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Preparing fisheries for climate change

Identifying adaptation options for four key fisheries in South Eastern Australia

Gretta Pecl, Tim Ward, Felipe Briceño, Anthony Fowler, Stewart Frusher, Caleb Gardner, Paul Hamer, Klaas Hartmann, Jason Hartog, Alistair Hobday, Eriko Hoshino, Sarah Jennings, Bastien Le Bouhellec, Adrian Linnane, Martin Marzloff, Stephen Mayfield, Craig Mundy, Emily Ogier, Andrew Sullivan, Sean Tracey, Geoff Tuck, Sally Wayte

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TRANSLATING**NATURE**INTO**KNOWLEDGE**

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el-nemo SOUTH EAST

1. 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 of these changes on communities and businesses will depend, in part, on how well fishing industries and resource managers adapt to these challenges.

BACKGROUND

This project was developed using the results of a formal assessment of the relative risk to climate change impacts on key fisheries species of south east 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/or distribution (snapper). Two species (rock lobster and abalone) are considered potential ecological indicators for rocky reefs, whereas snapper is an important component of coastal fish assemblages and blue grenadier occurs further offshore. The goal of the project was to identify adaptation options to enhance the profitability of commercial fisheries and maximise opportunities for participation in recreational fishing.

AIMS/OBJECTIVES

1. Identify likely key effects of climate change on four major fisheries species in south east 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 the four species and their habitats to ensure that they are suitable for measuring the likely impacts of climate change and other drivers.

METHODOLOGY & KEY FINDINGS

ABALONE

Abalone have limited ability to cope with high water temperatures and increased acidification, with blacklip preferring lower water temperatures and having lower thermal tolerances than greenlip. Abalone at locations with higher summer water temperatures have lower sizes at maturity and smaller maximum sizes than abalone at locations with 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 weaker than those for blacklip, but the general trend was for larger greenlip catches to have been obtained from 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. Greenlip catches have been smallest in areas with intense and lengthy summers and winters. Determining the extent to which climate change may influence the Australian abalone stocks was challenging. However, abalone stocks and fisheries are likely to be influenced by three elements of climate change: (1) gradual increases in water temperature and ocean acidification; (2) increased frequency and magnitude of extreme events (e.g. marine heat waves); and (3) range shifts and altered recruitment and growth rates of competitors and predators (e.g. range expansion of the long-spined sea urchin *Centrostephanus rodgersii)*. Collectively these changes are likely to result in reduced productivity and catches.

BLUE GRENADIER

The study involved an extensive review of current knowledge of the location and timing of spawning, larval life history and recruitment of blue grenadier because the production dynamics of this fishery are characterised by extreme variations in year class strength. Our analyses 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 July-November (i.e. the spawning and larval development period in surface waters). Predicted increases in sea surface temperature off western Tasmania may therefore have a long-term negative impact on average recruitment, while changes to the dynamics of wind strengths, although less certain from prediction models, could influence recruitment dynamics. Preliminary investigation of the link between recruitment dynamics and larval dispersal patterns (i.e. offshore vs inshore dispersal/retention) also suggested that larval dispersal trajectories are likely an important influence on recruitment dynamics. Climate change may influence recruitment dynamics of blue grenadier in uncertain ways. Therefore we also tested the performance of the current harvest control rule to various simulated scenarios of recruitment dynamics. Importantly, the current harvest control rule proved suitable for preventing stock collapse under a range of recruitment dynamics.

SNAPPER

Throughout the broad latitudinal range of snapper around the Australian continental shelf temperatures between 18-22˚C were consistently identified as the optimal for spawning and survival of snapper eggs and larvae. We conducted forecast modelling to assess how this optimal temperature window may change under climate change over the next 50 years. In Queensland and far northern NSW in 50 years time there may no 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 periods of optimal spawning temperatures. In the South Australian gulfs, water temperatures in 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, water temperatures around Tasmania are predicted to become more suitable for snapper spawning over longer periods, potentially 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 larvae and juveniles 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 with survival and recruitment reduced at temperatures above this level. 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 than water temperature alone. While for Port Phillip Bay, changes to the overall time period of optimal spawning temperature are predicted to be minimal, there will be significant changes to the timing and continuity of the optimal period. This may affect migratory dynamics and will have important consequences for how spawning timing overlaps with the optimal periods of prey availability for the planktonic larval stages, with uncertain implications for recruitment dynamics.

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 monthly and annual scales. Monthly investigations aimed to identify environmental signals immediately prior to settlement while the annual analyses acknowledged the long planktonic larval phase (~1 year). 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.

MANAGEMENT AND ASSESSMENT FRAMEWORKS

ABALONE

Governance systems for abalone fisheries vary greatly with respect to the presence of attributes that will enhance resilience to climate change impacts. The suitability of existing harvest strategies for maintaining biomasses at levels required to provide resilience to reductions in future productivity and increases in summer mortality events is poorly understood. The limitations of empirical measures traditionally used to assess abalone stock status (i.e. CPUE, fishery-independent surveys) are widely acknowledged and will also limit our capacity to detect future changes in abundance and productivity. Recent attempts to integrate multiple empirical measures into a single measure of status have met with some success. High resolution spatial data from commercial fishing may increase our capacity to detect future alterations in biomass and productivity resulting from climate change.

