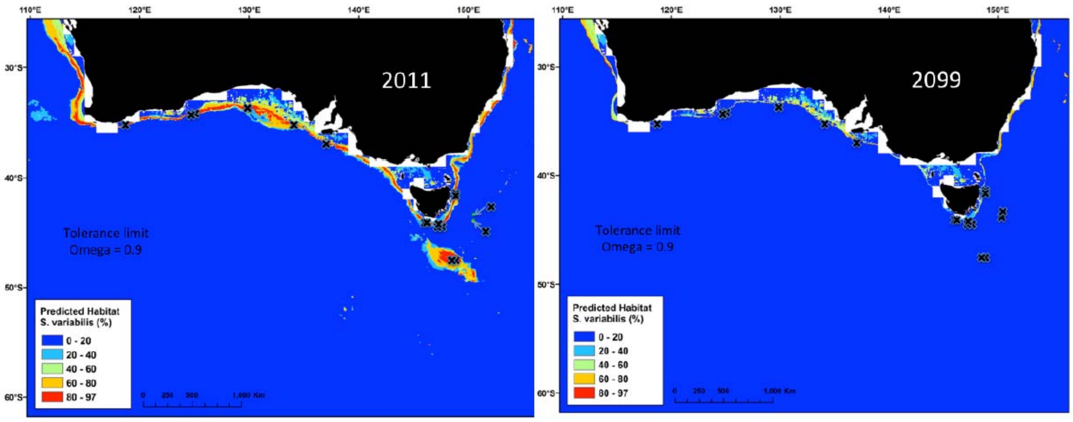
Pecl et al. [2009/070 p.41] found that temperature was the most commonly cited driver of current or potential climate change impacts for both fisheries and aquaculture species. Among other changes, increases in temperature impact growth rates and larval development, timing of annual migrations, onset of spawning, susceptibility to disease and geographical distribution. Potential changes in currents, freshwater flows and salinity were also important. Each jurisdiction in the south-eastern region had at least one of its two most important species classified as high risk. Fisheries species considered at highest risk also supported the region's highest value fisheries – Blacklip and Greenlip Abalone, and Southern Rock Lobster. These species demonstrate little capacity to move at adult stages, lower physiological tolerances, and have life history stages that are strongly affected by environmental associations (e.g. spawning and settlement).

2.3 Ocean acidification

Most conclusions to date about biological responses to ocean acidification in Australia's waters come from laboratory manipulations rather than observations. Reduced calcification observed in Southern Ocean zooplankton suggests ocean acidification is already impacting biological systems.

Pecl et al. [2009/070 p.41] suggest that the impacts of ocean acidification were associated with high uncertainty for all species in south-eastern Australia. The consequences of lowered pH may include reductions in calcification rates, increased physiological stress and disruption to settlement cues.

Thresher et al. [2010/510 p.57] examined the extensive coral reefs formed primarily by a single species, *Solenosmilia variabilis*, which occupy seamounts at depths of one to two km along Australia's southeastern coast, and have recently been protected in the SE Commonwealth Marine Reserves. These reefs are hotspots of deep ocean biodiversity and productivity, and are a focal habitat for deep-sea fisheries, such as Dories and Orange Roughy. Ocean acidification has been identified as a potential threat to the long-term survival of these reefs as the carbonate saturation horizon being, the depth at which calcium carbonate is fully saturated in seawater shoals changes, a consequence of increased ocean CO_2. The project determined that ocean acidification is likely to result in the loss over the next century of the cold water coral reefs that characterise seamounts in the SE Commonwealth Marine Reserve; identified possible refugia habitats for these cold water corals along the continental shelf of southern Australia; nominated adaptation strategies that involve assisted translocation of the reefs and the use of artificial substrates to provide suitable hard ground for coral growth; and raised the need to assess the feasibility of these strategies and to consider other options for maintaining the viability of these deep water ecosystems.

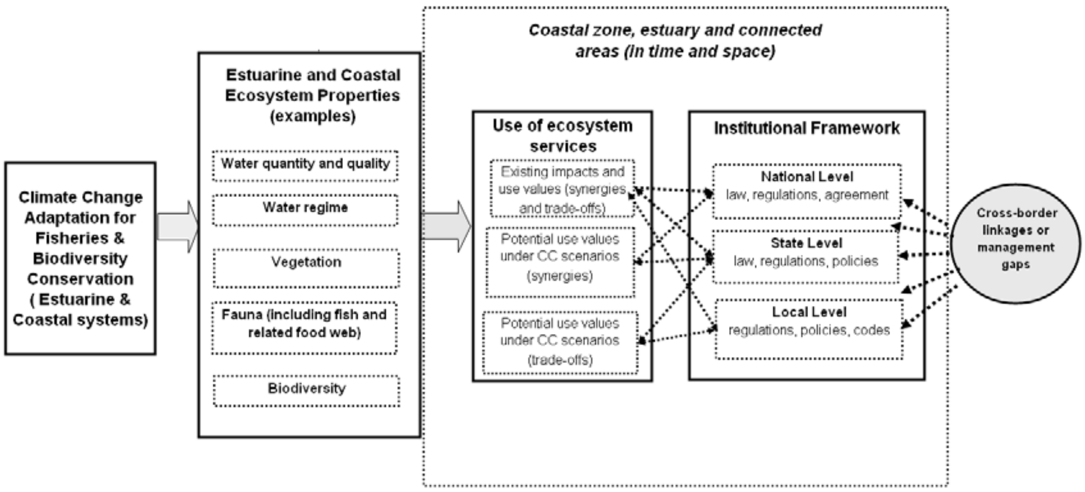


Habitat suitability maps for *S. variabilis* in southern Australia. Red is highest suitability. Xs indicate where live specimens have been found.

2.4 Mangroves, tidal wetlands and seagrasses

The red mangrove Rhyzophora stylosa is expanding within its range at its southern limits; the expansion is still to be attributed to climate change however knowledge of thermal limits suggests warming plays a role. A southern range extension of 300 km into Moreton Bay of the tropical seagrass Halophila minor is consistent with a warming and a strengthening East Australia current.

It is too early in these range shifts to determine any implications for ecosystems or their productivity. Sheaves et al. [2011/040 p.123] noted that because of the large-scale, slow development and pervasive nature of climate change and its impacts, it is vital to focus on large-scale public good outcomes. For Australia's coasts and estuaries and their resources, the key to this is ensuring ecosystem robustness and resilience are maintained at whole-of-resource scale. This is needed to support environments, fisheries productivity, food security and the viability of the industries that depend on them. From a broad range of perspectives, maximum public benefit accrues from maintaining and restoring resilient ecosystems that provide healthy human living environments, support optimal biodiversity and underpin robust and productive fisheries). This is best achieved by focusing on long-term transformative outcomes that provide ongoing benefits by enhancing resilience and reducing vulnerability in the long term. Focusing on maintaining and enhancing ecosystem resilience provides long-term durability and availability of resources because it supports continued ecosystem functioning in the face of substantial change; in essence future-proofing the system. In addition, because ecological systems are intimately influenced by the social systems that rely on them ensuring resource resilience needs to focus on the socio-ecological system as a whole.



Framework for establishing institutional linkages (connectivity) for the integration of climate change adaptation strategies in coastal zones, estuaries and ecologically connected areas.

Fulton et al. [2010/023 p.48] reinforced these views noting that integrated adaptive management (across all users of the marine and coastal environments) is the most effective means of maintaining sustainable, desirable and productive marine ecosystems under all levels of global change. There will be many more surprises still to come and flexibility to respond in a timely manner is critical.

Creighton [2012/036 p.142] took this issue of ensuring resilience to stresses such as a more variable climate one step further and suggested that there are many practical opportunities to repair coastal ecosystems and thereby ensure increased resilience in fisheries productivity to whatever changes might occur. Overall, repairing just the key achievable degraded areas of fisheries habitat remaining around Australia's estuaries will take time, often land purchase, an increased community awareness of the benefits of fishery habitat, locality by locality social licences and most importantly a rethinking of the private benefit versus public benefit paradigm that has driven most of the adverse landscape change, especially agricultural development.

The best and most easily calculated surrogate for the economic benefits of repair is the retail price of increased commercial seafood production. Prices are readily available; the technology is already in place to harvest increased productivity; the input costs for inshore fisheries are minimal and the domestic market is demanding locally produced, high quality and reasonably priced seafood.

Creighton detailed projections in increased productivity and flow-on benefits by examining through three case studies the likely break-even point for a proposed $350M investment in habitat repair. Using extremely conservative assumptions, only considering the value of these selected commercial fisheries – regional (Murray – Coorong); part of a state inshore (NSW); and part of an iconic fishery (Great Barrier Reef) – the total proposed Australia-wide investment of $350M in repair is returned in probably three years, certainly well less than five years, just from the returned productivity for the species selected from these commercial fisheries. To what degree such repair might also ensure increased resilience to climate-induced stress is difficult to quantify.

2.5 Macroalgae

*In eastern Tasmania a substantial decline in algal habitat is associated with southward expansion of a grazing sea urchin (*Centrostephenus *sp.) aided by the strengthening of the East Australian current and warmer temperatures.*

Barrett et al. [2010/506 p.52] found that the twenty-year dataset from Maria Island proved to be the most meaningful and could readily be matched with oceanographical variables derived from a nearby CSIRO monitoring station. While few individual species in this dataset could be clearly determined to be responding to climate signals through time, a range of community-level metrics did show significant trends when examined for the fish assemblage. Signatures of a warming trend could be seen in metrics such as functional trait richness, and functional diversity, reflecting increasing abundances of warm affinity species and species traits such as herbivory. It is this latter trait that may have one of the largest initial impacts in the south-east region, as, prior to recent warming, herbivorous fishes were relatively rare in the cool temperate zone, thus their increasing biomass may reflect a significant change in system function through time.

One notable feature was that in some metrics, such as thermal affinity, there was a differing response to warming between the unfished sites in the Maria Island marine reserve and adjacent fished reference sites. These differences reflect 'resilience' of the reserve to some aspects of climate change. The primary mechanism underlying this appears to be related to increased top-down control of sea urchins within the reserve (via lobster predation) reducing the extent of urchin barren formation that in turn provides habitat for many warmer affinity species. The message from this is that marine protected areas can provide increased 'resilience' to climate change effects, particularly when an ecosystem engineer such as the urchin *Centrostephanus rodgersii* drives these.

This resilience is context dependent, as in many areas such lobster/urchin interactions may not be the primary drivers of ecosystem function on reefs, or where they are, resilience can, and should, be enhanced in off reserve areas as well, by appropriate changes in fishery management. Ultimately this management needs to be informed by long-term studies examining differences between fished and protected areas at representative locations along our coastline, building on existing studies to extend that time series over future years of warming.

Bax et al. [2010/564 p.103] noted that conservation translocations are increasingly being considered as a climate adaptation strategy. Their project developed a framework to assist those decisions and evaluated the framework with particular reference to the Eastern Blue Groper in Tasmania.

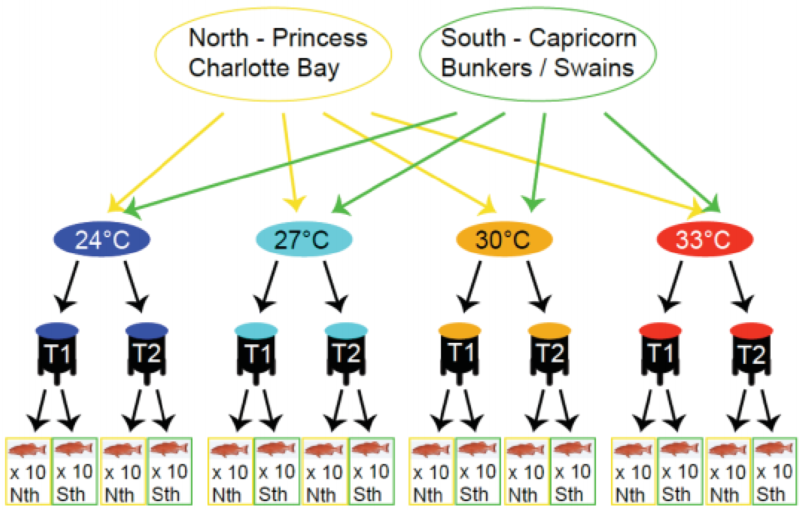
Contrary to the recent published literature, the research showed that it is unlikely that Eastern Blue Groper was present in Tasmania in the 1800s and if present was certainly not common. Therefore it was not fished to extinction as suggested by Last et al. (2010).

Bax et al. note that Eastern Blue Groper has recently been observed in north-eastern Tasmania which is considered to be a range extension from NSW waters. In NSW, adult Eastern Blue Groper are commonly seen in association with urchin grazed barrens and are thought to be a key predator of *C. rodgersii*. Based on evidence from NSW, populations of Eastern Blue Groper in Tasmania may have greater potential to improve the resilience of macroalgal habitat against an ecological shift to urchin grazed barrens habitat, than to reverse a stable urchin grazed barrens habitat back to macroalgal habitat. This suggests that any proposed translocation for this purpose would need to be part of a larger integrated management plan.

2.6 Tropical fish

Research suggests that some species have a greater capacity to acclimate to rising temperatures than previously thought, however for most species, whether such acclimation capacity is widespread in tropical marine fish and whether some critical processes such as reproduction and larval phases remain significantly impaired is unknown.

Pratchett et al. [2010/554 p.99] filled in part of the knowledge gaps for the commercially and recreationally important Coral Trout. This research has unequivocally shown that Coral Trout and particularly, *Plectropomus leopardus*, are sensitive to changes in habitat and environmental conditions expected to occur as a consequence of sustained and ongoing climate change. More specifically, Coral trout will be negatively affected by degradation of coral reef habitats (specifically, declines in abundance of *Acropora* colonies), increasing temperature, and ocean acidification.



Experimental design testing the thermal tolerance of P. Leopardus from the northern and southern GBR

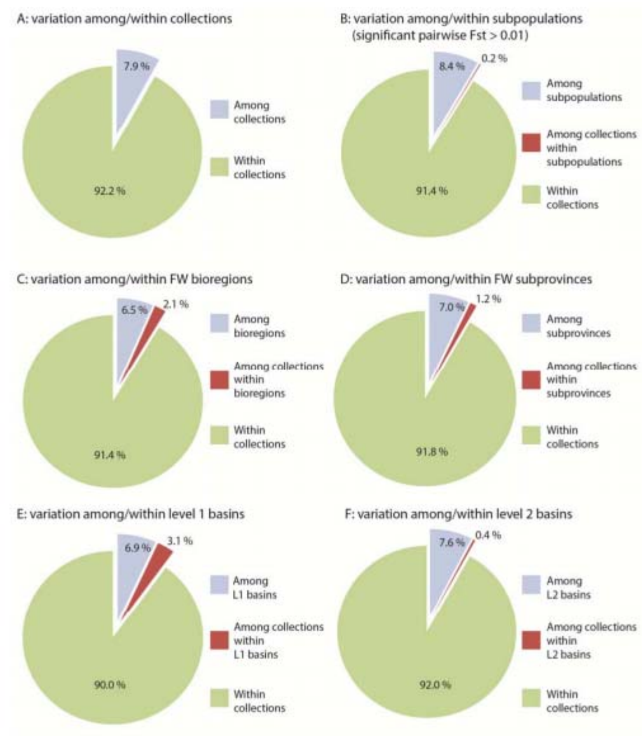
There are several different ways in which climate change will affect coral trout, but the most immediate and direct impacts relate to effects of increasing temperature on larval and juvenile life stages. The research suggests that wild populations of coral trout on Australia's Great Barrier Reef will be severely compromised due to limited survivorship of larval trout whenever or wherever ocean temperatures exceed 30^{o}C.

Tank-based studies of aerobic scope, suggest that these effects will be further compounded by declines in the size, growth and reproductive capacity of adult fishes regularly exposed to these temperatures. Average reef-wide sea surface temperatures on the Great Barrier Reef are expected to exceed 30^{o}C between 2065 – 2080, though maximum summer-time temperatures already approach (if not exceed) this threshold in the northern GBR.

If coral trout are unable to adapt or acclimate to increasing temperatures (behaviourally or physiologically) then it is very likely that the sustainability of fisheries for coral trout on the GBR will be undermined by sustained and ongoing increases in ocean temperatures, and these effects will be felt first and worst in the northern GBR, where temperatures are already much closer to the 30^{o}C threshold.

It is unclear if, when, or how these changes will impact the range, size, abundance and catchability of coral trout, which are key to understanding effects on the productivity and profitability of wild fisheries and particularly, commercial fisheries. More research is required to understand the specific effects on wild stocks and associated fisheries, as well as exploring appropriate adaptation options within each of the distinct fisheries sectors; commercial, charter, recreational and indigenous fisheries.

Jerry et al. [2010/521 p.59] noted that in northern Australia, Barramundi (*Lates calcarifer*) supports a strong commercial and aquaculture fishery (~$80 million), as well as being a species of high recreational and societal value. Given the iconic importance of this fish species to northern Australia there was a need to understand how future climate patterns will impact on both the wild fishery and growing Barramundi aquaculture industry.



Vulnerability of Barramundi to climate change.

Modelling of the wild fishery under different global climate models that make up the IPCC 'business as usual' greenhouse gas emissions scenario predicted that climate suitable for Barramundi in Australia will be extended in a southerly direction on both the eastern and western coasts due to increasing average and minimum temperatures. The optimal model incorporating climate-derived correlates of catch per unit effort (CPUE) predicts that future medium CPUE will also increase in key areas with climate change. Areas that currently yield the highest CPUE are expected to remain high into the future and all areas are expected to show some increase in CPUE. Accordingly, potential for new fisheries may arise as suitable climate for this species moves southward and it was recommended that resource planners begin to implement such scenarios into fisheries resource allocation planning models.

As with the wild Barramundi fishery, future climate-informed simulations predicted an increase in land area with thermal profiles suitable for Barramundi pond-based aquaculture, as well as overall increases in productivity, particularly in northern regions of the distribution. In particular, thermal profiles predict that Barramundi may be able to be farmed in pond and sea-cage systems far south of where temperature currently limits productive farming. Thus Barramundi aquaculture may be able to expand as an industry south as climate change proceeds towards 2080. This would be in addition to the existing aquaculture in recirculation systems. For this expansion to take place, however, State-based aquaculture development plans will need to be proactive and incorporate Barramundi as a new possible species that can be farmed in these southern regions.

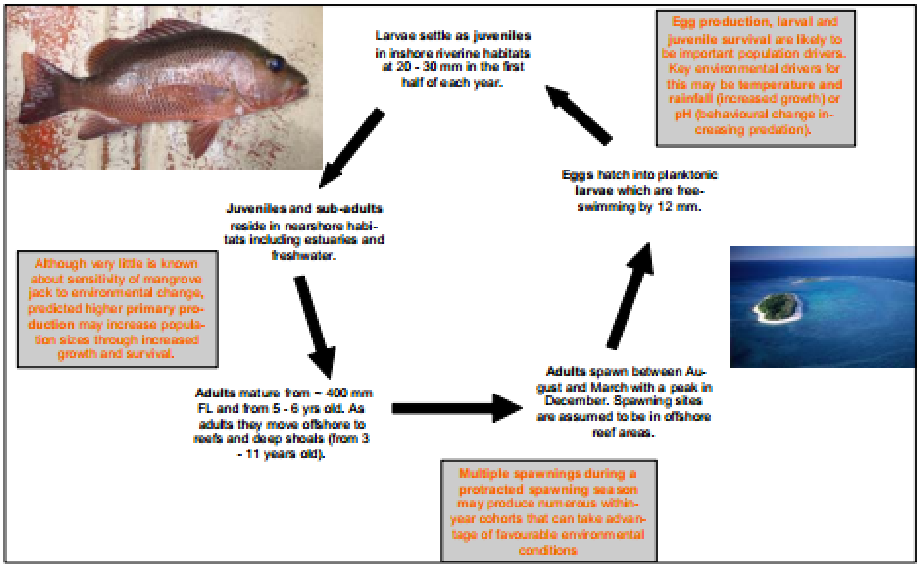
Welch et al. [2010/565 p.107] suggested that tropical species with the highest ecological vulnerability to climate change tend to have one or more of the following attributes:

- have an estuarine/nearshore habitat preference during at least part of their life cycle;
- have low mobility;
- rely on habitat types predicted to be most impacted by climate change;
- have low productivity (slow growth/late maturing/low fecundity);
- are known to be affected by environmental drivers;
- are fully or overfished.

Certain species were assessed with a high vulnerability and also high fishery importance and so should be given priority. The highest priority species were Golden Snapper, King Threadfin, Sandfish, Black Teatfish, Tiger Prawn, Banana Prawn, White Teatfish and Mangrove Jack. Barramundi was also included by Welch et al. in the group of species of high fishery importance, particularly recognising there may be changes, especially reductions and more variable river flow, though as Jerry et al. noted, with changing ocean temperature their actual range might extend.

By 2030, the most common impact identified across all species were reduced sizes of populations due mainly to lower rainfall and riverflow which affects primary productivity and therefore survival of early life history stages, and also indirect effects of habitat degradation on key life history stages of certain species. Sea surface temperature is also likely to impact some species by 2030 affecting early life history survival and development and causing southerly range extensions.

By 2070, changes in rainfall/riverflow, sea surface temperature and habitat alteration will continue to impact species and additionally, ocean acidification and salinity are likely to begin to impact species through disruption of early life history development and habitat effects, especially coral reefs.



Generalised lifecycle of the Mangrove Jack and the stages of potential environmental driver impacts.

Rainfall and riverflow are key environmental drivers for fisheries populations in northern Australia through enhancing local primary productivity and larval/juvenile survival, and by connecting key habitats such as estuaries and floodplains. The east coast in particular is a key area for concern due to projected lower rainfall, more extreme (longer) wet and dry periods, coupled with the expected increase in water extraction for land-based use and also having estuarine habitats already modified more than any other region of northern Australia (Creighton 2013). Many species use these and nearshore habitats and so are likely to be affected by these changed hydrological conditions, particularly barramundi that use all habitats during all stages of their life history.

Caputi et al. [2010/535 p.81] note that the marine heat wave in WA also had some short-term effect on range extension of tropical species and there have also been some long-term effects with increasing sea surface temperature. An important outcome 24 months on from the 2010/11 marine heat wave has been the range extension of several nearshore finfish species, whose resident breeding populations were previously found only as far south as the Gascoyne region. While individuals of each species have persisted in nearshore waters off the lower west coast over this period, range extension may well be permanent for at least one of these species. Available evidence suggests that a viable breeding population of Rabbitfish, *Siganus sp.,* has been established in the Cockburn Sound region near Perth where individuals of the species now regularly contribute to commercial and recreational catches. Monthly records of Fremantle Sea Level suggests the significantly earlier (January) onset of the strong Leeuwin Current during 2011 created the opportunity for larvae of this summer-breeding species from the Gascoyne to be transported south, and to settle in nearshore habitats off the lower west coast. It is postulated that elevated sea surface temperatures experienced during the two years since the marine heat wave have contributed to the survival of the newly settled juveniles.

Caputi et al. [2010/535 p.81] examined more than twenty species for climate change effects on key fisheries. The species include commercial invertebrate species such as Western Rock Lobster, Saucer Scallop, Blue Swimmer Crab, Abalone (2 species), Octopus, Pearl Oyster, Prawns (2 species), and key finfish species including Pink Snapper, Black Bream, Australian Herring, Pilchard, Spanish Mackerel, various Emperor spp., Whiskery and Thickskin Shark, and West Australian Dhufish. Environmental effects on some of the biological characteristics (particularly recruitment) of the species were assessed. The historic long-term trends of the environmental variables as well as available projected trends were examined. A risk assessment of WA's key commercial and recreational finfish and invertebrate species, was undertaken based on the sensitivity assessment method developed by the South-east Australian Climate Change group and the likely exposure to climate change. The assessment identified Perth Herring, Roei Abalone, Black Bream, Western Rock Lobster, Pink Snapper, Whiskery Shark, Tiger Prawns, Scallops, Blue Swimmer Crabs and Australian Herring, as having the highest risk to climate change.

2.7 Seabirds and marine mammals

Tropical and subtropical species breeding at Houtman Abrolhos, WA are now experiencing poor breeding success outside of El Niño years linked to warming. Large range extension is reported for Bridled Tern in south-west Australia in response to ocean warming.

Hobday et al. [2010/533 p.73] noted that for Australia's iconic higher trophic level marine taxa, such as seabirds and marine mammals, there is a knowledge gap as to their responses to climate change. These species are protected throughout Australia and in some cases are recovering from previous anthropogenic impacts. Resolution of climate change impacts from other anthropogenic threats is needed to underpin timely adaptive management responses. The project was targeted towards seabirds (rather than shorebirds) and sea lions (rather than all marine mammals) as these taxa are colony-based, particularly when breeding. Colony-based populations means that long time series are collected on the same population in the same space, and mostly at the same time.

Due to variability in data on these species, long time series are needed, and thus emphasise the value of ongoing monitoring. Some variables are better indicators than others. Careful selection of variables for monitoring is essential to detect impacts of climate change. The conservation status for the species studied, which include one endangered, five vulnerable, and three near-threatened species reinforces that an understanding of how these species respond to climate variability and change and determining the 'best' adaptation options is an important component in efforts to improve their population status.

Policy intervention may be required to offer additional protection to species threatened under climate change. Fortunately there is a wide range of options for reducing vulnerability of colony-nesting seabirds. Options appear to be more limited for marine mammals. Some management responses for known climate threats can be simple. The project also highlighted that monitoring to evaluate effectiveness of adaptation option is critical, and should be a focus in any adaptation experiments.

Shaw [part of 2011/503 p.138] in collaboration with the Abrolhos Islands fishing community documented environmental and social changes through photographs and narrative. The value of involvement of coastal communities in long-term monitoring initiatives is well demonstrated through this project and the interest the project findings created in the broader community.

2.8 Beaches and coastal recreation

As sea levels rise our beaches, the amenity they provide and the assets they protect will change. It is very difficult to predict the precise nature of this change, with changing weather and currents as well as sea level rise affecting longshore drift, erosion and accretion of sand beaches. Recreational preferences across the community vary.

Raybould et al. [FRDC 2010/536 p.88] suggest that potential beach-related recreation and tourism losses associated with climate change may be substantial. Current projections indicate that climate change will result in long-term beach recession and more frequent erosion events in some regions. Resident survey responses to scenarios about beach damage suggest that between 25% and 35% of residents' consumer surplus values for beach recreation could be lost as a result of major erosion events. Loss of recreation values on this scale would equate to a minimum $18 million p.a. on the Sunshine Coast and $10 million p.a. in the Clarence Valley. Tourist responses to similar beach damage scenarios suggest that between 17% and 23% of tourists would respond to major erosion events by switching to other possibly non-beach destinations. Loss of tourism receipts on this scale if there was a shift in visitation could equate to losses of approximately $56 million p.a. on the Sunshine Coast and $20 million p.a. on Victoria's Surf Coast. The time taken to repair the damage is critical and rapid action by authorities can reduce the duration and extent of these losses considerably.

Equally importantly, any intervention we might make in marine ecosystems will be how as we, as marine custodians, respond and adapt to our changing marine conditions, to extreme events, more variability in marine populations and the overall shift in the spatial range of populations. All projects across the program had as a core output to identify how their research findings could contribute to our adaptation to changing biophysical marine conditions.

2.9 Adaptation and fisheries management

Lynne et al. [2009/055 p.35], in categorising the types of changes as a basis for determining the nature of intervention required, suggest three broad types:

- the Regime Shift Scenario involving whole-scale ecological shifts in space/time and composition;
- abnormal Range Change Scenario involving species ranging beyond their core distributional limits; and
- localised Change Scenario involving changes within (historically) expected bounding ranges of species and processes.
- Jennings [2009/073 p.45], in setting the broad objectives for any adaptation interventions across all scenarios, suggests four key outcomes should be interwoven into all decision making:
- maximise wellbeing of communities;
- maximise economic performance;
- ensure environmental and ecosystem values retained; and
- strengthen management and governance.

Welch et al. [2010/565 p.107] broadly grouped adaptation options as:

- alteration of fishing operations;
- management-based options;
- research and development; and
- looking for alternatives.

These types of adaptation options were explored in several of the projects. Most of the adaptation options so identified involved regulatory changes and/or policy decision-making, generally underpinned by monitoring and in some cases further research to provide the evidence base for decision making. For northern Australia the major barriers to adaptation in fisheries were identified as costs, political opposition and bureaucracy.

For fisheries to adapt appropriately to climate change all stakeholders will need to play a role with government a lead player in this process. The Western Rock Lobster fishery provides an excellent example of how this can be successfully achieved. Caputi et al. [2010/535 p.81] note that the marine heat wave event during the summer of 2010/11 and the long-term (2006/07–2012/13) decline in the Western Rock Lobster puerulus settlement in WA represent case studies on how researchers, managers and industry have adapted to an extreme environmental event and a possible long-term environmental effect, respectively. The decline in puerulus settlement (including the lowest settlements in 40 years in 2008/09 and 2009/10) resulted in a pro-active management response before these puerulus year-classes entered the fishery (there is 3–4 year lag between settlement and recruitment to fishery) with a significant reduction in fishing effort (ca. 40–70%) since 2008/09 and introduction of individual catch quotas in 2010. The fishery provides an example of the type of enhanced fishery management required more generally across Australia's fisheries. Change in pre-recruitment abundance is being taken into account in the stock assessment with an appropriate management adaptation response to a significant decline in puerulus settlement. Catch and fishing effort were reduced to ensure that there was a carryover of stock into the years when the poor year-classes entered the fishery and that the spawning stock remained at sustainable levels. There have also been other climate change effects such as changes in size of migrating and mature lobsters due to water temperature increases that have been taken into account in the stock assessment model.

Pecl et al. [2011/039 p.117] examined four key fisheries – Abalone, Blue Grenadier, Snapper and Southern Rock Lobster and detailed various components to adaptation.

Abalone: it is likely that the current measures of stock status (i.e. CPUE as an index of relative abundance, size structure of the commercial catch, density estimates from fishery-independent surveys) will remain current. New indices (e.g. spatial performance indicators) may provide a valuable additional input to management. Reference points and decision rules for the Australian Abalone fisheries are being established with the potential impacts of climate change in mind. Targeted monitoring is recommended. In situ water temperature monitoring, and sampling periodically to monitor changes in growth rates, size at maturity and abundance to increase understanding and how best to respond to climate-induced changes. Testing harvest strategies using maximum sustainable economic yield will ensure responsiveness to changes in stock abundance and productivity.

Blue Grenadier: While Blue Grenadier has a highly developed management and assessment approach (i.e. Tier 1), the application and review of control rules will require improved understanding of recruitment dynamics, and potentially how growth rates and distribution of adults may change. There is very limited knowledge of juvenile distribution and ecology, which limits progress in understanding the process(es) that drive recruitment variation, or the development of suitable pre-recruit monitoring approaches. Research into recruitment dynamics is recommended. Studies into the juvenile life stages, including larval dispersal patterns of Blue Grenadier under different climate conditions will improve understanding of the implications of climate change on recruitment dynamics.

Snapper: Based on projected water temperature regimes the Snapper total population is likely to have the bulk of its biomass further south and to be more variable in actual total population. While water temperature regimes are amenable to predictive modelling of future conditions, the prediction of rainfall and river flow regimes is less so, and poses a major uncertainty when attempting to model climate change impacts on future Snapper recruitment success in key areas. Nevertheless, from a state-by-state perspective the projected changes and management implications are likely to be:

- **Victoria and South Australia** – changes to reproductive behaviour both spatially and temporally may increase the variability in recruitment that is already characteristic of the southern Australia fishery. The frequency of good and bad recruitment events may change with implications for monitoring, stock assessment and harvest strategies. Changes in exploitation rate limit points through harvest strategies is likely to be required to ensure that sufficient biomass survives the periods of poor recruitment to take advantage of when conditions are good for egg and larval survival.
- **Queensland and northern NSW** – viable Snapper fisheries may not be possible in the future due to a higher temperatures and therefore a lack of successful reproduction. Small fisheries may exist based on spill over/migrants from more southerly viable spawning populations. As the Snapper fisheries become more sporadic the reduction of their importance may reduce the need for assessment and management focus.
- **Northern Tasmania** – Snapper populations are likely to increase, and potentially become self-replenishing. This would lead to a greater emphasis on Snapper as a local fishery species and the need for a more formal management and assessment approach.

Southern Rock Lobster: The prolonged oceanic larval phase combined with large geographic range spanning different current systems means that predicting climate change impacts is complicated and outcomes are likely to vary across the fishery. A general expectation is that variation in recruitment from year to year is likely to become more pronounced. This presents a challenge for fisheries management. Analysis of economic performance of these fisheries under different recruitment scenarios showed that there were some quota-setting options that were less vulnerable to changes in recruitment. These tended to deliver consistently high economic yield with less volatility in business earnings and thus less exposure to climate change impacts. Biological information and modelling tools are in place for Southern Rock Lobster fisheries to respond to climate change but require two actions to assist adaptation. The first is that ongoing data collection for model inputs is required (especially recruitment, growth and business costs). The second is for extension of model outputs into management decision making as there tends to be industry resistance to application of model-based information.

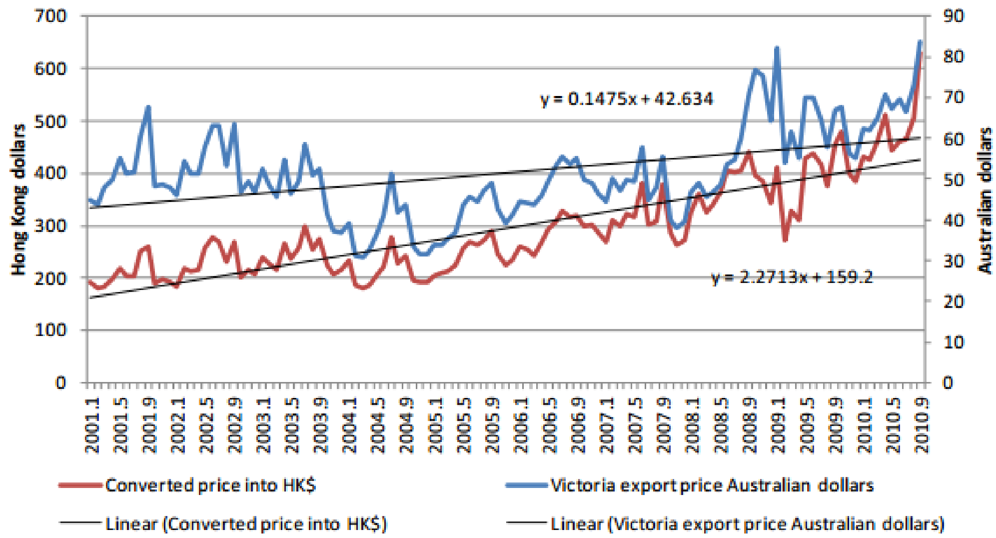
Change can bring opportunities for growth. Hobday et al. [2011/233 p.133] assessed growth opportunities in key Australian fisheries. The overall premise is that growth opportunities and adaptation by Australian fisheries and aquaculture sectors in the face of climate change can be achieved by:

- Increasing sustainable biological production (noting that an increased supply does not always mean increased growth for a fishery, as a market must exist for the product);
- Improving efficiency via a decrease in operating costs, by increasing catch rates, decreasing total allowable catches (TAC), or reducing competition for the catch by reducing the number of vessels or licences;
- Increasing value from existing production – value adding, or focussing on the more profitable markets or products, and reducing waste along the supply chain; or

- Minimising vulnerability and instability in the supply chain by identifying critical elements and internal vulnerabilities that can be addressed by industry or government actions.

Supply chain analysis was undertaken for:

- Southern Rock Lobster (*Jasus edwardsii*);
- the Commonwealth Trawl Sector: Blue Grenadier (*Macruronus novaezelandiae*), Tiger Flathead (*Platycephalus richardsoni*), Pink Ling (*Genypterus blacodes*) and Silver Warehou (*Seriolella punctata*);
- the Northern Prawn Fishery, especially Banana Prawn (*Penaeus merguiensis*);
- aquacultured prawns – particularly Black Tiger Prawns (*Penaeus monodon*), Kuruma Prawns (*Penaeus japonicus*) and Banana Prawns (*Penaeus merguiensis*);
- Sydney Rock Oyster (*Saccostrea glomerata*); and
- the Torres Strait component of the Tropical Rock Lobster (*Panulirus ornatus*).



Rock lobster price exports to Hong Kong through Victoria in Australian and Hong Kong dollars. Since 2006 prices received by Victoria producers have increased by 86% while prices paid in Hong Kong dollars have increased by 229% for the same product.

Creighton, Sawynok et al. [2011/037 p.113] explore what a changing climate with the resulting changes to fisheries biomass both spatially and temporally imply for recreational fishing. Change will affect social, ecological and economic levels. At the social level this will translate into changes in fisher behaviour in response to changes at the ecological level. In general individual recreational fishers have capacity to adapt based on the flexibility in their decisions about fishing activities. This adaptation will be influenced by how much they value particular species. Fishing organisations and professional fishers are less flexible being constrained by their gear and entitlements. Fisheries management is most constrained by the general lack of flexibility in legislation and regulations. Climate change will provide added pressure on existing fisheries management and will lead fishers to call for approaches and policies that provide a greater level of flexibility and responsiveness.

Monitoring will become increasingly important as stock abundance becomes increasingly more variable. Data collection should focus on recruitment and species distribution as well as taking note of anomalies such as species outside their normal range, Recreational fishers and spear fishers [Gledhill et al. 2010/524 p.64] can play a role in collecting such data. Building on the investment in monitoring, stock assessments incorporating biophysical, social and economic data should occur at regular intervals as a key input to improved fishery and marine biodiversity management.

Monitoring is the first step to information and then through analysis, knowledge that can improve management. Winberg et al. [2010/534 p.78] delivered a proof of concept, online, interactive mapping and data delivery tool for the oyster industry and estuarine catchment managers – www.oysterinformationportal.net.au. The purpose of this portal was to demonstrate that there is a benefit of collating data from multiple agency data collections on estuaries and associated catchments and delivering it as information though a user friendly online portal to provide insight into the environment and context of the oyster industry. With information such as water and food safety monitoring data, catchment data and industry and natural resource maps, the industry and its stakeholders are empowered to analyse the opportunities for improvement and intervention, to make informed decisions and develop adaptation options for an improved and resilient industry.

2.10 Adaptation and marine management – barriers and opportunities

Fulton et al. [2010/023 p.48] identified six types of barriers to adaptation:

- Biological and ecological – for example, the target species may move away, new species may enter the system and disrupt it, or productivity may change;
- Behavioural – flexibility is a key requirement in adaptation, but is not a universal feature of all personalities, nor is it always supported by social or cultural rules;
- Governance and regulation – for instance, some forms of management rules can constrain behaviour and prevent the flexibility needed for adaptation, management processes may be slow to respond to the need for changed reference points and there may be a lack of integration, which can cause economic and social hardship lowering adaptive capacity;
- Economic and markets – short term market drivers may not be aligned with what is required for long-term adaptation;
- Technological – for example, when technologies needed to change targeting or other behaviours does not exist, or when current technology encourages behaviours or system changes that are maladaptive;
- Scientific – a lack of tools or understanding can mean that insufficient information is available for adaptive decisions to be made (e.g. there is a strong need to develop more reliable shallow water primary production models as sensitivity analyses show that the direction of productivity shifts are critical – decreases in primary production will cause decreases in fishery catches and biomass of species which will prove challenging for management).

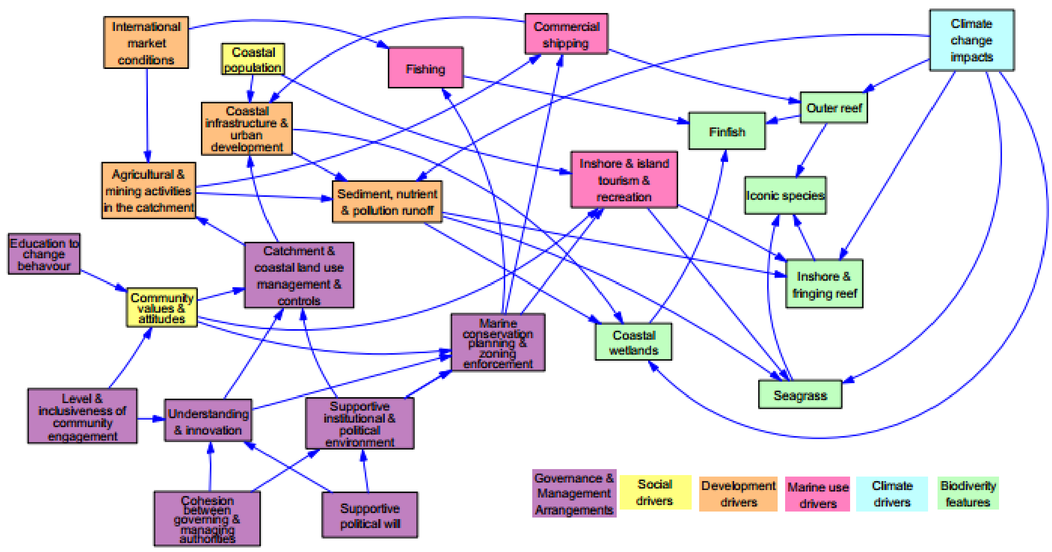
Fulton et al. note that across all the alternative IPCC emission scenarios, the greatest barriers to adaptation seen in the simulations were within the human dimensions of behaviour, markets and governance. While integrated adaptive management across all sectors active on the shelf and in the coastal zone leads to the most robust system state, some of the required regulatory and industry shifts are currently unpalatable to at least some segments of Australian society. For instance, the simulations showed that more stringent regulation of recreational fishing (which is effectively open access at present) would be required for sustainable management of inshore stocks. Simulations also indicated that smaller boats that were socially tied to a specific geographic region (and port) were economically vulnerable to the loss of target species, but also ecologically damaging. This is because they caused more localised depletions, as they were forced to rely on nearby stocks instead of being able to shift to the location of the most robust stocks. This means that either the society at large would need to be carefully led through why larger vessels are required (and can be used sustainably), so as to avoid the kind of controversy seen in 2013 around the potential use of a 'super trawler'. Alternatively, industry/government restructuring and resettlement plans would be periodically required to relocate and refit the vessels according to new ecological states.

Lockwood et al. [2010/532 p.69] through three case studies – Whitsundays, Tweed region and East Coast Tasmania explored governance arrangements, their effectiveness and the opportunities for improved marine management:

Whitsundays Case Study: Current governance arrangements exhibit good adaptive capacity though attention needs to be given to:

- knowledge of social drivers;
- capacity to deal with uncertainty and account for complexity;
- attitudes that are supportive of marine conservation;
- coordination between marine and terrestrial planning processes; and
- integration of conservation and fisheries management.

In particular, the declining condition of key reef ecosystems is a potential crisis that demands an overarching and integrated model of coastal/terrestrial and marine governance.



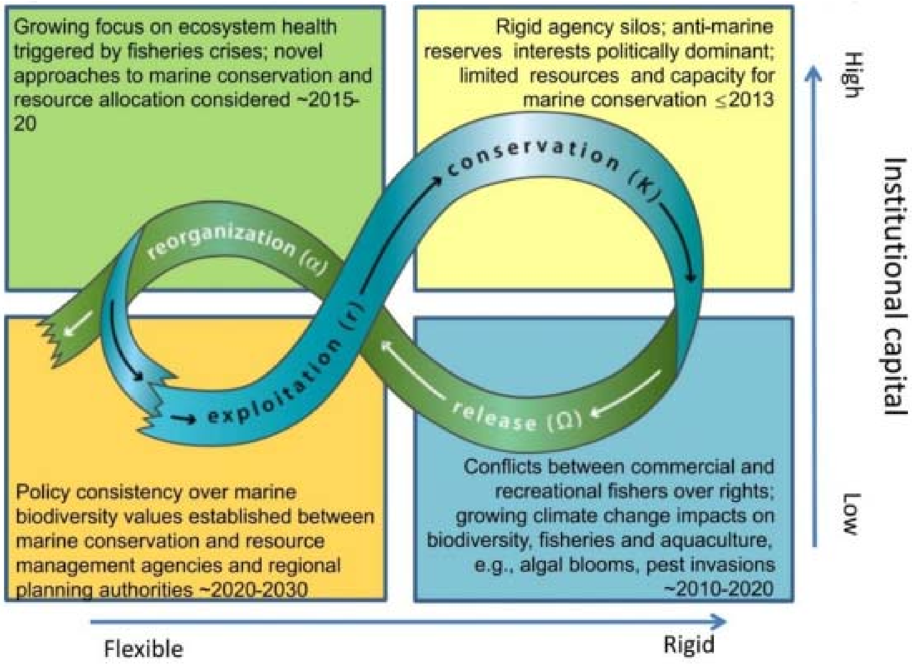
Whitsundays social ecological model.

Tweed region Case Study: Changes in marine ecosystems in response to climate change and other drivers can be addressed through ongoing development and implementation of the Marine Estate Management Strategy. Key issues in the provision of guidance for Tweed marine biodiversity governance is the enhancement of existing structures and arrangements through measures that:

- improve capacity to deal with uncertainty and account for complexity;
- build leadership capacities for critical reflection and learning;
- secure political support and resources;
- improve stakeholder engagement to overcome public distrust of the marine parks system as part of an integrated marine management; and
- further integrate the work of relevant agencies, especially between conservation and fisheries and between marine and terrestrial planning processes.

East coast Tasmania Case Study: Current governance is sectorally oriented. There is an acute need for coordination and governance systems that delivers across agencies to common goals. Building on linkages within existing legislative responsibilities provides a workable pathway for improvement in inter-agency collaboration. Resourcing a more integrative governance approach will be a challenge, as will be establishing processes, support and funding for environmental monitoring and policy review. Key issues include:

- institutional forms and processes;
- leadership and resources;
- engagement and decision-making; and
- cohesion and direction.



Governance regime stability.

Most importantly in managing our marine resources we must recognise that adaptation is about how we respond in our behaviours, management systems, community engagement and knowledge provision. Frusher et al. [2010/542 p.92] developed and trialled a 'blueprint' for community engagement and leadership in change processes. Three coastal community case studies (St Helens, Bowen and Geraldton) worked with the project team to refine the 'blueprint' so that it objectively integrated a suite of adaptation assessment and evaluation tools to facilitate choices among the adaptation options available for coastal communities

Shaw [2011/503 p.138] complemented Frusher et al., working with communities, groups and individuals to explore and test engagement strategies. The resulting general principles from the climate change pilots are equally important in all other change and community development processes – viz:

- understand stakeholder learning needs;
- build relationships and create trust (note that this may involve engagement over an extended period of time);

- ensure that the delivery of information is salient and credible;
- maximise participatory engagement and empower stakeholders; and
- facilitate different learning needs by using a diversity of approaches.

2.11 Marine Australia and carbon mitigation

One of the first order priorities for fisheries and Australia's marine ecosystems generally to be able to respond and adapt to any changes and impacts is to ensure a base of resilient and healthy ecological systems. Two projects [Lawrence et al. 2011/084 p.128 and Creighton 2012/036 p.142] addressed the issues of how marine and especially coastal ecosystems can best play their part in any carbon economy or 'direct action' responses while simultaneously fostering a more productive and resilient estuarine and coastal – nearshore marine environment.

Lawrence et al. [2011/084 p.128] provides summary data that demonstrates that coastal ecosystems of mangroves, salt marshes and seagrasses provide the highest per hectare carbon sequestration rates of any ecosystem.

There is evidence and growing consensus that through avoided emissions, conservation, repair and sustainable use the world's coastal wetland ecosystems can play a major role in carbon management. Known as blue carbon sinks, mangroves, seagrass and saltmarsh can sequester and store carbon in their sediments and biomass at higher rates than those of tropical forests. Unlike most terrestrial ecosystems, the carbon stored in coastal wetland ecosystem sediments has extremely long residence times, potentially for millennia.

Key findings in the review of available information on carbon sequestration opportunities are:

1. Australia's coastal wetland ecosystems sequester and bury carbon at rates of up to 66 times higher and store five times more carbon in their soils than those of our terrestrial ecosystems, including forests, on a per hectare basis;
2. Taking up less than 1% of landmass, the average national annual carbon burial of coastal ecosystems represents at least 39% of that for all ecosystems (183.2 Tg (million tonnes) CO_2 eq yr^{-1} of a total of 466.2 Tg CO_2 eq yr^{-1});
3. Australian coastal wetland ecosystems are estimated to store on average at least 5% of all carbon stored in Australian ecosystems (biomass and soils) (at least 22 Pg (billion tonnes) CO_2 eq of a total of 441.2 Pg CO_2 eq);
4. Australia is estimated to be losing its coastal wetland ecosystems at an annual rate of 0.01–1.99% for mangroves, 1.17% for saltmarsh and 0.05% for seagrass;
5. Degraded and lost coastal wetland ecosystems are estimated to have emitted at least 22.5 Tg (million tonnes) CO_2 eq into the atmosphere since European settlement and continue to emit up to 0.22 Tg CO_2 eq each year – this is the equivalent of an additional 4,397 cars on Australian roads each year;
6. There is potential for substantial gains in carbon sequestration associated with reinstatement of tidal flows to degraded coastal wetland ecosystems in a relatively short time (<20 years);
7. Healthy coastal wetlands ecosystems produce negligible amounts of greenhouse gases such as methane and nitrous oxide and in some cases, can act as methane sinks, unlike most terrestrial ecosystems and land uses.

Creighton working with all states and territories developed a set of high priority and achievable works or 'Direct Action' activities that would deliver marked improvement in fishery productivity and ensure a healthy more resilient suite of coastal ecosystems, including markedly increased carbon sequestration. This was developed as a Business Case, selecting those works activities that were attractive from a return on investment perspective, the returns on investment here measured in increased value of commercial seafood product as at 2013 Sydney Fish Market prices. The broad types of repair advocated in the Business Cases includes:

- **Restoring connectivity and fish passage** – barrages, blocks, inadequate culverts, causeways;
- **Restoring estuary processes** – especially tidal and freshwater flows and fluxes, pH and oxygenation;
- **Repairing drained floodplain wetlands** – removing or manipulating barrages to allow tidal water and wetland recovery and reshaping landforms to remove drains and levees, especially for acid sulphate soils thereby re-creating habitat and also removing the pollution from acidic deoxygenated run-off waters;
- **Re-establishing mussel and oyster reefs** – key within-estuary nursery through to adult fishery habitat as well as performing a water quality improvement function;
- **Seagrass re-establishment** – re-planting of initial colonisers especially in the SA Gulfs and the provision of seagrass friendly moorings in the heavily used recreational boating embayments of NSW and South East Queensland.

The Business Case concentrated on projected increased commercial returns from seafood and did not attempt to also quantify carbon mitigation benefits. This was because as the work developed it became apparent that Australia was unlikely to implement a 'Blue Carbon' policy in the short term.

3. Imperatives for enhanced marine biodiversity & fisheries management – a climate checklist

A changing climate will lead to altered physical conditions and ecological assemblages. It will also lead to altered responses, economic opportunities and conservation priorities. Climate and its impacts is but one of many issues that need to be part of the input to management decisions. Indeed marine management by virtue of being multi-objective and meeting diverse and sometimes competing user needs is best served by incorporating climate as just one of many issues to be accommodated. With this broader holistic scope in mind a checklist of criteria on which to assess proposed policy and management arrangements from a climate perspective will be useful.

Descriptors are likely to include flexible, adaptive, resilient, integrative and responsive. The checklist of principles and criteria under which to encompass climate issues as part of the many other issues, to evaluate various options and which builds on the findings of this program of R&D will include:

Dynamic, changing and responsive

Inshore, coastal and marine systems are dynamic. Our responses to a changing and more variable climate must also be dynamic and flexible.

Climate adaptation – a part of much larger social and economic adaptation

Climate change adaptation is part of the broader need to adapt to changing economic and social conditions. Climate change adaptation is therefore best undertaken as part of the overall management process for inshore, coastal and marine systems.

Climate – part of integrative, more multi-objective policy and management

Marine policy approaches include concepts such as ecosystem-based management, managing complexity, integrated monitoring and assessment, fostering regional economies, and ensuring food security. Climate and a changing climate is just part of this much more complex agenda.

Management approaches – developing policies that match in coverage what we seek to manage

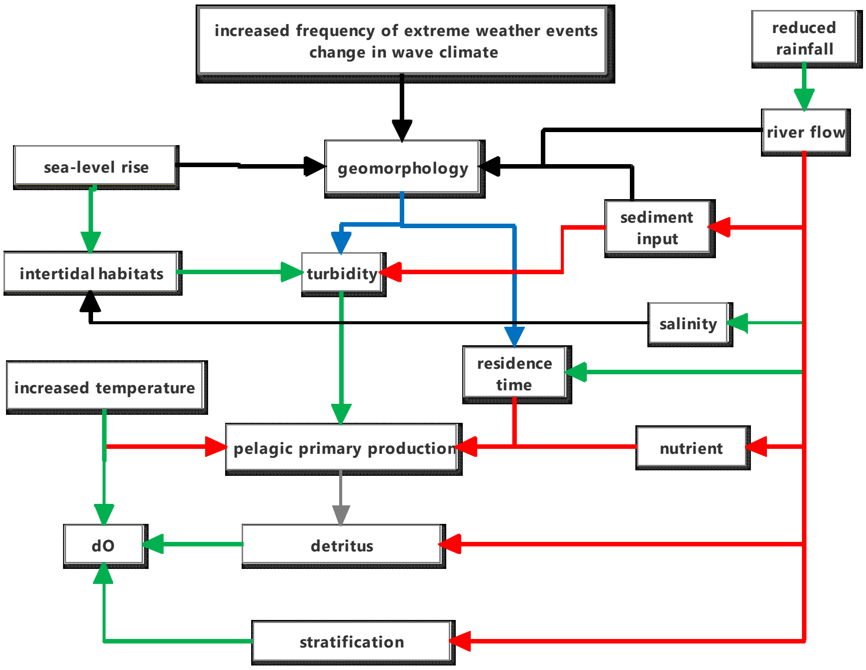
Australia's marine managers in the National Action Plan for Fisheries and Aquaculture sought to respond to our changing climate by proposing a regional approach to fisheries management – south-east, tropical and western. Climate is just one of the drivers towards this more holistic approach to cross-jurisdiction marine management.

Minimising the impact of extreme events – an imperative for fostering resilient healthy ecosystems

If we protect, repair, use and conserve inshore and marine resources for our sustainable benefit then the productive healthy ecosystems will be resilient to perturbations such as extreme events. Marine management must include fostering healthy ecosystems so that where possible the deleterious impacts of extreme climate events are minimised. (These extreme events include marine current heatwaves, cyclones, terrestrial droughts [and therefore lack of freshwater run-off to foster productivity in out estuarine and nearshore zones] and terrestrial floods [and often major fish kills from deoxygenation, massive increases in sediment load and sudden changes to water chemistry such as acidic effluent from drained wetlands that accompanies floods]).

Catchment management – essential for marine outcomes

Marine, estuarine to riverine ecosystems are inter-linked with two-way flows of material and biota. The health and vigour of these systems is adversely impacted by effluent from catchment uses. Climate change and the increasing likelihood of extreme flood events with ability to dump higher loads of effluent in receiving waters makes it even more imperative to reduce catchment effluent – sediments, nutrients and poisons, all of which adversely impact on the productivity, health and resilience of riverine, estuarine and marine ecosystems.



Potential effect of climate change on estuarine water quality and primary production.

Responding to variability – towards flexible total stock management

A changing and more variable climate will lead to changing and more variable fish stocks. Populations will change in both quantity and location. Incorporating climate impacts in fisheries management requires management processes, opportunities and controls to incorporate temporal and spatial variations in the target stock or the ecosystems that sustain that stock. Early detection of stock changes is essential as spawning stocks can become depleted if there is a downturn in recruitment that is undetected and fishing pressure is maintained. The Western Rock Lobster fishery avoided any reduction in spawning stock because of its early intervention on the decline in recruitment. However early intervention in the Shark Bay scallop fishery that resulted in the closure of the fishery did not avoid a major reduction in the spawning stock because of the severity of the recruitment downturn and mortality of adults.

Responding to changing interactions – including climate influences in any assessment

Fisheries management already seeks to take adequate account of multi-species and species – habitat interactions. Climate is part of what influences these interactions so that any changing climate and its impact on interactions will also need to be taken into account.

Responding to threatening processes – to ensure ecosystem integrity

Conservation management should focus on ecosystem integrity including stocks, flows, fluxes and ecosystem processes and must seek to minimise any threatening processes that impact on ecosystem integrity. Providing marine park protective management for a suite of representative ecosystems, bioregion by bioregion, without simultaneously seeking to minimise the impact of all threatening processes including climate impacts, will prove to be insufficient for biodiversity conservation. A changing climate will change the impact of many threatening processes. A changing climate also demonstrates the inadequacies of static management responses such as hard and fast marine park zonings and boundaries.

Responding to non-static conditions – policy, procedures and regulations must be as flexible as the stocks and ecosystems we seek to manage

Both fisheries and conservation management must recognise the dynamic nature of inshore and marine resources. There is no static or set of climax communities that we must strive to protect in say '1770 condition'. Our adaptive interventions must focus on seeking to ensure greater resilience so the ecosystems have the capacity to sustain shocks such as extreme climate events while recognising that there will be change such as those bought on by a changing and more variable climate that are beyond our ability to readily reduce.

Repairing for increased resilience – a priority for investment

The marine resources most degraded are the inshore and coastal resources – estuaries, wetlands, nearshore zone and beaches. These are also the resources most at threat from extreme climate events. Increased focus on repair and investment will enhance their resilience and optimise the multiple public benefits we derive from these inshore and coastal resources.

Protecting key species – site- and species-specific strategies will be essential

A changing climate will impact on key species of high conservation value such as seabirds and marine mammals. Site and species specific management to minimise the impacts of a changing climate is essential if we are to conserve these populations, their roosting or resting, breeding and feeding regimes.

Changing climate – a profitability opportunity

Some stocks will be advantaged by a changing climate (e.g. increasing Eastern Rock Lobster range over Southern Rock Lobster range that will decline). Likewise some production systems will be benefited (e.g. expansion south of suitable environments for Barramundi aquaculture) and others may decline (e.g. suitable inshore areas for Atlantic Salmon). A positive facilitative approach to industry development is essential and will be informed through value chain analysis and the identification of key opportunities.

Marine ecosystems – a key role in carbon sequestration

Coastal, nearshore marine and estuarine ecosystems, by virtue of being the most productive of the world's ecosystems are also the highest per hectare sequesters of carbon. Coastal, nearshore marine and estuarine ecosystems need to be incorporated in Australia's National Carbon Accounts and play a significant role in Government investment programs such as 'Direct Action'.

Carbon sequestration – part of a multi-objective approach

Similar to adaptation being multi-faceted, Australia's investments in climate change mitigation could most usefully focus on those opportunities that also provide multiple other benefits to the Australian community and economy. From a marine perspective, repairing coastal ecosystems of seagrasses, mangroves, salt marshes and floodplain wetlands provides not only the highest per hectare carbon sequestering opportunity but also deliver outcomes for Australia's food security, regional employment and biodiversity.

4. Priority knowledge needs – an outcome perspective

4.1 Knowledge to equip marine users & managers to adapt

- **Improved marine forecasting and ocean current / eddy forecasting** – The increasing variability and changes in ocean conditions, the increased dynamics of nearshore eddies and currents and responding changes to marine biodiversity on short-term time scales makes accurate predictive forecasting even more important for all marine users. Investment through the Bureau of Meteorology linked to the data sets being collated by the Integrated Marine Observing System (IMOS) could improve marine forecasting, develop user-specific modules and overall enhance information accessibility and applicability to all marine users. With ocean conditions influencing much of the terrestrial weather patterns, flow-on benefits to land weather services will be substantial.
- **Smarter and more real-time stock and population prediction** – Increasingly, for many of the short-lived target species such as all prawn species, annual populations will markedly vary. This is a direct consequence of increasingly variable climate, rainfall, run-off and sea surface temperatures. Influence on population dynamics will also extend to the estuary and nearshore dependent species that recruit to fisheries at age 3, such as Barramundi, Sea Mullet and Mulloway. Changing eddy and sea surface temperature dynamics will affect marine target species such as Tunas. Improved stock prediction, linked to climate and all other key variables will ensure effort can then be better matched to production. Underpinning this work is the need to measure ocean productivity, pre-recruitment for stock prediction and changes to habitat. This will lead to increased profitability and sustainability by better matching annual and varying sustainable economic yields to the stock available.
- **Biological trajectories** – There is still a lot of research required to better predict effects of climate change (e.g., increasing temperature, declining pH, declining aragonite saturation, changing current patterns) on the population dynamics of fish, seabirds and marine mammals (e.g. size structure, food web data, replenishment, resilience). Even for the best-studied fisheries stocks, there remains some ambiguity about specific physiological and population responses to changing climate and habitat condition. It is important that we are prepared for 'surprises' as it is not possible to understand all the ecosystem interactions that may be associated with climate change. Our knowledge of food chains, the drivers of food chain fluctuation and especially the impact of climate change on food chains and food sources are limited as is our ability to know where best to allocate resources for adaptation outcomes. Some changes might be irreversible.
- **Better biological information to equip for a changing assemblage due to climate** – For commercial species we need a better understanding of climate change driven tipping points and limitations for commercial species if we are to prepare for a transition to different species and/or boutique fisheries. There are also cross-jurisdiction issues with shared stocks between states and with neighbouring countries and climate impacts on these shared fisheries.
- **Ecological processes and habitat protection needs for adequate marine conservation** – Much of Australia's marine conservation has recently focused on retaining a representative set of marine environments. With a changing and more variable climate placing stress on key parts of marine and nearshore / inshore ecosystems, much more thought needs to be given to the sustaining ecological processes, the stocks and flows and overall habitat protection, especially nursery areas nearshore and within embayments and estuaries that sustain the juvenile phases of most of the populations Australia seeks to conserve. Improved knowledge on ecological processes and how best to retain and repair habitat is essential. Sea-level rise is also likely to impact on seabird/ marine mammal populations. We need to increase our understanding of which populations/colonies are

likely to be most affected and to assess adaptation options. For some species we may be able to offset losses due to sea-level rise by creating additional habitat or providing habitat through planning decisions to setting development back from critical habitats and erosion prone areas. Few potential adaptation options for marine mammals and seabirds, (if any) have been robustly tested. Monitoring to evaluate effectiveness of adaptation options is critical, and should be a focus in any adaptation experiments. Testing some of the adaptation options such as improved management of nesting sites would be a useful next step and build the experience of researchers and managers charged with securing the status of these iconic species.

- **Monitoring to calibrate projections and inform management** – Understanding the impact of our interventions is essential if we are to continuously improve our various management activities and policies. Monitoring across biophysical, social and economic components and closely linked to our various management and policy activities is essential if we are to understand both natural and management-induced perturbations and the influence of our interventions.

There will always be limited resources nevertheless Australia needs to test and then implement cost-effective and efficient long-term monitoring systems underpinned by data collection and management systems such as IMOS so that results can be analysed over time for trends and implications. Such monitoring and analysis needs to be ongoing, adequately cover our coastline and marine resources, and most importantly be strongly linked to all marine management activities for fisheries and biodiversity conservation.

4.2 Reinforcing the need to rethink marine management paradigms

- **Species management for a more variable climate** – Marine and inshore fisheries target species such as Snapper, Spanner Crab, Eastern and Southern Rock Lobsters are already documented as changing range and total stock under the influence of a changing and more variable climate. Their recruitment, growth, range and spawning processes have no regard for state boundaries or fishing zones. Likewise seabirds and marine mammals are not constrained to particular jurisdictions. With increasingly variable populations, moving to whole-of-stock / population monitoring and management, whatever the jurisdiction, is one of the next major steps in both fisheries management and species conservation. Testing cross-jurisdictional policy, practice and operationalising multi-species and population rather than jurisdiction management will take time and will need to be carefully underpinned by research. Equally important, as part of the management decision-making process, there is a need to document and incorporate in policy decisions not only production–catch issues but also the supply/value and life-cycle chains.
- **Encouraging flexible conservation and fisheries management** – Much of current fisheries and biodiversity management is strongly focused on inputs (e.g. allowable number of fishing dories, or rigid take or no-take zones within parks, roosting and breeding refuges and other spatial entitlements and zones). Many of our populations are at least 'sub-global'. For example seabirds and mammals that forage in Antarctic waters and spend part of the year in the north Pacific. A stronger focus on outputs and outcomes responding to and taking account of more variable populations, stocks, flows and fluxes will be essential if we are to ensure the sustainability of our inshore and marine resources. Audits of management arrangements and how they do or do not foster flexibility in management together with improvements in policy, management arrangements and regulations are needed and to be implemented must be based on best available science.
- **Enhancing market and food security** – Two key issues relate to extrinsic forcing on fisheries stocks – supply and demand. Increasing demand – what will be the projected change in demand for fisheries resources, both to meet local and national food requirements and increasing export demand? Supply – what will be the change in the

condition of stocks, communities and ecosystems due to climate change and other more direct anthropogenic effects such as ongoing habitat degradation? An increased focus on restoring productivity and profitability to our marine industries is essential and will underpin improved market arrangements and food security.

- **Fostering industry development** – While most of Australia's wild fisheries are already managed to ensure sustainable economic yield there are opportunities for increased productivity and profitability as well as improved protection and conservation. Repairing estuarine habitat, especially in southern Australia is a major opportunity that delivers both profitability and conservation outcomes. In northern Australia, prediction models are needed to inform aquaculture precinct planning and areas off northern coastline potentially suitable for offshore sea cage aquaculture based on ocean current forecasting could be explored further as part the Government's northern development strategy. Australia-wide research is also required into how climate shifts will open up further suitable areas for aquaculture. This will assist forward planning of land-based and nearshore aquaculture precincts. Identification of climate trigger points would indicate when sites should then be promoted for development.
- **Building improved recreational and indigenous futures** – Recreation values (including tourism) of the inshore, coastal and marine resources will continue to grow as Australia's population grows. Relationships between species or asset supply (stocks) and recreation demand will vary with region. Commercial fishing and various recreational uses will increasingly become competitive economic uses. Economic impacts of climate events leading to large-scale loss of species and of amenity (e.g. Clarence estuary, 2013; Richmond River, 2010; Gold Coast beach erosion 2013) are substantial. There needs to be systematic assessment of impacts and better understanding of what we can do to mitigate. The value of these public assets to regional economies is substantial and should be factored into our management responses to a changing climate.

4.3 Equipping inshore fisheries for increased productivity & resilience to more extreme shock events

- **Catchment and estuary health in a more variable climate** – The 2013 rain event on the Clarence estuary, northern NSW led to the death from deoxygenated acidic run-off of all benthos from Grafton to Yamba, essentially the entire estuary of about 90 km in length. Sydney Rock Oyster cultivation in NSW is now about 40% the 1970s production at least in part due to deleterious catchment run-off, especially derived principally from the drainage and floodgating of major wetland resources. Even the hardier and more rapid growing Pacific Oyster is facing increasing kills with run-off events. Redesigning catchment landscapes and repairing key elements of fisheries and biodiversity productivity with the flow-on multiple public and private benefits they all provide is essential if we are to equip our inshore resources with resilience to more frequent extreme events.
- **Expediting the transition to sustainable sustainable habitat & economic yield based management** – Under classic fisheries management theory and demonstrated around the world, fisheries typically move from 'nascent' to 'developed' and then to a 'sustainably developed' phase (with maximum sustainable yield as a goal). A more recent trend in fisheries management for the target species is towards 'economically sustainable yield' (maximum economic yield). In tracking this evolution, a commonly used metric is a measure of catch per unit effort (CPUE), with stable CPUE regarded as evidence of 'sustainable' fishing effort.

Such approaches have failed when stocks collapse towards the fished area, such that local CPUE remains constant while total population declines, or when fishing effort moves around to maintain CPUE (e.g. Abalone), again, while total population declines. Less recognised are changes outside the mandate of the fisheries management body that also impact on the exploited population.

For a range of coastal fisheries, fishing effort and catch may not be the major stressor. Loss of habitat, both physical habitat and declining water quality is for most inshore fisheries the major stressor on total population size. Loss of habitat is also a major stressor for marine mammals and seabirds. A change in paradigm is required towards stock productivity as the major metric for management.

To underpin sustainable fishing in the face of increasing coastal and population pressures, it is suggested the need to assess productivity potential based on the quality and extent of available habitat and to be able to track fishery productivity in addition to fishing effort. Where fisheries could be improved if habitat were repaired new thinking is needed to support investment in habitat repair as a major tool in fisheries management. Indeed it may be timely to re-think how we best manage the sustainable harvest of any wild population on sea or land.

4.4 Ensuring multi-objective marine resilience

- **Working towards all encompassing governance systems and funding models** – Much of our governance is single objective in focus and there are strong institutional dysfunctions between agencies. There is also no coherent funding model such as Trusts, as already proposed for the Great Barrier Reef, to cover the massive costs of marine management and monitoring across all sectors of marine use.

Part of the process is to take account of and assimilate information from successful examples (e.g. Georgia Basin, Washington state, US; and Puget Sound, Canada trans-boundary region) and then modify these as part of transferring improved governance to suit Australia's institutional, social and economic settings. Most importantly, without understanding the social and economic setting it is difficult to deliver on social and economic outcomes.

In time this might lead to multi-jurisdictional governance structures that are also cooperative and accountable across local, state and Australian Governments, industry, conservation groups and the broader community. Regional marine and landscape management concepts with a strong focus on the multiple benefits streams of food security, sustainability, conservation and increased productivity are likely to be welcomed by the Australian community.

- **Building the policy framework for 'blue carbon' to be part of climate mitigation investments** – Recognising that coastal wetlands, seagrasses, mangroves and salt marshes comprise less than 1% of the landscape yet sequester over 39% of Australia's carbon there are substantial opportunities for these areas to contribute to a carbon economy. Most importantly, such 'Direct Action' will have multi-objective outcomes of improved fisheries habitat, flood control, infrastructure improvement and increased biodiversity. Research is required to determine where and how best to capitalise on this opportunity as well as to finalise measurement and reporting systems so that these marine environments can become part of Australia's National Carbon Accounts.
- **Fostering more profitable systems across the value chain** – At the most basic level, variable climate means gluts and shortages in product; how can we have seafood processing and storage systems that deliver more profit to the entire value chain during gluts?

Moving to a longer-term view, what changes for marine Australia are required from a climate change perspective by 2070? What are industries of the future going to look like? What will be the drivers – more food production, balance of trade, employment, energy production, marine conservation etc.? Will Australia recognise the importance of coastal systems and radically change to offshore marine production systems, and if so what role does a changing climate play in this development? Will there be increased use of EEZ – (e.g. offshore artificial 'floating' reefs), a focus on production of quality seafood such as Lobsters and Abalone, or will we move to mass food production via algae production systems? The integration of marine production systems, energy production, tourism and recreational use with an increased population pressure and strong social licence for use of coastal regions will all intersect with climate and extreme events.

4.5 Fostering climate informed action through shared knowledge

Australia needs to develop systems, activities and management structures that will enable rapid adoption of new knowledge. This might be on the differential vulnerability of fisheries stocks, including capacity to moderate effort such as recreational licences and specifically zoned commercial licences; the need for private action to repair habitats for public benefits; the challenge of balancing conservation and exploitive uses, the application of incentives to modify behaviour and so on. Most importantly there is a need to improve processes for the uptake and delivery of knowledge. The issues being addressed are complex and controversial.

- **Ensuring extension activities apply a diversity of approaches and interaction techniques** – For uptake and incorporation into effective governance processes, increase in community understanding is particularly important. There is no one solution. Some of the issues for consideration include:
  - increased capacity of organisations with the role and function to move knowledge between the knowledge makers and decision makers – in this sense 'decision makers' includes managers, politicians as well as fishers and conservationists;
  - improve the general knowledge about fisheries, increasing the general public's understanding of how fisheries are actually managed such as the principles behind output controls and the relationship to efficient fleets;
  - foster a better understanding of the role and importance of active fishing fleets in small coastal communities;
  - understand the implications of price elasticity's for key fish species on regional economies;
  - increase community participation in delivery of knowledge through deliberative methods (e.g. 'photo voice');
  - foster better understanding and incorporate community values; and
  - develop and disseminate information that is regionally relevant in scale both spatially and contextually.

Climate adaptation is really about managing people's responses and adaptations to a changing environment.

4.6 Contributing to smarter energy use

To date the fishing and aquaculture sector has not been able to access incentives or other mechanisms to play their part in climate change mitigation. The 'Carbon Land Sector Package' of the previous Government was just that – only the land sector of Australia's primary industries. Recognising that Australia's role in the carbon economy is likely to be through more 'Direct Action' following are some examples of the types of incentives that would assist the seafood sector in participating in smarter more carbon benign practices:

- **Reducing the carbon footprint of marine users** – Fuel is a major part of the input costs for all wild fisheries, marine park and fisheries enforcement vessels and a high part of the costs of undertaking marine research. In other maritime nations such as New Zealand, specific initiatives have targeted fuel efficiency. This includes incentives for installing fuel flow meters, training in smarter boat use, systems for sea 'mooring' on the fishery, more fuel efficient gear such as otter boards and nets and designs that further reduce by-catch. An initiative targeted on more efficient marine practices would yield multiple dividends in increased profitability, reduced carbon footprint and reduced adverse impacts on such as by-catch and habitat.

- **Improved energy efficient & carbon smart aquaculture** – Energy is a major cost input to virtually all aquaculture systems. As the price of energy increases so do aquaculture industry costs and therefore reduced profit margins. Technical support for energy efficiency audits, assistance in developing the break even business cases for investment in energy miser paddlewheels and pumps or revised recirculation systems and energy efficiency training would foster a more profitable, reduced energy consuming Australian aquaculture industry. Integrated aquaculture being carbon sequestration and energy transfer systems on large scale require further research and development. A good example is macroalgae linked to prawn farms for protein production as a source for both agricultural and aquaculture feeds.

5. Priority knowledge needs – structures for conducting research

In conducting R&D&E to deliver on these high priority outcomes rigor in research program design is essential. Integrating research across social, economic and biophysical contexts of enquiry requires the following key components:

- strong links to data already available and with the research adding to this data system so that all data is current and readily available and can be built upon by other researchers;
- a common base of credible modelled projections;
- validation of projections through the application of monitoring to build a qualitative understanding of change and impacts;
- selective use of scenarios to develop options of intervention and management that optimise various outputs;
- rigor in the development of recommendations for management, policy and monitoring based on the above; and
- all recommendations to be framed from two perspectives – the overall outcomes sought and the achievability of the recommendations based on the existing management structures and their capability to implement the recommendations.

Graphically this is depicted in the following figure. The right hand side margin suggests a nominal percentage of effort across each of the components.

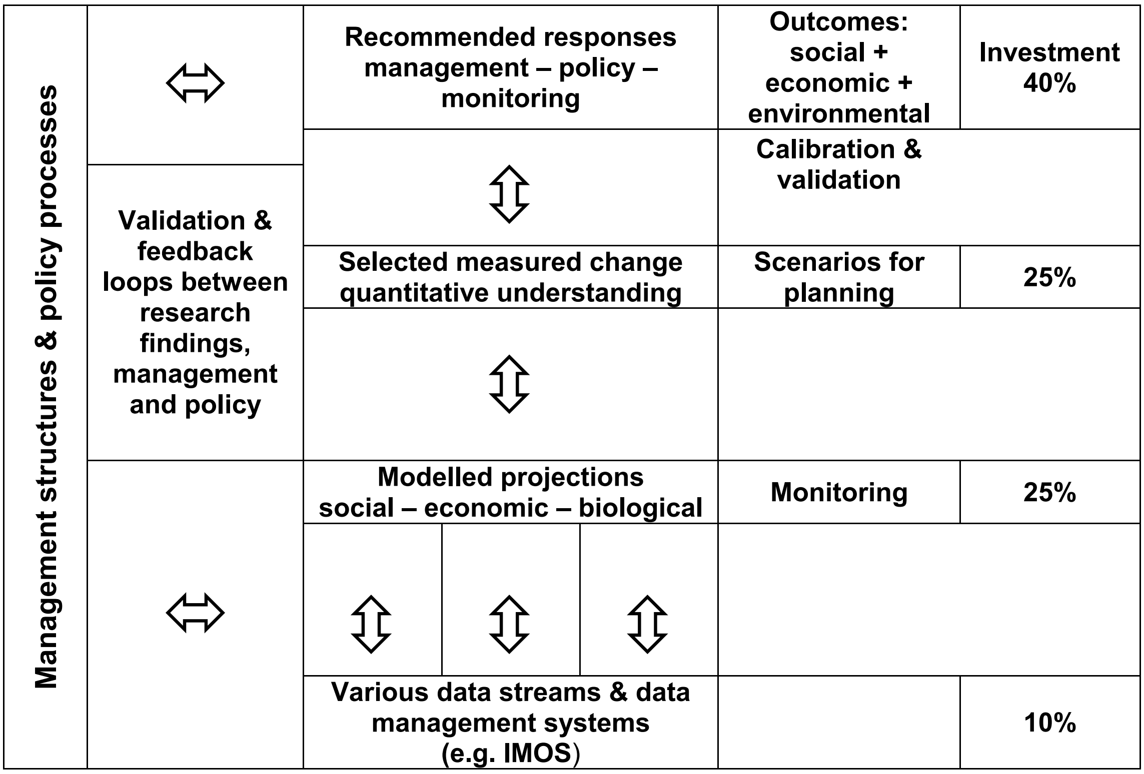


Figure 1. Conceptual framework for R,D&E investment

6. Conclusions

This multi-investor program of R,D&E has delivered substantial improvements in our knowledge on estuarine, nearshore and marine systems, their biota and use and how Australia might best adapt its policy and management. On that basis alone, as illustrated in Section 3 and Appendix 1, the program has proved to be an excellent investment.

Capitalising on the knowledge learnt via extension and interaction with policy makers, managers, fishers and the broad community is ongoing.

Most importantly, based on the findings of the projects and the recognition that an integrated approach is the most cost-effective response, many discussions now centre on how to factor in climate, its variability and change into the broader more generic area of **marine systems policy and management**.

This program and its investments will have a very successful legacy if more and more climate is included as another one of the key attributes being considered when determining marine policy and management. FRDC will be taking this approach. Most R,D&E invested in by FRDC that incorporate the issues of climate will be focused on including climate as an integral part of the continuous challenge to improve Australia's marine policy and management. Certainly there may be occasional climate-specific investments. Nevertheless, from an adoption perspective the challenge is include the implications of climate, climate change and climate adaptation within the broader perspectives of policy formulation and management of Australia's marine biodiversity and fisheries.

7. References

Creighton C (2013) *Revitalising Australia's Estuaries – the business case for repairing coastal ecosystems to improve fisheries productivity, water quality, catchment hydrology, coastal biodiversity, flood control, carbon sequestration and foreshore buffering.* Fisheries Research and Development Corporation, Canberra.

Poloczanska, ES, Hobday, AJ & Richardson, AJ (eds) (2012) *Marine Climate Change in Australia, Impactrs and Adaptation Responses. 2012 Report Card.* CSIRO. ISBN 978-0-643-10927-8.

8. Appendices – Research Findings – Executive Summaries

8.1 Development and testing of a national integrated climate change adaptation assessment framework [FRDC 2009/055]

Vincent Lynne, Tim Skewes, Donna Hayes, David Brewer, Roger Scott and Rick Porter-Smith

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2009-055-DLD.aspx

Objectives

- To develop an integrating climate change adaptation assessment framework for fisheries and aquaculture, suitable for use regionally and at a national level.
- To test and apply this framework in the south-eastern region to evaluate adaptation response options for stakeholders (managers, fishers, aquaculturalists).
- To assess the application of the framework to apply to other regions around Australia.

Executive Summary

The framework and associated tools to implement an Adaptation Framework for fisheries and aquaculture impacts arising from climate change are presented, and example applications are provided for SE Australia. The framework and tools are applicable across other regions of Australia.

The framework is a hierarchical scheme for assessing regional vulnerabilities and regional adaptation needs which cascade to provide context for vulnerable fisheries/local impacts and adaptation needs at that scale. Adaptations at both scales are linked through agreed targets and indicators for the intended adaptation outcomes – which include fisheries/ecosystem outcomes as well socioeconomic ones, and those related to management/operational adaptation performance.

The toolset developed in this project is unique in providing a mechanism to assess the cascade of risk from regional scales down to species. The toolset also includes options for adaptation at both the regional level (at ecosystems, habitats and/or trophic components), which in turn guides adaptation for species-level impacts. Decisions on adaptation are prioritised as trade-offs between regional/fisheries targets and a collection of targets that characterise desires based on socioeconomics, conservation and management. Adaptation in the face of climate change has to involve both performance measures on fisheries as well as those on based on ecological and livelihood dependencies.

The context in which changes are occurring in the environment determines the nature of the vulnerabilities, the cascade of risk from regional to local, and implications for the adaptation decision-making processes. The three situations identified range in order of the anticipated scale of changes:

- ***The Regime Shift Scenario*** involving whole-scale ecological shifts in space/time and composition;
- ***Abnormal Range Change Scenario*** involving species ranging beyond their core distributional limits; and
- ***Localised Change Scenario*** involving changes within (historically) expected bounding ranges of species and processes.

In situations where the future state of fisheries or ecosystems is difficult to predict through assessment models (particularly, for example, in Scenario (1) above), the performance of management processes/policies and the speed with which changes can be measured and responded to, takes priority. Thus co-management approaches where operators are immediately reporting back the state of fisheries, habitats and general observations/trends is critical. These bottom-up processes must also feedback rapidly through to regional managers who will need to assess implications for broader ecosystem and cross-fishery impacts.

In applying the framework to the SE we identified firstly that the region is undergoing a Regime Shift Scenario. This assessment is supported by early anecdotal information since 1994 of species range shifts, further reinforced by the collective findings of researchers reported at a 2005 CSIRO workshop of oceanographic and ecological shifts, and more recent sightings, such as those reported from Red Map of species extending their nominal ranges.

The key findings for the South East are reported under the two phases of the study:

1. The vulnerability assessment of bioregions and species to determine projections of future impacts from climate change – using the Business As Usual scenario as a baseline; and
2. The adaptation assessment framework based on scenarios of climate change to identify regional and sector specific adaptations and linkages.

Vulnerability Framework and Testing

In applying the framework to the SE bioregions, both positive and negative impacts are evident for a few stressors. Impacts increase progressively from 2030 through to 2100. Acidification is being flagged as a critical stressor throughout this period. Positive impacts are noted for macroalgae and seagrass (although their weighted values are small) with key contributions from temperature and acidification. Overall negative impacts outweigh the positive ones.

The framework was tested for Snapper (*Pagrus auratus*) in the SE, while some positive impacts (from temperature) are noted for the early years, by 2100 the negative impacts dominate. Acidification is a key negative stressor for Snapper eggs and larvae. Habitat change is a key negative stressor for juveniles and adults, and links back to impacts at the bioregional level – compared to more direct impacts on eggs and larvae. Although some uncertainties remain, juveniles and adults are projected to be more impacted than eggs and larvae. There is a clear bioregional influence on the former life history stages.

Adaptation Planning and Testing

SE Australia was found to be a global 'hotspot' for climate change undergoing a 'regime shift' involving broadscale changes to environments upstream of the East Australia Current and associated ecosystems. Signs of change were noticed in mid-1990s when the Longspine Urchin (*Centrostephanus rodgersii*) was making its way from NSW across Bass Strait. The effects of the urchin on shellfish stocks off the east coast are now in part offset by a lucrative industry exploiting the urchin for its roe that is exported as a delicacy to South East Asia.

Range changes to marine species were documented by Last et al. (2010). Climate change trends here are much higher than the global average due to both temperature changes and changes to the East Australia Current system driven by southward shifting wind systems (Cai et al., 2005). Compounded with the climate change are decadal oscillations that led, during the hot summers of 1998–2000, to the collapse of a major aquaculture operator. Aquaculture now is a sophisticated industry that is attempting to outpace climate change through selective breeding, better management of rearing, feeding and pests, and long-term planning of infrastructure (Batteglene et al., 2011).

SE Australia is therefore facing significant challenges both in understanding the vulnerabilities and in identifying adaptation options and the changes that are required in current 'Business As Usual' practices to enable the adaptations to take place. Benefits may be possible for aquaculture for such species as oysters, mussels and other shellfish while also providing opportunities to establish new industries around invading migrants such as the Longspine Urchin. At the same time, there has been a decline in the recruitment of the lucrative Southern Rock Lobster (*Jasus edwardsii*), and problems with the spread of an Abalone virus.

Application of the adaptation component of the framework to the SE showed that shifting ecosystems would affect fisheries management based on existing spatial jurisdictional boundaries. At a regional scale, regional management policies and decisions are needed to cope with changes in productivity, trophic relationships and habitats. Regional adaptation will require management to develop and enforce regional policies and to inform more local and sector specific management and adaptation. Regime shits are dynamic in scale and intensity and poses serious challenges for stable management practices and industry operations, and the cascade of risk from regional to local scales, as well as the potential for local problems to spread to regional scale (such as the spread of diseases, pollution related issues and socioeconomic dependences).

The regime shift unfolding in SE Australia will require an effective, and perhaps formal, regional adaptation strategy. Given that formal procedures are in place to administer the EPBC Act, one option to deal with the climate change impacts is to augment the Principles under the Act to cover the anticipated regional climate change impacts and the adaptation needs (regional coordination, collaboration, regional information collection and assessment, bioregional management planning). Other less formal arrangements may be needed in the interim until the regional needs are clearly identified.

The adaptation framework allows decision strategies to be based on a combination of fishery performance and human socioeconomic performance. In cases of conflict, participatory planning, or co-management, arrangements will be required to obtain agreement on how the context provided by the human needs will influence alternative decision choices/strategies that are consistent with the desired ecosystem and fishery performance based adaptation outcomes. The framework will facilitate the work of such co-management approaches by providing tools for incorporating ecological targets, fisheries performance and human needs.

Recommendations

1. The study recommends the urgent need to implement the adaptation framework in South East Australia to investigate adaptation strategies and to assess feasible options.
2. Further testing is recommended to refine and extend the tools as well as to provide a consistent national assessment of vulnerabilities and adaptation.

8.2 Understanding the biophysical implications of climate change in South East Australia: Modelling of physical drivers and future changes [FRDC 2009/056]

Alistair J. Hobday, Jason Hartog, John F. Middleton, Carlos E. Teixeira, John Luick, Richard Matear, Scott Condie

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2009-056-DLD.aspx

Objectives

1. Extract variables from Bluelink and Global Circulation Models (GCMs) for fishery regions around the South East of Australia
2. Validate variables derived from the Bluelink model against the Integrated Marine Observing System (IMOS) and other historical data
3. To complete development of South Australian Regional Ocean Model (SAROM) and validation against the IMOS and historical data for the February 2008 – March 2010 period
4. Compare the predictions of the two models to each other and to GCMs
5. Derive, extract and examine model outputs on derived variables, including acidification levels, in the SE region.
6. Provide these data in written and visual format to the biological and review teams for consideration
7. Consider historical changes in connectivity in the SE Region

Executive Summary

The waters of eastern and south-eastern Australian have been identified as being the most vulnerable marine area to both climate change impacts and overall exposure in Australia. This vulnerability relates to changes in the East Australian Current, which has strengthened by 20% in the last 50 years. As a result, water temperatures in the SE region have risen and continue to rise more rapidly than elsewhere in Australia (Figure 1). This warm East Australian Current and other oceanic currents such as the warm Leeuwin Current (which is understood to suppress oceanic upwelling such as the Bonney Upwelling), the cool Flinders Current, and the cool Tasman Outflow converge in this region and together with local ocean processes such as coastal upwelling, are important factors in structuring the composition of marine species, functional groups and communities.

The changing climate in the SE is already affecting many marine fishes and other organisms. These impacts will have flow-on implications for businesses, communities and economies that are dependent on the marine environment and its resources. Climate models predict that these physical trends in ocean conditions will continue into the future.

This project set out to improve the understanding of change in the physical environment and determine if further oceanographic model development was required to support biological, social and economic aspects of the SE initiative.

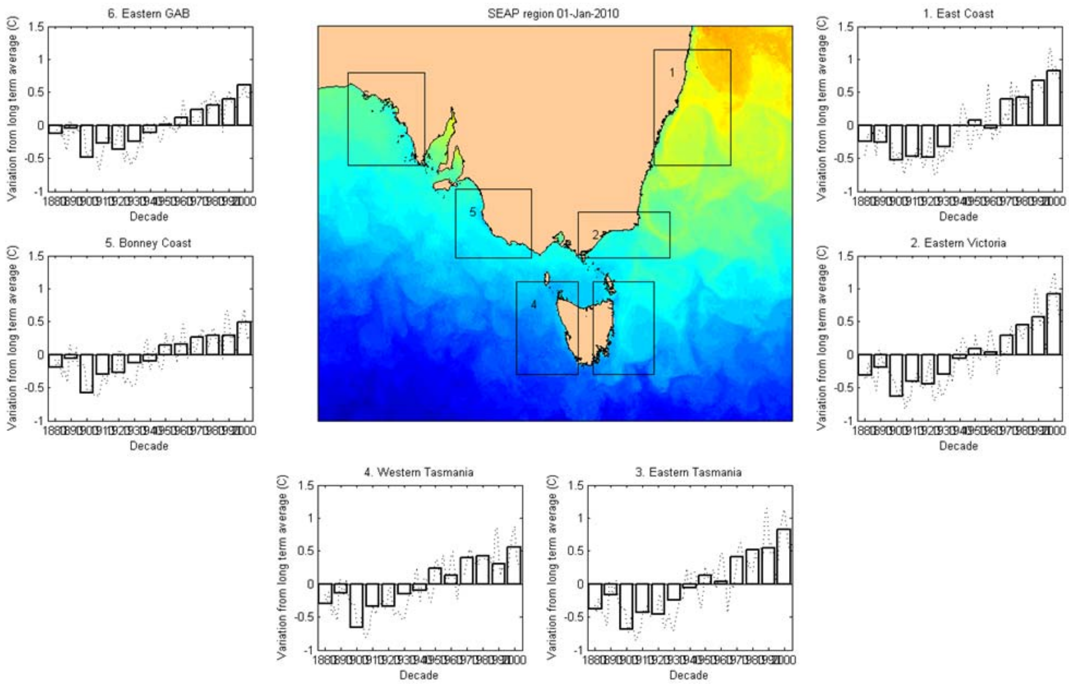


Figure 1. Historical change in surface temperature based on the HadlSST2 dataset for the period 1880–2010 for six regions in the south-east.

Oceanographic data for the SE region were extracted and archived from the Bluelink ocean model hindcasts for comparison with observations (**Objective 1)** and can be used to examine historical patterns of change. These variables included sea surface temperature (SST), temperature at depth (200 m), surface salinity, and currents. The Bluelink model variables were compared with observations at a range of distances from the coast (i.e. 'do they sufficiently represent reality') (**Objective 2)**, which showed that SST was the best performing variable, and the currents were the poorest at the spatial and temporal scales considered. Development of the South Australian Regional Ocean Model (SAROM) model, which covers a smaller region in South Australia, was completed and comparison with in situ IMOS data showed the performance was very good in the regions considered **(Objective 3).** Qualitative comparison of the regional models was completed **(Objective 4**) and we recommend that both models will be useful for a range of biological uses. Projections of future acidification levels were completed (**Objective 5**). There are few studies on the impact of ocean acidification for the SE region to date. Implications for commercial fishes and invertebrates (e.g. Rock Lobster and Abalone) are unknown, and there is a need for more experiments and field studies before impacts can be more specifically determined. The project has provided some estimates of pH levels, such that critical experiments using realistic values can proceed. Finally, methods to determine marine connectivity in the SE for the recent past were detailed and patterns of change reported **(Objective 7**). These analyses showed a recent trend towards increasing southward transport off eastern Tasmania, consistent with the documented increase in the strength of the East Australian Current and the associated warming of waters off eastern Tasmania that is predicted to continue over the next half century.

Recommendations

1. Data can be extracted from the existing set of physical ocean models that is suitable for retrospective analysis of biological patterns.
2. There is no single best ocean model for all purposes; careful selection and validation should be part of each use of model-based environmental variables. Each model does have strengths and will be appropriate for different uses. We suggest that case studies of fishery species in the SE discuss their modelling needs with physical oceanographers.
3. Development and improvement of the existing models is not a roadblock to further fishery adaptation planning in the SE.
4. The suite of available physical data is sufficient to support the next phase of biological case studies.

Peer-reviewed papers

Hobday, A. J. and J. Lough (2011). Projected climate change in Australian marine and freshwater environments. Marine and Freshwater Research 62: 1000-1014.

Lough, J. M. and A. J. Hobday (2011). Observed climate change in Australian marine and freshwater environments. Marine and Freshwater Research 62: 984-999.

8.3 Risk Assessment of Impacts of Climate Change for Key Species in South-Eastern Australia [FRDC 2009/070]

Gretta Pecl, Tim Ward, Zoë Doubleday, Steven Clarke, Jemery Day, Cameron Dixon, Stewart Frusher, Philip Gibbs, Alistair Hobday, Neil Hutchinson, Sarah Jennings, Keith Jones, Xiaoxu Li, Daniel Spooner, Richard Stoklosa

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2009-070-part2-DLD.aspx

Objectives

The oceans are the earth's main buffer to climate change, absorbing up to 80% of the heat and 50% of the atmospheric carbon emitted. Changes in temperature, environmental flows, ocean pH, sea level, and wind regimes are all contributing to modifications in productivity, distribution and timing of life cycle events in marine species, affecting ecosystem processes and altering food webs. The south-eastern region of Australia has experienced significant oceanographic changes over recent decades and this has been reflected by changes in the associated ecosystems: range extensions have been documented in several dozen species, major distributional shifts have been recorded in barrens-forming sea urchins, bivalves and gastropods, and major declines in Rock Lobster recruitment have also been related to ocean warming and changing circulation patterns.

The major goal of this project was to undertake a screening-level risk assessment of the potential impacts of climate change on key fishery species in the south-east Australian region. Specifically, we aimed to:

- Identify the life history stages, habitats and aquaculture systems of key species that may be impacted by climate change
- Identify the physical and chemical parameters that may determine the potential impacts of climate change on key species
- Conduct a preliminary screening-level risk assessment of each key species to the potential impacts of climate change
- Highlight critical knowledge and data gaps, relevant to future assessments of climate change impacts on key species and development of adaptation strategies.

Executive Summary

Key Outputs

- This project provides an objective framework for prioritising future research, based on the relative sensitivities of species to climate change drivers and recognition that limited resources will be available to support further work.
- We identified species at high risk to climate change impacts, enabling future research to be focussed on issues of greatest concern. Fisheries and aquaculture provide significant social and economic benefits for the south-eastern region, and early warning of changes in resource physiology, distribution or abundance will provide managers and stakeholders with the best opportunity to adapt to impacts.
- Outputs will allow fisheries managers to understand likely changes to fisheries under a range of climate change scenarios and assist marine industries to select and develop adaptation strategies that maximise positive outcomes.

Key biological findings

Thorough literature reviews and species assessment profiles were completed for key species to underpin the ecological risk analyses. Physical drivers of climate change stressors on each fishery species were identified. Wild capture fishery and aquaculture species were ranked according to their need for further assessment of their vulnerability to climate change (Table 1, Figure 1).

- Temperature was the most commonly cited driver of current or potential climate change impacts for both fisheries and aquaculture species. Among other changes, increases in temperature impact growth rates and larval development, timing of annual migrations, onset of spawning, susceptibility to disease and geographical distribution. Potential changes in currents, freshwater flows and salinity were also important.
- Impacts of ocean acidification were associated with high uncertainty for all species. The consequences of lowered pH may include reductions in calcification rates, increased physiological stress and disruption to settlement cues.

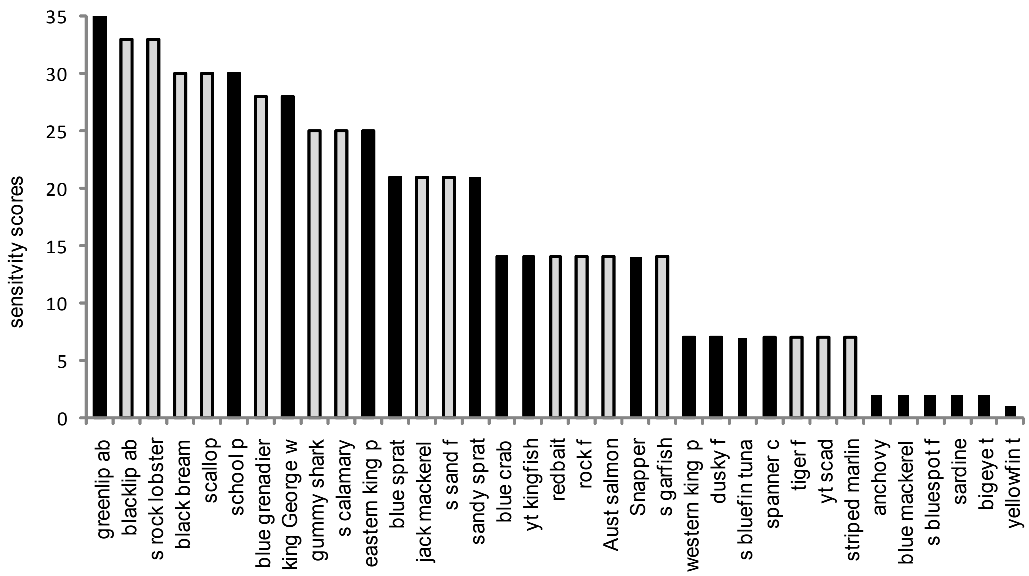


Figure 1. **Overall ranking of wild capture fishery species based on an average of all attributes (distribution, abundance and phenology). Black columns = species which are predicted to undergo a range extension; grey columns = species which are predicted to undergo a range contraction.**

Implications for fisheries management

Each jurisdiction in the south-eastern region had at least one of its two most important species classified as high risk. Fisheries species considered at highest risk also supported the region's highest value fisheries – Blacklip and Greenlip Abalone and Southern Rock Lobster. These species demonstrate little capacity to move at adult stages, lower physiological tolerances, and have life history stages that are strongly affected by environmental associations (e.g. spawning and settlement). Habitat loss via the barrens causing urchin *Centrostephanus* is also a major concern for both species. Changes in the distribution, abundance and species composition of our commercial fisheries resources as a function of changing climate is going to be unavoidable and our industries will need to adapt to minimise exposure to risks which, given constructive adaptive actions, could be avoided. It is imperative that industries and managers are proactive in positioning themselves to undertake a strategic and structured approach to adaptation planning and engage in subsequent actions to minimise losses and maximise opportunities arising from climate change. Successful adaptation planning is not just about implementing strategies to minimise vulnerabilities and potential losses, it is also concerned with ensuring adequate preparedness to maximise advantages offered by new opportunities. However, not all threats identified will be responsive to anticipatory actions and we need to focus on the threats posing the greatest future cost and that will be most responsive to anticipatory action.

Recommendations

Major knowledge gaps identified included:

- environmental tolerances of key life stages,
- sources of recruitment,
- population linkages,
- critical ecological relationships (i.e. predator-prey),
- influence of environmental variables on the timing of life cycle events and
- responses to lowered pH.

High value/high risk species need further research to identify likely key effects of climate change, particularly where these effects may impact the harvest strategies for these species.

Identifying options for improving assessment and management frameworks (e.g. fisheries models, performance measures, decision rules, and harvest strategies) to ensure that they perform effectively under likely climate change scenarios (e.g. account for assumptions of temporal stability in temperature-influenced parameters such growth and recruitment) should also be a priority.

Peer reviewed papers

Published

Doubleday Z, Clarke S, Li X, Pecl G, Ward T, Battaglene S, Frusher S, Gibbs P, Hobday A, Hutchinson N, Jennings S, Spooner D, Stocklosa R (2013). Assessing the risk of climate change to aquaculture: a case study from south-eastern Australia. *Aquaculture Environment Interactions* 3: 163-175

Submitted

Pecl GT, Ward T, Doubleday Z, Clarke S, Day J, Dixon C, Frusher S, Gibbs P, Hobday A, Hutchinson N, Jennings S, Jones K, Li X, Spooner D, and Stoklosa R (2012). Rapid assessment of fisheries species sensitivity to climate change in south-eastern Australia. In review, *Climatic Change*.

Table 1. Attributes, criteria and risk categories used to assess climate change risk for each species.

Sensitivity attribute		Risk category (sensitivity and capacity to respond to change)		
		High sensitivity (3), low capacity to respond (higher risk)	Medium (2)	Low sensitivity (1), high capacity to respond (lower risk)
Abundance	Fecundity – egg production	<100 eggs per year	100–20,000 eggs per year	>20,000 eggs per year
	Recruitment period – successful recruitment event that sustains the abundance of the fishery.	Highly episodic recruitment event	Occasional and variable recruitment period	Consistent recruitment events every 1–2 years
	Average age at maturity	>10 years	2–10 years	≤2 years
	Generalist vs. specialist – food and habitat	Reliance on both habitat and prey	Reliance on either habitat or prey	Reliance on neither habitat or prey
Distribution	Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species).	<2 weeks or no larval stage	2–8 weeks	>2 months
	Capacity for adult/juvenile movement – lifetime range post-larval stage.	<10 km	10–1000 km	>1000 km
	Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance.	<10° latitude	10–20° latitude	>20° latitude
	Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range.	No unoccupied habitat; 0 – 2° latitude or longitude	Limited unoccupied habitat; 2–6° latitude or longitude	Substantial unoccupied habitat; >6° latitude or longitude
Phenology	Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, & freshwater flows.	Strong correlation of spawning to environmental variable	Weak correlation of spawning to environmental variable	No apparent correlation of spawning to environmental variable
	Environmental variable as a phenological cue for settlement or metamorphosis	Strong correlation to environmental variable	Weak correlation to environmental variable	No apparent correlation to environmental variable
	Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season.	Brief duration; <2 months	Wide duration; 2–4 months	Continuous duration; >4 months
	Migration (seasonal and spawning)	Migration is common for the whole population	Migration is common for some of the population	No migration

8.4 Identifying management objectives hierarchies and weightings for four key fisheries in South Eastern Australia [FRDC 2009/073]

Dr Sarah Jennings

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2009-073-DLD.aspx

Objectives

To provide a clear articulation of management objectives in each of four South Eastern Australian fisheries (Abalone, Blue Grenadier, Snapper and Southern Rock Lobster) for use in evaluating alternative management arrangements, by

1. developing a management objective hierarchy and
2. eliciting a set of management objective weights for each fishery.

Executive Summary

Changes to fisheries management and governance arrangements will form an important part of climate change adaptation responses in the South East Australian region and will impact on various aspects of fishery systems and on their associated values. The ability to comprehensively evaluate management changes requires clear definition of a framework of objectives and of the relative importance of these often competing objectives. This framework is often missing from climate change adaptation evaluation, and adaptation priorities and plans are often developed without reference to either adaptation goals or to the general aims of fisheries management.

The aim of this project was to develop a transparent and clearly articulated framework of weighted objectives, against which the performance of selected management adaptations can be assessed. The method used was the Analytical Hierarchy Process (AHP) and comprised two stages. The first stage involved developing an overarching, generalised hierarchy of objectives (Figure 1).

The hierarchy developed comprised four general, or high-level, objectives, three of which mapped broadly to the triple bottom-line objectives of environmental, economic and social performance. The hierarchy also included the high-level objective of strengthening management and governance as a way of capturing the importance of these aspects of fisheries systems to effectively respond to pressures arising from climate change and other stressors. Lower level objectives reflected more detailed or specific objectives related to each of the general objectives.

In the second stage, an interactive, Excel-based AHP survey was designed to measure individual preferences across the range of high and lower-level objectives detailed above. The AHP survey required respondents to make a series of pair-wise objective importance comparisons and provided a relatively simple yet powerful means of deriving individual level objective preference structures or weightings.

A letter of invitation to participate in the survey was sent to 131 individuals, 50 of whom were members of SEAP Industry and Management Committees and Scientific Working Groups. A total of 64 useable surveys were returned for the four fisheries and for a group who had responded generally, or for no particular fishery.

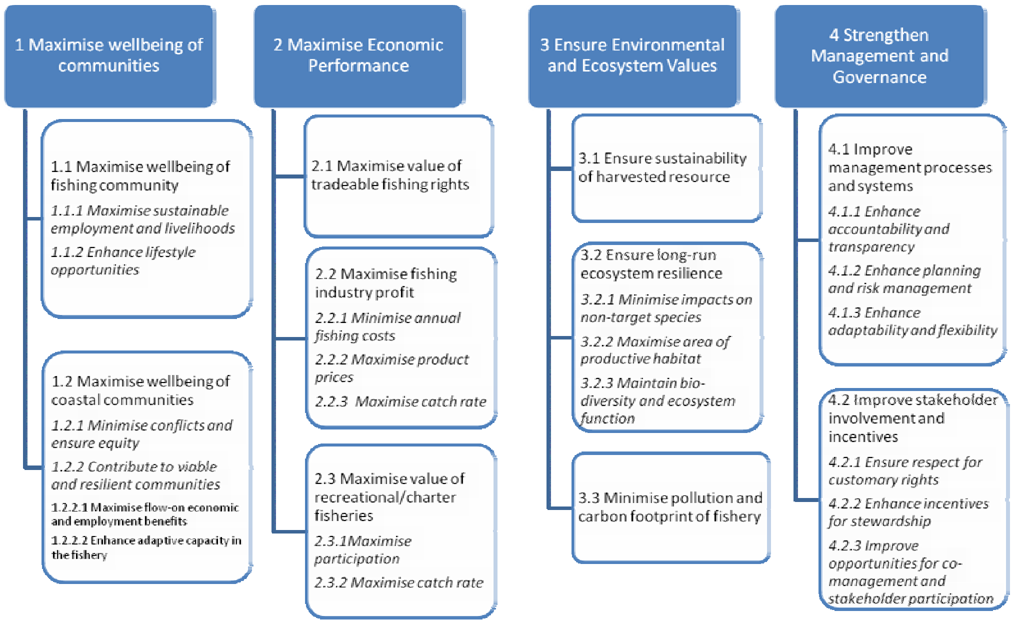


Figure 1 SEAP Adaptation Case Study Fisheries Objective Hierarchy

Average weightings attributed to various objectives were quite consistent across the different fisheries groups, with a very strong preference shown in all fisheries for ensuring that adaptations sustain environmental and ecological values, particularly through sustaining the harvested population. This may reflect a general belief that the environmental component of the 'triple bottom line' is a pre-requisite for ensuring sustainable economic and social outcomes and, in the face of climate change, that adaptations that contribute to this objective should be given priority. While there was some variation in the average ranking of other high level objectives there was a high degree of coherency across all respondents when considering the broad objectives, suggesting that a single high level assessment framework across the region might be acceptable.

Our results indicated a strong level of agreement about the relative importance of the high level objectives within each fishery group, but revealed strong differences between individuals' preferences about the relative importance of lower level objectives, particularly in the Abalone, Blue Grenadier and Southern Rock Lobster fisheries. Over all groups, there is stronger agreement about relative weights for lower level objectives in the areas of community wellbeing and management and governance, with less agreement on detailed objectives for environmental and economic objectives.

This project has provided weighted fisheries management objectives frameworks for each of four key fisheries species in South Eastern Australia (Abalone, Blue Grenadier, Snapper and Southern Rock Lobster) and for a general fishery group.

Providing these frameworks will enable selected management adaptation options identified in *DCC/FRDC Project 2011/039 Preparing fisheries for climate change: identifying adaptation options for four key fisheries in South Eastern Australia*, and in other studies, to be assessed consistently and transparently against weighted objectives, averaged across individuals involved in each fishery. The frameworks will also assist in the identification of areas of potential conflict that might act as barriers to adoption of management changes across diverse fisheries.

The exercise of developing objective hierarchies and of participating in the objective weighting survey has also served as a capacity building process as individuals involved are forced to consider the trade-offs between often competing environmental, social and economic objectives as is required in fisheries management.

Recommendations

1. Continue to highlight the importance of articulating the objectives of fisheries management as an early step in fisheries adaptive management and of integrating climate-change driven changes into this process.
2. Develop and trial alternative methods and processes for developing consensus objectives for fisheries, with an emphasis on robustness, repeatability and cost effectiveness.

Peer-reviewed papers

Submitted

Sarah Jennings, Sean Pascoe, Sophie Hall-Aspland, Bastien LeBouhellec, Ana Norman-Lopez, Andrew Sullivan and Gretta Pecl. Setting objectives for evaluating management adaptation actions to address climate change impacts in south-eastern Australian fisheries Fisheries Oceanography – Special SPICES volume (under review).

8.5 Potential futures for Australia's south eastern marine ecosystems, quantitative Atlantis projections [FRDC 2010/023]

Elizabeth A. Fulton, Penelope Johnson, Rebecca Gorton, Gary Griffiths

FRDC URL: (To be finalised)

Objectives

1. Assess what the challenges are for fisheries and aquaculture management arrangements in managing the interactions between fish and fishers within a changing climate
2. Identify potential barriers (for both Government and industry) to adaptation
3. Inform on changes to management arrangements that provide for sustainable management of the resource, provide for efficient operation of markets, foster industry adaptation and enable businesses to manage challenges and take advantage of any emerging opportunities all in the face of uncertainty that will remain associated with climate impacts for decades to come.
4. Determine how to detect significant attribute changes to inform a management response again in the face of considerable ongoing uncertainty

Executive Summary

Cumulative human pressures on the Earth's oceans are changing marine ecosystems in a multitude of ways. Shifts in temperature, water levels, winds, currents, stratification, oxygen concentrations, nutrient availability, and the frequency and intensity of extreme events are leading to changes in the distribution and abundance of flora, fauna and biogenic habitats. For industries, such as fisheries, and societies who rely on marine resources the key questions revolve around what forms of adaptation will best cope with these ecosystem shifts and keep fisheries viable.

Model projections done for SE Australian performed using the Atlantis end-to-end ecosystem model show that there are six forms of adaptation relevant to the region:

1. Biological and ecological – the primary productivity of the system and the abundance of some target species may change substantially, while other species may move in to the system, together these changes could disrupt the ecosystem;
2. Behavioural – not all fishers in the south east have equal flexibility to respond and adapt, the smaller operators appear to be the least able to cope;
3. Governance and regulation – sound sustainable and integrated adaptive management has the potential to facilitate adaptation, leading to an altered system but one as productive and socioeconomically healthy as today (or more so); however the regulatory system can inhibit adaptation, for instance by imposing delays in the management system, or by promoting strategies that cause economic and social hardship;
4. Economic and markets – may not help as they are confounded by social drivers, or short term market drivers which can act counter to what is required for long-term adaptation;
5. Technological – are only beneficial if technologies needed to change targeting or other behaviours exist, or if current technology encourages behaviours or system changes that are adaptive;
6. Scientific – adaptive management and understanding is reliant on information, so uncertainty, insufficient information or poor communication can hinder decision making and stall adaptation.

Across the range of potential emissions scenarios defined by the IPCC there is a non-linear relationship with biodiversity and socioeconomic state, with a threshold point occurring around 550–560ppm of atmospheric CO_2e (Figure 1a). Prior to this point the ecosystem components are largely biologically capable of adapting, meaning that associated socioeconomic impacts of changes in target species and their food webs is less than the extremes suggested by taxonomically based exposure assessments (Figure 1b). However, beyond 550ppm biological adaptation and acclimation appears to be overwhelmed, with species relying on spatial range shifts as the major coping mechanism – ultimately running out of shelf habitat in the 2070s. Significant social, market and industry adaptation is required to remain viable through such trying times. For example, seafood markets may need to be much more diverse in 2050–2070.

(A) (B)

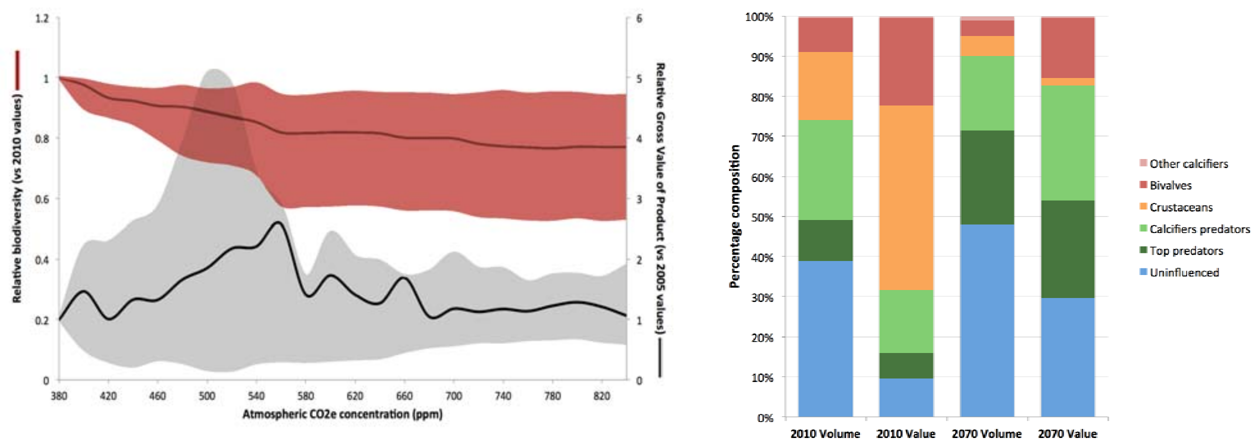


Figure 1: (a) Relative economic status and biodiversity as atmospheric CO_2e levels shift and (b) the realised catch composition (by volume and value) observed in 2010 and model projection for 2070 under the highest IPCC emissions scenario.

Across all the alternative IPCC emission scenarios, the greatest barriers to adaptation seen in the simulations were within the human dimensions of behaviour, markets and governance. While integrated adaptive management across all sectors active on the shelf and in the coastal zone leads to the most robust system state, some of the required regulatory and industry shifts are currently unpalatable to at least some segments of Australian society. For instance, the simulations showed that more stringent regulation of recreational fishing (which is effectively open access at present) would be required for sustainable management of inshore stocks. Simulations also indicated that smaller boats that were socially tied to a specific geographic region (and port) were economically vulnerable to the loss of target species, but also ecologically damaging. This is because they caused more localised depletions, as they were forced to rely on nearby stocks instead of being able to shift to the location of the most robust stocks. This means that either the society at large would need to be carefully led through why larger vessels are required (and can be used sustainably), so as to avoid the kind of controversy seen in 2013 around the potential use of a 'super trawler'. Alternatively, industry/government restructuring and resettlement plans would be periodically required to relocate and refit the vessels according to new ecological states.

Other major findings from the modelling indicate that:

- A regime shift may occur off Eastern Bass Strait resulting in a significant shift in productivity and system structure
- Even without a regime shift the synergistic action of changes in ocean temperature, ocean acidification and fishing tend to drive all parts of the SE system toward more pelagic fast

growing, small bodied species, or the most robust target species, at the cost of the invertebrate and deep water demersal parts of the system (Figure 2)

- The response of the fishing fleets (defined by gear, vessel type and targeting) is dependent on the management strategy in place in combination with system productivity rather than to the environmental changes alone
- Management delays (e.g. lags in multi-year assessments) can have serious implications for stock status and harvest volatility when system productivity is changing
- Focusing on conservation and management of mesopelagic species may provide greater than expected returns in protecting the food web from both direct and indirect synergistic effects of fishing and climate change on predator-prey relationships.

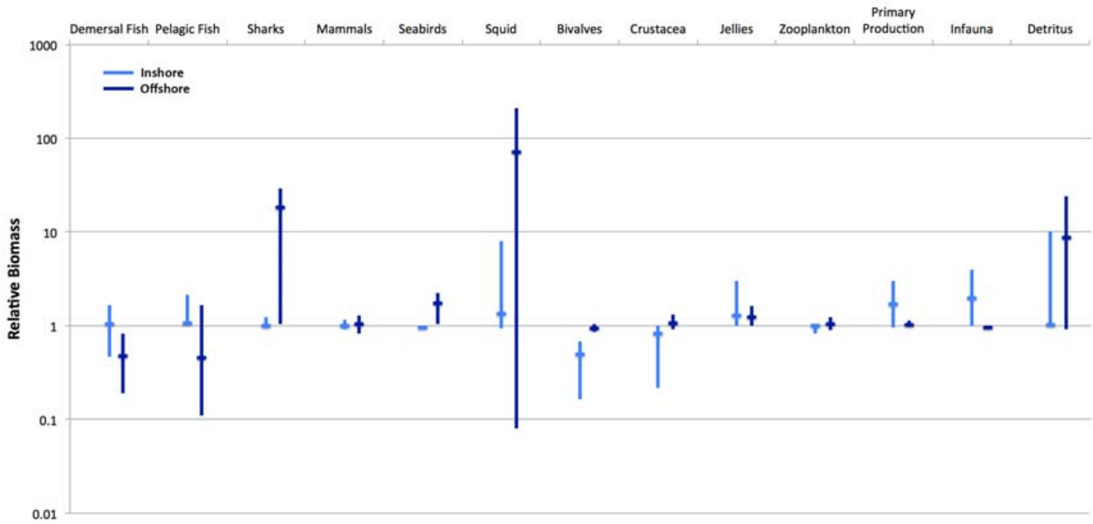


Figure 2: Relative biomass of major functional guilds around south-eastern Australia in 2070 (median and range of values across the IPCC scenarios).

Recommendations

1. Given the sensitivity of the system to barriers to adaptation associated with human responses, education around potential changes and adaptation strategies (across all parts of society) are very important if maladaptive responses are to be avoided.
2. Integrated adaptive management (across all users of the marine and coastal environments) is the most effective means of maintaining sustainable, desirable and productive marine ecosystems under all levels of global change. There will be many more surprises still to come and flexibility to respond in a timely manner is critical.
3. Centralised or cooperative management arrangements (where management jurisdiction matches species extent) are an effective means of retaining sustainability and cost effective management as species distributions shift. This avoids 'lock-in' to increasingly prescriptive management actions driven by climate change associated distributional shifts (which may erroneous be interpreted as overfishing in more pole ward jurisdictions). It may however require new means of allocating costs and sharing benefits as 'source' and 'sink' locations will likely arise (with one location acting as a source and being tasked with a conservation role while other locations receiving the exploitable fish 'downstream').
4. Fisheries dependent monitoring can indicate to some extent shifts in distribution and system status (if confounding market shifts can be accounted for it may even be possible to detect regime shifts form variability of catches). However, sustained ocean observing, not just of physical properties but ecological components (spanning primary production, habitats, fish and higher trophic levels) is the most reliable means of detecting and

attributing climate change in a timely manner. There are significant logistic costs associated with such exercises at large scale regional or national scales and best use of technology would be critical for being able to support such efforts long term. The cost is offset (or negated) however, by avoiding costs to regulators and industry associated with cascading management responses required under current legislation when the cause of changes in stock status is uncertain.

5. The work to date has largely occurred assuming a global context not substantially different in effect to today (e.g. there is a global demand for Australian fish product, global fuel and aquaculture feed markets exist etc.). An assessment of Australia's vulnerability to being shut out of world markets, and the local effects of such an eventuality, would be important for rounding out this assessment of potential futures for Australia's southeastern fisheries. With the rise in economic power of India, China, Brazil (etc.) and the changing magnitude of world market flows it can not be assumed that Australia's production and demand will be serviced in the same way as today. This is already being seen in pharmaceuticals and the manufacturing industries so it would be apposite for fisheries too.

Peer reviewed papers

Published

Brown, C.J., Fulton, E.A., Possingham, H.P and Richardson, A.J., 2012. How long can fisheries managers afford to delay action on climate change? *Ecological Applications* 22:298–310

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

Griffith, G.P. and Fulton, E.A. in press. Challenges facing the use of models as tools for exploring the interplay of anthropogenic effects. *Marine Ecology Progress Series*

Griffith, G.P., Fulton, E.A. and Richardson, A.J. 2011. Effects of fishing and acidification-related benthic mortality on the southeast Australian marine ecosystem. *Global Change Biology* 17:3058-3074

Submitted

Fulton, E.A, Johnson, P., Griffith, G., Gorton, R., Audzijonyte, A. (in review). Facing Colliding Barriers to Marine and Coastal Adaptation.

Griffith, G., Fulton, E.A., Strutton, P., Semmens, J., Ross, V. (in review). Identifying key species or groups from the complex interaction effects of global environmental change on marine systems.

In preparation

Fulton, E.A, Johnson, P., Gorton, R. (in prep). Ensemble assessment of potential futures for Australia's south-eastern coastal fisheries.

Fulton, E.A, Gorton, R. Audzijonyte, A. (in prep). Modelling diversity and evolution in marine ecosystems.

8.6 Adaptive management of temperate reefs to minimise effects of climate change: Developing new effective approaches for ecological monitoring and predictive modelling [FRDC 2010/506]

Neville Barrett, Amanda Bates, Maria Beger, Craig Syms, Andre Belo Couto, Neil Holbrook, Nathan Knott, David Booth, Brendan Kellaher, Colin Buxton and Graham Edgar

FRDC URL: (To be finalised)

Objectives

1. To collate and analyse the long-term marine ecological data records for southeast Australian reefs and use these to quantitatively describe relationships between species' distribution and abundance and changes in ocean temperature, salinity and EAC position as key drivers of climate change
2. To identify optimal locations and species for monitoring programs (including Reef Life Survey – a cost-effective, ecological monitoring program using trained recreational divers – and comparable agency-based programs) to best inform adaptive management via delivery of up-to-date relevant information
3. To assess the costs and benefits of existing temperate Marine Protected Areas for biodiversity-conservation management in response to CC and evaluate the robustness of adaptive management frameworks given uncertainty in predictions
4. To develop models that quantify and predict the impacts of climate change on inshore reef communities of fishes, invertebrates and macroalgae across the southeast Australian region so that potential responses to change can be identified, considered and developed appropriately.

Executive Summary

Waters along Australia's most densely populated south-east coast are warming at 3.8 times the global average rate, the most rapid change in the Southern Hemisphere. Ecosystems in this region are therefore likely to be severely impacted by climate change and significant biodiversity change is expected. The rapid nature of these ecosystem changes requires science-based decisions about where, how and when to apply adaptive management interventions. Well informed predictive models are needed to estimate likely ecological changes and inform management actions such as spatial closures to protect vulnerable habitats, translocation of key predators, or direct manipulation of abundances of threatening and or threatened species. Our study addressed these challenges using a mix of long-term (up to 20-yr) monitoring records of fishes, invertebrates and macroalgae in, and adjacent to marine reserves in the region undertaken as part of University and/or State agency research programs. This was coupled with spatially extensive species abundance data derived from the Reef life Survey citizen science program (http://reeflifesurvey.com/) to examine past, and predict future ecological responses to warming, including assemblage changes, kelp decline and predator-prey relationships.

In the initial phase of the study we focussed on examining temporal patterns in species abundance and the relationship with physical drivers such as temperature. For many species there was no clear relationship evident, as the time-series of observations were, as yet, generally insufficient through time to detect relationships with changing environmental variables such as mean monthly temperature. The 20-year dataset from Maria Island proved to be the most meaningful in this context, and could readily be matched with oceanographical variables derived from a nearby CSIRO monitoring station (Fig. 1). While few individual species in this dataset could be clearly determined to be responding to climate signals through

time, a range of community level metrics did show significant trends when examined for the fish assemblage. Signatures of a warming trend could be seen in metrics such as functional trait richness, and functional diversity, reflecting increasing abundances of warm affinity species and species traits such as herbivory (Figs. 2&3). It is this latter trait that may have one of the largest initial impacts in the SE region, as, prior to recent warming, herbivorous fishes were relatively rare in the cool temperate zone, thus their increasing biomass may reflect a significant change in system function through time.

One notable feature was that in some metrics, such as thermal affinity, there was a differing response to warming between the unfished sites in the Maria Island marine reserve and adjacent fished reference sites. These differences reflect 'resilience' of the reserve to some aspects of climate change. The primary mechanism underlying this appears to be related to increased top down control of sea urchins within the reserve (via lobster predation) reducing the extent of urchin barren formation that in turn provides habitat for many warmer affinity species. The message from this is that MPAs can provide increased 'resilience' to climate chance effects, particularly when these are driven by an ecosystem engineer such as the urchin *Centrostephanus rodgersii*. However, this resilience is context dependent, as in many areas such lobster/urchin interactions may not be the primary drivers of ecosystem function on reefs, or where they are, resilience can, and should, be enhanced in off reserve areas as well, by appropriate changes in fishery management. Ultimately this management needs to be informed by long-term studies examining differences between fished and protected areas at representative locations along our coastline, building on existing studies to extend that time series over future years of warming.

In the second phase of the study we modelled the latitudinal species abundance curves of a wide range of fish and mobile invertebrate species in order to identify the current shape of the curves and their abundance centres, and use these distributions to predict both likely future distributions and the relative contributions of individual species under possible climate change scenarios. The use of Reef Life Survey (RLS) data was essential for this modelling, as existing data from MPA monitoring programs was too sparse to identify both core abundance areas in addition to detecting rarer abundances in the tails of species distributions. In addition, in many cases, knowing the upper thermal limit of distributions is important for refining models and examining likely losses at northern extent of ranges, and the RLS dataset was unique in providing abundance data across that range. Overall, the modelled distributions are invaluable for estimating the extent that some species will extend their central maximum abundance distributions into parts of SE Australia, or to the south of Tasmania and hence be lost, or simply increase/decrease marginally in influence if the distribution has a long tail around a central peak. The predicted likely emergent community at any location is clearly dependent on site (exposure regime etc), likely temperature increase through time, and the time for communities to come to equilibrium. Recent research suggests there will be a 2 degree Celsius increase in temperature in the SE region by 2060 (Oliver et al. 2014). Under that basis we can determine likely assemblages based on our distribution data, and use that to inform discussions by the biological and resource management community as to future adaptation options, both with respect to conservation and fishery management outcomes.

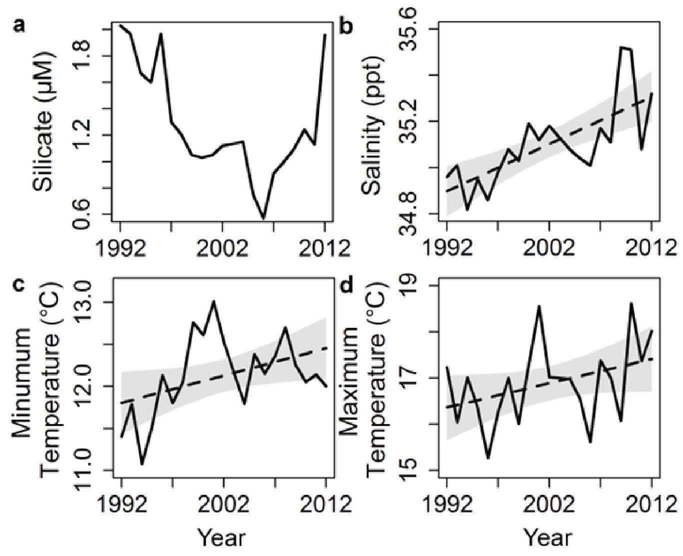


Figure 1. Oceanographic variables, obtained from CSIRO's long-term observing station, driving reef assemblage change at Maria Island. a, Mean annual silicate and b, salinity, and c-d, extreme surface temperatures.

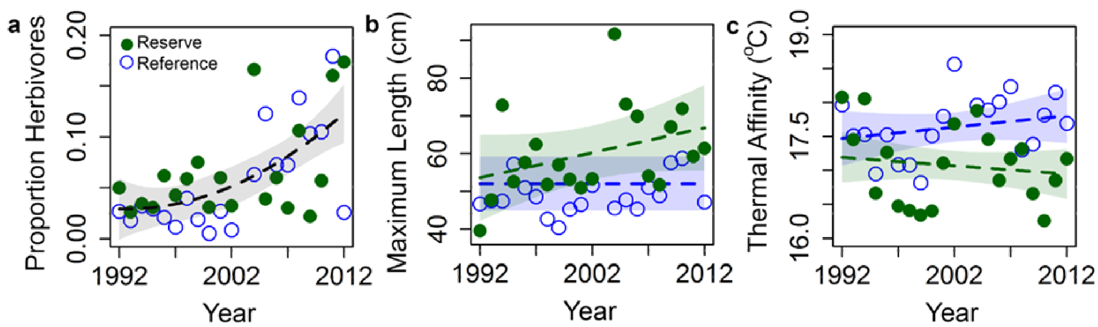


Figure 2. Community weighted biological trait values calculated based on biomass. a, Proportion herbivores kg-1; b, maximum body length kg-1 and c, thermal affinity kg-1 biomass. Regression slopes (dotted lines) and 95% confidence intervals (shading) are in colour when a significant difference between the reference and reserve sites was observed, predicted from linear mixed effects models.

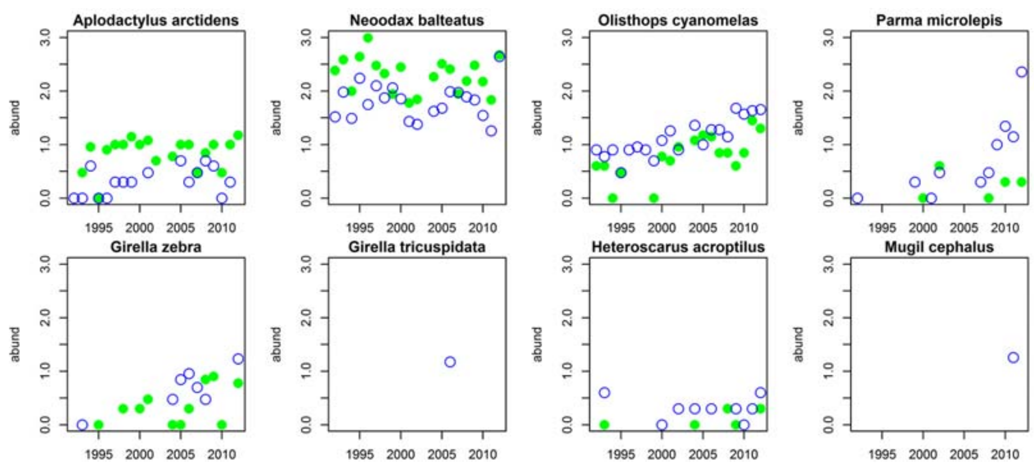


Figure 3. The log abundance, through time, of herbivorous fishes within the Maria Island marine reserve (green circles) and adjacent fished reference sites (open circles). Warm affinity herbivours increasing through time include *O. cyanomelas, G. zebra* and *P. microlepis.*

Recommendations

1. Long-term monitoring is essential for detecting and describing change, as well as informing appropriate management responses, thus appropriate monitoring programs need to be in place for informing adaptive management of temperate reef systems. Additionally, such monitoring needs to involve MPAs as reference areas to understand the extent that fishing and other human activities interact with climate change, such that off-reserve management may adapt to prevent adverse effects where/if possible. Such monitoring could readily and cost-effectively include and build upon current MPA/biodiversity/reef health programs in temperate WA, SA, Vic, Tas and NSW that utilise a common methodology, and, based on existing MPA networks, provide a good spatial framework for detecting and understanding regional trends, as well as national ones. As these programs are spatially isolated, and often constrained to particular habitats, further monitoring by cost-effective programs such as RLS are essential to adequately describe changing abundances over the ranges of key species, as well as documenting changes in habitats and depths not adequately surveyed by current government based monitoring programs.
2. Well-established and adequately protected MPAs are an essential component of a monitoring framework that untangles fishing and other human impacts from climate change, allowing magnitudes of impacts and resilience to be determined and management options to be evaluated realistically against 'natural' benchmarks. While our evidence suggests no-take MPAs can provide resilience to change, such resilience can take decade scales or more to establish, hence MPAs need to be established with the long-term reference and resilience goal in mind. Flexible 'adaptive' MPAs are unlikely to be an option for adaptive management due to the time required for resilience to develop. Discussions are needed between stakeholders to determine whether additional 'scientific reference' MPAs are needed in SE Australia (and other regions in general) given that not all typical coastal reef ecosystems are included, or adequately protected in the existing framework throughout the region, hence adaptive management may not be adequately/fully informed by the current configuration. The extent that MPAs can further contribute to climate change adaptation as a management response to protecting biodiversity in their own right depends upon the extent that off-reserve resource management can adapt quickly enough and sufficiently to counter negative impacts such as *Centrostephanus* barren formation, vie reestablishment of essential ecosystem function. Ultimately this is a policy/social/ political issue that can only be informed by adequate monitoring such as that arising from the focus on Maria Island over the past two decades.
3. Species distribution models are now available for a wide range of temperate reef species, along with future temperature predictions. The overall intersection with predicted species abundances and the community structure that follows after warming is something that requires further expert evaluation, establishment/refinement of conceptual models, and ongoing discussions about the overall implications and potential for adaptive management. A workshop will be held following the completion of this study to begin this process, but it will need to be an ongoing one over the remainder of this century, and a clear recommendation is that a regional committee be established and meet regularly to review new information as changes evolve, and to examine potential adaptation options for resource managers. If, as the predictions of Oliver et al. (2014) are correct, and we can expect a further 2C increase in SST in inshore waters of SE Australia within 60 years from now, our models suggest many Tasmanian endemic species will contract their range to southern Tasmania or be lost entirely. The overall community structure in NE Tasmania will also be vastly different with assemblages dominated by many 'typically' southern NSW species and the likelihood that *Centrostephanus* barrens will be widespread. Our initial workshop, examining possible management options indicated there were very few clear options available for management. For endemic species at risk of loss for example, the Tasmanian Government is unlikely to be able to deal with a small subset of the range

of terrestrial species, much less marine species that might need to be maintained artificially in aquaria. For protection against widespread habitat loss via mechanisms such as *Centrostephanus* barren formation, rebuilding of natural predator stocks is one of the few clear options, and this is currently being implemented by management via changes to lobster fishing effort. Monitoring of the effectiveness of this, and future adaptive measures, will be a critical part of the evaluation and feedback process.

Peer-reviewed papers

Resilience and signatures of tropicalisation in protected reef fish communities (2013) Amanda E. Bates, Neville S. Barrett, Rick D. Stuart-Smith, Neil J. Holbrook, Peter A. Thompson and Graham J. Edgar. *Nature Climate Change DOI:10.1038/NCLIMATE2062*

Statistical solutions for error and bias in global citizen science datasets (2013). Tomas J. Bird, Amanda E. Bates, Jonathan S. Lefcheck, Nicole A. Hill, Russell J. Thomson, Graham J. Edgar, Rick D. Stuart-Smith, Simon Wotherspoon, Martin Krkosek, Jemina F. Stuart-Smith, Gretta T. Pecl, Neville Barrett, Stewart Frusher. *Biological Conservation* *http://dx.doi.org/10.1016/j.biocon.2013.07.037*

8.7 Adapting to the effects of climate change on Australia's deep marine reserves [FRDC 2010/510]

Ronald E. Thresher, John Guinotte, Richard Matear and Stewart Fallon

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-510-DLD.aspx

Objectives

1. To develop practical options for SEWPAC to manage the impacts of climate change on the South East Commonwealth Marine Reserve
2. To develop a generic model that can be applied to forecasting the impacts of climate change on other deep sea biota

Executive Summary

This project has:

1. determined that climate change in general, and ocean acidification in particular, is likely to result in the loss over the next century of the cold water coral reefs that characterise seamounts in the SE Commonwealth Marine Reserve;
2. identified possible refugia habitats along the continental shelf of southern Australia;
3. identified possible adaptation strategies that involve assisted translocation of the reefs and the use of artificial substrates to provide suitable hard ground for coral growth; and
4. raised the need with key stakeholders for a workshop to assess the feasibility of these strategies and to consider other options for maintaining the viability of these deep water ecosystems

Extensive coral reefs formed primarily by a single species, *Solenosmilia variabilis*, occupy seamounts at depths of one to two km along Australia's south-eastern coast, and have recently been protected in the SE Commonwealth Marine Reserves. These reefs are hotspots of deep ocean biodiversity and productivity, and are a focal habitat for deep-sea fisheries, such as Dories and Orange Roughy. Climate change in general and ocean acidification in particular, has been identified as a potential threat to the long-term survival of these reefs, as the carbonate saturation horizon the depth at which calcium carbonate is fully saturated in seawater shoals, a consequence of increased ocean CO2.

The literature suggests that the coral will struggle to grow its carbonate skeleton in under-saturated conditions. If global CO2 levels continue to rise as predicted, a shoaling carbonate saturation horizon could push Australia's temperate deep water reefs to the tops of the seamounts they occupy and, with nowhere else to go, they may simply disappear. The magnitude of the risk to the reefs in the marine reserves depends on two factors:

1. how sensitive *Solenosmilia variabilis* is to low carbonate levels, and
2. future conditions in the seamount environment.

This project assesses these factors, using all available information to determine the corals tolerance limits and using state of-the-art ocean biogeochemical models to estimate future environmental conditions in the marine reserves. From these analyses, we begin to quantify the risk to the reef, determine critical time frames for developing management responses to mitigate the threat, if any, and help identify mitigation options. Using a range of approaches, we estimate that established colonies of the coral can persist in water as low as 16% under-saturated ($\Omega = 0.84$, where an Ω of 1.0 is fully saturated).

However, the data suggest that long-term viability requires saturation levels no lower than 0.90 – 0.94 and that extensive reefal development may require saturation levels closer to 1.0. To determine how these values compared with likely future environmental conditions, we downscaled a coupled ocean-atmosphere biogeochemical model to the reserve location and to the mean depth of the present day reef (1100 m) and predicted saturation states over the next century. The model indicates that under an IPCC 'business as usual' atmospheric CO2 scenario, carbonate saturation levels by 2100 at the site of the present day reefs could be as low as 0.77 and as high as 0.92, but most likely will be in the range of 0.83–0.86.

Comparison of these values with the coral's tolerance limits suggests that if the IPCC scenario is maintained some *S. variabilis* will survive in the reserves until the turn of the century. However, the corals are likely to be under severe physiological stress and probably will not sustain the extensive reefs that currently characterise the seamount habitats. In practice, global CO2 levels are rising faster than the IPCC 'business as usual' model, suggesting strongly that even these predictions for the corals may be optimistic.

Preliminary spatial modelling indicates some coastal habitats may remain suited for the species locally and could serve as refugia for the ecosystem, although this depends very much on both the coral's abilities to tolerate rising ocean temperatures and the availability of suitable hard ground on which to grow. Most shelf edge habitats along the southern Australian coasts are soft or sandy sediment or mudstone, none of which appears to be a suitable substrate for the coral. Local survival of the species, its reefs and associated biota may require assisted translocation of coral colonies and the use of artificial structures to provide suitable hard ground environments.

Recommendations

1. We recommend that a small workshop of relevant stakeholders be convened to consider the feasibility of these options, to canvas other adaptation strategies, and to assess additional implications of our analyses for management of the ecosystems in the SE Commonwealth Marine Reserves.

8.8 Vulnerability of an iconic Australian finfish (Barramundi, *Lates calcarifer*) and related industries to altered climate across tropical Australia [FRDC 2010/521]

Dean R. Jerry, Carolyn Smith-Keune, Alexander G. Carton, Igor Pirozzi, Lauren Hodgson, Jeremy vanderWaal and Kate S. Hutson

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-521-DLD.aspx

Objectives

- Define current genetic stock structure of Barramundi using microsatellite markers and overlay genetic structure with environmental data to identify climatic scenarios stocks may be exposed to in the future.
- Examine current thermal tolerances and associated physiological/energetic consequences of thermal adaptation in genetically divergent Barramundi stocks across tropical Australia.
- Quantify parasite impacts on sea-cage aquaculture of Barramundi under different temperature and salinity conditions leading to the development of adaptive management strategies to minimise impacts under altered climate change scenarios.
- Develop predictive models incorporating new physiological and genetic data with available population genetic, environmental and fisheries data, to identify potentially vulnerable wild stocks and associated stakeholders under realistic climate change predictions. Opportunities for expansion of fisheries and aquaculture will be determined.

Executive Summary

In northern Australia, Barramundi (*Lates calcarifer*) supports a strong commercial and aquaculture fishery (~$80 million), as well as being a species of high recreational and societal value. Given the iconic importance of this fish species to northern Australia there was a need to understand how future climate patterns will impact on both the wild fishery and growing Barramundi aquaculture industry. Before this project began, climate-orientated models were restricted to the east coast Queensland wild Barramundi fishery and there had been no efforts to predict how climate change would influence wild fisheries in other regions of northern Australia. Similarly there had been no studies to identify opportunities and threats to aquaculture farming of Barramundi under future climate change scenarios.

Australian Barramundi has been previously shown to be a genetically structured species and there was accumulating evidence that the different genetic stocks differed in their thermal tolerances, particularly to high temperatures. These differences in thermal tolerances may have influenced physiological and disease responses and the capability of Barramundi from the various stocks to respond to warming conditions. Consequently, a series of experiments were conducted to ultimately inform simulation models as to how the major genetic stocks of Barramundi respond to temperature.

Firstly, an extensive collection of Barramundi from northern Australia was undertaken and fish were genotyped at 16 microsatellite DNA genetic markers to provide a high-resolution picture of the genetic structure of Barramundi across the entire species range. This genetic analysis, which is the most comprehensive conducted for the species to date, identified the presence of 21 discernible genetic populations of Barramundi in Australia that were within five major stocks (Figure 1). Comparisons of the genotypes of several collection localities that were temporally separated by >15 years showed that this Barramundi genetic structure in

Australia has remained stable over this timeframe, despite commercial fishing and hatchery-derived population stockings.

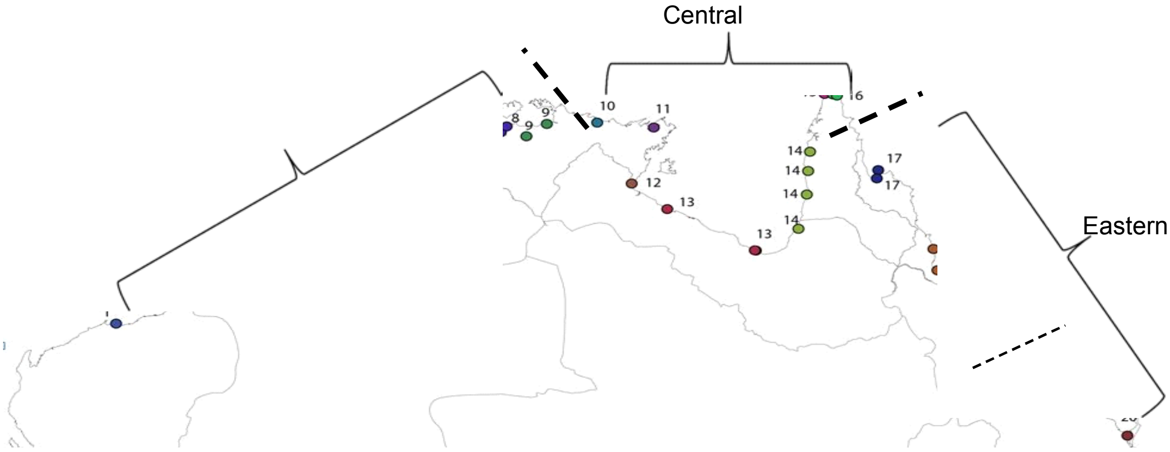


Figure 1. Map of northern Australia showing localities sampled for Barramundi in the present study (dots) and their allocation into genetic differentiated populations (indicated by the same colours and numbers). Unbroken lines represent the geographic location of populations that cluster together as major genetic stocks, whilst broken lines represent significant substructure below the level of these major stocks.

Based on the genetic analyses, Barramundi obtained from six hatchery populations from four of the genetic stocks (Broome, Darwin, Karumba, Cairns, Bowen, and Gladstone) were subjected to phenotypic temperature challenge testing to discern if stocks differed in their tolerance to upper thermal stress. Previous research had shown that in Barramundi there was a strong correlation between fin tissue cell death and fish loss of swimming equilibrium under thermal stress, and thus the cell death method was used as the proxy to estimate thermal tolerance of the various stocks. From this trial significant differences were observed in the upper thermal tolerances of Australian Barramundi, with Barramundi from Broome and Karumba exhibiting the highest tolerance to warm temperatures, followed by Darwin, Cairns and Bowen. Barramundi tested from the southernmost part of the species distribution (Gladstone) were the least heat tolerant. This trial therefore established that Barramundi genetic stocks do exhibit differing tolerance to warm water temperature and that possibly under warming climate conditions in the future that some stocks might be more resilient to rapid changes in temperature than others.

Oxygen consumption (MO_2) is a useful proxy for metabolism and energy demand and often correlates with the ability of an organism to cope with various environmental stressors, such as temperature. Consequently, to determine if differences in the underlying physiological mechanism for the observed response to thermal stress could be elucidated, Barramundi from four genetic stocks were subject to temperature challenges and their respiratory responses determined. Firstly, routine metabolic rate (RMR) was established for fish from the stocks over a 20 °C temperature range (18 – 38 °C). Whilst fine-scale variation in RMR was observed among the Barramundi stocks (i.e. RMR of Broome fish was significantly lower than Karumba and Gladstone at 28 and 38 °C), overall RMR data fell within the 95% CI explained by the equation RMR (mg O_2 $kg^{-0.8}h^{-1}$) = $11.02 - 0.2804T + 0.08026T^2$, where T = temperature (°C). This suggests no major differences among the RMR of Barramundi across the thermal range tested. Barramundi were also challenged to hypoxia at various temperatures, as one major consequence of warmer temperatures is a decrease in the oxygen carrying capacity of water. Here all fish maintained a constant oxygen consumption rate ($\dot{M}O_2$) as air saturation of the water decreased from 100% down to a critical oxygen saturation ($[O_2]_{crit}$) of 15.44 ± 3.20% (mean ± SD) and 21.07 ± 3.92% at 26°C and 36°C respectively. Mean $[O_2]_{crit}$, used as a performance measure of hypoxia tolerance, did not differ between populations. No differences were found for resting $\dot{M}O_2$ between sub-populations at 26 °C, however, modest differences were observed at 36 °C (3.36 ± 0.62 and 2.83 ± 0.27 mg $O_2 \cdot kg^{-1} \cdot min^{-1}$ for Gladstone and Broome sub-populations respectively). Overall, it is concluded that both hypoxia tolerance and resting $\dot{M}O_2$ are conserved across the distribution of Barramundi in Australia, which reflects the capacity of this species to cope in environments with large fluctuations in both temperature and dissolved oxygen.

A further aspect of Barramundi biology that might be affected by changes in climate is that of parasite tolerance. It is conceivable that Barramundi from different stocks exhibit a varied response to parasitic infection. Of interest also is how changing climate might impact on the biology of important parasites themselves. To address these questions a pathological examination of 70 wild and farmed Barramundi was undertaken and along with information from published reports metazoan pathogens of marine Barramundi identified. An associated risk assessment was also undertaken to flag pathogens of particular concern. Along with the risk assessment, a series of experiments to determine the impact salinity and temperature have on both the life cycle and infectivity of an important Barramundi marine parasite, *Neobenedinia*, were also conducted. Results from these trials showed a) *Neobenedinia* hatching success was significantly affected by both temperature and salinity, with highest hatching at 32 °C and 35 ppt. Water temperatures > 32 °C, however, resulted in reduced hatching success regardless of salinity; b) infectivity of Barramundi with *Neobenedinia* was also influenced by temperature, increasing up to 34 °C, though no differences in susceptibility of Barramundi from three stocks (Darwin, Cairns and Gladstone) were observed. These results highlight that as water temperatures increase so will the life cycle and hatching success of *Neobenedinia* dictating the need for increased monitoring and surveillance. There are, however, upper limits in water temperatures at which the parasites biology becomes negatively impacted. All Barramundi stocks may be equally susceptible to infection.

Finally, temperature-dependent Barramundi growth data was modelled against various future climate change scenarios to predict how changes in temperature in the future may impact on both the occurrence and productivity of Barramundi stocks. Here growth models in the literature were validated against real data and the effect temperature has on yearly growth and area of land suitable for Barramundi mapped. Simulation models predict that currently 32.8% of continental Australia is thermally suitable for Barramundi, with the majority of suitable area restricted to northern Australia (Figure 2). Within this suitable area yearly weigh gain ranges between 296 – 2989 g. Low temperatures experienced are the critical factor limiting Barramundi growth. Under future climates, all global climate scenarios predicted the occurrence of a southward expansion of suitable thermal conditions for the wild fishery and aquaculture production, as well as dramatic increases in productivity through increased weight gain. By 2030, landmass with suitable thermal conditions for Barramundi increases to 47.5%, in 2050 to54.5%, and to 66% by 2080. Additionally Barramundi will grow faster due to higher temperatures and a lower prevalence of cooler temperature periods. This growth is predicted to increase over that currently by an average of 238.4 g per pear in 2030, up to 354.5 g by 2080. Thus climate-based predictions indicate that the Barramundi fishery will not only expand from its current distribution, but that individuals will also exhibit faster growth.

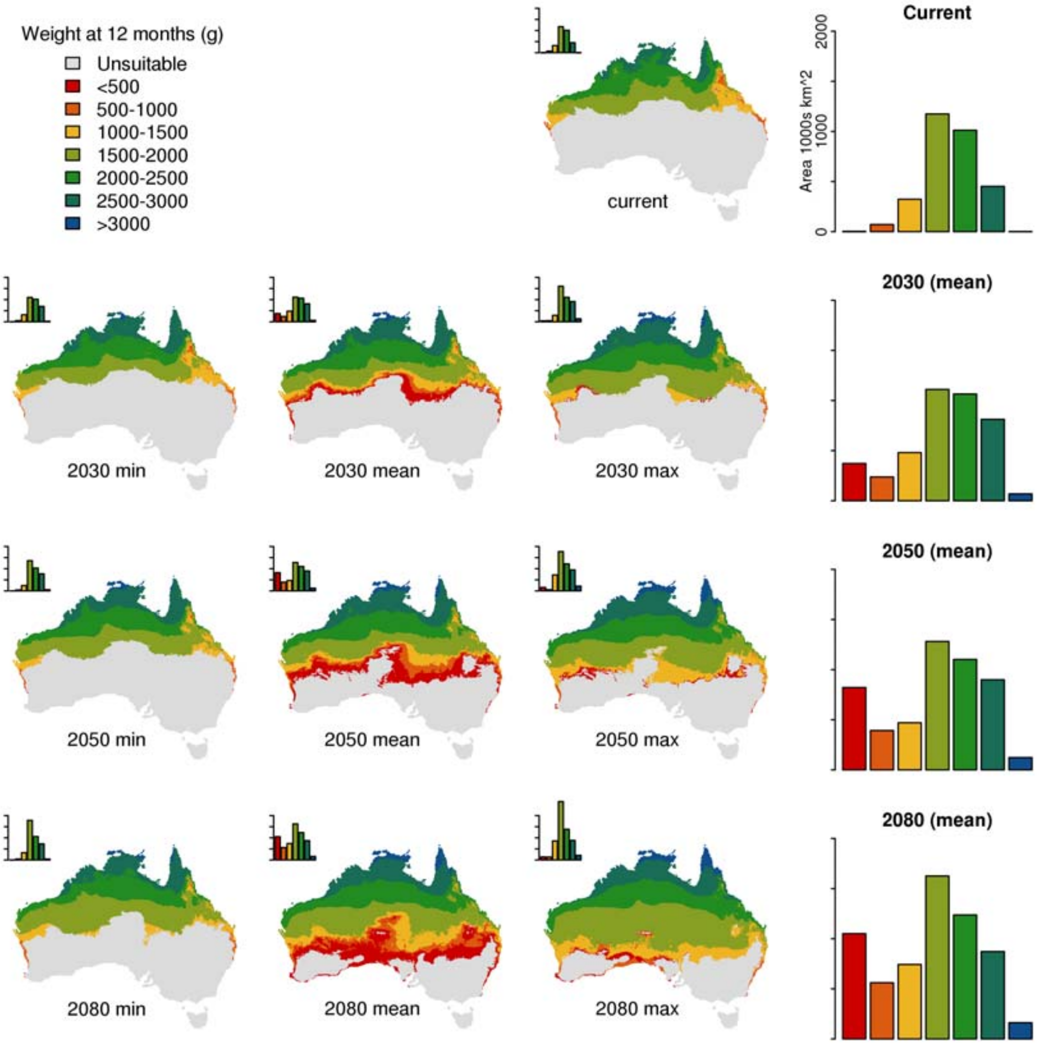


Figure 2. Current and future suitability (estimated as gain in grams per day for one year) for Barramundi aquaculture. Where monthly mean temperature during the coldest month reached 15°C these areas were considered unsuitable and are marked in grey. Future scenarios show SRES a1b, weighted mean of 30 runs of 8 GCMS. Area within each growth category shown on barplots in 1000's km^2

Recommendations

- Modelling of the wild fishery under different Global Climate Models that make up the IPCC 'business as usual' greenhouse gas emissions scenario predicted that climate suitable for Barramundi in Australia will be extended in a southerly direction on both the eastern and western coasts due to increasing average and minimum temperatures. The optimal model incorporating climate derived correlates of catch per unit effort (CPUE) predicts that future medium CPUE will also increase in key areas with climate change. Areas that currently yield the highest CPUE are expected to remain high into the future and all areas are expected to show some increase in CPUE. Accordingly, potential for new fisheries may arise as suitable climate for this species moves southward and it is recommended that resource planners begin to implement such scenarios into fisheries resource allocation planning models.

- As with the wild Barramundi fishery, future climate-informed simulations predicted an increase in land area with thermal profiles suitable for Barramundi pond-based aquaculture, as well as overall increases in productivity, particularly in northern regions of the distribution. In particular, thermal profiles predict that Barramundi may be able to be farmed in pond and sea-cage systems far south of where temperature currently limits productive farming. Thus Barramundi aquaculture may be able to expand as an industry south as climate change proceeds towards 2080. For this expansion to take place, however, State-based aquaculture development plans should be proactive and incorporate Barramundi as a new possible species that can be farmed in these southern regions.

Peer-reviewed papers

Published

Brazenor, A.K and Hutson, K.S. (2013). Effect of temperature and salinity on egg hatching and description of the life cycle of *Lernanthropus latis* (Copepoda: Lernanthropidae) infecting barramundi, *Lates calcarifer*. *Parasitology International* 62(5), 437-447.

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Collins, G.M., Clark, T.D., Rummer, J.L. and Carton, A.G. (2013). Hypoxia tolerance is conserved across genetically distinct sub-populations of an iconic, tropical Australian teleost (Lates calcarifer). Conservation Physiology 1: doi:10.1093/conphys/cot029.

Gamble, S., Carton, G., Pirozzi, I. (2014). The routine metabolic rate of barramundi, *Lates calcarifer*, measured in both closed and open-top static respirometers. Marine and Freshwater Behaviour and Physiology (47): 19-28. DOI:10.1080/10236244.2013.874119

8.9 Identification of climate-driven species shifts and adaptation options for recreational fishers: learning general lessons from a data rich case [FRDC-DCCEE 2010/524]

Daniel Gledhill, David J. Welch, Alistair Hobday, Stephen Sutton, Adrian Jeloudev, Matt Koopman, Matthew Lansdell, Adam Smith and Peter Last

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-524-DLD.aspx

Objectives

1. Examine change in the distribution of coastal fishes in eastern Australia over the past four decades and examine correlation of these to changes in environment, such as warming sea surface temperatures
2. Investigate the perceptions of the representative group of recreational fishers regarding climate-induced change and effects this may have on the distribution and abundance of coastal fishes, and identify potential adaptation options
3. Develop and test a process model for engagement and development of climate change adaptation options suitable for deployment to other fishing sectors and user groups, including commercial fishers

Executive Summary

Australia's SE region is recognised as a global hotspot for rising sea surface temperatures. Impacts from this rapid change have already been recorded for coastal marine species, but with sparse decadal-scale, high quality datasets available, we remain poorly informed as to the detail of how change unfolds and which species may be affected. These rapid changes are already proving challenging for fishery management, from both a scientific and engagement perspective.

This project would have been impossible without a significant investment of time and effort on behalf of spearfishers and spearfishing clubs. Likewise, scientists gaining access to spearfishing club datasets will depend on spearfishers trusting scientists to engage with clubs, to make appropriate use of those data, and to best ensure outcomes from associated projects don't negatively affect data owners. One objective of the project was to gain a better understanding of how engagement for effective partnerships should occur and to develop a process model for engagement and development of climate change adaptation options.

Through a partnership approach we successfully developed and implemented an engagement model aimed at improving such activities with community groups. This model contains elements suitable for broader application to other fishing groups and beyond the fishery sector. Importantly, the process also identified many of the challenges that need to be overcome in such engagement. Some 150 members of spearfishing clubs participating in this project were also surveyed to gain a better understanding of their attitudes and beliefs on engagement with fisheries science and management, as well as their observations regarding climate change and potential impacts on the marine environment.

Most respondents agreed that spearfishers and scientists (69% of respondents), and spearfishers and resource managers (59%) have common goals concerning the management and conservation of marine resources. However, most respondents disagreed that scientists (68%) and managers (79%) have a good understanding of spearfishers and spearfishing, and few (30%) reported having a good understanding of how scientific information is used in resource management. Likewise, few respondents reported having high levels of trust in resource managers to do what is best for the conservation of marine resources (13%) or to

consider the concerns of spearfishers in decision-making (10%). Few respondents agreed that they are well informed about how their interests are considered in decision-making (22%), that they are adequately consulted about management decisions (6%), or that they receive fair treatment in the decision-making process (3%).

Similarly, the social survey has provided improved understanding of the beliefs among the target group regarding human induced climate change. Most (74%) respondents indicated that they believe there has been substantial change to earth's climate over the past 25 years and that humans are partially (41%) or largely (33%) responsible for those changes. Most respondents reported being moderately concerned about climate change in general (57%) and moderately (59%) or very (31%) concerned about the potential negative effects of climate change on the fisheries resources that they use. Most respondents also believed it to be moderately (41%) or very (47%) necessary to take steps to reduce greenhouse gas emissions that are thought to cause climate change.

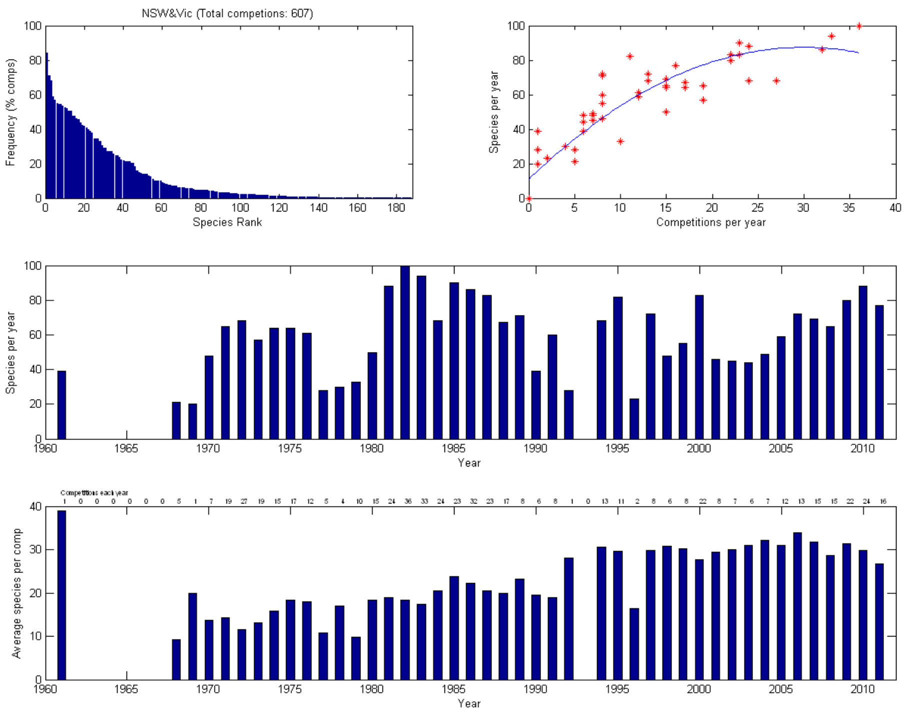
The survey highlighted species that may have experienced population changes. These data also improve our understanding of spearfisher perceptions of the benefits and costs of engaging with scientists and provide a basis for further development of a general engagement model for marine resource user climate-change adaptation. They also challenge us to more positively and actively engage with spearfishers, and other member groups.

Spearfishing clubs provided records from some 730 competitions dating from the 1960s to the present, of which some 600 competitions (267 Victorian and 335 New South Wales), were analysed. A database was developed to store these data and has been returned to clubs to enhance their own capabilities for ongoing monitoring and engagement. The earliest competition dates from 1961 in NSW, with consistent data available from late 1960s until 2011. Data were from competitions held at 43 sites in Victoria and 50 in NSW, ranging from Coffs Harbour in NSW to near Portland in western Victoria, representing >19,000 'diver days', nearly 130,000 individual fish and >150 species.

These 'fish' data represent one of the most comprehensive, multi-decadal digitised records based on recreational fisher activities in Australian waters from which to measure human impacts. Quantitative analyses demonstrate a 'tropicalisation' effect (increasing percentage of tropical species) and a change in trophic level among fish communities from NSW waters.

The 50 most common species from NSW catches underwent a statistically significant shift toward a more tropical community, and this effect was robust across 'summer' and 'winter' periods. Examining the top 25 and top 26–50 species as separate units demonstrated the complexity of change occurring, with varying responses over different seasonal periods. Victorian records demonstrated no discernible change in the tropicalisation index for the 50 most common species, possibly resulting from the scoring criteria used.

Examination of Victorian species for trophic-level change among the top 20 or top 50 species since 1970 detected no change. Restricting analyses to the top 21–40 most common species, did record a change, with species from lower trophic levels becoming more common. Examination of the trophic-level index for NSW species shows a significant increase in the index for the top 50 species across both 'summer' and 'winter' periods, with an apparent increase in higher trophic-level species (e.g. piscivores) in combination with a tropicalisation effect. Higher trophic level species may be of higher value to many spearfishers than lower trophic level species, changes in these ratios might therefore have a positive effect on their fishing experience.



Summaries of digitised data for Victoria and New South Wales: (a) species rank as a percentage of occurrence across all competitions; (b) species accumulation curve; (c) number of species caught per year; and (d) the average number of species represented in each competition for each year.

Some species also show evidence of range extension in SE Australia, while others appear to have increased in abundance within the southern limits of their previously recorded range. These data demonstrate the complexity of changes occurring in natural communities, providing new understanding of ranges, range shifts, and movement, and aid in ongoing engagement with spearfishers as they seek to understand the impacts of climate change on their recreational activities.

Spearfishers have a history of adaptation, for example, to new fishing practices, the impacts of fishing, and to changing community attitudes. They are likely to continue to be reactive in adapting to change, many of which are considered positive, at least in the short term. Positive changes include the appearance of novel species, and the likely extension of the Victorian fishing season, currently limited during the cooler months. This history will likely serve them well in short term adaptation, but broader changes expected in the medium to longer-term may prove more challenging.

Spearfishers can be valuable observers of biological change in the ocean, and as such can provide information that can underpin increased societal awareness and galvanise actions to reduce the impacts of climate change through mitigation and widespread adaptation efforts. Spearfishers partnering on the project have requested further scientific examination of their data to better understand localised change from both environmental and human impacts (including commercial fishing, urbanisation and flooding). It is apparent that this engagement partnership, using data owned by the community group, is a powerful approach to developing adaptation options.

Following the extensive investment — both from spearfishers and researchers — to build this relationship, there is an opportunity to further explore these data to investigate questions raised by spearfishers during the engagement activity, and to better understand change currently occurring. There is potential to investigate more complex interactions between species-level change, environmental signals, and anthropogenic impacts including both commercial and recreational fishery management. Additional recreational-fisher data could be digitised to fill gaps, and clubs could be supported in continuing to populate electronic databases which may assist measuring and interpreting change into the future – a resource that would benefit greatly from ongoing technical support. Such a dataset could be revisited every five years, building an ongoing long-term resource for monitoring a range of impacts on coastal species.

The success of this project rests on the foundation and development of a successful partnership which now offers considerable opportunity, both as an ongoing engagement activity, and to further interrogate these novel data.

Recommendations

The data accessed and digitised during this project are a unique resource for studying multi-decadal change in Australian coastal marine communities. These data, curated and maintained by clubs, have proven the increasing importance of non-traditional data sources to put a temporal perspective on the change currently unfolding.

Following the extensive investment — both from spearfishers and researchers — to build this relationship, there is now a unique and time-sensitive opportunity to further explore these data to investigate questions raised by spearfishers during the engagement activity, and to better understand change currently occurring. There is potential to investigate more complex interactions between species-level change, environmental signals, and anthropogenic impacts including both commercial and recreational fishery management. Clubs are being provided electronic databases they can continue to populate, these may assist measuring and interpreting change into the future, and are a resource that would benefit greatly from ongoing technical support.

The engagement model developed and implemented here would also benefit from broader testing for transferability. This could be undertaken with alternative recreational fisher groups, or more broadly to better engage the community in natural resource management and in climate change adaptation.

Clubs have expressed a strong desire to undertake further collaborative projects, and we'll be looking for opportunities to develop these.

Further development could include:

- Digitisation of additional data. These could include remaining spearfishing competition data from Victoria and NSW (other states where available), and potential for inclusion of other recfisher datasets;
- Comparison of available data with other pertinent datasets, including: other recreational fisher data, state-based commercial fishery data, and oceanographic data;
- Explore changes noted in the spearfisher survey, and examine correlations with climate and other variables;
- Broader testing of the engagement model, this could be on another recreational group or community group, and could extend to a terrestrial or freshwater focus; and
- Continuation of the existing relationship could see an extension in the time series of data collected. Ongoing interaction from the research team could ensure these data are suitable for ongoing analyses.

Peer-reviewed papers

In preparation

Daniel C. Gledhill, Alistair J. Hobday, David J. Welch, Stephen G. Sutton, Matthew J. Lansdell, Mathew Koopman, Adrian Jeloudev, Adam Smith and Peter R. Last (submitted) Collaborative approaches to determining ecological change in eastern Australia: coastal fish and recreational spearfishing club data.

Daniel Gledhill, Alistair J. Hobday, Matthew Lansdell, David Welch, Stephen Sutton, Adrian Jeloudev, Matt Koopman, Adam Smith and Peter Last (in preparation) Trends in abundance and distribution of coastal fishes determined from recreational spearfisher competition records.

Sutton et al., (in preparation) Spearfishers perceptions of climate change, fishery science and management.

Daniel Gledhill, Alistair J. Hobday, David Welch, Stephen Sutton, Adrian Jeloudev, Matt Koopman, Adam Smith and Peter Last (in preparation) Developing and evaluating an engagement framework: a case study with recreational spearfishers.

8.10 Changing currents in marine biodiversity governance and management: responding to climate change [FRDC 2010/532]

Michael Lockwood, Julie Davidson, Marcus Haward, Marc Hockings, Lorne Kriwoken

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-532-DLD.aspx

Objectives

1. Identify the requirements for adaptive marine biodiversity conservation governance and management in the context of climate change.
2. Assess how well current regimes, with a particular focus on marine protected areas, meet these requirements, and determine any necessary changes.
3. Identify alternatives to current regimes that are likely to enhance adaptivity and assess their governance and management effectiveness.
4. Offer advice to governance and management authorities on how regime improvements might be achieved.

Executive Summary

Australia's marine systems and biota are known to be exposed to a range of likely impacts from human-induced climate change: ocean acidification, warming sea surface temperatures, rise in sea level, increases in cyclone intensities, changes in rainfall and run-off of land-based pollutants and sediments. While some responses of marine species and ecosystems to climate change impacts will necessitate straightforward improvements in current governance and management arrangements, others will pose a challenge and demand a significant rethink. As the implications of a changing climate have not been considered in the design of current arrangements, they are likely to be deficient in essential capacities for supporting and enabling change management. Consequently, research into the form and content of current and potential alternative regimes is critical to securing marine biota and associated dependent values.

Key outcomes achieved to date are as follows.

Adaptive governance requirements. Through an iterative Delphi (expert) process supplemented by scholarly literature, thirty-six requirements for adaptive governance were identified, under seven broad themes. These requirements were used as standards in the assessment of current marine conservation governance performance in the three case study regions – Whitsundays, Tweed and East Coast Tasmania. We found a significant degree of divergence among the three regions (Table 1), with Whitsundays governance significantly more adaptive than the other two cases, and East Coast Tasmania the least adaptive of the three.

Governance challenges. Governance challenges or deficiencies were identified from the assessments of adaptive capacity. While individual cases have their own specific challenges, mostly related to the level of maturity of current institutional arrangements, we found a degree of overlap among them. Common challenges were improving knowledge of the social-ecological system; stakeholder communication and information; improving capacity to deal with uncertainty and complexity; preparedness for change; lack of broad public and political support for the values of marine biodiversity; and integration and coordination gaps amongst and across governance levels and agencies. As a response to these challenges, draft governance proposals were developed for each case study.

Table 1. Assessment of current governance performance

Adaptive governance requirement	Whitsundays	Tweed	East Coast Tasmania
Systems understanding, networks and learning	Good	Neutral	Poor
Values and works views	Neutral	Good	Poor
Institutional forms	Neutral	Neutral	Poor
Leadership and resources	Good	Neutral	Poor
Engagement and decision making	Good	Good	Poor
Cohesion and direction	Neutral	Neutral	Poor
Governance quality	Good	Good	Poor

Drivers of biodiversity outcomes, development of scenarios and effects of our proposals. For each study area, scenarios for 2030 were developed based on key drivers and critical uncertainties associated with regional development and climate change. Stakeholder and advisor assessments of the likely effects of the draft governance proposals on drivers and biodiversity outcomes ranged from strongly positive (e.g. effects on community values and attitudes, runoff from catchments, and tourism impacts), to little or no effect (e.g. climate change impacts, population growth, and tourism demand).

Likely effects of reforms on key biodiversity features. Assessments of the likely effects of the proposals on the area and condition of key biodiversity features showed improvements for most biodiversity features of the Whitsundays and Tweed regions. These improvements were evident across scenarios of (high climate change – high development and use of marine and adjacent terrestrial areas); (high climate change – low development/use); (low climate change – high development/use); and (low climate change – low development/use). The results supported the value of the proposals for improving marine biodiversity outcomes.

Governance pathways. Based on the predicted favourable influences of the draft governance proposals on marine biodiversity drivers and biodiversity outcomes, as well as the responses of our advisors, governance pathways and specific recommendations were prepared for each study area, as summarised in Table 2.

Table 2. Summary of governance proposals

Requirement theme	Pathway	Specific changes to arrangements
Institutional forms and processes	Strengthen the existing intergovernmental and governance framework	Strengthen the Great Barrier Reef Intergovernmental Agreement between the Commonwealth and Queensland Governments and in particular, the Ministerial Forum, by requiring that it meets more frequently and by increasing its responsibilities so that it is required to present the Outlook Report directly to the Australian Parliament
		Require that Outlook Reports include recommended actions and that subsequent reports give an account of the progress and effectiveness of their implementation
		Strengthen provisions of the Intergovernmental Agreement to ensure collaborative conservation and fisheries management and establish relevant collaborative structures and processes
Leadership and resources	Strengthen commitment from state government to the existing governance model	Maintain and enhance legislative support for, and political commitment to, existing collaborative programs aimed at building resilience through a strong NGO-led coalition of scientists and conservation stakeholders
Engagement and decision-making	Improve engagement of local government, CMAs and local advisory bodies	Enact State legislation to encourage the development of collaborative and inclusive local and regional level institutions for integrated terrestrial and marine planning and management
Cohesion and direction	Improve integration of marine and terrestrial governance, planning and	Activate provisions of the Sustainable Planning Act 2009 that provide for regions to be designated over local government areas and over Queensland waters adjacent to local government areas

Requirement theme	Pathway	Specific changes to arrangements
	governance, planning and management	Reinstitute a regional planning framework that ensures alignment of land use and coastal planning with natural resource management (NRM) planning and the activities of regional organisations
Systems understanding	Build better understanding of land-sea dynamics and of the drivers of change	Charge the new Independent Scientific Panel with leading investigations into the connections between terrestrial and marine environments in the context of increasing understanding of social-ecological systems
Leadership and resources	Provide leadership and resources to realise the proposed integrated approach to marine management	Build a broad consensus around the intrinsic value of marine biodiversity and the importance of marine protected areas to climate change adaptation by expanding engagement through marine advisory committees to include all marine stakeholder groups – commercial/recreational fishers, marine tourism operators, and conservation NGOs
Engagement and decision-making	Build the capacity of stakeholders through collaborative engagement	Expand collaborative engagement of local communities beyond local marine park advisory committees to involve marine stakeholders such as commercial/recreational fishers, marine tourism operators, conservation NGOs
Cohesion and direction	Improve integration of marine and terrestrial governance, planning and management	Reinstate regional catchment-based arrangements for NRM and foster integrated planning and management of landscapes and seascapes at the regional scale
		Work towards the longer-term objective of establishing an integrated coastal and marine management authority with powers to work with CMAs, terrestrial and marine park authorities, and local government
	Develop a bilateral discourse between Queensland and NSW governance authorities	Establish an informal cross-boundary cooperative group composed of agency personnel, scientists, policy-makers, representatives of organisations such as SEQ Healthy Waterways Partnership, local governments and NRM authorities and charge the group with keeping a watching brief on marine biodiversity developments
Institutional forms and processes	Build improved integration of agency functions	Build on existing relationships between management agencies and work with NGOs and NRM bodies to increase engagement with and between agencies and industry sectoral groups and peak bodies
Leadership and resources	State Government to establish a framework to support adaptive management	Empower DPIPWE with a lead role in ensuring that commitments to adaptive management are incorporated into key policies and plans in a manner that supports implementation of the adaptive cycle
Engagement and decision-making	Maintain and strengthen commitment to adaptive management	Make explicit provision for adaptive management in key policy documents and guidance, including regular reporting and review of achievements (and challenges)
Cohesion and direction	Focus on integrating marine and terrestrial governance, planning and management	Develop an integrated terrestrial coastal and marine plan that incorporates provisions for sustainability of the coast and protection of biodiversity in coastal habitats in current policy and planning documents

Key conclusions

In the Whitsundays, current governance arrangements exhibit good adaptive capacity in many respects, but attention needs to be given to knowledge of social drivers; capacity to deal with uncertainty and account for complexity; attitudes that are supportive of marine conservation; coordination between marine and terrestrial planning processes; and integration of conservation and fisheries management. Our proposals address these challenges in terms of institutional forms, leadership and resources, engagement, and cohesion and direction. Our principal concern in the Whitsundays is the enhancement of existing structures and arrangements through selected changes that address these key governance requirements. In particular, the declining condition of key reef ecosystems is a potential crisis that demands an overarching and integrated model of coastal/terrestrial and marine governance.

The Tweed region will experience further changes in marine ecosystems over the coming years in response to climate change and other drivers. These changes can be addressed through ongoing development and implementation of the Marine Estate Management Strategy. Our principal concern in the provision of guidance for Tweed marine biodiversity governance is the enhancement of existing structures and arrangements through measures that improve capacity to deal with uncertainty and account for complexity; build leadership capacities for critical reflection and learning; secure political support and resources; improve stakeholder engagement to overcome public distrust of the marine parks system; and further integrate the work of relevant agencies, especially between conservation and fisheries and between marine and terrestrial planning processes.

Current governance for East Coast Tasmania is sectorally-oriented. However, there is an acute need for joined up governance. Building on linkages within existing legislative responsibilities provides a workable pathway for improvement in inter-agency collaboration. Resourcing a more integrative governance approach will be a challenge, as will be establishing processes, support and funding for environmental monitoring and policy review. In our proposals, we focus on institutional forms and processes, leadership and resources, engagement and decision-making, and cohesion and direction. We argue that the government resource management and environmental agency needs to play a lead role in ensuring commitments to adaptive management are incorporated into key policies, plans support implementation of adaptive management, and processes and resources are targeted to completing the adaptive cycle.

Recommendations

1. Further research is needed into the practicalities of implementing adaptive governance reforms, especially in the context of fluctuating political support. We recommend an action research approach, whereby governance authorities work with researchers to undertake regional-scale implementation trials of reform proposals such as those generated by this project.
2. Further research is needed into the links between biodiversity outcomes and governance arrangements, followed by incorporation of learnings from these assessments into governance reviews and, where necessary, reforms. Our work demonstrates the power of a qualitative, stakeholder-driven approach, based on social-ecological system thinking and an outlook orientation, for undertaking such research.

Peer reviewed papers

Published

Haward, M., Davidson, J., Lockwood, M., Hockings, M., Kriwoken, L. (2013) Climate change, scenarios and marine biodiversity conservation. *Marine Policy* 38: 438-446.

Lockwood, M., Davidson, J., Hockings, M., Haward, M., Kriwoken, L. (2012) Marine biodiversity conservation governance and management: regime requirements for global environmental change. *Ocean and Coastal Management* 69: 160-172.

Kriwoken, L., Davidson, J., Lockwood, M. (2012) Marine protected areas and transboundary governance, in Warner, R., Marsden, S. (eds) *Transboundary environmental governance: inland coastal and marine perspectives*. Ashgate, Farnham.

Submitted

Lockwood, M., Davidson, J., Haward, M., Hockings, M., Kriwoken, L. (in review) Governance challenges for marine biodiversity conservation: adapting to environmental change in the Whitsundays, Australia. *Journal of Coastal Management*.

In preparation

Davidson, J., Lockwood, M., Haward, M. (in prep.) Prospects for adapting marine conservation governance regimes through the lenses of the adaptive cycle and governance effectiveness.

8.11 Developing adaptation options for seabirds and marine mammals impacted by climate change [FRDC 2010/533]

Alistair J. Hobday, Lynda E. Chambers, John P.Y. Arnould, Toby A. Patterson, Chris Wilcox, Geoff N. Tuck, Robin B. Thomson

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-533-DLD.aspx

Objectives

1. Connect researchers, managers and policy makers, to focus on climate-ready monitoring and adaptation options for conservation-dependent seabirds and marine mammals.
2. Link ongoing monitoring programs around Australia for seabirds and marine mammals with relevant wildlife and conservation management agencies.
3. Extract climate signals for selected time series around Australia using cutting-edge statistical approaches.
4. Develop protocols for monitoring impacts of environmental variation on indicator species and develop an indicator suite of spatial and temporal metrics for climate change impacts.
5. Combine the indicator metrics to develop multi-species productivity indicators for Australian regions.
6. Provide practical adaptation guidelines for science and management, including on-ground monitoring protocols

Executive Summary

Climate change is impacting marine species around Australia. Changes in distribution, abundance, physiology, and phenology have been documented at a range of lower trophic levels including phytoplankton, seaweeds, intertidal and subtidal invertebrates, coastal and pelagic fish. For Australia's iconic higher trophic level marine taxa, such as seabirds and marine mammals, there is a knowledge gap as to their responses to climate change. These species are protected throughout Australia and in some cases are recovering from previous anthropogenic impacts. Resolution of climate change impacts from other anthropogenic threats is needed to underpin timely adaptive management responses.

Evidence of responses to environmental variability and the functional processes driving these affects is limited for most species. Managers perceive this as a major impediment to ongoing conservation management and planning for climate variability and change. The project was targeted towards seabirds (rather than shorebirds) and sea lions (rather than all marine mammals) as these taxa are colony-based, particularly when breeding. Colony-based populations means that long time series are collected on the same population in the same space, and mostly at the same time.

To achieve the project objectives, the project team first reviewed known climate impacts on seabirds and marine mammals by way of (i) literature reviews for climate impacts for Australian seabirds and marine mammals, (ii) case studies involving detailed investigation of representative time series to illustrate different climate signals, (iii) an expert elicitation survey of Australian researchers to determine perceived climate impacts, and (iv) additional case studies by partner scientists with the project team providing methodological, data and statistical support (**Figure 1**).

Summaries of this information was presented in workshops, and led to increased awareness and connections between researchers and managers, and is presented in detail in publications. In workshops we also generated adaptation options for particular climate threats for both

seabirds and marine mammals. Rather than presenting a long list of options, we then developed a set of tools to evaluate the potential for a subset of all the adaptation options, and tested these in workshops with researchers and managers.

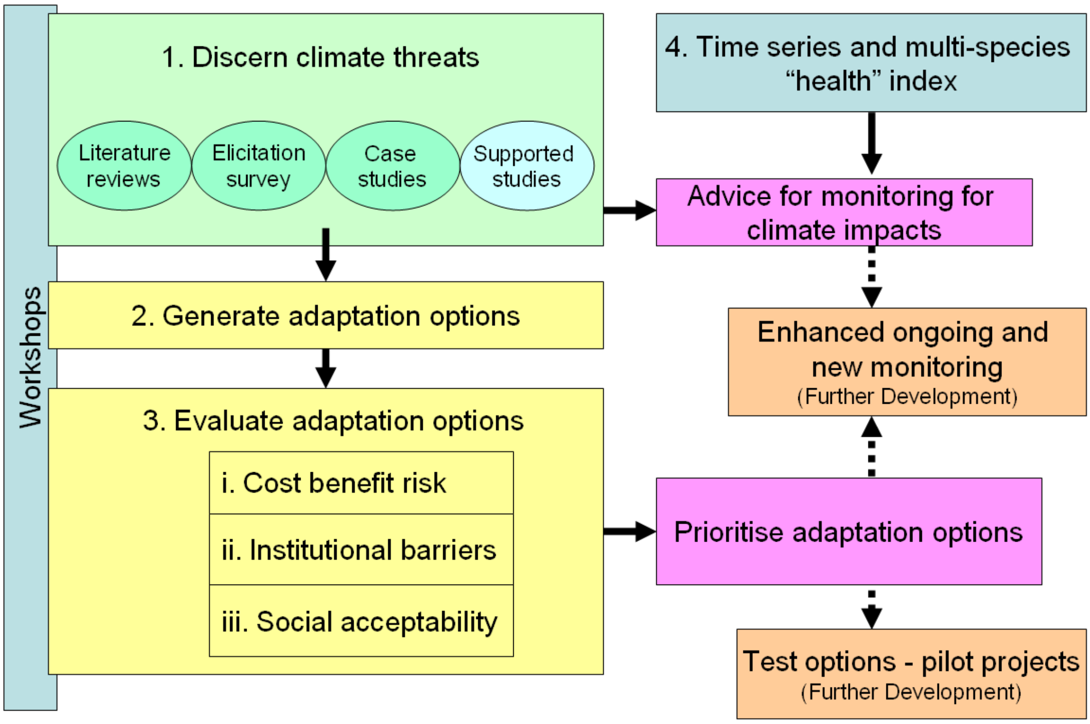


Figure 1. Overview of the project illustrating the main segments of project activity: discerning climate threats to marine mammals and seabirds (1), generating and evaluating adaptation options (2 & 3), and developing a multi-species ocean health index (4). Workshops with stakeholders provided connectivity between the segments, and were used to generate and evaluate adaptation options.

The project reviewed the range of climate impacts that are already impacting on marine mammals and seabirds, and improved the connectivity between researchers and managers with respect to climate adaptation thinking (**Objectives 1 and 2**). In five case studies we investigated additional impacts of climate change, using a range of analytical approaches (**Objective 3**). Using expert elicitation, we surveyed experts around Australia to generate a summary of expectations for change in biological variables that can also be used to guide monitoring approaches (**Objective 4**). We generated multi-species indices that can be used as indicators of ocean and biodiversity 'health' (**Objective 5**). In consultation with researchers, managers and policy makers, a range of adaptation options were generated in response to impact scenarios (**Objective 6**). Three tools were developed to evaluate 25 of these adaptation options. These tools allow a rapid screening of:

- cost-benefit-risk (**Figure 2**),
- identify potential institutional barriers in implementing adaptation options, and
- assess likely social acceptance of these options.

Together, these evaluation tools allow relative prioritisation and identification of issues associated with each scenario that might need to be considered before implementation.

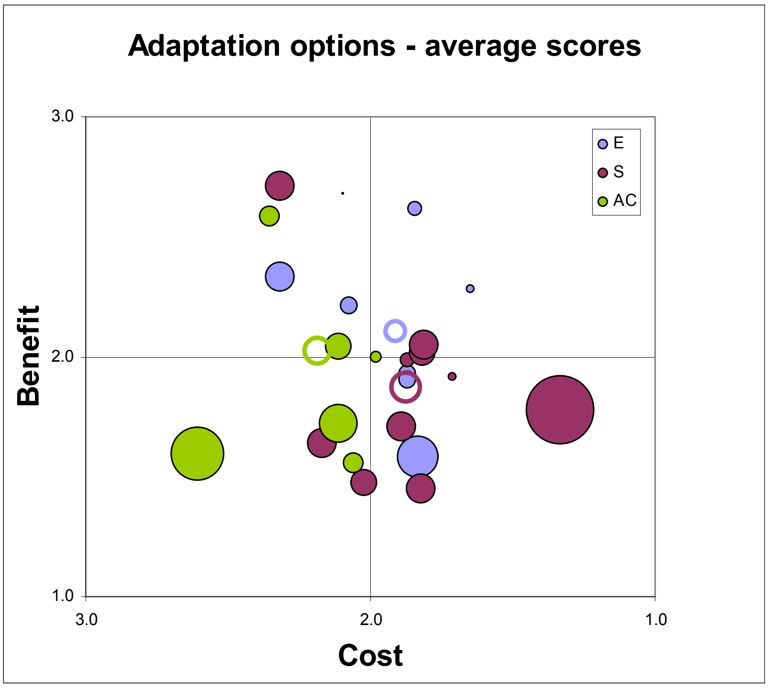


Figure 2. Summary cost-benefit-risk plot for 25 adaptation options evaluated in the project. Open circles represent the mean value for options that reduce exposure (E) or sensitivity (S), or increase adaptive capacity (AC). The size of the bubbles represents the risk score (small represent low risk, large is higher risk).

As for other taxa in Australia, climate is projected to have an impact on marine mammals and seabirds. Due to variability in data on these species, long time series are needed, and thus emphasise the value of ongoing monitoring. Some variables are better indicators than others. Careful selection of variables for monitoring is essential to detect impacts of climate change. The conservation status for the species studied, which include one endangered, five vulnerable, and three near-threatened species reinforces that an understanding of how these species respond to climate variability and change and determining the 'best' adaptation options is an important component in efforts to improve their population status.

Policy intervention may be required to offer additional protection to species threatened under climate change. Fortunately there is a wide range of options for reducing vulnerability of colony-nesting seabirds. Options appear to be more limited for marine mammals. Some management responses for known climate threats can be simple. The project also highlighted that monitoring to evaluate effectiveness of adaptation option is critical, and should be a focus in any adaptation experiments.

Recommendations

1. Develop pilot adaptation projects for seabirds testing the intervention options to further build the experience of researchers and managers charged with securing the status of these iconic species.
2. Additional workshops or expert consultation to develop a set of actions around marine mammals.
3. Apply to set of prioritisation tools to develop options for other natural resource systems, such as deep reefs or coastal habitats.

Peer-reviewed papers

Published

Seabirds: Marine Report Card. Chambers L.E. et al. (2012) Seabirds. In Marine Climate Change Impacts and Adaptation Report Card for Australia 2012 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson). Available at www.oceanclimatechange.org.au. ISBN: 978-0-643-10928-5

Marine Mammals: Marine Report Card. Schumann, N. Gales, N. J., Harcourt, R. G. & Arnould, J. P. Y. (2012) Marine Mammals. In Marine Climate Change Impacts and Adaptation Report Card for Australia 2012 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson). Available at www.oceanclimatechange.org.au. ISBN: 978-0-643-10928-5

Cannell, B., Chambers, L. E., Wooller, R. D. & Bradley, J. S. 2012 Poorer breeding by little penguins near Perth, Western Australia is correlated with above average sea surface temperatures and a stronger Leeuwin Current. Marine and Freshwater Research, http://dx.doi.org/10.1071/MF12139. (Paper 2d)

Schumann, N., Gales, N. J., Harcourt, R. G. & Arnould, J. P. Y. (2013) Impacts of climate change on Australian marine mammals. Australian Journal of Zoology. http://dx.doi.org/10.1071/ZO12131 (Paper 1b)

Knox, T., H. Stuart-Williams, R. M. Warneke, A. J. Hoskins and J. P. Y. Arnould (2013). Analysis of growth and stable isotopes in teeth of male Australian fur seals reveals inter-annual variability in prey resources. Marine Mammal Science: DOI: 10.1111/mms.12078. (Paper 2e)

Hobday, A. J., L. E. Chambers and J. P. Y. Arnould (in press). Methods to prioritise adaptation options for iconic seabirds and marine mammals impacted by climate change. Applied Studies in Climate Adaptation: Australian Experiences. J. P. Palutikof, S. L. Boulter, J. Barnett and D. Rissik, Wiley. (Paper 6)

Submitted or in revision

Chambers, L. E., Patterson, T. A., Hobday, A. J., Arnould, J. P. Y., Tuck, G. N., Wilcox, C. & Dann, P. (in revision) Analysis methods for long-term marine predator data: determining trends and environmental drivers. Regional Environmental Change. (Paper 1a)

Woehler, E. J., Patterson, T. A. & Hobday, A. J. (in revision) Climate or competition? Environmental variability and abundance trends in Tasmanian native and invasive gull species. Marine Ecology Progress Series (Paper 2a)

Thomson, R. B., R. L. Alderman, G. N. Tuck and A. J. Hobday (in review). Effects of climate change and fisheries bycatch on shy albatross (Thalassarche cauta) in southern Australia. PLoS ONE. (Paper 2c)

Wilcox, C., A. J. Hobday and L. E. Chambers (in review). Expert elicitation of anticipated climate impacts on iconic Australian marine species. Journal of Applied Ecology. (Paper 3)

In preparation

Patterson, T. A., Chambers, L. E., Hobday, A. J. & Priddel, D. in preparation Examining trends in demographic time series with respect to climate for shearwaters on Montague Island. (Paper 2b)

Hobday, A. J., Patterson, T. A., Chambers, L. E., Arnould, J. P. Y., Litzow, M. A. & et al. in preparation Multi-species marine mammal and seabird indices for Australia. (Paper 4)

Hobday, A. J. Chambers, L. E., Arnould, J. P. Y., Patterson, T. A. in preparation. An evaluation of adaptation options for seabirds and marine mammals impacted by climate change (Paper 5)

8.12 Ensuring the Australian Oyster industry adapts to a changing climate: a natural resource and industry spatial information portal for knowledge and informed adaptation frameworks [FRDC 2010/534]

Dr. Ana Rubio, Dr. Pia Winberg, Dr. Lisa Kirkendale, Dr. Robin Warner & Assoc. Prof. Andrew Davis

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-534-DLD.aspx

Objectives

1. To source and review spatially referenced data of relevance to both the oyster industry and natural resource management of estuaries in light of climate change, and to align primary data and metadata standards.
2. To engage the oyster industry in developing the content style and delivery of natural resource and industry information in an on-line portal, including industry sourced data from Quality Assurance Programs and Environmental Management Systems.
3. To deliver a pilot, online, spatially referenced, natural resource and industry information portal, making use of extensive primary data sources, metadata standards and national spatial data delivery initiatives.
4. Identify pathways for the spatial information portal to inform governance and statutory authorities (e.g. NRM, State and LGA), monitoring programs, strategies (e.g. oyster industry and NRM strategies) and planning policies (e.g. development application processes).

Executive Summary

This project has delivered a proof of concept, online, interactive mapping and data delivery tool for the oyster industry and estuarine catchment managers: The oyster Information Portal (OIP: www.oysterinformationportal.net.au). The project was undertaken at the University of Wollongong in collaboration with multiple stakeholders of the Australian oyster industry. The purpose of this portal was to demonstrate that there is a benefit of collating information from multiple agency data collections on estuaries and associated catchments and delivering it though a user friendly online portal, in order to provide unique insight into the environment and context of the oyster industry. With such information knowledge, through easily accessible and referenced spatial data, including water and food safety monitoring data, catchment data and industry and natural resource maps, the industry and stakeholders are empowered to make informed decisions and develop adaptation options for an improved and resilient industry in light climate change.

The report describes the need, the concept and the development process of the OIP, as well as presents feedback and case study analyses for the data contained therein. The current portal prototype uses four estuarine systems from the northern to southern limits of NSW, including Camden Haven Inlet, Lower Hawkesbury River, Shoalhaven River and Pambula Lake.

With the demonstrated onset of climate change, which will have a particularly large impact in the coastal zone, the predominantly estuarine and ocean embayment oyster industry faces unprecedented, unknown and unpredictable challenges. The oyster industry in Australia does not have access to estuarine and catchment information that it can use to predict, observe or respond to in light of these changes, and is left with best guessing or speculating on the causes of impacts on their productivity. Industry must be better informed about where and how key threats exist to manage risks (knowledge action) and adapt to and reduce the potential for local or regional collapse.

The concept of collating information in data portals is not new, however it has been historically difficult until information systems technology developed. Now the concept of accessible data has been facilitated by rapid technological developments, however the human and data management systems have been slow to develop and keep up. Most of the existing data portals are rarely relevant or useful to on the ground stakeholders. In contrast, the OIP was developed with a stakeholder bottom-up approach, where end-users, their needs and technical capabilities were identified prior to establishing the portal.

Together with a majority of industry representatives and stakeholders, this project identified and selected categories of data and information sources that were relevant to both the oyster industry and estuarine resource managers in NSW and nationally. The types of data that the industry and its stakeholders require was reviewed and sourced for four catchments, resulting in a suite of extensive data sets that included local government water quality monitoring, Food Authority water and microbial testing, regional and state government catchment use and remediation, and natural resource agency data on habitat types and extent.

The oyster industry, a cornerstone of the NSW seafood industry, prioritised water quality and catchment management, and this was evident throughout the workshops and in the survey results. Similarly, water quality was a priority information need by catchment management agencies, despite the presumption that these agencies have good access to and a handle on such information. Thus, the focus for the development of the Oyster Information Portal prioritised the integration of water quality and other locally relevant data from over ten organisations with monitoring programs in a proof of concept, online portal for four oyster growing areas in NSW: Camden Haven Inlet, Lower Hawkesbury River, Shoalhaven River and Pambula Lake. This prototype was developed in a GIS environment and delivered through an online website with graphical interpretation of spatial and temporal, environmental and industry data. Additional information and links to climate projections, governance and research outputs also formed part of the OIP to provide a more holistic and integrated synthesis of information related to the catchment. The oyster industry and stakeholder representatives were liaised with throughout the development of the OIP.

This project demonstrated that the extent of data and information relevant to the oyster industry and estuarine management is extensive. However this information is dispersed across diverse organisational structures with independent mandates and objectives; thus the data and information is effectively inaccessible to stakeholders such as the oyster industry as well as managers thereof. In addition there has been limited analysis and interpretation of this data even within custodian organisations, and therefore the true value of investment has not been realised. Thus the opportunity to monitor for temporal shifts that might be related to climate change and that might affect the oyster industry was unexplored.

The Oyster Information Portal prototype was successfully designed and integrated data from multiple stakeholders for a synthesis and delivery of this previously inaccessible data. The online format had been developed with and was therefore suitable to the use of oyster industry representatives themselves, as well as stakeholders such as local government and other State Authority staff. A nationwide context of the oyster industry is presented spatially and users can then gradually soon in to their local estuary, from the four cases developed, and then to their own lease. From here they can identify monitoring points from multiple agencies in close proximity to their lease, as well as spatial maps of catchment condition.

The key implication of the Oyster Information Portal was that it was useful to the oyster industry and government management agencies alike. The OIP demonstrated and provided access to multi-jurisdictional data and information from each estuary for the first time; thus an oyster lease could be found in an estuary and water and catchment data relevant to that lease location could be found. Some examples of analytical outcomes and interpretation from data provided through the oyster information portal were demonstrated. These range from detailed and statistical analysis of core data that showed, for example, an instance of a decadal shift in harmful algae bloom dominance; locational variability in the productivity and condition of oysters; to referencing of locational concerns of the oyster industry in managing the development of the catchment. For these reasons and more, the development of the OIP was supported by key catchment stakeholders that recognise the need for a tool that integrates existing information to inform response decision making and long-term adaptation.

In addition, it was identified that a limiting set of data and information that might render the industry vulnerable today, as well as in light of climate change, was an understanding of species and genetic resources within the industry. Analysing this data revealed substantial genetic vulnerability within the existing industry, but also an untapped opportunity for increased resilience and adaptation for the oyster industry through improved recognition, use and management of genetic resources.

Recommendations

A core issue in progressing the concept of OIP across the whole of the Australian oyster industry is the logistical coordination of data from multiple jurisdictions. Thus the long-term viability of this concept relies on the development of an agency mandate to identify, establish data management processes and quality control the delivery of data to storage systems; thus providing identifiable data that can consequently be accessed. It was evident that coordinating individuals or agencies to adopt in-house management practices that could keep up to date with the latest requirements and technological developments in delivering accessible data would be inefficient, and is probably not feasible. Rather, One nominated node of government is required to coordinate the multi-jurisdictional data management systems and to provide support to multiple agencies' that have invested time and effort in the collection of data.

Such government nodes are already in existence, however the extension to on the ground data custodians has not been made. Considerable investment has been made on standards of the data management practices and metadata creation systems; but for a return on investment without outcomes such as the OIP to be realised, the final logistical challenge of establishing data processing and management practices must be overcome. The majority of this data is publicly funded and as such can be delivered or filtered to deliver value back to industry and society under diverse forms of creative commons licensing, and this is a minor issue compared to the logistical one.

Once data can be coordinated and deposited in this way, there are a wealth of information technology systems that exist and that can source and incorporate this data into analysis systems targeted to specific user groups. These systems are under continual development across a range of interests, sectors and user groups. Here the OIP was delivered through an isolated and simple technology platform that could deliver and demonstrate the concept. In addition a Business Intelligence System dashboard technology adopted one instance of the OIP to demonstrate the outputs from a more sophisticated system. This system provides provide control over user access conditions, but importantly can provide defined and customised information across selected data sources within an analytical environment that is user driven. For example, a user may wish to correlate water quality data with catchment conditions or events within a specific time frame or set of locations. Thus once data is accessible the technology is available to deliver.

A one size fits all strategy for adapting to climate change is not realistic for the oyster industry as a whole. Regionally specific stressors will affect the industry differently across estuaries and nationally across states. Local resilience will require local information and local solutions. However the common need to access information from within a framework that is locally relevant and nationally positioned is required. The OIP demonstrates the usefulness of a scalable spatial-information tool for knowledge action and adaptive responses to catchment and climate change.

8.13 Management implications of climate change effect on fisheries in Western Australia [FRDC 2010/535]

Nick Caputi, Ming Feng, Alan Pearce, Jessica Benthuysen, Ainslie Denham, Yasha Hetzel, Richard Matear, Gary Jackson Brett Molony, Lindsay Joll, Arani Chandrapavan

FRDC URL: Annette to add

Objectives

1. Assess future climate change effects on Western Australia marine environments using a suite of IPCC model projections, downscaled to the key shelf regions and the spatial and temporal scales relevant for key fisheries
2. Examine the modeled shelf climate change scenarios on fisheries and implications of historic and future climate change effects
3. Review management arrangements to examine their robustness to possible effects of climate change

Executive Summary

The key outcomes of this project include:

- identification of historical trends in environmental variables and their effects on fisheries;
- downscaling of projected climate change trends of environmental variables and an assessment of the risk to fisheries;
- a risk ranking of key fish and invertebrate species so that research, management and industry can take them into account in forward planning;
- an evaluation of the effect of an extreme event (marine heat wave) on fisheries;
- an evaluation of research, management and industry response to climate change effects on the Western Rock Lobster fishery.

The key environmental trends affecting the marine environment in Western Australia (WA) include: (i) changing frequency and intensity of ENSO events; (ii) decadal variability of Leeuwin Current (iii) increase in water temperature and salinity; (iv) change in frequency of storms affecting the lower west coast; and (v) change in frequency and intensity of cyclones affecting the north-west. A reduction of the Leeuwin Current transport (strength) by 15–20% from 1990s to 2060s is projected under the IPCC A1B scenario. However the Leeuwin Current has experienced a strengthening trend during the past two decades, which has almost reversed the weakening trend during 1960s to early 1990s. The climate models tend to underestimate the natural climate variability on decadal and multi-decadal time scales so that while the greenhouse gas forcing induced changes may be obvious in the long-time climate projection, e.g. 2100, for an assessment of short-term climate projection, e.g. 2030s, natural decadal climate variations still need to be taken into account.

The Ocean Forecasting Australia Model (OFAM) that captures the dynamics of the Leeuwin Current (LC) and its eddies has been used to show the response of the WA marine environment in greater details compared with what is projected with a coarse resolution Global Climate Model (GCM). The climate change projection with the OFAM produced a decrease in the LC with reduced eddy activity. Both reduced LC and reduced eddy activity are associated with reduced nutrient supply to the upper ocean and a reduction in phytoplankton concentration and primary productivity in the oligotrophic WA water off the west coast.

The downscaling simulations indicate sea surface temperature (SST) warming from the 1990s to the 2060s that is consistent with current warming trends. Downscaling to 2–3.5 km resolution has been undertaken with the Regional Ocean Modelling System (ROMS) for the lower west coast of WA. The ROMS downscaling model shows that the higher resolution better resolves ocean circulation in coastal regions. Changes in along shelf wind stress may be compensated by changes in along shelf sea surface height, reducing changes in Capes Current transport with increasing equatorward wind stress in the future climate. At two selected latitudes, OFAM and ROMS models show similar upwelling and downwelling patterns; and there is no clear change in coastal upwelling from the 1990s to the 2060s. The annual mean SST over the shelf of the lower west coast of WA shows greater warming than the northwest shelf or the south coast of WA. Seasonally, the greatest increase in SST is in spring off the Northwest Shelf and winter off the west coast. On the south coast, the seasonally averaged fields show warming and a weakening in the zonal jet speed due to a weaker LC.

More than twenty species were examined for climate change effects on key fisheries. The species include commercial invertebrate species such as Western Rock Lobster, Saucer Scallop, Blue Swimmer Crab, Abalone (2 species), Octopus, Pearl Oyster, Prawns (2 species), and key finfish species including Pink Snapper, Black Bream, Australian Herring, Pilchard Spanish Mackerel, various Emperor spp., Whiskery and Thickskin Shark, and West Australian Dhufish. Environmental effects on some of the biological characteristics (particularly recruitment) of the species were assessed. The historic long-term trends of the environmental variables as well as available projected trends were examined. A risk assessment of WA's key commercial and recreational finfish and invertebrate species, was undertaken based on the sensitivity assessment method developed by the South-east Australian Climate Change group and the likely exposure to climate change. The assessment identified Perth Herring, Roei Abalone, Black Bream, Western Rock Lobster, Pink Snapper, Whiskery Shark, Tiger Prawns, Scallops, Blue Swimmer Crabs and Australian Herring, as having the highest risk to climate change (Table 1).

The marine heat wave event in the Gascoyne and mid-west region of WA during the summer of 2010/11 (Fig. 1) and the long-term decline in the Rock Lobster puerulus settlement (Fig. 2) are used as major case studies to examine how researchers, managers and industry have adapted to the results of an extreme environmental event and a long-term environmental effect. The heat wave had a short-term effect of fish kills and temporary range extension of some tropical species moving south as well as a long-term effect on spawning and larval phase of some species. A major immediate effect was the 99% mortality of Roei Abalone in the Kalbarri region. The Abalone fishery in this region has been shut and research trials on the translocation of Abalone from nearby unaffected areas into the depleted areas and the release of hatchery-reared Abalone are being assessed. A longer-term effect has been the lack of recruitment of Scallops in Shark Bay and Abrolhos Is and Blue Swimmer Crabs in Shark Bay. The adult populations of these stocks, particularly the Scallops, have also been severely affected. The fisheries for Scallops and Crabs in this area did not fully operate during 2012 and 2013. The annual pre-recruitment survey of Scallops that has been undertaken in Shark Bay since 1982 has proved valuable for managers and the fishing industry in the early detection of this poor Scallop recruitment year class and adult abundance so that management and commercial industry decisions were made to not fish in 2012. The abundance of Shark Bay Crabs in the deep water region has also been monitored since 2000 and has been valuable in the detection of the downturn of this fishery and fishing ceased from April 2012.

An important outcome 24 months on from the 2010/11 marine heat wave has been the range extension of several nearshore finfish species, whose resident breeding populations were previously found only as far south as the Gascoyne region. While individuals of each species have persisted in nearshore waters off the lower west coast over this period, range extension may well be permanent for at least one of these species. Available evidence suggests that a viable breeding population of rabbitfish, *Siganus sp.,* has been established in the Cockburn Sound region near Perth where individuals of the species now regularly contribute to commercial and recreational catches. Monthly records of Fremantle Sea Level suggests the significantly earlier (January) onset of the strong Leeuwin Current during 2011 created the opportunity for larvae of this summer-breeding species from the Gascoyne to be transported south, and to settle in nearshore habitats off the lower west coast. It is postulated that elevated SST experienced during the two years since the marine heat wave have contributed to the survival of the newly settled juveniles.

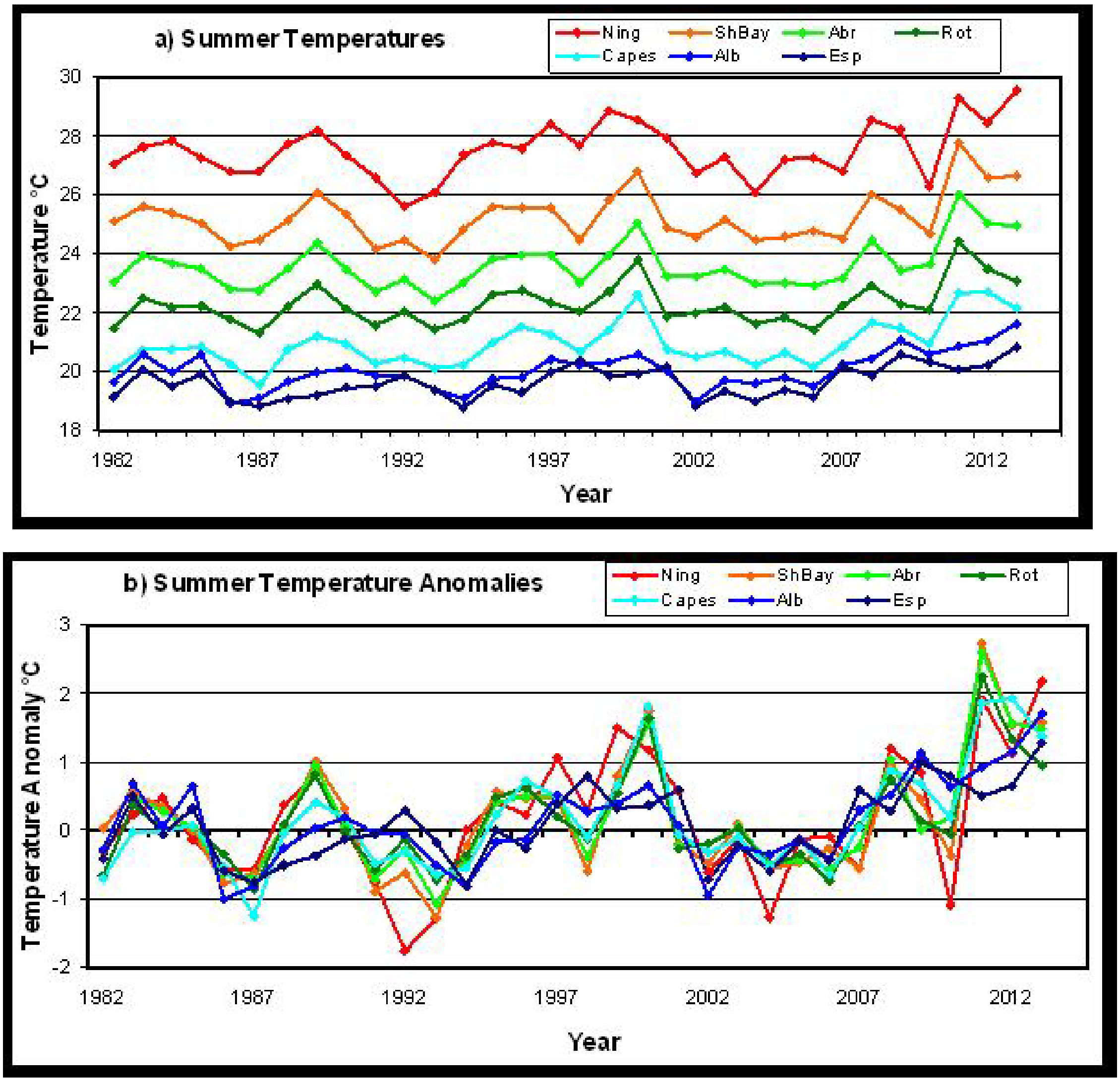


Figure 1. (a) Summer water temperatures from the Reynolds SST dataset for the 1-degree blocks off Ningaloo, Shark Bay, the Abrolhos Islands, Rottnest Island, the Capes region, Albany and Esperance. (b) Summer temperature anomalies from the long-term annual cycle. Summer is defined as December-February with 2012 referring to the 2011/12 summer.

Two marine heat wave workshops have been held to examine the effect of the heat wave on the marine environment. The first was held in May 2011 about two months after the peak of the heat wave event in February/March 2011. This workshop focused on the oceanographic conditions associated with the event as well as the short-term (1–2 mo.) effects observed such as fish kills and southerly range extension of a number of tropical fish species. The second workshop in March 2013 focused on: (a) the environmental factors that caused the heat wave event and the oceanographic conditions in the following two years; (b) the longer-term (6–24 mo.) effect on fisheries; and (c) the effect on the marine environment such as seagrass/algae habitat, coral communities and range extension of tropical species.

The Western Rock Lobster fishery is one of the best fisheries in Australia to examine effects of climate changes because of the availability of long time series of data to assess trends in the fishery and its location in one of the hotspots of long-term increases in SST in the Indian Ocean. The decline in puerulus settlement in the last seven years appears to be due to long-term environmental factors which makes it a good candidate to study climate change responses. There has been a pro-active management response before these low puerulus year-classes entered the fishery (there is 3–4 year lag between settlement and recruitment to fishery) with a significant reduction in fishing effort (ca. 40–70%) since 2008/09. The fishery provides an example of the change in pre-recruitment abundance being taken into account in the stock assessment with an appropriate management adaptation response to the long-term decline in puerulus settlement. Catch and fishing effort were reduced to ensure that there was a carryover of stock into the years when the poor year-classes entered the fishery and that the spawning stock remained at sustainable levels. There have also been other climate change effects such as changes in size of migrating and mature lobsters due to water temperature increases that have been taken into account in the stock assessment model.

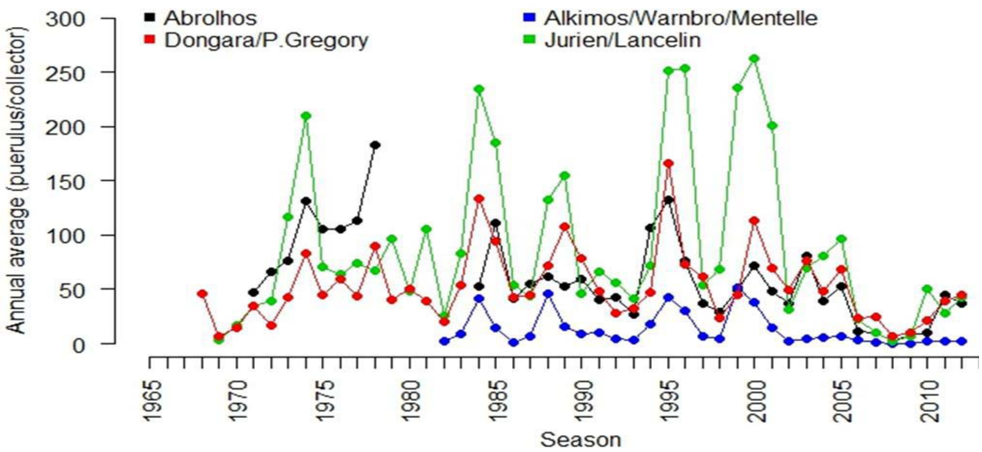


Fig. 2. Annual puerulus settlement of the Western Rock Lobster fishery at various locations throughout the fishery.

These case studies have highlighted the value of having a reliable pre-recruit abundance for an appropriate early management adaptation response. The pre-recruit information enables early detection of changes in abundance that allow for proper assessment and management recommendations before fishing takes place on the poor year classes. The Rock Lobster and marine heatwave case studies have demonstrated the ability of research, management and industry to react quickly to changing abundance of fish stocks. In addition, the marine heatwave-nearshore finfish case study highlighted the value of web-based community databases (such as Redmap) and well established nearshore finfish recruitment surveys in terms of tracking changes to coastal fish faunas in the future. This study has contributed to a report on the climate change effects on the Leeuwin Current and on fisheries as part of the 'Marine Climate Change Impacts and Adaptation Report Card for Australia 2012'.

Table 1. The preliminary risk assessment ranking (1–5) of WA's commercial and recreational finfish and invertebrate species, based on sensitivity criteria developed by the South-East Australian Climate Change group (Pecl et al. 2011) and exposure rankings (1–5).

Common Name	Sensitivity score	Sensitivity rank	Exposure rank	Risk score	Risk rank
High risk (5)					
Perth Herring	7.25	5	5	25	5
Black Bream	6.75	5	5	25	5
Roe's Abalone	6.5	5	5	25	5
Western Rock Lobster	6.25	5	5	25	5
Whiskery Shark	6.25	5	5	25	5
Pink Snapper	6.25	5	5	25	5
Tiger Prawn	6.5	5	4	20	5
Australian Herring	6	4	5	20	5
Southern Saucer Scallop	5.75	4	5	20	5
Blue Swimmer Crab	5.75	4	5	20	5
Medium-high risk (4)					
Bight Redfish	6	4	4	16	4
Western Blue Groper	5.75	4	4	16	4
Baldchin Groper	5.75	4	4	16	4
Thickskin	5.75	4	4	16	4
WA Dhufish	5.75	4	4	16	4
Spangled Emperor	5.75	4	4	16	4
Brownlip Abalone	6.75	5	3	15	4
Greenlip Abalone	6.5	5	3	15	4
Silver lipped Pearl Oyster	6.25	5	3	15	4
King Prawn	5.75	4	3	15	4
Whitebait	5.5	3	5	15	4
Blue Threadfin	5.75	4	3	12	4
King Threadfin	5.75	4	3	12	4
Tailor	5.5	3	4	12	4
Pilchard	5.5	3	4	12	4
Medium risk (3)					
Sandfish (Beche-de-mer)	5.5	3	3	9	3
Stripey Snapper	5.5	3	3	9	3
Bluespotted Emperor	5.5	3	3	9	3
Grass Emperor	5.5	3	3	9	3
Mud Crab	5.75	4	2	8	3
Spanish Mackerel	5.25	2	4	8	3
Eight bar Grouper	5	2	4	8	3
Medium-Low risk (2)					
Goldband	5.5	3	2	6	2
Red Emperor	5.25	2	2	4	2
Gloomy Octopus	4.75	2	2	4	2

Recommendations

1. That monitoring of key environmental variables and habitat be continued or established so that changes in environmental conditions that may affect fish stocks are identified.
2. That understanding decadal climate variations and downscaling of projected climate change trends of environmental variables continue to be undertaken, particularly for north-west and south coast of Western Australia, and an assessment of the risk to fisheries
3. That monitoring of year-class strength, preferably using pre-recruit surveys, be undertaken to enable early detection of changes in abundance and therefore allow for proper assessment and management recommendations before fishing takes place on the year classes.
4. That the robustness of fisheries management under climate change conditions continues to be examined.

Peer-reviewed papers

Published

Caputi, N., Mellville-Smith, R., de Lestang, S., Feng, M., Pearce, A. 2010. The effect of climate change on the western rock lobster fishery. Can. J. Fish. Aquat. Sci. 67:85-96

Caputi, N., Jackson, G. and Pearce, A. 2014. The marine heat wave off Western Australia during the summer of 2010/11 – 2 years on. Fisheries Research Report 250, Department of Fisheries, Western Australia. 47pp.

Caputi, N., S. de Lestang, S. Frusher and R. Wahle (2013). The impact of climate change on exploited lobster stocks. In: Lobsters: biology, management, aquaculture and fisheries (Ed. B Phillips) Wiley-Blackwell UK. p. 84-112

Caputi, N. S. de Lestang, A. Hart, M. Kangas, D. Johnston, J. Penn (2014). Catch predictions in stock assessment and management of invertebrate fisheries using pre-recruit abundance; case studies from Western Australia. Reviews in Fisheries Science 22:1, 36-54

Feng, M., M. J. McPhaden, and T. Lee (2010). Decadal variability of the Pacific subtropical cells and their influence on the southeast Indian Ocean, Geophys. Res. Lett., 37, L09606, doi:10.1029/2010GL042796.

Feng, M., C. Boning, A. Biastoch, E. Behrens, E. Weller, and Y. Masumoto (2011). The reversal of the multi-decadal trends of the equatorial Pacific easterly winds, and the Indonesian Throughflow and Leeuwin Current transports. *Geophys. Res. Lett*., 38, L11604, doi:10.1029/2011GL047291.

Feng, M., N. Caputi, A. Pearce (2012). Leeuwin Current. In A Marine Climate Change Impacts and Adaptation Report Card for Australia 2012 (Eds. E.S. Poloczanska, A.J. Hobday and A.J. Richardson).

Feng, M., McPhaden, M. J., Xie, S., & Hafner, J. (2013). *La Niña* forces unprecedented Leeuwin Current warming in 2011. *Scientific Reports* **3**, 1277; DOI:10.1038/srep01277 (2013).

Pearce, A.F. and Feng, M. (2012). The rise and fall of the 'marine heat wave' off Western Australia during the summer of 2010/2011. Journal of Marine Systems http://dx.doi.org/10.1016/j.jmarsys.2012.10.009

Pearce, A., R. Lenanton, G. Jackson, J. Moore, M. Feng, & D. Gaughan (2011). The 'marine heat wave' off Western Australia during the summer of 2010/11. Research Report 222, Department of Fisheries, Western Australia, 36 pp.

In preparation

Caputi, N., A. Denham, M. Kangas, Y. Hetzel, A. Pearce & A. Chandrapavan (in prep.) Effect on a marine heat wave on invertebrate fisheries of Western Australia.

Benthuysen, J., Feng, M., Zhong, L., (In prep.) Spatial patterns of warming off Western Australia during the 2011 Ningaloo Niño: quantifying impacts of remote and local forcing.

Lenanton, R.C., Dowling, C. and Jackson G. (in prep.) Marine heatwave induced changes with coastal fish fauna on the lower west coast of Australia.

8.14 Beach and surf tourism and recreation in Australia: vulnerability and adaptation [FRDC 2010/536]

Mike Raybould, David Anning, Dan Ware, Neil Lazarow

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-536-DLD.aspx

Objectives

1. Locality scale identification and assessment of the vulnerability to climate change of assets that are key drivers of marine and coastal tourism and recreation.
2. Valuation of existing income streams due to beach-related tourism and recreation in case-study locations.
3. Application of valuation tool (developed in previous stage) in identified sea-change localities to test transferability of results.
4. Identify social and behavioural responses to climate change impacts on vulnerable tourism and recreation assets.
5. Report on the net vulnerability of regional locations to climate change.

Executive Summary

This project has produced estimates of economic values for recreation and tourism related to beach and surf amenities across four case-study locations in Australia.

Table 1 Resident beach recreation consumer surplus estimates

Case-study location	Consumer surplus per adult per visit ($/person/day)	
	Fuel only model	Fuel only plus time @40% of hourly rate
Sunshine Coast	3.36	8.50
Surf Coast	3.27	5.15
Clarence Valley	6.10	9.30
Augusta-Margaret River	3.28	12.21

Estimates of the non-market consumer surplus values of beach recreation indicate that beach recreation is worth around: $70 million per annum (p.a.) to residents of the Sunshine Coast (Qld), $32 million p.a. to residents of Clarence Valley (NSW), $6 million p.a. to residents of the Surf Coast (Vic) and $4 million p.a. for residents of Augusta-Margaret River (WA).

In addition to the non-market values, real market expenditures are incurred by tourists in order to visit and stay in coastal locations. The value of this tourism expenditure that is specifically related to beach and surf recreation is estimated to be in the order of: $270 million annually for the Sunshine Coast (Qld), $32 million p.a. for Clarence Valley (NSW), $107 million for the Surf Coast (Vic) and $25 million for the Augusta-Margaret River (WA) region.

Table 2 Summary of BASTRA value estimates for recreation and tourism

Case-study location	Annual value of resident beach recreation (A$m)	Annual value of tourist expenditure related to beaches (A$m)
Sunshine Coast	69.59	270.17
Surf Coast	6.09	106.63
Clarence Valley	31.60	32.13
Augusta-Margaret River	3.72	24.58

Market expenditure specifically associated with tourist use of beach and surf recreation amenities is estimated at between 2% and 13% of gross regional product across the four case study regions.

Potential beach-related recreation and tourism losses associated with climate change may be substantial. Current projections indicate that climate change will result in long-term beach recession and more frequent erosion events in some regions. Resident survey responses to scenarios about beach damage suggest that between 25% and 35% of residents' consumer surplus values for beach recreation could be lost as a result of major erosion events. Loss of recreation values on this scale would equate to a minimum $18 million p.a. on the Sunshine Coast and $10 million p.a. in the Clarence Valley. Tourist responses to similar beach damage scenarios suggest that between 17% and 23% of tourists would respond to major erosion events by switching to other destinations. Loss of tourism receipts on this scale would equate to losses of approximately $56 million p.a. on the Sunshine Coast and $20 million p.a. on Victoria's Surf Coast. The time taken to repair the damage is critical and rapid action by authorities can reduce the duration and extent of these losses considerably.

Table 3 Recreation management responses to climate change impacts on coastal locations

General description	Actions/Examples	Key benefits
Increase beach space	Beach nourishment, offshore reefs, park development	Provides buffer to erosion, reduces congestion, can reduce exposure
Increase alternative recreation sites	Need to provide facilities and promote alternatives	Can select locations which are 'climate-resilient'
Increase beach access	Provide facilities, manage environmental impacts	
Increase resilience of beaches	Beach nourishment and/or grooming	Maintain usage of existing sites
Behaviour management	Provide current information about beach state, reduce use of 'ideal' images in promotion and marketing	Provides flexibility, a more adaptive beach user group can accommodate a range of potential future scenarios

Recommendations

Coastal managers may utilise a menu of adaptive management strategies to minimise the economic losses associated with climate change impacts on beaches including:

1. Increase resilience of heavily used beaches and their recreation carrying capacity through beach nourishment and enhancement of adjacent beachside parks.
2. Increase supply of beach recreation space by improving access to beaches that are currently difficult to get to.
3. Increase supply of alternative recreation sites such as estuary, river, and reservoir beaches.
4. Reduce sensitivity of popular beaches to climate change impacts through beach grooming and construction of off-shore artificial reefs and breakwaters to minimise wave damage.
5. Manage user expectations and behaviour through information provision.

Peer-reviewed and conference papers

Conference Papers

Anning, D., Withycombe, G., Dominey-Howes, D., & Raybould, M. (2011). *The dollars and sense of coastal valuation in Australia.* Paper presented at the 20th NSW Coastal Conference: 20/20 Vision: Lessons learnt and looking toward future improvement, Tweed Heads, Australia, 8-11 November 2011.

Anning, D., Ware, D., Raybould, M., & Lazarow, N. (2013). Valuing beach and surf tourism and recreation in Australian sea change communities. Paper presented at the Queensland Coastal Conference, Townsville, October 2-4.

Anning, D., Raybould, M., Ware, D., & Lazarow, N. (2012). *Behavioural responses to beach erosion and climate change.* Paper presented at the Coast to Coast 2012: Living on the Edge, Brisbane, Australia, 17-21 September 2012.

Anning, D., Sano, M., Lofthouse, J., Raybould, M., Tomlinson, R., Lazarow, N., & Ware, D. (2013). Behavioural responses to beach erosion and coastal management interventions. Paper presented at Coasts and Ports 2013, Sydney, September 11-13.

Raybould, M., Lazarow, N., Anning, D., Ware, D., & Blackwell, B. (2011, 8-11 November, 2011). *A Travel Cost Model of Local Resident's Beach Recreation Values on the Gold Coast.* Paper presented at the 20th NSW Coastal Conference: 20/20 Vision: Lessons learnt and looking toward future improvement, Tweed Heads, Australia, 8-11 November 2011.

Raybould, M., Anning, D., Ware, D., & Lazarow, N. (2012). *Beach and surf tourism and recreation in Australia: Vulnerability and adaptation.* Paper presented at the Coast to Coast 2012: Living on the Edge, Brisbane, Australia, 17-21 September 2012.

Raybould, M., Anning, D., Ware, D. & Lazarow, N. (2012). *Estimating consumer surplus values for beach recreation in Australia using travel cost methods.* Paper presented at The Australia New Zealand Society for Ecological Economics (ANZSEE) Conference 2012, Gold Coast, 13-15 November 2012.

Ware, D., Anning, D., Raybould, M., Lazarow, N., & Tomlinson, R. (2011). *Is a wide beach more valuable? -The impact of the Tweed River Entrance Sand Bypass Project on nearby Property.* Paper presented at the 20th NSW Coastal Conference: 20/20 Vision: Lessons learnt and looking toward future improvement, Tweed Heads, Australia, 8-11 November 2011.

Ware, D & Mustelin, J. (2013). The limitations of climate adaptation as resource allocation problem: The need for equity and values approaches in robust adaptation governance Paper accepted to the Earth System Governance Conference: Complex Architectures, Multiple Agents Tokyo Japan 28-31 January 2013.

Book Chapters

Blackwell, B., **Raybould**, M., & Lazarow, N. (2013). Beaches as societal assets: Council expenditure, recreational returns, and climate change. In C.A. Tisdell (Ed.). *Handbook on Tourism Economics: Analysis, new applications and case studies*. p. 443-467. World Scientific Publishing.

Lazarow, N., **Raybould**, M., & Anning, D. (2013). Beach and surf tourism. In C.A. Tisdell (Ed.). *Handbook on Tourism Economics: Analysis, new applications and case studies,* p. 361-389. World Scientific Publishing.

In preparation

The report authors and various collaborators are currently preparing papers for submission to international journals based on this research project with the following themes: (a) valuing beach and surf tourism and recreation in Australia; (b) estimating consumer surplus for local resident's beach recreation values using travel cost approaches; and (c) sensitivity analysis of the treatment of time in travel cost models.

8.15 A marine climate change adaptation blueprint for coastal regional communities [FRDC 2010/542]

Stewart Frusher, Nadine Marshall, Malcolm Tull, Sarah Metcalf, and Ingrid van Putten

FRDC URL: (To be finalised)

Objectives

1. Develop and trial a 'blueprint' using three marine community case studies in south-eastern, western and northern Australia, that objectively integrates a suite of adaptation assessment and evaluation tools for the provision of best choice marine climate change adaptation options to these coastal communities.
   - Compare and synthesise potential adaptation options across case studies to develop
   - an understanding of the context dependence of adaptation in marine communities, and
   - a portfolio of generic adaptation options for sub-tropical to temperate coastal and regional marine communities in Australia.
2. Based on the outcomes of 1 and 2, determine the broad representativeness of the blueprint to address the needs and priorities of coastal rural communities throughout Australia.
3. Develop capacity for inter-disciplinary research by training and mentoring two early career researchers.

Executive Summary

An innovative methodological approach (Fig. 1) to developing adaptation options was tested in three Australian case study communities in Tasmania, Queensland, and Western Australia. Qualitative models were used to determine the effect of current marine climate and non-climate pressures on the regional coastal community's marine sectors. Recognising the combined role of climate and non-climate change pressures in shaping marine sectors in small coastal communities is important to allow a holistic overview to be developed and thus avoid potential unintended adaptation consequences.

The information for the qualitative models was gathered by means of semi-structured interviews. The semi-structured interview approach is a good alternative to, for instance, workshops or focus groups in communities where it is difficult to engage stakeholders or where the issues of interest are controversial or of a perceive political nature. We used a boundary organisation (Oceanwatch) to engage community members in the research. This engagement process was particularly successful where Oceanwatch officers were locally resident or embedded in the local community.

The adaptation options, generated using the qualitative modelling approach and through discussion with community members and experts, were mostly location and industry specific but some were generally applicable across the different communities (Table 1). Some adaptations were in response to positive marine climate change impacts. Such positive impacts arose, for instance, from income and labour opportunities for charter and recreational fishing associated with new range shifting species. Community level adaptations to negative impacts of marine climate pressures, like reduced abundance of commercial species due to increasing sea temperatures and range shifting pest species, were mainly in terms of finding species alternatives and diversification into other sectors; adaptation was facilitated where communities and individuals had high capacities for mobility and flexibility.

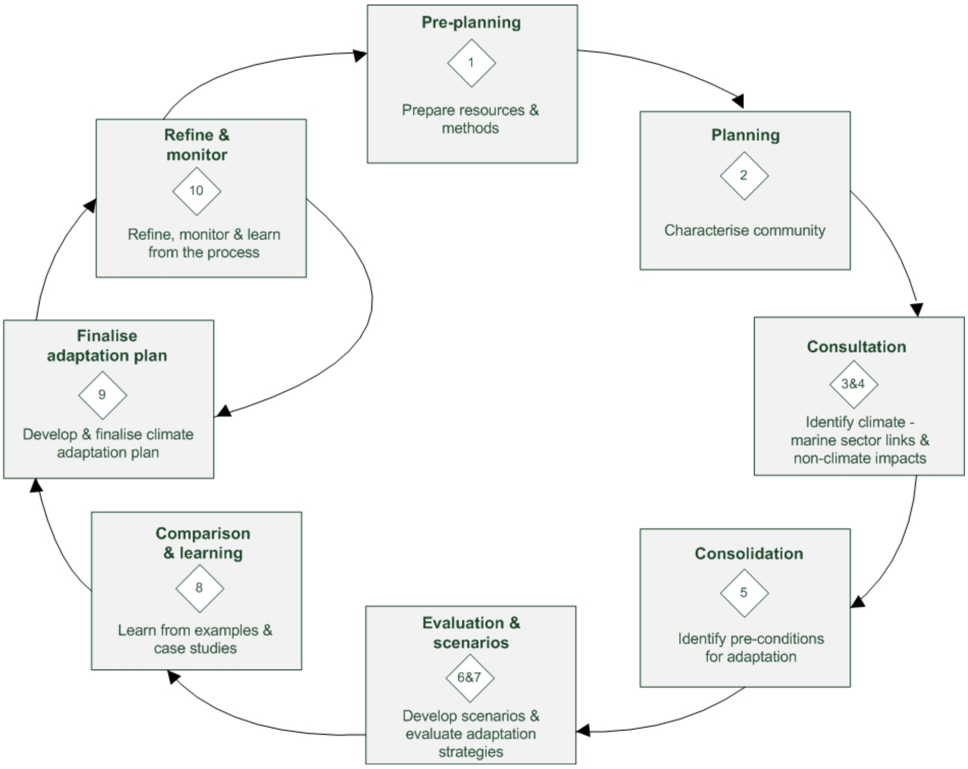


Figure 1. Structure of the approach taken to assess current climate impacts and develop adaptation options in coastal communities.

The community consultation process not only generated information for the qualitative models and resulting adaptation options but also provided insight into the community's knowledge of, and concern about, marine climate change. In general marine climate change knowledge is present as it is readily observed through new species being caught by recreational, charter and commercial fishers. Programs like REDMAP (www.redmap.org) have significantly helped raise awareness of, for instance, range shifting species.

Knowledge of marine climate change is also gained though locally observed changing species abundance. However, community respondents were often less clear about the link between abundance and marine climate change as abundance changes were perceived to be at least equally likely driven by fisher behaviour or fishery management. So, even though the impacts of marine climate change were known and observed, it often gained limited recognition due to the multitude of non-climate pressures on the marine sector (the well-known attribution problem). The attribution problem may lead to a lack of interest or perceived need to undertake adaptation planning for climate change as it is felt by industry and community that priority should be given to addressing non-climate pressure as they were short-term and more easily managed (e.g. change in abundance managed through input/output controls). Because the negative marine climate impacts were not perceived to be directly linked to climate change while the positive impacts were already being adequately captured there was a seeming reluctance to address adaptation to marine climate change *per se*. In other words, there may be a certain level of inertia to overcome with respect to convincing communities to undertake marine climate change adaptation planning.

Table 1. Adaptations and their reasoning, identified for all locations. Each adaptation strategy was more detailed for each location but are essentially the same (i.e. result in increased tourism etc.).

Sector	Adaptation type	Adaptation	Type of capital increased (within local community)	Reasoning
Commercial fishing	Market	Diversify, re-establish and maintain a local & domestic market for commercially captured fish	Financial (indirect)	Reliance on single export markets is risky. Can mitigate effects of falling export markets and increasing costs by providing domestic income. Provide locals/businesses with fresh local fish.
Commercial fishing	Information	Develop courses that inform fishers about: the potential financial implications of species range shifts the implications of changing species abundance on quota succession planning	Human	Fishers may wish to learn how to develop investment plans to determine if investing in new opportunities, e.g., larger vessel, purchasing more/selling quota, is worthwhile. Provide information sessions on the value of different retirement options that are available with respect to retaining or selling quota.
Commercial fishing	Information	Monitoring of pre-recruit abundance as an early warning to changing abundance of key stocks	Financial and natural (indirect)	An early warning to changing abundance of fish stocks gives industry and managers an ability to adapt fishing practices and avoid overfishing of poor year classes
Commercial fishing	Market	Encourage more transparency for fishers in pricing systems set by processing industry to allow greater understanding of value-adding over the supply chain and provide fishers with improved bargaining power	Financial (indirect)	Fishers often become price takers, as they are increasingly bound to processors/buyers that set fish prices. There is little competition between processors/buyers due to their limited numbers. Improved bargaining power is desirable to support commercial fisheries into the future.
Commercial fishing	Labour	During boom times in other sectors – labour shortages in fishing could be addressed by incentives to retain skill base and labour. Short term shortages could be addressed through temporary migration visas.	Financial (indirect)	High wages in the mining and oil & gas sectors mean fishers have trouble retaining reliable deckhands and therefore can struggle to maintain catches.
Commercial fishing	Management	Balanced representation on co-management committees and industry bodies through better rotation times, term limitations and incentives to participate.	Social	Need for balanced representativeness and membership renewal for industry bodies and co-management decision committees. Adequate reimbursements and more locally held meetings are required to help overcome issues such as loss of fishing time.
Aquaculture	Market/labour	Increase aquaculture output/function	Financial (indirect)	Provides an alternative source of employment for wild capture fishers forced to leave the industry due to climate, quota, cost issues. Also supports associated industries such as transport/ processing which may provide critical employment opportunities. Provides fish to local, domestic and international markets.
Aquaculture	Management/ information	Support local aquaculture by increasing collaboration	Social (direct) and financial	Close collaboration with research institutions can increase knowledge and reduce the influence of high

Sector	Adaptation type	Adaptation	Type of capital increased (within local community)	Reasoning
		with research institutions to enhance diversification to new species in anticipation of marine climate pressures.	(indirect)	development costs associated with new aquaculture enterprises through co-funding arrangements.
Aquaculture	Management/ Information	Encourage investigation of closed on-land systems to ensure development of aquaculture into the future.	Human and Physical	At-sea aquaculture is constrained by available farming space and limited expansion is possible in the majority of situations. Knowledge of and construction of on-land systems can allow industry expansion to occur.
Recreational fishing	Management/ Information	Improve recreational catch monitoring to reduce conflict between sectors, more policing of rules, and establish a catch share arrangement between commercial and recreational fishers so that each sector is responsible for itself.	Social and human (both indirect)	A more frequent official 'count' of participation and catch estimates is necessary. Although difficult to estimate, illegal catches should/could be better accounted for and incorporated into catch estimates.
Recreational fishing	Management	Keep infrastructure provisions in step with growth in recreational fishing.	Physical	Provide reasonable access to jetties to avoid 'boat ramp rage' with increasing recreational fishing participation.
Recreational fishing	Management	Flexible and adaptive rule development for 'unmanaged' species.	Financial (indirect)	When new (commercial) species appear in local waters management decisions have to be prompt and flexible to avoid a 'gold rush' and maintain the fishery into the future.
Marine tourism	Marketing/ information	Encourage increased tourism through improved marketing /promotion. Develop good information dispersal to inform public (elsewhere) about access and local conditions after severe weather events.	Financial (indirect)	Provides more consistent income to tourism operators and associated businesses. Access to towns is often affected by extreme events and needs to be managed quickly to maintain tourist visitation. Distribution of correct information on reef state is needed.
Marine tourism	Information	Encourage opportunities for community participation in 'scientific research'.	Social and human	Local participants in marine sectors feel they have valuable knowledge but there are few avenues available to use that information (apart from Redmap).
Community	Labour	Maintain local engineering /support services to maintain contribution to local employment and economy.	Financial and physical (both indirect)	With a declining commercial fishing sector in small local communities, the infrastructure and service provision to remaining fishers becomes increasingly problematic. Supports local employment and helps to maintain infrastructure.

Table 2. Unique adaptations and their reasoning by location.

Location	Sector	Category	Adaptation	Type of capital increased (within local community)	Reason
St Helens	Commercial fishing	Labour	Increase urchin factory production.	Financial (indirect)	Provide a source of local employment.
St Helens	Processing	Market	Separate processors from investors.	Financial (indirect)	To provide more transparent and flexible pricing of fish.
Bowen	Commercial fishing	Labour	Closure of cyclone-damaged area and shift of fishing effort elsewhere.	Natural and financial (both indirect)	To allow stock regeneration on affected reefs and ensure employment and local fish availability are maintained.
Geraldton	All	Information	Increase research in renewable energy, aquaculture and fisheries. Increase education for commercial and recreational fisheries compliance.	Human and financial (indirect)	To allow utilisation of likely impacts from climate change through renewable energy and continue to increase production of aquaculture and wild caught species.
Geraldton & Bowen	Community	Information	Better communication of the benefits of aquaculture products and renewable energy. Distribute public information regarding the level of impact from local aquaculture (particularly prawn) and renewable energy ventures.	Human	Aquaculture and renewable energy are often perceived to damage nearby coastal ecosystems, species or visual amenity. This is often not the case and these negative perceptions may be mediated by improved communication and public education.
Geraldton	Renewable energy	Labour	Increase renewable energy production & sales.	Financial (indirect)	Utilise climate change impacts to provide an additional source of local employment and produce cheaper energy.
Geraldton	Commercial fishing	Management	Maintain Rock Lobster fishing quota system.	Financial	After initial loss of fishers following implementation of quota system, the new system has been found to allow better catch rates and require fewer fishing days per year as fishers are now fishing close to the maximum economic yield (i.e. maximum profits).

Even though there was much knowledge with respect to locally observed climate related phenomena, there appeared to be a lack of knowledge and awareness of flow-on consequences and knock-on economic effects of marine climate pressures. In contrast to the lack of interest in marine climate planning for individual marine sectors, these cumulative knock-on effects were considered to be an important issue for regional coastal communities with relatively high reliance on the different marine sectors. Comparative community level vulnerability assessment and impact analysis based on projected marine climate pressures is an area of interest that is often not captured in adaptation research.

In this project a web-based blueprint is developed that takes into consideration these case study findings (coastalclimateblueprint.org.au). Firstly the aim of the blueprint is to raise awareness of marine climate change and the potential flow on effects into regional coastal communities. The general and locally specific information on marine climate adaptation as derived from the case studies will be useful in the web-based blueprint for illustrative purposes. Secondly, the blueprint provides a conduit for communities to undertake more detailed adaptation planning based on the knowledge and information garnered through the web-based blueprint. Using a Sustainable Livelihoods Analysis, an interactive assessment of community vulnerability to climate change allows community members or local governments to assess where their strengths and vulnerabilities may lie. For example, one community may have very high education levels and financial capital but be lacking in the necessary coastal infrastructure to allow commercial fisheries and aquaculture development. This interactive assessment provides each community with a first-step indication of where specifically adaptation may be needed to ensure they remain sustainable into the future.

Recommendations

1. Benefits of WORKING WITH a boundary organisation to provide on-ground contact and establish the groundwork, especially when interviews are required. Personal knowledge and industry contacts were vital in establishing good rapport with community members in close-knit communities. Trust in the boundary organisation contact allowed a broader range of conversation, such as climate change and fishery impacts, and issues with administration, than may have otherwise been possible.
2. The need to INTEGRATE climate change with other stressors, such as population change, to enhance stakeholder engagement as stakeholders find it hard to consider issues beyond the immediate/short term. Assisting engagement with a broader range of issues can improve the capacity for the community to adapt to future changes and remain a sustainable coastal community.
3. The benefit of bringing together both the biophysical and human dimensions so that the broader impacts on the community can be established. Indirect and non-intuitive effects of change can easily be overlooked when focussing on specific and direct impacts. Bringing together multiple dimensions through social, economic and ecological analysis and modelling assist in producing an holistic assessment of change.
4. The benefit of considering the entire marine community as opposed to specific sectors to BETTER determine the overall influence on the community and to demonstrate where both losses and gains can be made. Such information is vital in ensuring a community can adapt to change. Knowledge of strengths and weaknesses enable the development and implementation of adaptation strategies that are more likely to produce successful outcomes.
5. The benefit of combining qualitative and quantitative approaches to demonstrate and develop key linkages between physical, biological and socioeconomic components and associated metrics. When qualitative data is one of the main sources of information available, means of assessment to ensure that crucial pieces of information are not lost are critical. In addition, the integration of qualitative data with the available quantitative information then provides another dimension to the results and ensures that all relevant dynamics are considered.
6. The need for and desire in communities for access to up-to-date research findings with regard to climate change impacts in the local area. This can provide improve the human capital (through knowledge) of the community and potentially assist adaptation to change.

Peer Reviewed Papers

Metcalf SJ, van Putten EI, Frusher SD, Tull M, Marshall N (2014) Adaptation options for marine-industries and coastal communities using community structure and dynamics. Sustainability Science, 9 (1). pp. 1-15. DOI 10.1007/s11625-013-0239-z

van Putten EI, Metcalf S, Frusher S, Marshall N, Tull M (In press) Fishing for the impacts of climate change in the marine sector: A case study International Journal of Climate Change Strategies and Management.

van Putten EI, Metcalf S, Frusher S, Marshall N, Tull M (In press) Transformation of coastal communities: Where is the marine sector heading? Australian Journal of Regional Studies.

Frusher SD, Metcalf S, van Putten EI, Marshall N, Tull M, Holbrook N, Jennings S, Hobday A, Haward M and Pecl G. (in review) From physics to folk via fish – connecting the socio-ecological system to understand the ramifications of climate change on coastal rural communities. Journal of Fisheries Oceanography

Metcalf SJ, van Putten EI, Frusher S, Marshall N, Tull M, Caputi N, Haward M, Hobday A, Holbrook N, Jennings S, Pecl G, Shaw J (in prep) Adaptive capacity and vulnerability in the successful implementation of adaptations to climate change. Ecology and Society.

8.16 Effects of climate change on reproduction, larval development, and population growth of coral trout (*Plectropomus* spp.) [FRDC 2010/554)

Morgan S. Pratchett, Vanessa Messmer, Adam Reynolds, Jenna Martin, Timothy D. Clark, Philip L. Munday, Andrew J. Tobin, and Andrew S. Hoey

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-554-DLD.aspx

Objectives

The overarching objective of this study was to test the sensitivity of coral trout (mainly, *Plectropomus leopardus*) to changes in habitat and environmental conditions (specifically, increasing temperature and ocean acidification) linked to ongoing climate change. Comprehensive understanding of all direct and indirect effects of climate change on coral trout, and across all different life stages, will require extensive ongoing research. This study comprised four independent projects intended as the first step towards understanding whether large, commercially important fisheries species will be more or less vulnerable compared to small site-attached reef fishes on which prior research has been conducted. These four projects explored:

1. Effects of increasing temperature and ocean acidification on fertilisation and egg development using gametes obtained *P. leopardus* that were spawned in captivity
2. Effects of ocean acidification (declining pH) on the sensory discrimination and behaviour of early post-settlement *P. leopardus*
3. Variation in sensitivities and responses of adult *P. leopardus*, directly comparing between fishes from northern and southern sections of the Great Barrier Reef
4. Reliance on live corals for settlement and post-settlement survivorship, to test whether coral trout will be adversely affected by climate-induced bleaching and coral loss.

Executive Summary

This project has unequivocally shown that coral trout and particularly, *Plectropomus leopardus*, are sensitive to changes in habitat and environmental conditions expected to occur as a consequence of sustained and ongoing climate change. More specifically, coral trout will be negatively affected by degradation of coral reef habitats (specifically, declines in abundance of *Acropora* colonies), increasing temperature, and ocean acidification. It is unclear if, when, or how these changes will impact the size, abundance and catchability of coral trout, which are key to understanding effects on the productivity and profitability of wild fisheries and particularly, commercial fisheries. However, this project shows that coral trout are vulnerable to climate change and so, more research is required to understand the specific effects on wild stocks and associated fisheries, as well as exploring appropriate adaptation options within each of the distinct fisheries sectors; commercial, charter, recreational and indigenous fisheries

The key biological findings were:

1. Development, growth and survival of larval coral trout (*Plectropomus leopardus*) were severely impacted at 2–3^{o}C above current ambient temperatures, at 30–32^{o}C. Unless *P. leopardus* is able to adapt to increasing temperatures (e.g., by spawning earlier in the year) fertilisation success and larval development and survival are likely to be much lower with ongoing temperature increases, especially in the northern GBR.

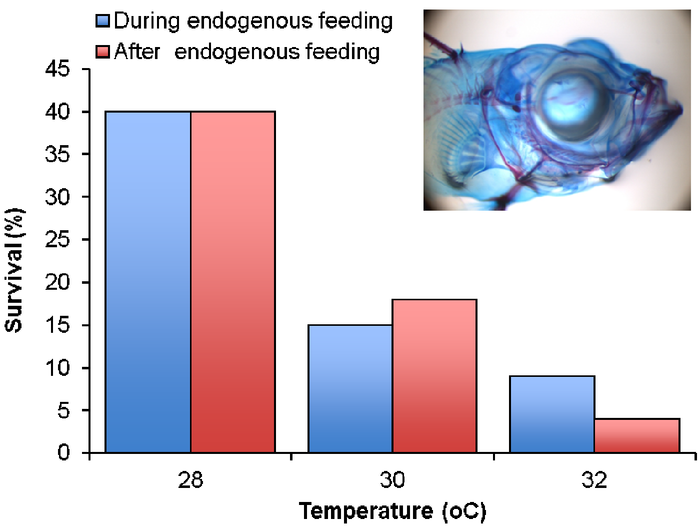


Figure 1. Extreme sensitivity of early life-history stages of coral trout (*Plectropomus leopardus*) to increases in temperature.

2. Although ocean acidification did not seem to have an effect on larval growth and survival, it greatly altered the behaviour of common coral trout larvae. At levels of pH expected by the end of the century, *P. leopardus* larvae spent a lot less time in the safety of shelter and were attracted to predator odour instead of avoiding predators in current (control) conditions. This is expected to lead to much lower levels of survivorship in newly settled larvae and juveniles.

3. Juvenile coral trout (specifically, *P. maculatus* had a strong reliance on live corals at settlement. Importantly, >70% of trout that were <15cm TL were found living in close association with live colonies of *Acropora* corals in the Keppel Islands. This strong affinity with one specific habitat, suggests that live coral must offer a significant fitness advantage in terms of growth and survivorship. Therefore, ongoing declines in the abundance of *Acropora*, which is particularly susceptible to climate induced bleaching, would be expected to reduce successful recruitment. Tests of the generality of these findings for other corals trout (e.g., *P. leopardus*) are ongoing.

4. Temperature had a strong effect on the metabolism (aerobic scope) and survival of adult *P. leopardus*. The cost of staying alive increases with temperature, but energy available for activities such as foraging were greatly reduced at 33°C. Furthermore, coral trout were unable to survive exhausting physical activities at 30°C and 33°C, but were not affected at 24°C and 27°C.

5. Populations of *P. leopardus* from the northern and southern GBR seemed to be equally affected by absolute (not relative) temperature increases. If coral trout are adapted to local temperature regimes the northern population would be expected to be able to tolerate higher temperatures than southern populations. Our findings suggest that the common coral trout has a very limited capacity to adapt to increasing temperatures.

6. Although higher temperatures require fish to spend more energy to meet metabolic demands, individual fishes did not compensate by increasing food intake. Unless fish are able to behaviourally adapt to increasing temperatures (e.g., by moving to deeper cooler waters), they are likely to lose condition during hot summer months, which would lead to reduced growth and reproductive output.

Recommendations

i) Implications for fisheries management

There are several different ways in which climate change will affect coral trout, but the most immediate and direct impacts relate to effects of increasing temperature on larval and juvenile life stages. Our research suggests that wild populations of coral trout on Australia's Great Barrier Reef will be severely compromised due to limited survivorship of larval trout whenever or wherever ocean temperatures exceed 30^{o}C.

Tank-based studies of aerobic scope, suggest that these effects will be further compounded by declines in the size, growth and reproductive capacity of adult fishes regularly exposed to these temperatures. Average reef-wide sea surface temperatures (SST) on the Great Barrier Reef are expected to exceed 30^{o}C between 2065–2080, though maximum summer-time temperatures already approach (if not exceed) this threshold in the northern GBR.

If coral trout are unable to adapt or acclimate to increasing temperatures (behaviourally or physiologically) then it is very likely that the sustainability of fisheries for coral trout on the GBR will be undermined by sustained and ongoing increases in ocean temperatures, and these effects will be felt first and worst in the northern GBR, where temperatures are already much closer to the 30^{o}C threshold.

The key is to understand how individual fish and populations as a whole respond to fluctuations in ocean temperatures, both on very short (days to weeks) and longer time-frames (generations). It may be that tank-based studies conducted here, overestimate the vulnerability of coral trout to increasing temperatures and other climate-induced changes in environmental and habitat-conditions by failing to account for behavioural responses that can occur in the wild. For example, large mobile fishes, such as coral trout, would expected to have increased capacity (compared to small site-attached reef fishes) to escape areas of warm water by moving offshore and to greater depths.

ii) Further research

This project represents the very first step in assessing the vulnerability of coral trout to climate change, using manipulative experiments to assess the sensitivity of fishes to projected changes in environmental and habitat conditions. Given the limited time and budget, research was focussed on several processes and life-stages (e.g., survivorship of zygotes immediately after fertilisation) that were expected to be extremely vulnerable. Even so, the sensitivity of coral trout to increasing temperature, ocean acidification and climate-induced habitat degradation was far greater than was expected. The imperative now is to understand how these effects will manifest in terms of the productivity and sustainability of fisheries for wild stocks on the GBR. Essential future research falls in to three key areas:

1. Explore the comprehensive range of effects that climate change will have on the individual condition, demography and population dynamics of coral trout, considering not only *P. leopardus*, but also other fishery target species.
2. Repeat the aforementioned experiments across a range of large piscivorous fishes to establish whether there are some species that will benefit (or are less affected) by climate induced changes in environmental and habitat conditions

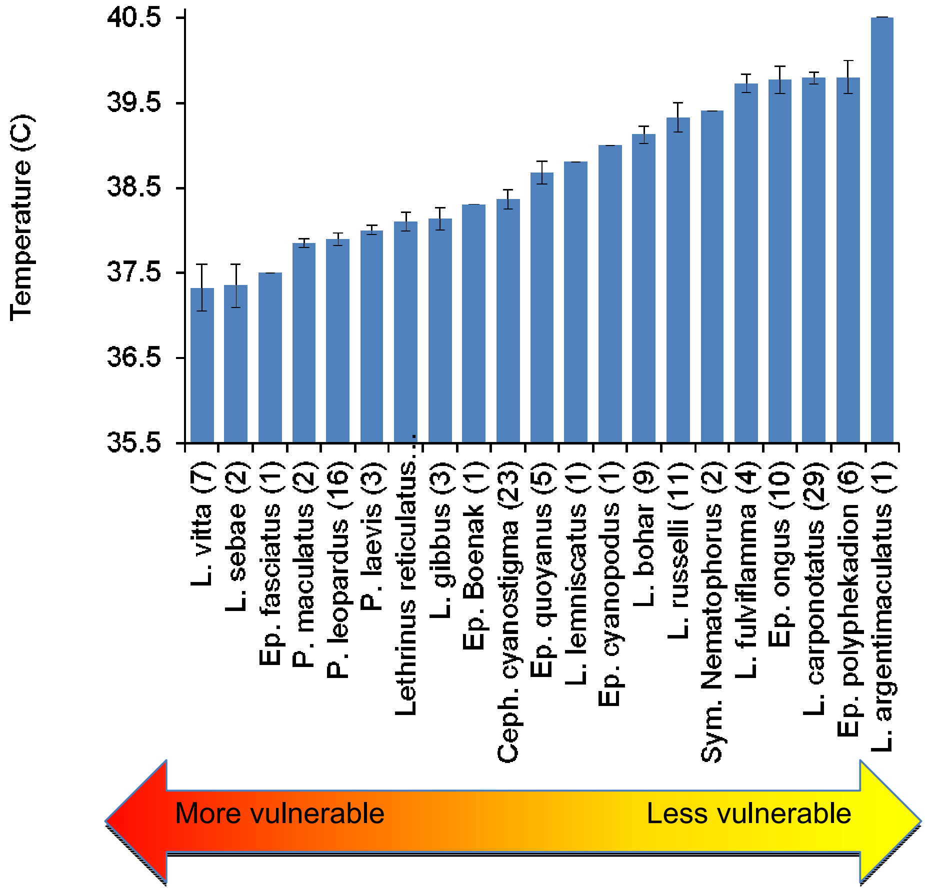


Figure 2 Preliminary estimates of critical thermal limits for different fisheries species, indicating which species will be more or less vulnerable to effects of ocean warming.

3. Explore behavioural and physiological responses of individuals and populations to environmental extremes, in order to better understand the adaptive capacity of coral trout. This is key to understanding the consequences of climate change on wild stocks and associated fisheries.

4. Explore adaptation options for fishers and fisheries that rely heavily on coral trout. While it is not yet clear if or when coral trout populations will be compromised, there are significant advantages (in maximising the range of adaptation options available) to initiating research in to the adaptive capacity of the fishery as soon as possible.

Peer Reviewed Publications

Johansen JL, Messmer V, Coker DJ, Hoey AS, Pratchett MS (2014), Increasing ocean temperatures reduce activity patterns of a large commercially important coral reef fish. Global Change Biology 20: 1067–1074

Munday PL, Pratchett MS, Dixson DL, Donelson JM, Endo GGK, Reynolds AD, Knuckey R (2013) Elevated CO2 affects the performance of an ecologically and economically important coral reef fish. Marine Biology 160(8): 2137-2144

Wen C, Pratchett MS, Almany G, Jones GP (2013) Patterns of recruitment and microhabitat associations for three predatory coral reef fishes on the southern Great Barrier Reef, Australia. Coral Reefs 32(2): 3899-398

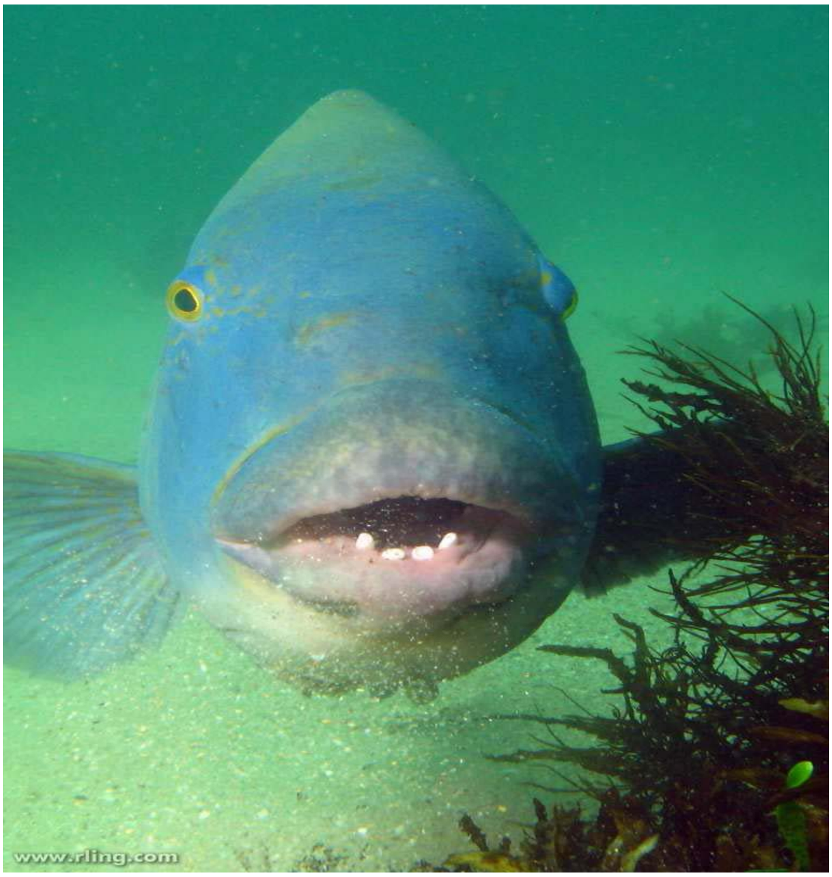
8.17 Pre-adapting a Tasmanian coastal ecosystem to ongoing climate change through reintroduction of a locally extinct species [FRDC 2010/564]

Nicholas Bax, Neville Barrett, Alistair Hobday, Ruth Casper

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2010-564-DLD.aspx

Objectives

1. Develop and promote a national framework to evaluate potential translocations of native marine species.
2. Determine the feasibility of reintroducing Blue Groper as a test case.
3. Design a monitoring and evaluation program to determine the effects of a trial re-introduction.
4. Reach the critical decision point on whether to re-establish Blue Groper in Tasmania, or take an alternative approach indicated by the research. Develop a proposal to support this outcome.



Executive Summary

Conservation translocations are increasingly being considered as a climate adaptation strategy. It is likely that contemporary and future rapid climate change scenarios will see an increasing need for timely and transparent decisions to be made on conservation translocation proposals. This project developed a framework to assist those decisions and evaluated the framework with particular reference to the Eastern Blue Groper in Tasmania.

Contrary to the recent published literature, our research showed that it is unlikely that Eastern Blue Groper was present in Tasmania in the 1800s and if present was certainly not common. Therefore it was not fished to extinction as suggested by Last et al. (2010).

Eastern Blue Groper has recently been observed in north-eastern Tasmania which is considered to be a range extension from NSW waters. In NSW, adult Eastern Blue Groper are commonly seen in association with urchin grazed barrens and are thought to be a key predator of *C. rodgersii*. Based on evidence from NSW, populations of Eastern Blue Groper in Tasmania may have greater potential to improve the resilience of macroalgal habitat against an ecological shift to urchin grazed barrens habitat, than to reverse a stable urchin grazed barrens habitat back to macroalgal habitat. This suggests that any proposed translocation for this purpose would need to be part of a larger integrated management plan.

The need for a comprehensive decision framework with which to assess proposals has exacerbated the lack of progress in the current, often highly charged, debate surrounding this strategy. A decision framework was designed in collaboration with the Tasmanian and Victorian governments to assist decision-makers evaluate proposals for managed translocation (Fig. 1). Our model for assessing proposals systematically considers relevant socioeconomic, governance and scientific issues and is based on the Common Assessment and Reporting Framework model (MACC 2010) designed to facilitate implementation across the science/policy interface. It is structured around an adaptive management framework.

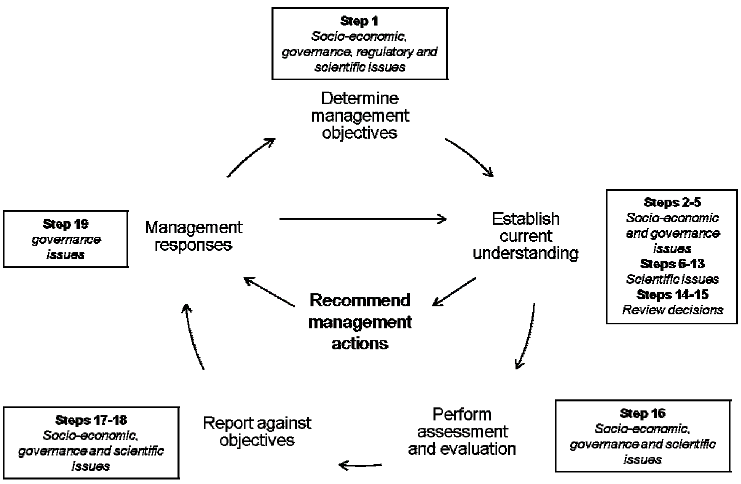


Figure 1. The Conservation Translocation decision framework

Management objectives are articulated at step 1. Risk analyses of socioeconomic and governance issues (steps 2–5), and scientific issues (steps 6–13) are then carried out. Although the decision steps in the framework are sequential, collection of the corresponding data is unlikely to always be linear. Therefore, the framework includes a review section (steps 14–15) where prior decisions are revisited in light of the complete set of data collected during the process. This minimises the risk of underestimating uncertainty at any of the decision steps. If a project is implemented, appropriate performance indicators should be monitored and then evaluated at step 16. Findings and recommendations are then reported to management (steps 17–18), who then determine and implement appropriate responses (step 19).

Our framework suggests that a project should not be implemented for Eastern Blue Groper at this stage as the aims are inadequately supported by available scientific evidence. The framework was also tested against 3 other examples described in the published literature. Although this decision framework was developed to assess proposals as an ecosystem-level climate change adaptation strategy, we demonstrated that this model can also successfully test proposals with other ecosystem oriented goals from a range of ecological contexts. This decision framework is a flexible and utilitarian model for assessing CT proposals, which can be modified where necessary and used effectively across a variety of situations. Above all, this framework is intended as a tool to facilitate progressive and constructive discussion, as well as assessment and implementation of conservation translocation proposals as a climate change adaptation strategy.

The framework was developed in consultation with the Tasmanian and Victorian governments. Discussions are ongoing with Tony Roberts who chairs the Biodiversity Thematic Oversight Group (Bio TOG) that reports to SCEW (via the Senior Officials Group), and Dr Subho Banerje, chair of the Select Council on Climate Change (SCCC) Adaptation Working Group (AWG), to determine how or whether this framework can be considered to support decision making by all Australian governments.

Conclusion

1. Conservation translocations are increasingly being considered as a climate adaptation strategy. It is likely that contemporary and future rapid climate change scenarios will see an increasing need for timely and transparent decisions to be made on CT proposals. This project developed a framework to assist those decisions and evaluated the framework with particular reference to the Eastern Blue Groper in Tasmania.
2. Contrary to the recent published literature, our research showed that it is unlikely that Eastern Blue Groper was present in Tasmania in the 1800s and if present was certainly not common. Therefore it was not fished to extinction as suggested by Last et al. (2010).
3. Eastern Blue Groper has recently been observed in north-eastern Tasmania which is considered to be a range extension from NSW waters. Eastern Blue Groper has been observed to eat *Centrostephanus rodgersii* in NSW waters suggesting that it might have an important ecological role to play in Tasmania temperate reef areas.
4. Eastern Blue Groper are protogynous hermaphrodites and it is expected that it would take many years for a reproductively viable population to establish in Tasmania. Managed translocation could speed this process
5. A decision framework was designed in collaboration with the Tasmanian and Victorian governments to assist decision-makers evaluate proposals for managed translocation.
6. The need for a comprehensive decision framework with which to assess CT proposals has exacerbated the lack of progress in the current, often highly charged, debate surrounding this strategy. Our model for assessing CT proposals systematically considers relevant socioeconomic, governance and scientific issues.

7. Our framework suggests that a CT project should not be implemented for Eastern Blue Groper at this stage as the aims are inadequately supported by available scientific evidence.
8. Despite Eastern Blue Groper currently being rare in Tasmanian waters, future anticipated warming and increasing influence of the EAC could see Eastern Blue Groper increasing in numbers and importance as a *Centrostephanus* predator in this region through time. As this species is particularly vulnerable to capture in recreational gillnets and to spearfishing, a precautionary approach to allowing Eastern Blue Groper numbers to become established may be to give this species full protection under fishery legislation in a similar manner adopted recently in Victoria. Facilitating a 'natural' establishment of Eastern Blue Groper in NE Tasmania would be an ideal first step towards gathering the necessary scientific evidence to evaluate future CT options involving this species in north-east Tasmania and eastern Victoria.

Peer Reviewed Papers

Published

Casper RM, Barrett NS, Bax N, *et al.* 2011. Review of the eastern blue groper. Hobart: Institute of Marine and Antarctic Studies. http://eprints.utas.edu.au/11977.

In preparation

Ruth M Casper, Neville S Barrett, Nic Bax, Alistair J Hobday (in prep). Translocations as an ecosystem-level-climate change adaptation strategy: A practical decision support plan.

8.18 Implications of climate change on fisheries resources of northern Australia. Vulnerability assessment and adaptation options [FRDC 2010/565]

David J. Welch, Thor Saunders, Julie Robins, Alastair Harry, Johanna Johnson, Jeffrey Maynard, Richard Saunders, Gretta Pecl, Andrew Tobin and Bill Sawynok.

FRDC URL: (to be finalised)

Objectives

- Describe the projected climate-driven changes that are relevant to northern Australian fisheries resources.
- Assess the potential impacts of climate change on key fisheries and species in northern Australia.
- Identify approaches that are adaptive to potential climate change scenarios.

Executive Summary

Northern Australia is predicted to be affected by future changes in climate attributes including increased water temperatures, changes in rainfall patterns and river flows to the marine environment, increased intensity of cyclones, ocean acidification, and altered ocean current patterns. These changes will affect habitats and directly and indirectly impact on fishery species including modified phenology and physiology, altered ranges and distributions, composition and interactions within communities, and fisheries catch rates. For fishery sectors in northern Australia to be able to respond positively and adapt to climate-induced changes on fish stocks there is a need to determine which stocks, and where, when and how they are likely to be affected, and prioritise species for further actions.

Outcomes

Scenario-driven recommendations of adaptive management approaches that provide for the sustainability of northern Australia fisheries in a changing climate. Scenarios were based on the reviews of species biology and ecology, as well as future localised climate projections, and described the likely response of key species to climate change. For example, the abundance of Barramundi on the east coast is likely to decrease by 2030 due to reduced rainfall and increased water extraction, as well as because of habitat changes. Adaptation options across all species were grouped as: Alteration of fishing operations, Management-based options, Research and Development and Looking for Alternatives. With these options stakeholders also identified the likely barriers and who is responsible for their implementation. Cost was identified as a key barrier to most options as well as political opposition.

Determination of the vulnerability of northern Australia's fisheries to climate change. A key output from the project was the development and application of vulnerability assessments for fishery species from three key regions of northern Australia. The assessment framework is semi-quantitative and draws on the elements of exposure, sensitivity and adaptive capacity. The vulnerability assessments focused on 2030, a medium-term outlook, and one considered to be more relevant to fishers and managers. An assessment was also carried out based on the A1FI emissions scenario for 2070.

Greater understanding of the impacts of short and long-term climate variability on northern Australia's key fisheries species, fisheries and regions of northern Australia, and the key environmental drivers. The project has delivered as a major output, summary tables of the likely impacts of climate change on key northern Australian fishery species and habitats, also identifying the climate attributes of significance. Generally, inshore species were assessed to be more likely to be affected by future climate change. The east coast was identified as a critical region given that rainfall (riverflow) is projected to decrease and many species populations are known to be positively associated with riverflow. This is amplified by the likely increase in water extraction for land-based uses, particularly on the east coast. Across all regions in northern Australia the species identified as highest priority (high vulnerability and high fishery importance) were: Golden Snapper, King Threadfin, Sandfish, Black Teatfish, Tiger Prawn, Banana Prawn, Barramundi and Mangrove Jack.

Improved capacity for fisheries management agencies and industry to assess current practices and policies to optimise positioning for future predicted scenarios. Collectively, the key outputs of this project provide an informed basis for management and industry to assess current fisheries management against likely future scenarios. Management as well as commercial and recreational fishing interests were key participants in the project.

Conclusions and Recommendations

Key species

- Across northern Australia there are many species important to fisheries. The two major species across the entire area are Barramundi and Mud Crab, while other species were important in some but not all regions e.g. Banana and Tiger Prawns, Coral Trout, Golden Snapper and Black Jewfish, Spanish Mackerel and King Threadfin.
- The knowledge of how environmental variation affects fishery species is rated as good for at most 2 species, rated moderate for a few species but generally is poor for most species. There is certainly scope for environmental sensitivity-based research. Priority species for this research are listed in the report.

Climate

- Changes in climate across northern Australia will be highly variable. The overall trend is for warmer, less saline and more acidic waters, a rising sea level, more intense cyclones and changed oceanographic conditions that are not yet well understood.
- Climate attributes and the level of change will vary region by region. By 2030, north-western Australia will be 0.6 – 0.9 °C warmer, the Gulf of Carpentaria will be 0.3 – 0.6 °C warmer, and both regions will have similar or slightly higher rainfall (0 – 5%) and river flow, and a sea level rise of between 10 and 20 cm. There will be a weakening of the Leeuwin current on the west coast. By 2030, the east coast will be 0.3 – 0.6 °C warmer, will have 0 – 10 % *less* rainfall and river flow, a sea level rise of between 5 and 15 cm and a strengthening of the East Australian Current.

Habitats

- Projected increases in sea surface temperature will cause more coral bleaching, and ocean acidification will reduce coral growth and structural integrity, resulting in a loss of reef diversity and structure.
- Increased storm severity and extreme riverflow events, resulting in increased sediment transport and turbidity and reduced solar radiation will reduce seagrass cover and species diversity.
- Sea level rise will cause a landward migration of mangroves and, coupled with altered rainfall patterns, will change the connectivity between rivers and floodplains, resulting in the potential loss of any remaining freshwater floodplain wetlands.

Data analyses

- Analyses of Barramundi Catch per Unit Effort (CPUE) in the Northern Territory provided evidence of the positive influence of rainfall, riverflow and floodplain inundation on Barramundi catchability and possibly recruitment.
- In southeast Queensland Saucer Scallop recruitment is enhanced in years of cooler water. Recruitment also appears to be positively influenced by higher local riverflow and by the presence of a cyclonic current eddy in the Capricorn region.
- Recruitment of Spanish Mackerel on the east coast appears to be linked to sea surface temperature with cooler years positively influencing recruitment, however the causal mechanism is unclear. Analyses did support the hypothesis of a single east coast stock.

Vulnerability and potential impacts

- The project has prioritised species so that further analysis and management can focus on species that are both likely to experience impacts from climate change and are also those that represent the most important socially and/or economically for the northern Australia regions.
- Species with the highest ecological vulnerability to climate change tend to have one or more of the following attributes: have an estuarine/nearshore habitat preference during at least part of their life cycle; have low mobility; rely on habitat types predicted to be most impacted by climate change; have low productivity (slow growth/late maturing/low fecundity); are known to be affected by environmental drivers; are fully or overfished.
- Certain species were assessed with a high vulnerability and also high fishery importance and so should be given priority. The highest priority species were Golden Snapper, King Threadfin, Sandfish, Black Teatfish, Tiger Prawn, Banana Prawn, Barramundi, White Teatfish and Mangrove Jack.
- By 2030, the most common impact identified across all species were reduced sizes of populations due mainly to lower rainfall and riverflow which affects primary productivity and therefore survival of early life history stages, and also indirect effects of habitat degradation on key life history stages of certain species. Sea surface temperature is also likely to impact some species by 2030 affecting early life history survival and development and causing southerly range extensions.
- By 2070, changes in rainfall/riverflow, sea surface temperature and habitat alteration will continue to impact species and additionally, ocean acidification and salinity are likely to begin to impact species through disruption of early life history development and habitat effects, especially coral reefs.
- Rainfall and riverflow are key environmental drivers for fisheries populations in northern Australia through enhancing local primary productivity and larval/juvenile survival, and by connecting key habitats such as estuaries and floodplains. The east coast in particular is a key area for concern due to projected lower rainfall, more extreme (longer) wet and dry periods, coupled with the expected increase in water extraction for land-based use and also having estuarine habitats already modified more than any other region of northern Australia (Creighton et al. 2013). Many species use these and nearshore habitats and so are likely to be affected by these changed hydrological conditions, particularly Barramundi that use all habitats during all stages of their life history.
- There is a high level of uncertainty in how species, particularly early life history stages, will be affected by changed sea surface temperature, pH and salinity. Recent research on Coral Trout demonstrating behavioural changes that are adverse for survival, suggest there will be surprises in terms of species responses.

Adaptation options

- The adaptation options were grouped as:
  - Alteration of fishing operations,
  - Management-based options,
  - Research and Development, and
  - Looking for alternatives.

  Most of the adaptation options identified involved regulatory changes and/or policy decision-making.
- The major barriers to adaptation for northern Australian fisheries were identified as costs, political opposition and bureaucracy. For fisheries to adapt appropriately to climate change all stakeholders will need to play a role with government a lead player in this process.

  Due to the number of fishery species assessed across a vast area, this project took a broad approach to determining the relative vulnerability of key fishery species in northern Australia. Similarly the adaptation options identified were broad in scope. For the implementation of appropriate adaptation to a changing climate, further engagement and analysis is essential. This must include detailed analysis of options; prioritisation of adaptation responses; impact assessment and profitability analysis for indigenous, recreational and commercial fishers; and detailed specification of the pathways and actions to be implemented for successful adoption.

Papers In preparation

David J. Welch, Thor Saunders, Julie Robins, Alastair Harry, Johanna Johnson, Jeffrey Maynard, Richard Saunders, Gretta Pecl, Andrew Tobin and Bill Sawynok. A semi-quantitative climate change vulnerability assessment framework applied to northern Australian fisheries.

Alastair V. Harry, David J. Welch, Andrew J. Tobin, Sue Helmke and Jo Langstreth. Environmental influences on the recruitment of Spanish mackerel, *Scomberomorus commerson*, on the Australian east coast.

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Table 1. Likely impacts on key northern Australian fishery species based on climate change projections for 2030 (A1B & A1FI).

Species	Key potential effects of climate change (based on 2030 projections)
Banana Prawn	Sea-level rise may increase/decrease abundance due to alteration of mangrove habitat availability, depending on local barriers for mangrove replenishment and migration (e.g. coastal development) (+/-) Altered rainfall will likely result in concomitant changes in population abundance (slight increase in NWA and GoC, decrease on the EC)(+/-) Increasing SST will likely result in a poleward distributional shift into NSW waters on the EC (+/-)
Eastern King Prawn	Changes in the EAC and onshore wind patterns may affect larval movement and recruitment (+/-) Increased SST may result in lower abundance in the SE Queensland region (-) Increasing SST may result in a poleward range contraction from SE Queensland (-ve for Qld, +ve for NSW)
Tiger Prawns (Brown and Grooved)	Predicted negative impacts on seagrass beds may reduce abundance due to decreased juvenile growth and survival (-) Increasing SST may compromise growth and survival of Torres Strait stock of brown Tiger Prawn as they are near their northern range limit (-) Altered rainfall may affect the catchability of Tiger Prawns (slight increase in NWA and GoC, decrease on the EC) (+/-)
Mud Crab	Increased SST may result in higher catch rates (+) Altered rainfall (riverflow) and may increase Mud Crab abundance in NWA and GoC, and decrease abundance on the EC (+/-) Sea-level rise may increase/decrease abundance due to alteration of mangrove habitat availability, depending on local barriers for mangrove replenishment (eg. coastal development) (+/-)
Sandfish	The effects of climate attributes on sandfish life history stages are poorly understood. Predicted impacts on seagrass meadows may affect survival of juvenile sandfish as it is their preferred habitat for settlement.
Saucer Scallop	Increasing SST may result in poleward movement of SE Qld spawning grounds or into deeper water as spawning occurs at the coolest time of year (-) Lower rainfall in SE Qld may reduce recruitment (-) Changes in major currents (Leeuwin in WA, EAC on EC) may impact recruitment success (+/-)
Black Teatfish	Increasing SST may compromise reproductive success since they spawn during winter in far northern areas, e.g. Torres Strait, resulting in range contraction poleward (-)
Tropical Rock Lobster	Increasing SST may promote faster growth and higher larval supply, but may decrease juvenile survival. The net result may be a reduction in spawning biomass (-) Adults are likely to move to deeper to less accessible fishing areas or father south with increases in water temperature (and extremes) (-) Changes in currents in the northwest Coral Sea may alter settlement areas and recruitment rates (+/-)
Barramundi	Altered rainfall may affect the abundance, growth and catchability of Barramundi (slight increase in NWA and GoC, decrease on the EC). A potential increase in the GoC may be offset by proposed water extraction from Gulf rivers for land use (+/-) Sea-level rise may alter the availability of suitable floodplain nursery areas for post-larvae and juveniles: NWA and GoC (+/-) and EC (-) Increased variation in rainfall may reduce the frequency of large flood events reducing overall population sizes on the EC. Longer periods of drought predicted for the east coast could significantly reduce Barramundi populations (especially periods > ~7 years). This is likely to be exacerbated by increased water extraction for land use (-)
Coral Trout – Common / Barcheek / Passionfruit	Increases in intense storm activity may periodically reduce the catchability of coral trout (-) Increased water temperatures (particularly in areas where SST exceeds 30 °C) may reduce survival and development of egg and larval stages resulting in lower population sizes. Adults may also move poleward or to deeper water: In northern regions (-); in southern regions (+) Increased SST compromising coral reef habitat may affect juvenile survival (-) Spawning may occur earlier than currently (region-specific) (+/-)
Golden Snapper	Potential range expansion poleward on the east and west coasts (+) Relationships with climate variables poorly understood however their resilience to future changes may be poor due to their late maturity and overfished status in some areas (-)

Species	Key potential effects of climate change (based on 2030 projections)
King Threadfin	Altered rainfall may affect the recruitment and abundance of king Threadfin (slight increase in NWA and GoC, decrease on the EC) (+/-) Increased SST may result in a range extension poleward on the east and west coasts (+) Resilience to future changes may be poor due to their large size and older age at sex change (to female) and overfished status in some areas (-) Localised population impacts may be evident due to their fine scale stock structure (+/-)
Red Throat Emperor	Increases in intense storm activity may periodically increase the catchability of Red Throat Emperor (+) Increasing SST may result in a range shift poleward associated with a contraction of the northern range limit (+/-)
Spanish Mackerel	Increasing strength of the EAC likely to cause a poleward range extension (+ve for SE Qld/NSW & SW WA) Increasing SST could also cause a poleward shift of the main spawning (and fishery) area on the east coast and/or lower east coast population sizes (+/-)
Mangrove Jack	Altered rainfall may affect the juvenile survival and therefore population abundance; NWA and GoC (+/-) and EC (-) Sea-level rise may alter the availability of suitable floodplain nursery areas for juveniles: NWA and GoC (+/-) and EC (-)
Black Jewfish	Altered rainfall may affect the juvenile survival and therefore population abundance; NWA and GoC (+/-) and EC (-) however this is poorly understood for this species Their current overfished status in all regions reduces their resilience to cope with potential negative impacts of climate change (-)
Grey Mackerel	Altered rainfall may affect the juvenile survival and therefore population abundance; NWA and GoC (+/-) and EC (-) however this is poorly understood for this species

8.19 Implications of climate change for recreational fishers and the recreational fishing industry [FRDC 2011/037]

Colin Creighton and Bill Sawynok

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2011-037-DLD.aspx

Objectives

1. Through case studies of vulnerable species in each of the three mega regions of Australia explore and propose activities and strategies such as improved fisheries management measures which could be adopted to assist agencies, recreational fishers and the recreational fishing industry adapt and deal with climate change impacts
2. Explore climate change adaptation responses and provide recommendations for regional arrangements that foster a more flexible and responsive approach to recreational fisheries and fisher needs
3. Identify high priority mitigation opportunities so that the recreational sector can contribute to the global issue of reducing greenhouse gas emissions

Executive Summary

In Brief

This report is the first national perspective of the implications of climate change on recreational fisheries and the recreational fishing industry, providing a platform for further discussion of the ecological impact on species and the opportunities for adaptation and mitigation.

The findings highlighted that with climate change will come increasing climate variability and stressors such as changing sea level and varied ocean currents. It is recognised that all management activities that assist in ensuring resilience of fish populations will be a useful first strategy in responding to a changing climate.

The report also demonstrates the need for monitoring to focus on data that can be used to better predict future stocks, especially in the areas of recruitment, productivity and changes in species range. These are areas where recreational fishers can play a role in data collection and can support analysis activities and information dissemination.

There is a need for greater flexibility and responsiveness in fisheries management and to move to a whole of stock management approach as climate change alters the dynamics and distribution of fish stocks.

Understanding and mitigating the impacts of climate change on recreational fishing has important human dimensions, such as understanding the choices fishers make in response to climate change and the flow-on effects of these choices.

Methods

Project team members from three mega regions examined the implications of climate change within these regions and then used these findings to collate an Australia-wide perspective. The regions, as specified in the DAFF Climate Change Action Plan were:

- Tropical (northern Australia encompassing Qld, NT and northern WA)
- South East (encompassing New South Wales, Victoria, South Australia, Tasmania)
- Western (southern Western Australia)

Workshops were held in the Tropical and South East regions to address the project objectives with each workshop having a slightly different focus. The Tropical region focused on social aspects of climate change while the South East region focused on ecological aspects. In the Western region a series of interviews with key stakeholders and researchers were held and the information collated.

Regional reports were then prepared based on the findings of the workshops and the species risk assessments.

Within each region a number of key species were selected and their vulnerability to climate change was assessed. Species considered important to recreational fisheries were selected using a similar methodology to that set out in Risk Assessment and Impacts of Climate Change for Key Marine Species in South Eastern Australia (Pecl et al. 2013). Species selection also took into account other climate change projects that were also undertaking vulnerability assessments.

Findings

The effects of climate change will apply at social, ecological and economic levels. At the social level this will translate into changes in fisher behaviour in response to changes at the ecological level. Adaptation is a measure of the extent to which change occurs at the social level.

In general individual recreational fishers have capacity to adapt based on the flexibility in their decisions about fishing activities. This adaptation will be influenced by how much they value particular species. Fishing organisations and professional fishers are less flexible being constrained by their gear and entitlements. Fisheries management is most constrained by the general lack of flexibility in legislation and regulations. Climate change will provide added pressure on existing fisheries management and will lead fishers to call for approaches and policies that provide a greater level of flexibility and responsiveness.

Monitoring may inform management changes. Data collection should focus on recruitment and species distribution as well as taking note of anomalies such as species outside their normal range, Recreational fishers can play a role in collecting such data.

With the onset of increasing climate variability fish populations will also fluctuate, especially in response to wet and dry periods, variable ocean currents and temperatures. Monitoring should ensure managers have excellent predictive knowledge on population fluctuations and changes in range. Decision rules for management changes will be needed so that fisheries management can implement changed harvest strategies and rapidly respond to population and range fluctuations.

Mitigation can play a role at both the social and ecological levels. Mitigation is a measure of changes to greenhouse gas emissions that are likely to reduce the impacts of climate change. There are no current measures of the contribution of recreational fishing to greenhouse emissions or of any changes to those levels. All members of the Australian community can play a role by altering behaviours to reduce energy use, for example, through solar power supplementing electricity grids, solar hot water systems, efficient lighting and insulation, reduced air conditioning, walking and biking rather than using cars and so on. Recreational fishers can be part of this general change in behaviours. Recreational fishers can also as a specific group think through their energy use in getting to their fishing grounds. Fishing closer to home, or using non-powered craft such as kayaks are simple strategies. Recreational fishers can also play a significant role in mitigation through a reduction in carbon emissions by moving to lower emission and more fuel-efficient outboards.

At the more general level of the entire fishing industry and its linkages to the natural environment is the issue of estuary and wetland repair. Mangroves, salt marshes and seagrasses comprise less than 1% of the Australian landscape yet they sequester up to 39% of the carbon. Equally importantly, sequestration in these environments is essentially no risk. Compare this nil risk to other mitigation options proposed such as rangelands management or revegetation – in these terrestrial ecosystems risk remains high because of Australia's frequency of wild bushfires and droughts. From the recreational fishing industry perspective, any work to retain and repair fisheries habitat will also, as well as improving fishery productivity, have a carbon mitigation dividend.

The vulnerability of 14 key recreational species to climate change in the three regions was assessed with eight species assessed as resilient, four species assessed as uncertain and two species assessed as vulnerable. Each region provided a detailed assessment of the life histories of each species and their vulnerability at different stages of their life cycle. The SE region was able to build on prior research funded under the South East Adaptation Program and suggest adaptation and mitigation measures that could be taken for the key species in their region.

The work was confined to estuarine/marine species as there are detailed projections to 2030 on changing sea surface temperature beyond normal variability. The work of RedMap has already shows changing ranges. For freshwater fisheries much of the impact from climate change up until 2030 will be increasingly more variable rain events / river flows. This is a recognised feature of freshwater fishing and recreational freshwater fishing already adapts to the variable stream flow/runoff conditions that characterise the Australian landscape.

Northern region	South East region	Western region
Mangrove Jack (*Lutjanus argentimaculatus*)	Black Bream (*Acanthopagrus butcheri*)	West Australian Dhufish (*Glaucosoma herbaicum*)
Spotted Mackerel (*Scomberomorus munroi*)	King George Whiting (*Sillaginodes puntatus*)	Baldchin Groper (*Cheorodon rubescens*)
Red Emperor (*Lutjanus sebae*)	Mahi Mahi (*Coryphaena hippurus*)	King George Whiting (*Sillaginodes puntatus*)
Barred Javelin (*Pomadasys kaakan*)	Yellowtail Kingfish (*Seriola lalandi*)	Spanish Mackerel (*Scomberomerus commerson*)
Dusky Flathead (*Platycephalus fuscus*)		Australian Salmon (*Arripis truttaceus*)
		Roe's Abalone (*Haliotis roei*)

(green)	Considered to be resilient to climate change
(yellow)	Vulnerability to climate change uncertain
(orange)	Considered to be vulnerable to climate change

Recommendations

1. **Increased attention to Coastal Fisheries Habitat Protective Management or 'No Habitat – No Fish':** With a more extreme and variable climate all possible steps should be taken to ensure resilient stocks. This especially involves protection, management and repair of fisheries habitat – our estuaries, seagrasses and wetlands, mangroves through to fresh wetlands. In many of our coastal systems much damage to habitat has occurred through other lands uses, roads, blocking of tidal flows, reclaiming, draining, floodgating, ponded pastures and so on. Repair of estuary and wetland systems to ensure long-term productive fisheries are therefore an imperative. Equally importantly, these ecosystems are the highest per hectare of all Australian ecosystems in their sequestering of carbon or 'blue carbon' as it is known. Repairing estuaries and wetlands therefore delivers on both adaptation and mitigation objectives.

The first step is to maximise the opportunity for all species to successfully breed. Coastal and nearshore habitat of estuaries, mangroves, seagrasses, salt marshes, fresh to brackish wetlands and coral reefs all play crucial roles in the nursery phases of recreational species. Protective management to minimise damage to habitat, water quality, tidal and freshwater flows is essential. Where states do not already provide for protective management of habitat, this needs to be added to their fisheries regulations. The Queensland Fisheries legislation provides a good example of how best to afford protective management.

2. **Australia-wide Program of Estuary and Wetland Repair – Repairing Coastal Productivity:** Many of Australia's coastal ecosystems have been reduced in productivity through barrages, drains, causeways, bunds and floodgates that restrict or prohibit tidal flows and fish passage. Coastal ecosystems of estuaries and wetlands also sequester per hectare more carbon than any other ecosystem type. Drained fresh to brackish wetlands emit methane – adding to the greenhouse gas problem. Many of these now non-productive areas can be repaired to deliver multiple outcomes of fisheries productivity, improved water quality, enhanced biodiversity and coastal buffering against sea level rise. An Australia-wide program of repair is needed. The first steps towards this have been funded through a partnership between FRDC and the Biodiversity Fund. (see *Revitalising Australia's Estuaries* FRDC 2012–036)

3. **Moving to 'whole-of-stock management':** For many species such as Snapper along the Eastern Australian coast the changing sea surface temperatures and eddies will change the location of the fish populations. State based fisheries management of stocks will become increasingly sub-optimum. Increased cooperation between fisheries management agencies across State boundaries and across State–Commonwealth waters will be essential. It is recommended that joint management arrangements of the total stock be developed for Snapper, Yellowtail Kingfish, Mahi Mahi, Dusky Flathead and Spotted Mackerel

4. **Continued investment in monitoring:** Recent experiences of 'outliers' of various species and opportunistic take of these species are detailed in the SE region report. RedMap provides a monitoring tool for all fishers to record fish beyond their characteristic range. Keeping track of fish changes in range over time provides early warning information that in time can be translated into better fisheries management. Continued investment in RedMap will ensure data are collected and analysed. Monitoring of particular species and their productivity should move to focus more on recruitment and the drivers of recruitment as in the 'Crystal Bowl' project in Queensland predicting Barramundi stocks in the Fitzroy River.

5. **Flexibility in Bag Limits and Catch Regulations:** With increasingly variable climate and increasingly wet or dry periods, fish and prawn stocks will vary. In some years the increased abundance will allow for a loosening of bag limits. In other years, limits might need to be tightened. It is recommended that climate and its impact on abundance of recreational species populations be incorporated within an approach towards more flexible and population responsive bag limits. Suggested species to pilot this approach are King George Whiting, Snapper, Barramundi and Black Bream.

8.20 Preparing fisheries for climate change – assessing alternative adaptive options for four key fisheries in south-eastern Australia [FRDC 2011/039]

Gretta Pecl and Tim Ward

FRDC URL: (to be finalised)

Objectives

This report is the output of a two-year project focussing on four case study fisheries across south-eastern Australia – Abalone, Blue Grenadier, Snapper and Southern Rock Lobster. The objectives of the project were to:

1. Identify likely key effects of climate change on four major fisheries species in south-eastern Australia, particularly where these effects may impact the harvest strategies for these species.
2. Identify options for improving assessment and management frameworks (e.g. fisheries models, performance measures, decision rules, and harvest strategies) to ensure that they perform effectively under likely climate change scenarios (e.g. account for assumptions of temporal stability in temperature-influenced parameters such growth and recruitment).
3. Evaluate options for adjusting management arrangements to reduce negative impacts and maximise uptake of opportunities that climate change may provide to commercial and recreational fisheries (including improvements in coordination and consistency among jurisdictions).
4. Identify improvements to current monitoring systems for Rock Lobster, Abalone, Snapper and Blue Grenadier and their habitats to ensure that they are suitable for measuring the likely impacts of climate change and other drivers.

Executive Summary

Over the next century, the marine ecosystems of south-eastern Australia are expected to exhibit some of the largest climate-driven changes in the Southern Hemisphere. The effects on these changes on the communities and businesses of the region will depend, in part, on how well the fishing and aquaculture industries and their managers respond to the challenges that climate change presents.

This project was developed using the results of a formal assessment of the relative risk to climate change impacts of key fisheries species of south-eastern Australia. Species selected as case studies in this project were identified as being at high (Rock Lobster, Abalone, Blue Grenadier) or medium (Snapper) risk to climate change impacts and having high commercial value and/or recreational importance. The case study species were also identified as being likely to provide useful insights into how fisheries can adapt to changes in productivity (Rock Lobster) and distribution (Snapper). Two species (Rock Lobster and Abalone) are considered potential ecological indicators for rocky reefs, whereas Snapper is an important component of the coastal fish assemblages that occur in the region’s estuaries and large embayments. Blue Grenadier is an important Commonwealth pelagic species.

The project aims to identify options for adjusting management arrangements to ensure that both the profitability of commercial fisheries and opportunities for participation in recreational fishing are enhanced. The scientific information that is required to underpin the improvement of fisheries management systems was provided by working groups that included fisheries scientists, marine ecologists, oceanographers and climate change scientists from State and Commonwealth research agencies and universities.

This project is part of the El-nemo South East Australia Program (SEAP, http://www.frdc.com.au/environment/south-east) which was developed by State and Commonwealth marine resource management agencies and research organisations (DPI Victoria, PIRSA Fisheries, DPIPWE Tasmania, IMAS, SARDI, and CMAR), together with FRDC and DAFF. The primary aim is to improve understanding of the biophysical, social and economic implications of climate change and to facilitate the preparation and adaptation of the sectors and fisheries management arrangements to these changes.

Methods & Key Findings

Abalone: An extensive review of the literature identified that Abalone have reduced ability to cope with warm water temperatures and increased acidification (Table 1), with Blacklip having both a lower preferred water temperature and thermal tolerance than Greenlip. We identified that at warmer temperatures the size at maturity and maximum size estimates were smaller than those at cooler summer water temperatures. For Blacklip, warmer water temperatures during summer were typically associated with lower Blacklip catches (however, there were exceptions to this pattern). Relationships between Greenlip catches and the oceanographic variables considered in this study were less clear than those for Blacklip, but the general overall trend was for larger Greenlip catches to have been obtained from those areas with (1) slower tidal flow rates; and (2) relatively stable water temperatures with a low incidence of high summer, cold summer and cold winter temperatures. Thus, Greenlip catches have been smallest in areas with intensive and lengthy summers and winters. Determining the extent to which climate change may influence the Australian Abalone stocks is challenging. However, these Abalone stocks, and the fisheries that are dependent on them, are likely to be influenced by climate change in three ways: (1) the gradual increase in water temperature and ocean acidification; (2) increased frequency and magnitude of extreme events (e.g. marine heat waves); and (3) range shifts, altered recruitment and altered growth rates of competitors and predators (e.g. range expansion of the long-spined sea urchin *Centrostephanus rodgersii)*. Collectively these are likely to result in reduced productivity and thus catch.

Blue Grenadier: The study involved an extensive review of what is known about Blue Grenadier spawning location and timing, and the larval life stage with the focus around recruitment (year class strength) driven by the fact that this fishery is characterised by extreme variation of recruitment, which is the primary influence on fishery production dynamics. This analysis indicated a positive relationship between recruitment strength and wind strength in the autumn (i.e. just prior to the winter spawning period), and a negative relationship between recruitment strength and sea surface temperature during the July–November period (i.e. the spawning and larval development period). Increases in sea surface temperature may therefore have a negative impact on recruitment. We applied a management strategy evaluation to test how robust the current harvest strategy for Blue Grenadier would be in the face of different changes to the frequency of good and bad recruitment events. While the current harvest strategy, including the assessment model and associated control rules was found to perform well in maintaining the stock biomass above limit points in the face of different regimes of recruitment variation, the exercise clearly demonstrated that changes to recruitment dynamics could have a major impact on how the fishery operates under the current control rule. For example, more episodic recruitment would lead to major cycles in fishery production with intermittent periods of low or even zero Total Allowable Catch. Under such scenarios review of control rules and fishery management plans/objectives may be required to ensure the economic performance of the fishery was maximised.

Snapper: Throughout the broad latitudinal range of Snapper around the Australian continental shelf water temperatures between 18–22˚C were consistently the optimum for spawning of Snapper and survival of their eggs and larvae. With knowledge of the optimal spawning temperature window we then conducted forecast modelling of how this optimal temperature window is expected to change over the next 50 years under climate change. In Queensland and far northern NSW in 50 years' time, due to ocean warming, there may no longer be any period during the year when the water temperature is suitable for Snapper spawning. The implications were not as extreme for central and southern NSW and Victoria, where there will be either increased opportunities for spawning or minor changes to the timing and/or length of the optimal spawning temperature periods. However, in the case of South Australian Gulfs the water temperatures on the traditional northern gulf spawning areas are predicted to be too warm for Snapper spawning during the entire current spring/summer spawning period, with uncertain but potentially major negative implications for the fisheries in these areas. On the positive side, the water temperatures around Tasmania will become more suitable for Snapper spawning over longer periods, most likely allowing for growth of Snapper populations and increased fishery opportunities in this region. While spawning behaviour is intimately linked to water temperature regimes, the survival of the young appears to be related to different climatic factors in different areas. For the spawning stocks in the SA gulfs water temperature appears to be important, with higher survival/recruitment success in warmer summers, up to about 24˚C, but above this survival and recruitment appear to be reduced. In Port Phillip Bay the situation is more complex, with river flow and associated nutrient input regimes and plankton food chain dynamics being more critical in influencing larval survival rates and juvenile recruitment.

Southern Rock Lobster: The study examined the effects of environmental variables on Southern Rock Lobster (*Jasus edwardsii*) puerulus settlement across South Australia, Victoria and Tasmania, at both a monthly and annual temporal scale. Monthly investigations aimed to identify environmental signals immediately prior to settlement while the annual analyses acknowledged the long planktonic larval phase of the species (approx. 1 year). Unlike other regions within Australia (e.g. the Western Australia Rock Lobster fishery), there were no clear signals between environmental variables (current, wind speed, temperature and rainfall) and monthly puerulus settlement. However, within specific regions, signals were identified at the annual scale. For example, egg production in the Eastern Zone of Victoria was related to future settlement in both the Western Zone of Victoria and the Southern Zone of South Australia. In addition, wind strength appeared to be a reasonable indicator of future settlement in specific regions of Victoria and South Australia. Overall, the results highlighted a number of environmental variables that impacted on settlement but these varied regionally. In addition, the explanatory strength of these variables was not strong, suggesting that other unknown processes also impact on settlement. As a result, it is difficult to predict the impact of climate change on Rock Lobster fisheries. However, given that puerulus settlement is highly variable between years, the impact of recruitment variability is important in relation to potential climate change scenarios. As a consequence, the study examined how variations in recruitment might impact on current harvest strategies for Rock Lobster fisheries. This component of the study identified a range of quota setting scenarios that removed the vulnerability of fisheries to recruitment-induced variation. For example, TACCs below 1200t within South Australia are robust to variation in recruitment.

Key Implications

Abalone: It is likely that the current measures of stock status (i.e. CPUE as an index of relative abundance, size structure of the commercial catch, density estimates from fishery-independent surveys) will remain current. New indices (e.g. spatial performance indicators, may provide valuable additions to these. Reference points and decision rules for the Australian Abalone fisheries are currently being established with the potential impacts of climate change in mind. Consequently, it is not known if they will need to be adjusted to account for climate change.

Blue Grenadier: While Blue Grenadier has a highly developed management and assessment approach (i.e. Tier 1), the application and review of control rules in the future will require improved understanding of recruitment dynamics, and potentially how growth rates and distribution of adults may change in the future. There is very limited knowledge of juvenile distribution and ecology, which limits progress in understanding the process(es) that drive recruitment variation, or the development of suitable pre-recruit monitoring approaches.

Snapper: For both Victorian and South Australia, changes to reproductive behaviour (both spatially and temporally) may enhance/alter the variability in recruitment that is characteristic for this species in southern Australia. The frequency of good and bad recruitment events may change from what is currently experienced, with implications for monitoring program, stock assessment and harvest strategies. Changes in exploitation rate limit points (i.e. harvest strategies) may be required to ensure that sufficient biomass survives the periods of poor recruitment to take advantage of when conditions are good for egg and larval survival. For Queensland and northern NSW, viable Snapper fisheries may not be possible in the future due to a lack successful reproduction. Small fisheries may still exist in these regions based on spill over/migrants from more southerly viable spawning populations. The Snapper fisheries in Queensland and northern NSW will likely become more sporadic, and the reduction of their importance may reduce the need for assessment and management focus. In northern Tasmania Snapper populations are likely to increase, and potentially become self-replenishing. This would lead to a greater emphasis on Snapper as a local fishery species and the need to implement a more formal management and assessment approach.

Southern Rock Lobster: The prolonged oceanic larval phase combined with large geographic range spanning different current systems means that predicting climate change impacts is complicated and outcomes are likely to vary across the fishery. However, a general expectation is that variation in recruitment from year to year is likely to become more pronounced with climate change, which presents a challenge for fisheries management. Analysis of economic performance of these fisheries under different recruitment scenarios showed that there were some quota setting options that were less vulnerable to changes in recruitment. These tended to deliver consistently high economic yield with less volatility in business earnings and thus less exposure to climate change impacts.

Recommendations

Abalone**:** *In situ* water temperature monitoring, and sampling periodically to monitor changes in growth rates, size at maturity and abundance are required to understand and respond to climate-induced changes. Harvest strategies should be tested using maximum sustainable economic yield to ensure responsiveness to changes in stock abundance and productivity

Blue Grenadier: Studies into the juvenile life stages, including larval dispersal patterns of Blue Grenadier under different climate condition are recommended to improve understanding of the implications of climate change on recruitment dynamics.

Snapper: While water temperature regimes are amenable to predictive modelling of future conditions, the prediction of rainfall and river flow regimes is less so, and poses a major uncertainty when attempting to model climate change impacts on future Snapper recruitment success in key areas.

Southern Rock Lobster: Biological information and modelling tools are in place for Southern Rock Lobster fisheries to respond to climate change but require two actions to assist adaptation. The first is that ongoing data collection for model inputs is required (especially recruitment, growth and business costs). The second is for extension of model outputs into management decision-making as there tends to be industry resistance to application of model based information.

Peer reviewed papers

Published

Linnane A, McGarvey R, Gardner C, Walker T, Matthews J, Green B and Punt A (2014). Large-scale patterns in puerulus settlement and links to fishery recruitment in the southern Rock lobster (*Jasus edwardsii*), across south-eastern Australia. *ICES Journal of Marine Science*

Submitted

Briceño F, Leon R, Gardner C, Hobday A, Andre J, Frusher S, Pecl GT. Spatial variation in mortality by within-pot predation in the Tasmanian Rock Lobster Fishery. *Fisheries Oceanography.*

In preparation

Tuck G and Wayte S. Does Australia's fisheries harvest strategy adequately perform under climate change induced patterns of episodic recruitment: an example from the south eastern trawl fishery.

S. Mayfield, C. Mundy, J. Dent, D. Matthews, A.J. Hobday, J. Hartog, B. Stobart, P. Burch, T. Ward and G.T. Pecl. Influence of water temperature on commercial wild-catch production: implications of climate change for the Australian abalone fisheries.

Pecl GT, Ward T, Briceño F, Fowler A, Frusher S, Gardner C, Hamer P, Hartmann K, Hobday A, Hoshino E, Jennings S, Le Bouhellec B, Linnane A, Mayfield S, Marzloff M, Mundy C, Ogier E, Sullivan A, Tracey S, Tuck G. Preparing fisheries for climate change: identifying potential impacts, adaptation options and barriers to change in fishery systems.

Ogier, E., Pecl, G., Sullivan, A., Hobbay, A., Ward, T., Frusher, S., Jennings, S. Evaluating adaptation options for four key fisheries in South Eastern Australia.

Fowler A and Hammer P et al. Potential impacts of climate change on the biology and ecology of Snapper, *Chrysophrys auratus.*

Table 1 – Summary results of a comprehensive global literature review of climate change impacts on Abalone. Red indicates negative effects and green positive.

Region	Age/Species	Direct: Growth – Juveniles	Direct: Growth – Adults	Direct: Mortality – Juveniles	Direct: Mortality – Adults	Direct: Disease expression – Juveniles	Direct: Disease expression – Adults	Direct: Recruitment – All	Indirect: Competition – All	Indirect: Predation – All	Indirect: Habitat – All
Europe	*H. tuberculata*	27 (green)	27 (green)			39,40	39,40				
Asia	*H. diversicolor supertexta*					9	9				
Asia	*H. discus hannai*	10									
Americas	*H. cracherodii*				21		1	21			
Americas	*H. sorenseni*	23		23							
Americas	*H. corrugata*	24		24							
Americas	*H. fulgens*	24,25 (green)	25	14,24				37 (green)			41
Americas	*H. rufescens*	13,24,38,41		13,24		41	33	33,41,42			41
Americas	*H. kamtschatkana*	4,22		4,11							
S. Africa	*H. midae*	5,17		17						32,28	
Australasia	*H. australis*							29 (green)			
Australasia	*H. iris*	30,35	30								
Australasia	*H. coccoradiata*							7,8			
Australasia	*H. roei*			31	31						
Australasia	*H. rubra*	6,15,19	15	6,15,19	15	12,16	16	18	2,3,26,36		2,3,26,36
Australasia	*H. laevigata*	6,15,19,20	15	6,15,19,34	15			18			

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3. Andrew et al. (1998)
4. Beaudry (1983)
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23. Leighton (1972)
24. Leighton (1974)
25. Leighton et al. (1981)
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28. Mayfield and Branch (2000)
29. Moss (1998)
30. Naylor et al. (2006)
31. Pearce et al. (2011)
32. Plaganyi et al. (2011)
33. Rodgers-Bennett et al. (2010)
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8.21 Estuarine and nearshore ecosystems – assessing alternative adaptive management strategies for the management of estuarine and coastal ecosystems [FRDC 2011/040]

Marcus Sheaves, Cathy Dichmont, Pat Dale, Roy Deng, Ilva Sporne, Rodrigo Bustamante, Ingrid van Putten, Marie Savina, Leo Dutra, Rachel Harm, Hector Lozano-Montes, Nina McLean, Martha Brians

FRDC URL: (To be finalised)

Objectives

1. Synthesise and integrate all current knowledge, data, tools and processes for the development of a national assessment of impacts and adaptation strategies for management of estuarine and coastal marine ecosystem under Climate Change that takes account of bioregional differences and differences among estuary types.
2. Evaluate the key adaptation strategies recognising that there needs to be a process to harmonise adaptation strategies for the public benefit.
3. Develop tools and guidelines, at a National level, for developing adaptation strategies for the estuarine environment that take bioregional and typological differences among estuaries.

Executive Summary

NEED:

- to ensure that our coastal ecosystems and their fisheries remain healthy and resilient in the face of climate change, and as a result ensuring food security and livelihoods of those relying on coastal resources into the future.

METHODS:

1. We synthesise and integrate all current knowledge, data, tools and processes for the development of adaptation strategies for management of estuarine and coastal marine ecosystem under Climate Change.
2. We evaluated key adaptation strategies recognising that there needs to be a process to harmonise adaptation strategies for the public benefit, and that takes account of bioregional differences and differences among estuary types.
3. We evaluated available tools and guidelines for developing adaptation strategies.
4. We evaluated the requirements for strategies to deliver public good outcomes, and the impediments to achieving those outcomes given current approaches to developing Climate Change actions.

MAIN CONCLUSIONS:

1. Because of the large scale, slow development and pervasive nature of Climate Change and its impacts, it is vital to focus on large-scale public good outcomes. For Australia's coasts and estuaries and their resources, the key to this is ensuring ecosystem robustness and resilience are maintained at whole-of-resource scale. This is needed to support environments, fisheries productivity, food security and the viability of the industries that depend on them.
2. There are many climate change adaptation frameworks available. Many models have logical structures but in practice wouldn't provide a process for someone to develop

climate change actions. Some frameworks are too specific (e.g. City of Melbourne (Fig. 1a)) or too general (e.g. Klein (Fig. 1b)). Very general models don't provide specific direction for operation, while very specific models are too complex to adapt beyond the situation at hand. In either case, the available frameworks will usually provide little actual help in a new situation, necessitating the development of a case-specific solution; the pathway that has led to the development of the narrowly focused specific models. What is required is an Adaptation Strategy that provides Operational Guidance, in the sense that someone could use it to lead them through the development of adaptation plans for their situation.

3. We developed a detailed framework (Fig. 1), that was detailed enough for testing on current case studies. We tested this framework on initial case studies and came to the conclusion that, while a 'guideline framework toolbox' is a useful in detailing the specific steps in developing adaptation plans and actions, the cannot fully address the underlying objective of developing an Adaptation Strategy. This is because; (i) a structure with a series of steps doesn't fit with the reality of a diversity of climate change problems, location-specific and context-specific scenarios, and the need for flexible entry points, and more importantly (ii) it doesn't provide the high level conceptualisation and focus needed to direct adaptation strategy development.

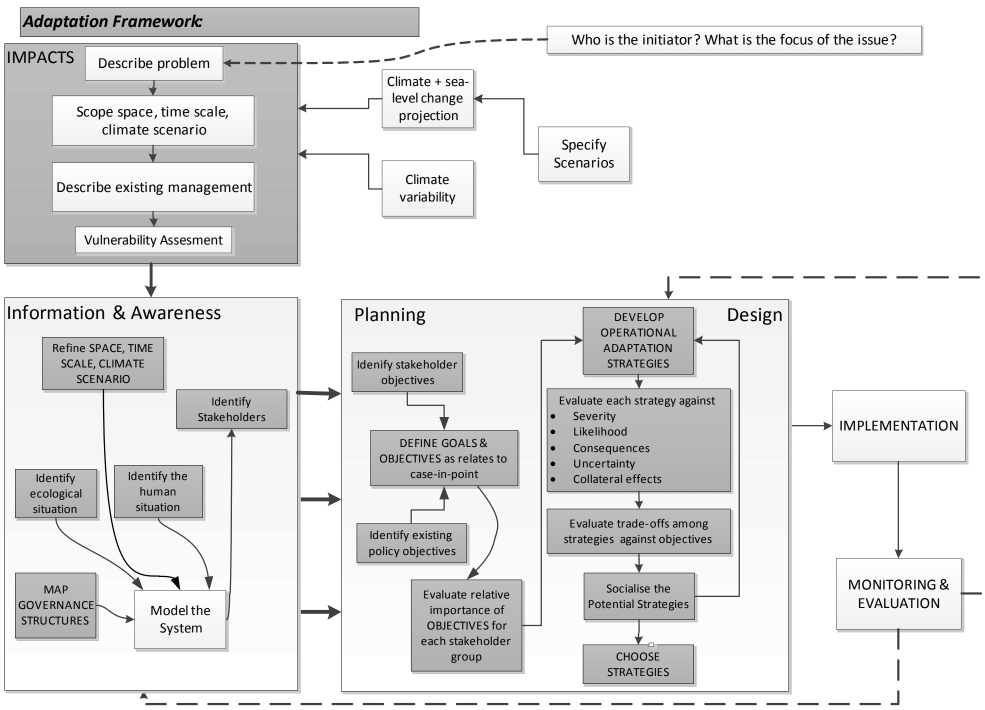


Figure 1: Detailed Guideline Framework based on the model of Klein et al. (1999).

4. We developed a simplistic, but very generic, model (Fig. 2) to act as a bare-bones guide to the factors that need to be considered when developing an adaptation strategy. Together with this we are developing an 'advice roadmap' to support the development of adaptation strategies, and so provide practical outcomes for managers.

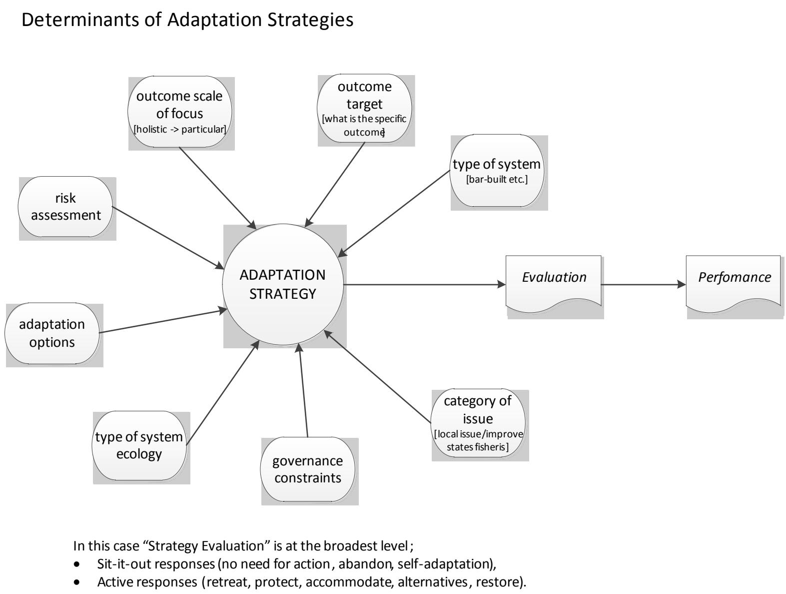


Figure 2: A generic adaptation framework.

5. We are in the process of conducting a final round of case studies with groups that have been involved with developing adaptation actions to understand the processes they have used, the motivation for the action, and the constraints for achieving success. It is already clear that although the need is for strategies that delivery overall public good outcomes, few current approaches are specifically focused on achieving this. This is because (a) they are developed at a local level and so target local issues rather than focusing on broader public good issues, and (b) there is a disjunction between the levels at which legislation and policy are developed, and the level where actions occur. A further impediment to effective public good strategy development is a widespread lack of understanding of the uncertainty of particular outcomes resulting from specific actions. This means there are overoptimistic expectations about the outcomes of adaptation actions. This uncertainty means that what are needed are strategies that do not rely on tightly predicted outcomes but are robust (i) in the sense that they do not do harm if an unexpected course of events occurs, and (ii) do not close of the possibility of future actions. These also need to be achievable.

<u>Recommendations</u>

1. **Successful adaptation strategies need a to be developed in a broad, holistic context**

   Climate change is only one of a broad suite of factors that impact coastal systems with many of the impacts of climate change only representing changes in the frequency of stressors that have been active for millennia. Strategies need to be developed in a SES landscape where there are many competing interests to be considered; for example, actions that might be good for shoreline protection might negatively impact industry, livelihoods, fisheries, tourism or the environment. The embedding of Climate Change in an array of stressors and the need to consider the multiple ways in which any action can impact other facets of the SES, together with the need to consider short- and long-term goals and effects, means strategies need to be developed in a broad, holistic context.

2. **Focus on whole-of-system, long-term transformative outcomes for socio-ecological systems**

   From a broad range of perspectives, maximum public benefit accrues from maintaining and restoring resilient ecosystems that provide healthy human living environments, support optimal biodiversity and underpin robust and productive fisheries). This is best achieved by focussing on long-term transformative outcomes that provide ongoing benefits by enhancing resilience and reducing vulnerability in the long term. Focussing on maintaining and enhancing ecosystem resilience provides long-term durability and availability of resources because it supports continued ecosystem functioning in the face of substantial change; in essence future-proofing the system. In addition, because ecological systems are intimately influences by the social systems that rely on them ensuring resource resilience needs to focus on the socio-ecological system as a whole.

3. **Employ robust strategies that minimise harm across human and natural systems**

   Strategies need to be considered with respect to the lifetime of their consequences; decisions with short-term consequences are usually only taken in the context of the current climate or with a short-term change horizon. In contrast, adaptation decisions aimed at long-term outcomes need to accommodate future predicted change. In the absence of the ability to look into the future and choose desirable rather than maladaptive pathways, decision makers need to adopt strategies that limit the risks of unforeseen consequences. This requires the development of robust strategies that recognise the intrinsic uncertainty of our knowledge of the future and the consequent limitations on our ability to predict future events and the consequences of actions. These strategies should be robust across the range of future possibilities, and not rely on tightly predicted outcomes but are robust in the sense that they do no harm if an unexpected course of events occurs, and do not close of the possibility of future actions.

4. **Acknowledge a multi-scale vision and incorporate a multi-scale approach**

   The coastal space is by nature complex; it has a large range of stakeholders with very different and, potentially, conflicting objectives. Furthermore, governance systems are fractionated into different tiers of government and local bodies, making a coordinated approach to management difficult. Furthermore, the adaptive management loop may show up the benefit of an action at totally different time and spatial scales than was originally intended. In fact, due to the long-term nature of some climate adaptations, the system response to an action may be well beyond the life cycle of a management body. Consequently, comprehensive adaptation strategies need a vision that that embraces multiple scales and leads to decisions and actions that embrace multi-scale understanding.

5. **Ensure Fair, Representative and Equitable Stakeholder Engagement**

   Comprehensive stakeholder engagement is important to achieve natural resource outcomes in the context of adaptation to climate change. Engagement of all stake-holders in strategy development in a participatory approach combining top-down and bottom-up perspectives provides both a richer suite of perspectives and legitimacy through participation and consideration of stakeholder aspirations. Stakeholder involvement needs to occur from beginning to end to ensure translation of large-scale objectives to local solutions. Keeping stakeholders engaged requires facilitation of ongoing stakeholder interest and involvement through mentoring and championing, and ensuring they are intimately involved in decision-making.

6. **Harmonise legislation, policy and actions to achieve large-scale, long-term public benefits**

   Harmonising actions and public benefit will involve increasing the concordance between the scales at which ecological and biophysical processes occur, the scales at which legislation and policy are made (central government), and the scales where actions are taken (local governments/regional bodies).

7. **Effective Governance that is clear, consistency and complementarity**

   The complexity of governance relating to climate change, and responses to it, means there is a need for clarity, consistency and complementarity in defining responsibilities and policy implementation of different management/governance authorities. Consequently, substantial success requires integrated top-down (State, Commonwealth) policies and legislation and bottom-up (local, community) level actions, together with a clear definition of roles and responsibilities.

8. **Focus on achievable and realistic delivery of adaptation strategy outcomes and outcome-support tools**

   Do no fixate on different frameworks; this is a sidetrack and the strict structure of a framework can lead to unrealistic outcomes. Rather, concentrate on what is needed for the task at hand and only choose a framework if it helps achieve a specific, realistic and achievable outcome.

9. **Optimise outcomes by employing adaptive feedback cycles appropriately**

   Adaptation options that include adaptive management cycles should be seen as the 'normal' way to do business: flexible adaptive management that allow whole of system approach across different management levels. An adaptive framework should be adopted because, although complex relationships between cause and effect (a 'wicked problem') usually mean that optimal solutions are impossible, adaptive frameworks allow movement towards a defined goal.

Peer-reviewed papers

Submitted

Bradley, M, L. Dutra, I. van Putten, I. Sporne, P. Dale, C. Dichmont, R. Bustamante, M. Sheaves. Marine climate change adaptation planning in Australia's coastal councils: An assessment of progress. *Marine Policy*

Dichmont, C.M., Deng, R.A., Sheaves, M., Bustamante, R., van Puten, I. Dutra, L., McLean, N., Dale, P., Sporne, I., Savina-Rolland, M. Which estuarine climate adaptation tool suits your needs? A review and assessment of tools to support climate adaptation for estuaries. *Regional Environmental Change*

In preparation

Dutra, L.X.C. E. Ligtermoet, I. van Putten, I. Sporne, P. Dale, C. Dichmont, R. Bustamante, M. Sheaves. Attributes of governance that strengthen adaptive capacity in the coastal zone

Dutra, L.X.C. E. Ligtermoet, I. van Putten, I. Sporne, P. Dale. Attributes of social-ecological systems that support effective co-management arrangements: a case study from Northern Australia

Sheaves, M, R. Bustamante. C. Dichmont, L. Dutra, M Savina-Rolland, M., I. van Putten, I. Sporne, P. Dale Estuaries dynamics and cross-systems linkages under climate change.

Sheaves, M, R. Bustamante. C. Dichmont, M. Brians. Projected impacts on Australia's estuarine nekton assemblages, ecosystem linkages and productivity in the face of climate change.

8.22 Comparative sequestration and mitigation opportunities across the Australian landscape and its land uses [FRDC 2011/084]

Anissa Lawrence, Elaine Baker and Catherine Lovelock

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2011-084-DLD.aspx

Objectives

The objectives of this project were to:

- undertake a comparative assessment of the carbon sequestration potential and climate change mitigation opportunities from coastal wetland ecosystems (in particular mangroves, saltmarsh and seagrass) in comparison with other key Australian ecosystems and their land-uses.
- recognise and estimate the relative contribution of poorly managed and drained coastal wetlands and the emission reduction benefits associated with remedial activities – for example, through increasing tidal flow, removing barriers, repairing mangrove, saltmarsh, seagrass habitats and compare these to other proposals for ecosystem management such as changed fire regimes for tropical savannas or livestock and manure management.
- derive a series of look up tables that compare and contrast various sequestration/reduced emissions opportunities.

Executive Summary

This report summarises the ability of Australia's coastal wetland ecosystems, particularly mangroves, saltmarsh and seagrass to capture and store carbon. Coastal carbon capture and storage has then been compared against Australia's terrestrial ecosystems, including native forests, grasslands, croplands, freshwater wetlands and agricultural lands and their land uses. In summary:

It is internationally recognised that carbon sequestration, or removing carbon from the atmosphere and storing it in vegetation and soils is a key part of the strategy to mitigate against the world's changing climate. The focus of Kyoto and many other international forums has been on accounting for emissions and removals of greenhouse gases from the land – the growth and life cycles of forests and agricultural crops, soils, land cover change and land management.

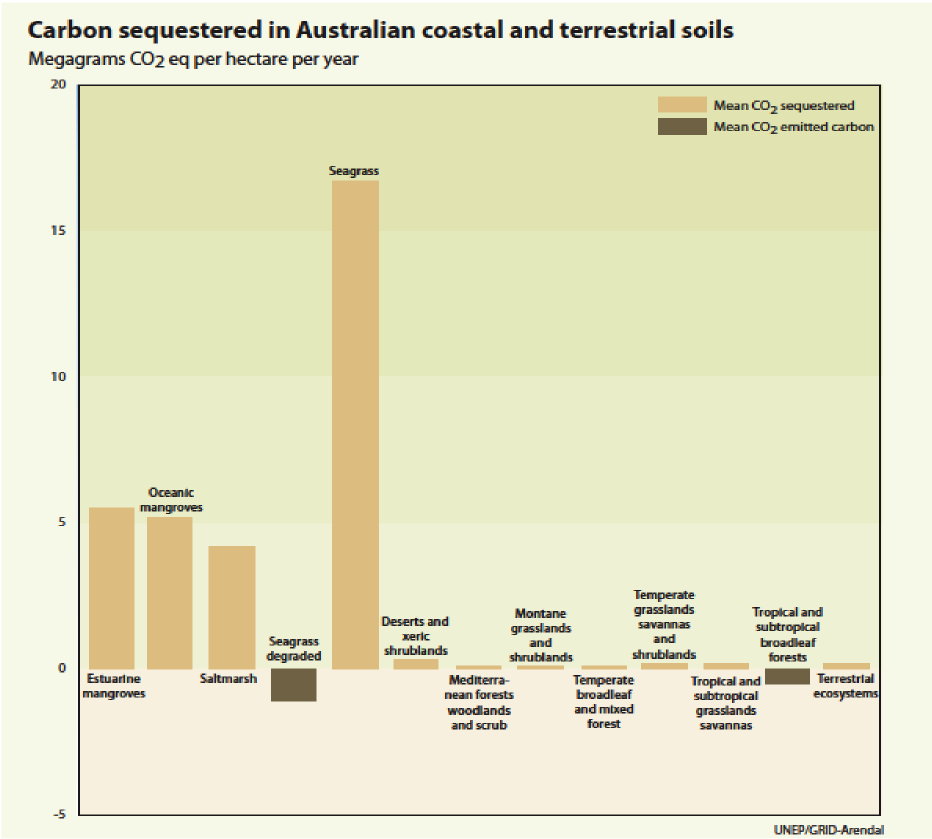
There is evidence and growing consensus that through avoided emissions, conservation, repair and sustainable use the world's coastal wetland ecosystems can play a major role in carbon management. Known as blue carbon sinks, mangroves, seagrass and saltmarsh can sequester and store carbon in their sediments and biomass at higher rates than those of tropical forests. Unlike most terrestrial ecosystems, the carbon stored in coastal wetland ecosystem sediments has extremely long residence times, potentially for millennia.

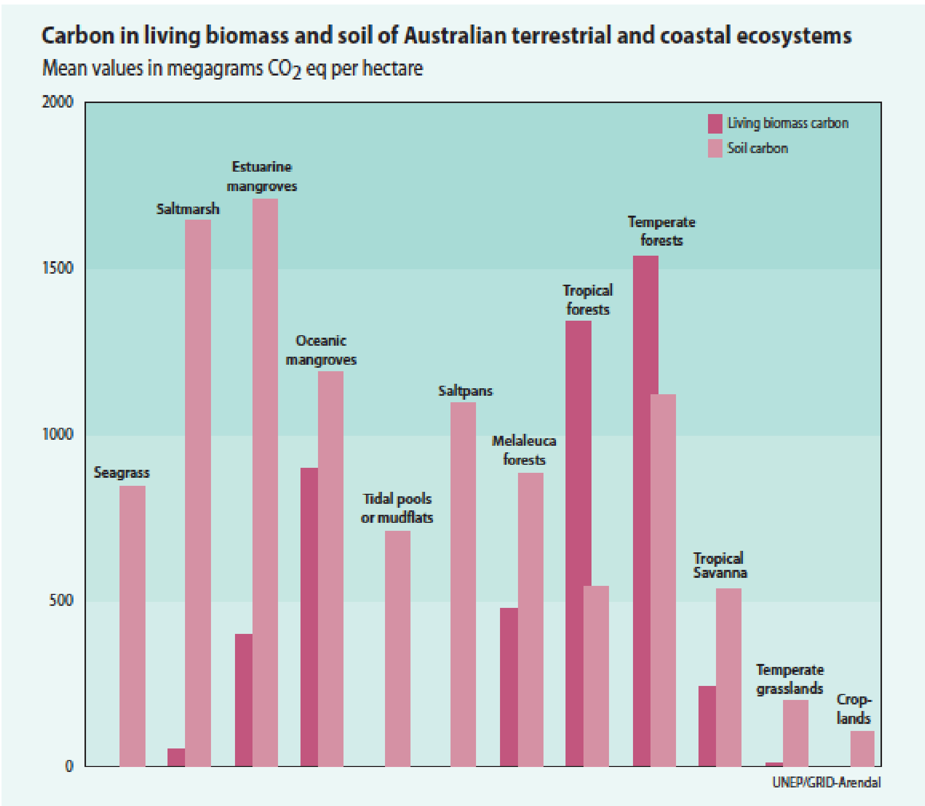
Key Findings

1. Australia's coastal wetland ecosystems sequester and bury carbon at rates of up to 66 times higher and store 5 times more carbon in their soils than those of our terrestrial ecosystems, including forests, on a per hectare basis
2. Taking up less than 1% of landmass, the average national annual carbon burial of coastal ecosystems represents at least 39% of that for all ecosystems (183.2 Tg (million tonnes) CO_2 eq yr^{-1} of a total of 466.2 Tg CO_2 eq yr^{-1})
3. Australian coastal wetland ecosystems are estimated to store on average at least 5% of all carbon stored in Australian ecosystems (biomass and soils) (at least 22 Pg (billion tonnes) CO_2 eq of a total of 441.2 Pg CO_2 eq)
4. Australia is estimated to be losing its coastal wetland ecosystems at an annual rate of 0.01–1.99% for mangroves, 1.17% for saltmarsh and 0.05% for seagrass.
5. Degraded and lost coastal wetland ecosystems are estimated to have emitted at least 22.5 Tg (million tonnes) CO_2 eq into the atmosphere since European settlement and continue to emit up to 0.22 Tg CO_2 eq each year. This is the equivalent of an additional 4,397 cars on Australian roads each year.
6. There is potential for substantial gains in carbon sequestration associated with reinstatement of tidal flows to degraded coastal wetland ecosystems in a relative short time <20 years
7. Healthy coastal wetlands ecosystems produce negligible amounts of greenhouse gases such as methane and nitrous oxide and in some cases, can act as methane sinks, unlike most terrestrial ecosystems and land uses

Australia has yet to fully recognise the important role that coastal ecosystems can play in carbon management. Coastal ecosystems are not part of our National Carbon Accounts. The Australian Government Clean Energy Futures Package through the Carbon Farming Initiative (CFI) is only supporting farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land. Coastal ecosystems are the habitats or 'productive farms' for our fishers, yet the Carbon Farming Initiative specifically excludes coastal ecosystems. Through these policy limitations Australia is not only limiting its carbon management options, but is ignoring the many other community benefits of food production, biodiversity, flood control, coastal buffering, water quality and so on that coastal ecosystems provide. For example, as a direct flow on of coastal ecosystems being omitted from Australian policy, the peer reviewed literature relating to carbon sequestration and storage for coastal wetland ecosystems for Australia is very limited compared to that for terrestrial ecosystems and their land-uses. Contrastingly, scientific understanding of carbon sequestration and potential emissions from coastal wetland ecosystems globally is much higher. This body of international knowledge is sufficient to develop the first tier of effective carbon management, policy, and conservation incentives for coastal carbon in Australia.

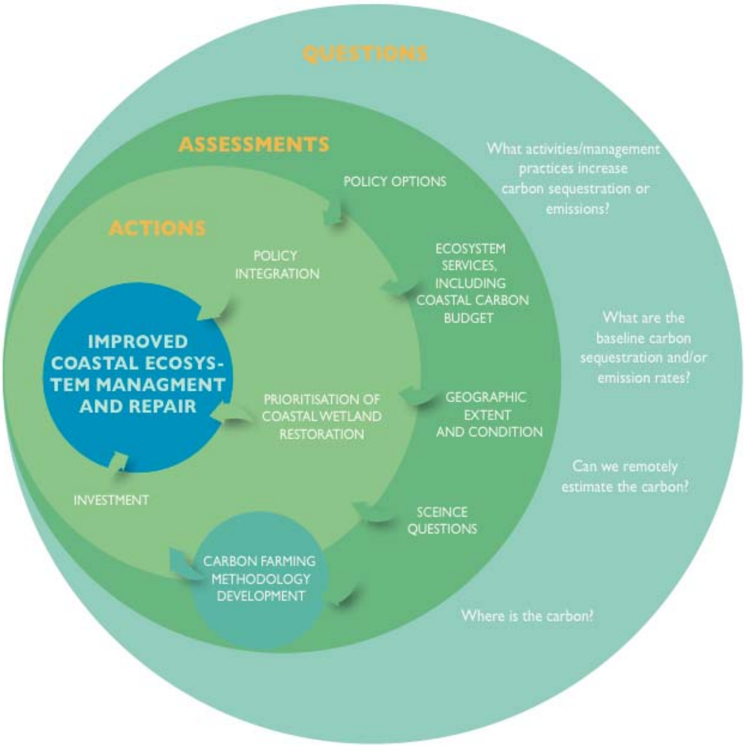
While the data we do have is generally in line with global estimates, it is imperative that we strengthen the evidence base to improve the accuracy of information needed for this decision-making process. The recognition and management of the carbon storage and sequestration potential of these coastal wetland ecosystems not only provides the global community with an additional tool with which to mitigate carbon dioxide concentrations in the atmosphere, but an opportunity to strengthen socioeconomic resilience of Australia's coastal communities and estuarine and marine based industries, avoid significant emissions from ecosystem degradation, while also supporting existing wetland conservation efforts.





The newly adopted definition of wetland drainage and rewetting under the Kyoto Protocol provides an incentive to account for anthropogenic greenhouse gas emissions and removals by Annex-I Parties, of which Australia is one. These represent further potential mechanisms for reducing emissions of coastal blue carbon to the atmosphere.

To move forward we suggest Australia needs a comprehensive approach that leads to improved management and restoration for coastal wetland ecosystems in Australia as shown below:



<u>**Recommendations**</u>

Policy and management

Australia could set in place a timetable and processes to integrate *Blue Carbon* into national climate policy

There would be a range of follow on implications including:

- ensuring coastal ecosystems are a priority within implementation initiatives such as the Carbon Farming Initiative and Biodiversity Fund, commensurate with their high carbon management outcomes;
- identifying site and landscape scale restoration priorities to deliver improvements to coastal wetland ecosystems providing (or with the potential for) high carbon and other values such as fisheries habitat repair;
- updating for mangroves and seagrass ecosystems , and in the case of saltmarsh, developing national datasets mapping the areal extent and assessing condition to provide a comprehensive understanding of status and land-use changes, comparable across regions and states and as a contributor to National Carbon Accounting;
- recognising the multiple values as well as carbon management of coastal ecosystems, develop and implement a National Action Plan for the Conservation and Restoration of Australia's coastal ecosystems, that seeks to standardise conservation and management regulations and measures across regions and states and supports restoration and rehabilitation of priority coastal wetlands ecosystems;
- exploring the feasibility of community monitoring approaches, management intervention and providing incentives for maintaining carbon rich ecosystems Participation of key stakeholder groups such as commercial and recreational fishing groups and indigenous

communities in projects to generate new revenue streams related to coastal wetland repair would mirror what is happening in other developed countries such as the USA;

Internationally and possibly as a participant in a range of globally based activities, Australia would need to think though its policy and position as part of the United Nations Framework Convention on Climate Change and its related processes and mechanisms.

Scientific understanding

We need to build on existing scientific data, analysis and available technologies to develop a coherent Australia-wide data gathering and assessment initiative focusing on:

- recognising that coastal ecosystems when compared to terrestrial ecosystems are a very significant part of Australia's carbon stores and carbon management opportunities, develop interim carbon sequestration levels for all coastal ecosystems, being agreed and conservative estimates that are sufficient to allow the above policy and management activities to proceed
- addressing gaps in knowledge in relation to carbon storage and sequestration for Australian coastal wetland ecosystems, utilising consistent internationally accepted measurement and assessment methodologies that are comparable across coastal and terrestrial ecosystems;
- undertaking detailed baseline carbon inventories of coastal wetland ecosystems and incorporate coastal carbon into the Australian Terrestrial Carbon Budget (being undertaken by CSIRO) to quantify national coastal carbon storage, sequestration and losses;
- undertaking a baseline assessment of related Australian coastal wetland ecosystem services (the need for a bundled/layered/stacked Blue Carbon + ecosystem services approach);
- conducting targeted research and monitoring to more accurately quantify the greenhouse gas emissions resulting from degradation, conversion and destruction of coastal ecosystems;
- establishing a network of field projects that demonstrate the capacity for carbon storage for coastal wetland ecosystems and the emissions resulting from degradation, conversion and destruction of coastal ecosystems; and
- conducting research quantifying the consequences of different coastal restoration and management approaches on carbon storage and emissions in coastal wetland ecosystems.

8.23 Growth opportunities & critical elements in the supply chain for wild fisheries & aquaculture in a changing climate [FRDC 2011/233]

Alistair Hobday, Rodrigo Bustamante, Anna Farmery, Aysha Fleming, Stewart Frusher, Bridget Green, Sarah Jennings, Lilly Lim-Camacho, Ana Norman-Lopez, Sean Pascoe, Gretta Pecl, Eva Plaganyi-Lloyd, Ingrid van Putten, Peggy Schrobback, Olivier Thebaud, Linda Thomas

FRDC URL: http://frdc.com.au/research/final-reports/Pages/2011-233-DLD.aspx

Objectives

1. Describe the current state of biology, fishery, policy and management of each case study fishery.
2. Develop supply chains for each of the selected fisheries, with biological, social and economic input.
3. Develop future models of these supply chains to identify opportunities and barriers with regard to environmental change, biology, social and economic factors.
4. Develop strategies to overcome the barriers and take advantage of the opportunities.

Executive Summary

It is now apparent that climate change is impacting the oceans around Australia, in particular significant warming of ocean temperatures has been documented on both the east and west coasts. Such changes are in turn impacting coastal marine ecosystems by altering the distribution, growth, recruitment, and catch of exploited marine species, and as result, marine resource-based industries, such as fishing and aquaculture, are expected to see both opportunities and losses. Seafood industries may need to adjust practices in order to maintain or enhance production. This adjustment is important as seafood plays an important role in food and economic security and supplies about 10% of world human calorific intake, and is an important regional industry and employer in Australia. The response of fisheries to climate change is an area of active investigation, however, the bio-physical elements of these industries have so far received the most attention. Long-term shifts in target species and fisher activity have been reported from Australia and elsewhere, while climate-related extreme events such as floods and cyclones also impact fisheries and aquaculture. Planning responses to climate change relies on a solid biophysical understanding, yet this is not sufficient as the full range of opportunities and threats that will confront fisheries and aquaculture as a result of climate change are not just at the production end of fisheries. Consideration of the impacts of climate change along seafood supply chains, the steps a product takes from capture to consumer is vital to safeguard the ongoing supply of seafood.

The overall premise to this project is that growth opportunities and adaptation by Australian fisheries and aquaculture sectors in the face of climate change can be achieved by:

1. Increasing sustainable biological production.

However, an increased supply does not always mean increased growth for a fishery, as a market must exist for the product.

2. Improving efficiency via a decrease in operating costs, by
   - increasing catch rates,
   - decreasing total allowable catches (TAC), or
   - reducing competition for the catch by reducing the number of vessels or licences.

However, a change in price may not always occur due to other market constraints.

3. Increasing value from existing production – value adding, or focussing on the more profitable markets or products, and reducing waste along the supply chain
4. Minimising vulnerability and instability in the supply chain by identifying critical elements and internal vulnerabilities that can be addressed by industry or government actions.

Thus, growth and adaptation opportunities will be enhanced through increased awareness of markets and opportunities along the supply chain. Here we developed supply chains for a set of seven fishery and aquaculture case studies: Southern Rock Lobster (Tasmanian sector), tropical Rock Lobster (Torres Strait fishery), Western Rock Lobster, Sydney Rock Oyster, wild Banana Prawns (NPF sector), aquaculture prawns, and Commonwealth trawl sector (CTS). These selected sectors allowed comparison between competing wild products (e.g. lobster fisheries), wild and aquaculture products (prawns), and domestic and international markets (e.g. lobster and CTS).

These supply chains were used to support a number of related analyses including life cycle assessment (LCA) which can underpin improvement in the use of resources along the supply chain. Such improvements may be increasingly important to consumers with increased climate awareness (e.g. carbon miles) and producers (e.g. carbon tax). Interviews with stakeholders generated insight into current awareness of important supply chain issues, while economic analyses showed from the markets end of supply chains, where links between seafood sectors may restrict the range of adaptation options. For example, where competing products (e.g. SRL and WRL) are seen as substitutes in the market, an adaptation strategy to reduce the catch of one species in order to boost price may not achieve the desired result. A new method was developed to assess the stability of supply chains and identify critical elements, and represents a significant advance in supply chain approaches. This method identified elements in the supply chain where efforts should be directed to make the whole supply chain more resilient (**Figure 1)**.

Future scenarios and potential adaptation options were also identified. The specificity required for adaptation options required a small set of 'general' options to be considered in the project. Two to three scenarios for each case study were considered, collectively representing three supply-driven changes (slow change in abundance, shock change in abundance, slow change in distribution) and three demand-driven changes (slow change in consumer preference, slow change in market/competition, or a market shock). These scenarios can result in increases and decreases in environmental performance across the supply change. As examples of scenarios and impacts on the supply chain, LCA for four of the case studies suggested that for:

- Southern Rock Lobster – changes in abundance and distribution are most likely to impact on the catch phase and hence global warming potential (GWP) of the supply chain. If reducing greenhouse gas emissions becomes important to consumers, the emissions generated in catch phase will need most attention.
- Wild prawns – a potential increase in availability of wild prawns may lower CPUE with some reduction in GWP at the catch phase, but in the longer term, increases in the export phases may increase the environmental footprint as assessed by the LCA indicators.
- Commonwealth trawl sector – long-term increases in efficiency may occur as a result of fleet and logistic movements southwards (following the fish), but an increased environmental footprint is expected in the short-term in response to these changing fish distributions.
- Tropical Rock Lobster – a decrease in the environmental footprint of the supply chain is expected from a change in the pathway to the export market (increased efficiency in transport)

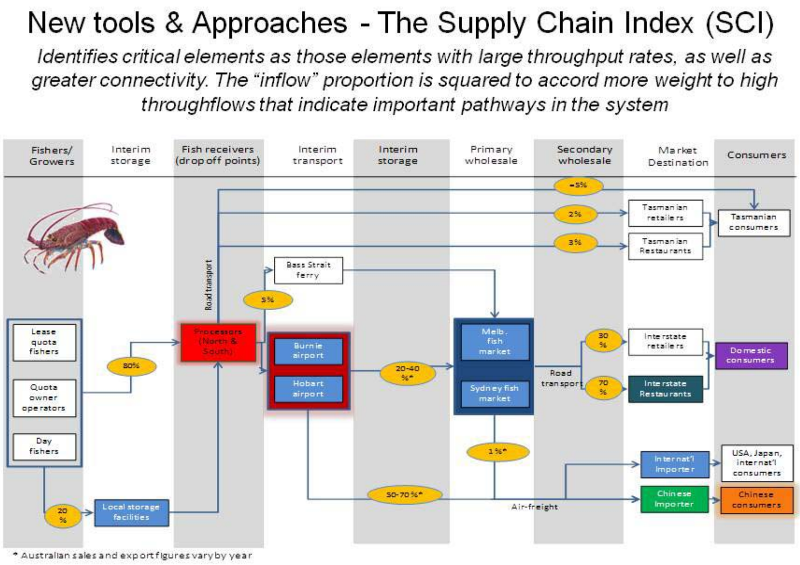


Figure 1. Example of the Southern Rock Lobster supply chain with various color coding to highlight key critical elements identified using the SCI [Plaganyi et al. (In prep.]

Importantly, development of options to overcome barriers should be undertaken in partnership with industry and managers, focusing on an agreed set of options and after defining 'supply-chain' related objectives for each fishery. The tools and outputs from this project can also be used to undertake detailed exploration of trade-offs between different adaptation options.

The outputs arising from this project document the inefficiencies and potential points for enhancing profitability including recommendations in relation to efficiencies and reduction of the carbon footprint. Strengths and weaknesses in the chain were identified using critical element analysis and together with the LCA, informed the development of adaptation options. Economic analyses underpinned identification of influence of market factors on the price and profit options for selected sectors. A final set of stakeholder interviews evaluated the potential responses and the acceptability of adaptation options for participants in the case studies, and showed that stakeholders still see most actions to be taken at the production end of supply chains (**Figure 2)**.

The potential impact of the research include the seafood sector stakeholders becoming more engaged in planning their future across the supply chain, and developing future strategies take advantage of opportunities identified in the LCA, critical metric and economic analyses. Development of these approaches to other seafood sectors will see improved outcomes for Australia in the face of a changing environment. Overall, we have developed a set of approaches to generate realistic adaptation management and policy options to enhance 'growth and opportunities' along the supply chain. These will directly benefit the adaptation efforts of the seven selected seafood sectors, and can be applied to additional sectors in future.

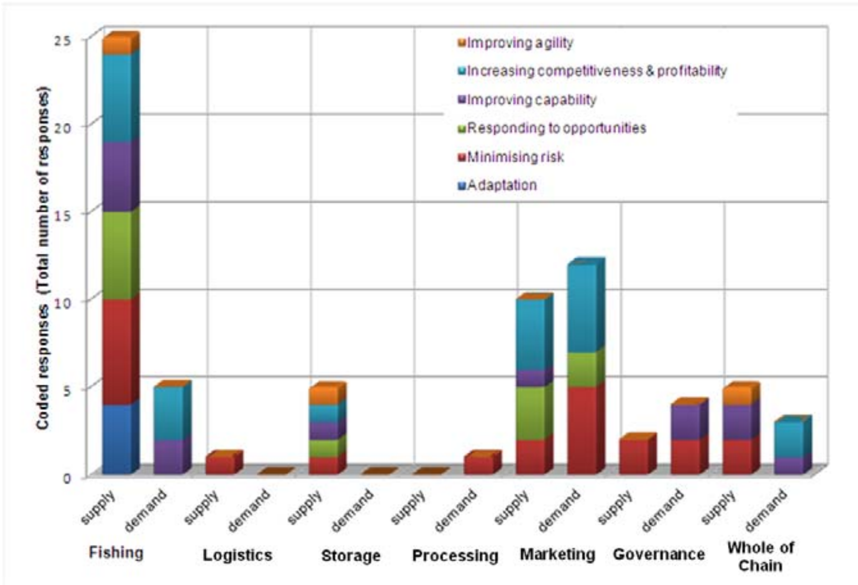


Figure 2. Types of adaptation responses to future supply and demand change scenarios across seafood supply chain stages (see Lim-Camacho et al., in review).

Peer-reviewed papers

Published

Norman-Lopez, A., Pascoe, S., Thebaud, O., van Putten, E. I., Innes, J., Jennings, S., Hobday, A. J., Green, B. & Plaganyi, E. 2013 Price integration in the Australian rock lobster industry: implications for management and climate change adaptation. Australian Journal of Agriculture and Resource Economics, doi: 10.1111/1467-8489.12020. (Paper 3)

Fleming, A., A. J. Hobday, A. Farmery, E. I. van Putten, G. T. Pecl, B. S. Green and L. Lim-Camacho (2014). Climate change risks and adaptation options across Australian seafood supply chains - a preliminary assessment. Climate Risk Management: http://dx.doi.org/10.1016/j.crm.2013.12.003. (Paper 1)

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Submitted

van Putten, E. I., Farmery, A., Green, B. S., Hobday, A. J., Lim-Camacho, L. & Norman-López, A. in review The supply chains of two Australian rock lobster fisheries under a changing climate. Journal of Industrial Ecology. (Paper 2)

Norman-Lopez, A., Pascoe, S., Hobday, A. J. & Plagányi, E. E. in review Long run price flexibilities for prawns in the Australian domestic market and the implications for industry growth. for Journal of Aquaculture Economics and Management. (Paper 5).

Lim-Camacho, L., Hobday, A. J., Bustamante, R. H., Farmery, A., Fleming, A., Frusher, S., Green, B. S., Norman-Lopez, A., Pecl, G., Plaganyi, E. E., Schrobback, P., Thebaud, O., Thomas, L. & van Putten, E. I. in review Facing the wave of change: Stakeholder perspectives on climate adaptation for Australian seafood supply chains. Regional Environmental change. (Paper 7)

Norman-Lopez, A., Pascoe, S., Thebaud, O., Mwebaze, P., Hobday, A. J. & van Putten, E. I. in review Price effects on supplies of Australian rock lobster in domestic and international markets. Journal of Agricultural Economics. (Paper 6)

Fact sheets

A set of fact sheets – one per fishery.

8.24 Climate Change Adaptation: Building community and industry knowledge [FRDC 2011/503]

Jenny Shaw

FRDC URL: (To be finalised)

Objectives

- Increase knowledge and understanding of likely climate change and adaptation measures that are open to local communities
- Support a Case Study (Blueprint Project) for Australia in adaptive management that cross-correlates regional needs with Australia-wide policy and management policies
- Tailor extension and knowledge sharing for regional needs
- Synthesise, analyse and assist in adaptation of key climate change information, in the context of external drivers to marine biodiversity and fisheries business

Executive Summary

Climate change science can be complex, difficult to understand, confusing and contentious. To maximise opportunities for adaptation, increased knowledge and understanding of climate change is essential. The project known as the 'Knowledge Project' was developed to address this need. Additionally, the Knowledge Project was closely linked to the FRDC project '*A climate change adaptation blueprint for coastal regional communities*' known as the 'Blueprint Project'.

The project was divided into a number of key components:

- Perception Analyses: assessment of two organisations with close links to the fishing industry
- Case Study (Blueprint Project) Support: facilitating community participation
- Assessment of Knowledge Needs: community and industry surveys, boundary organisation effectiveness
- Increasing Knowledge Uptake using Innovative Approaches: participatory co-production of knowledge
- Climate Change Communication Products: development, production and uptake of climate science knowledge

To achieve the project aim, collaborations with other agencies and groups were initiated, including the development of partnerships with two organisations having strong fishing industry links; OceanWatch Australia (OWA) and the Women's Industry Network Seafood Community (WINSC).

Coastal towns in three regions of Australia were used for both this and the Blueprint project – St Helens in the southeast, Bowen in the tropics and Geraldton in the southwest.

The results of perception surveys of OWA and WINSC indicate that these groups had a greater acceptance that climate change was occurring compared to the general Australian population. However, according to both OWA and WINSC, the fishing industry was likely to have a lower acceptance, less knowledge and limited interest in climate change when compared to the two peak groups. Other areas of this project including direct feedback from fishers and project staff supported this perception that the fishing industry has a limited interest in climate change knowledge.

A range of barriers for climate change knowledge uptake was identified including economics, fisheries management, time pressure, social licence to operate, and habitat and related stock loss. These barriers create a significant challenge for climate change knowledge extension and uptake, where climate change issues take a low priority because the threat is not perceived as an immediate one.

The project facilitated 83 interviews as part of the Blueprint project in St Helens, Bowen and Geraldton with the information providing direct support for Blueprint project objectives. OWA was used to engage community members in the Blueprint project research and this engagement process was particularly successful where OWA officers were locally resident or embedded in the local community.

The project explored the function and effectiveness of organisations in moving complex technical information such as climate change science from scientists to the community and decision makers. These organisations may be referred to as boundary organisations. An organisation may be well placed to function as a boundary organisation because of their high levels of trust and credibility in local communities. However, they may require additional support to function effectively with a subject such as climate change science which is a complex and contestable area. Effective knowledge transfer may be further complicated because of strong ties to their industry, and an unwillingness to engage industry members in complex and controversial issues that they believe may negatively impact the relationship with the industry.

This project was successful in engaging a large number of fishers and members of coastal communities around Australia in the uptake of climate change science. For example, up to 27,000 visitors experienced the '*Seeing Change*' exhibition that was exhibited in three coastal fishing communities in WA. Survey results during the exhibition indicate the 'Photovoice' method was an effective way of increasing knowledge uptake of climate change science for both the participants and exhibition visitors.

An extensive range of climate change knowledge uptake products was developed and distributed to the three regional coastal communities and more broadly throughout Australia. The products used a variety of formats and media, and were tailored for their distribution area and audience. The products used input from all the results produced from other parts of the FRDC Program to address specific community and industry needs, reflecting the adaptive nature of the project.

The project received extensive media coverage and was successful in National and State awards.

Over the course of the project, a number of general principals appeared to be relevant for maximising the uptake of climate change science:

- understand stakeholder learning needs
- build relationships and create trust (note that this may involve engagement over an extended period of time)
- ensure that the delivery of information is salient and credible
- maximise participatory engagement and empower stakeholders
- facilitate different learning needs by using a diversity of approaches.

Conclusions

The two partner organisations for this project (OWA and WINSC) had close links to the fishing industry and provided valuable insights on their perceptions of climate change and the functions of their organisations. OWA and WINSC were also able to provide a useful understanding of fishing industry perceptions related to climate change.

The use of organisations, individuals or tools that can effectively cross the boundaries between science and the community proved valuable at a national and regional level. Organisations and individuals which effectively function as boundary organisations or boundary agents may require additional capacity to increase knowledge uptake in contentious and politically contested areas such as climate change where salience, credibility and legitimacy are important characteristics of successful knowledge uptake.

Climate change knowledge within coastal communities and the fishing industry can be built using a range of traditional and innovative communication methods. Innovative participatory techniques were shown to be successful in increasing community knowledge.

In fishing communities where participants were reluctant to articulate their views, approaches using shared experiences and shared knowledge were effective. Importantly, the use of information that was considered salient, credible and was respectfully delivered by trusted sources appeared to increase engagement and knowledge uptake.

A strong perception was recorded that the fishing industry does not see climate change knowledge and adaptation as important issues. To overcome the challenge of knowledge uptake for a reluctant audience, structuring programs to increase knowledge uptake appears to require specialised understanding and approaches.

Recommendations

The following recommendations have resulted from the delivery of the project and are based on building industry and community knowledge of climate change:

1. Develop a direct and more detailed understanding of fisher perceptions of climate change knowledge and understanding to allow targeted knowledge uptake approaches and activities.
2. Deliver participatory community projects such as 'Photovoice' in priority coastal fishing communities around Australia to increase understanding of climate change and adaptation opportunities.
3. Develop guidelines to support and increased capacity for appropriate organisations to function more effectively as boundary organisations, specifically to build climate change knowledge in coastal fishing communities.
4. Further develop practical guidance based on the general principles identified from this study regarding effective climate change knowledge uptake for the fisheries sector:
    - understand stakeholder learning needs
    - build relationships and create trust
    - ensure that the delivery of information is salient and credible
    - maximise participatory engagement and empower stakeholders
    - facilitate different learning needs by using a diversity of approaches.

Peer-reviewed papers

Published

Shaw, J., Danese, C., Stocker, L. (2013) Spanning the Boundary between Climate Science and Coastal Communities; Opportunities and Challenges. Ocean & Coastal Management **86**. 80 – 87.

Clarke, B., Stocker, L., Coffey, B., Leith, P., Harvey, Baldwin, C., N., Baxter, T., Bruekers, G., Danese, C., Good, M., Hofmeester, C., De Freitas, D.M., Mumford, T., Nursey-Bray, M., Kriwoken, L., Shaw, J., Shaw, J., Smith, T., Thomsen, D., Wood, D. (2013) Enhancing the Knowledge-Governance Interface: Coasts, Climate and Collaboration. Ocean & Coastal Management **86.** 88 – 99.

In preparation

Shaw, J and Stocker, L. Seeing Change: an influential exhibition about climate change impacts on a WA fishing community.

Shaw, J. Caputi, N., and Stocker, L. Climate adaptation in the Abrolhos Islands fishing community: a cascade of climate, environment, management, economic and social changes.

Shaw, J, Noble, L. and Stocker, L. Environmental changes and social impacts: women's perspectives from a fishing community in Western Australia.

Shaw, J., Baldwin. C., and Stocker, L. Engaging fishers on climate change.

8.25 Revitalising Australia's Estuaries [FRDC 2012-036 & Biodiversity Fund LSP 942260-580]

Colin Creighton

FRDC url: http://frdc.com.au/research/Documents/2012-036-Business-Case.pdf

Objectives

1. Use case studies in NSW and Qld that build on previous activities and that demonstrate the multiple benefits and opportunities for further investment in connectivity & wetland repair
2. Develop an Australia-wide business plan suitable for 5-year investment that focuses on the remedial works, activities, planning, institutional arrangements and legislation to retain and repair ecological function in estuarine and wetland ecosystems
3. Present within 12 months the business case to a wide range of government, industry and community stakeholders so that understanding and support is fostered for the proposed investment initiative
4. Capitalise on a whole host of prior research and wetland mapping activities so that the Australia-wide business case is well foundered and demonstrates the return on investment from repair activities

Executive Summary

Four pilot estuary systems, two in NSW and two in Qld were investigated for the Biodiversity Fund investment of $200,000 in works. All pilots raised issues and lessons that were essential to the formulation of the Australia-wide business case and must be accounted for and managed in the roll out of any major investment. In brief these key issues and lessons learnt include:

- Initial fish re-population by at least some 'pathfinder' species (e.g. Barramundi, Mullets, crustaceans) can be relatively rapid. The pilots were of too short a duration to estimate the time lag until climax community assemblages and populations would be present. Likewise, predictions on the likely fisheries productivity enhancement over time could not be predicted from these one-year pilots.
- Initial salt impact on freshwater weeds can be equally as rapid. Re-colonisation by typically estuarine plant assemblages was not as rapid as for the 'pathfinder' fish species. Longer periods of monitoring than that able to be achieved in this one-year project are required. Nevertheless, based on other studies, the natural re-colonisation by mangroves, salt marsh and seagrass species is expected over the medium term of 3 to 5 years.
- Works undertaken within wholly public lands such as National Parks to repair the landscape towards natural condition and natural processes are comparatively easy to undertake from both administrative and social license perspectives. The land/water manager is committed to repair, approval processes are generally more streamlined and community engagement is more about promoting the success of the repair works than seeking endorsement.
- What might appear to be the most simplest repair works, where the current structures are unauthorised / illegal and there has been no clear benefit stream such as irrigation use or even irrigation licenses paid up to date can prove to be impossible to rectify in the short term. The difficulty in rapidly gaining approvals to undertake repair works can be compounded if the local Authority is risk adverse and / or too close to various lobby groups to make strategic whole of community decisions.

- Expediting approval processes can best be achieved through 3rd party representations to Government agencies. Recreational, indigenous and professional fishing and conservation groups will need to take a lead role in advocacy against vested interests and the overall inertia of community resistance to change if there is to be social license for repair works.
- Repair works within a predominantly agriculture dominated floodplain landscape are difficult and at best will involve substantial compromises and win-win floodplain landscapes. Where major re-thinking of floodplain management is necessary to foster multiple benefits and the return of fisheries habitat and productivity, the time taken for community engagement and to develop a social license will be considerable. Local leaders that are both visionary and advocates for change will be essential for success.
- Repair within an urban environment and where the lands and waters are earmarked for public open space and recreation are comparatively easy to implement from a community engagement perspective. The local community is often an immediate beneficiary of repair works e.g. the provision of urban fishery habitat is strongly supported by recreational groups and young fishers.

Overall, repairing even the key degraded areas of fisheries habitat remaining around Australia's estuaries will take time, often land purchase, an increased community awareness of the benefits of fishery habitat, locality by locality social licenses and most importantly a rethinking of the private benefit versus public benefit paradigm that has driven most of the adverse landscape change, especially agricultural development.

The Australia-wide business case was prepared in two parts:

- Great Barrier Reef estuaries and coastal wetlands; and
- Australia-wide, including chapters for NSW, Vic, SA, WA and Tas, the Northern Territory and for Queensland, a chapter on southeast Qld, being the non-GBR estuaries and nearshore assets.

This approach was undertaken at the request of the Australian Government and its Reef Rescue team, expediting completion of the Great Barrier Reef component to provide the science base and strategic direction for what then became the investment of up to $40M in 'Systems Repair' as part of the Great Barrier Reef, Reef Rescue II package.

For Australia, the business case was completed as a draft and provided to both Ministers and shadow Ministers well prior to the 2013 Australian Government election. This Australia-wide business case was finalised following input from state counterparts in August 2013. Three science papers separately funded by FRDC underpin the break-even point analysis for return on investment, being case studies for the Murray, NSW inshore and GBR prawn fisheries. A fourth paper summarised the total project.

Both business cases drew heavily on prior research and involved teamwork with key Australian and state agencies, natural resources management groups and both recreational and professional fishing groups.

All research and pilot works activities were undertaken within the context of three longer-term outputs:

- To repair, where practical, the productive function of estuarine and wetland ecological systems – on a national basis for all beneficiaries (fisheries, biodiversity, water quality, carbon sequestration and recreational amenity);
- To develop suitable delivery models that build on local conditions and needs and provides for works, maintenance, planning, governance and protective management of Australia's estuarine and wetland assets (there are multiple delivery models that can be capitalised on including Reef Guardian, Indigenous partnerships, lead state & local government

agencies, NRM groups, fishing industry groups, community groups, Oceanwatch Australia, Wetland Care Australia); and

- To advocate market driven mechanisms that capitalise on carbon and other markets to sustain this initiative.

Repair work is now underway on a more strategic footing in the Great Barrier Reef estuaries through the investment in 'Systems Repair'. In terms of delivery models, as demonstrated by the varied institutional background of the participants in this project from across the states and their regions, clearly leadership and delivery may take multiple forms. As found in the pilots, the rapidity of delivery will also vary, especially as a function of the local community and their attitudes to landscape repair for public benefit.

The broad types of repair advocated in the business cases include:

- **Restoring connectivity and fish passage** – barrages, blocks, inadequate culverts, causeways
- **Restoring estuary processes** – especially tidal and freshwater flows and fluxes, pH and oxygenation
- **Repairing drained floodplain wetlands** – removing or manipulating barrages to allow tidal water and wetland recovery and reshaping landforms to remove drains and levees, especially for acid sulphate soils thereby re-creating habitat and also removing the pollution from acidic deoxygenated runoff waters
- **Re-establishing mussel and oyster reefs** – key within-estuary nursery through to adult fishery habitat as well as performing a water quality improvement function
- **Seagrass re-establishment** – re-planting of initial colonisers especially in the SA Gulfs and the provision of seagrass friendly moorings in the heavily used recreational boating embayments of NSW and South East Queensland.

Recognising the flow-on public good that follows estuary repair, it is likely that initial investment Australia-wide, as with the Great Barrier Reef, will need to be fostered through Government with management then devolved to various groups of beneficiaries. Because of this role for Government, the focus on investment analysis has been on estimating the likely break-even point in terms of the Australian economy for the benefits to the economy to match the investment in repair. The best and most easily calculated surrogate for Australian economic benefits is the retail price of increased commercial seafood production. Prices are readily available; the technology is already in place to harvest increased productivity; the input costs for inshore fisheries are minimal and the domestic market is demanding locally produced, high quality and reasonably priced seafood.

Projections for benefits were undertaken by examining through 3 case studies the likely break-even point for the proposed investment. Using extremely conservative assumptions, only considering the value of these selected commercial fisheries:

- regional (Murray – Coorong);
- part of a state inshore (NSW); and
- part of an iconic fishery (Great Barrier Reef)

the total proposed Australia-wide investment of $350M is returned in probably 3 years, certainly well less than 5 years, just from the returned productivity for the species selected from these commercial fisheries.

This return on investment is outstanding. The break-even analysis did not include the value of increased commercial product in other states such as WA, the rest of SA, Vic, Tas, SEQ and NT and indeed does not even consider all product caught in the three case study areas. No attempt was made to value recreational or indigenous fishing, yet over 3.4 million Australians claim in surveys to recreationally fish. Likewise no attempt was made to value any of the other benefits such as enhanced biodiversity or carbon sequestration; or to speculate on other potential investment streams that would increase the outcomes from Australian Government investment such as state matching contributions or private sector donations. At least in several states these co-investments are likely to be substantial from both state and local government with sources of revenue such as recreational fishing and boating licenses already allocated on a smaller scale to these objectives.

1 Fisheries Productivity e.g. - Richmond floodplain – massively drained for low value grazing

Recommendations

2. The findings of the Australia-wide study are widely communicated with a view gaining substantial investment in repair of Australia’s estuaries and embayments for the multiple benefits of fisheries productivity, jobs, regional development and lifestyle.
3. Should funding as a specific initiative not prove to be feasible, the various priority projects in each state be pursued project by project through Oceanwatch, recreational and professional fishing organisations, conservation and natural resources groups.
4. For the Great Barrier Reef catchments where up to $40M potential funding has already been committed, professional and recreational fishing groups together with conservation and natural resources management groups work collaboratively to define, propose and gain funding for the highest priority repair works.
5. Investment in companion research and development be structured around the two broad themes of:
   - Ecosystem Ecology & Responses; and
   - Human Interactions with Estuarine Ecosystems.

Peer reviewed papers

Published

Sheaves S, Brookes J, Coles R, Freckelton M, Groves P, Johnston R, Winberg P (2014,) 'Repair and revitalisation of Australia's tropical estuaries and coastal wetlands: opportunities and constraints for the reinstatement of lost function and productivity' Marine Biology

Winberg, PC, Copeland C, Taylor,MD, Hall-Aspland S and Sheaves, M (2014) 'The potential role of estuarine rehabilitation for enhanced coastal fisheries productivity: A south east Australian perspective' AMBIO

Submitted

Creighton, C, Boon,PI, Brookes, JD, Winberg, P, and Sheaves, M (submitted to Marine and Freshwater Research, Jan 2014) Repairing Australia's estuaries for improved fisheries production – what benefits at what cost?

In preparation

Brookes J, Aldridge K, Bice C, Deegan B, Ferguson G, Paton D, Sheaves M, Qifeng Ye and Zampatti B (in prep,) 'Fish productivity in the Lower Lakes and Coorong, Australia'

Repair the wetlands to minimise fish disease and oyster deaths.

Big Swamp, Manning – pollution could be fish production.