BLUE GRENADIER

The governance system for blue grenadier includes many of the attributes likely to provide resilience to potential reductions in future recruitment or shifts in recruitment dynamics (i.e. changes in the frequency and/or magnitude of high and low recruitment events). The age- and sex- structured model used for stock assessment is suitable for detecting and tracking changes in biomass that may result from climate-induced influences on recruitment and demography. We applied a quasi-management strategy evaluation to test how robust the current harvest strategy (harvest control rule) 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 TAC. Under such scenarios, a review of control rules and fishery management plans/objectives may be required to ensure the economic performance of the fishery is maximised.

SNAPPER

Governance systems for snapper fisheries vary among jurisdictions with respect to the presence of attributes likely to provide resilience to climate change. Changes in the frequency of strong and weak recruitment events will have major implications for the fisheries in Victoria and South Australia. CPUE is currently the primary indicator of abundance in most jurisdictions being used either directly or in stock assessment models. Potential to establish fisheries independent estimates of abundance is currently being evaluated in South Australia, and an ongoing fishery independent pre-recruitment monitoring program has occurred in Port Phillip Bay since 1993. Future harvest strategies will need to ensure that sufficient biomass survives periods of poor recruitment to take advantage of good conditions for egg and larval survival when they occur. In Queensland and northern NSW, future water temperatures may not be suitable successful reproduction. Future snapper fisheries in these regions may only exist based on spill over/migrants from spawning populations further south. The reduced importance of future snapper fisheries in Queensland and northern NSW may lessen the need for focused assessment and management in these regions. In northern Tasmania, snapper populations are likely to increase and potentially become self-replenishing. This would lead to a greater emphasis on snapper fishing and the need to implement more formal assessment and management arrangements.

SOUTHERN ROCK LOBSTER

The prolonged oceanic larval phase of southern rock lobster combined with its large geographic range spanning jurisdictions with different management systems complicates the prediction of climate change impacts. 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. Governance systems for rock lobster generally include many attributes likely to provide resilience to climate change. The bio-economic model developed for southern rock lobster provided an opportunity to evaluate the economic performance of these fisheries under different recruitment scenarios. These analyses showed that some quota setting options are provide more resilience to changes in recruitment others. For example, TACCs below 1200t within South Australia are robust to variation in recruitment. These quota settings also tend to deliver consistently high economic yield with less volatility in business earnings and thus reduce industry exposure to climate change impacts.

FUTURE RESEARCH NEEDS

ABALONE

In situ water temperature monitoring and periodic sampling to monitor changes in growth rates, size at maturity and abundance will be required to understand and respond to climate-induced changes. Future harvest strategies should be tested using management strategy evaluation (MSE) to ensure responsiveness to changes in stock abundance and productivity.

SNAPPER

Further investigations of factors affecting recruitment success are needed to expand the preliminary investigations undertaken in the present study. Improved predictions of future water temperatures in sheltered bays, particularly Port Phillip Bay, and rainfall and river flows regimes will be needed to model climate change impacts on future snapper recruitment in some key areas. These improved predictions of future climatic conditions could be used as input to biophysical models currently under development (i.e. Port Phillip Bay) to provide more quantitative measures of implications for recruitment and fishery productivity.

BLUE GRENADIER

Future management strategy evaluations would ideally evaluate options for optimizing economic performance under a range of recruitment scenarios that could emanate from climate change impacts. An improved understanding of recruitment dynamics, and potential changes in growth rates and adult distribution under climate change scenarios is needed underpin these future reviews. Improved knowledge of larval/juvenile distribution and ecology is needed to better understand the process(es) that drive recruitment variation and inform the development of methods for monitoring pre-recruit abundance and paramertising larval dispersal models.

SOUTHERN ROCK LOBSTER

Ongoing collection of data (especially recruitment, growth and business costs) is required to inform future bio-economic modelling. Model outputs should be used to inform the development of future harvest strategies.

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

The overall effects of climate change on the four species considered are likely to be negative, with future catches likely to be below historical levels. Adaption options that maintain biomasses at levels likely to enhance resilience to increased variability in recruitment success may need to be established. These biomass levels may also improve economic performance by reducing the costs of fishing and increasing prices. There are opportunities to improve the governance systems of many fisheries to enhance adaption to climate change and other stressors. Formal Harvest Strategies need to be established in several fisheries. These should be explicitly designed to provide resilience to climate change impacts. Ecological, economic, social and community performance indicators need to be established in most fisheries. Importantly, transparent mechanism for making trade-offs between competing objectives need to be developed. Ideally complimentary Harvest Strategies would be established across jurisdictions. The Australian Fisheries Management Forum provides a suitable platform for leading and facilitating the collaborative processes that will be required to achieve this ambitious goal. Abalone, snapper and southern rock lobster would provide suitable cases studies. Individual fisheries/jurisdictions need to identify the key parameters that need to be measured to assess the impacts of climate change and determine whether cost effective options for collecting these data are in place or can be established. The fishing industry should consider participating in a strategic environmental monitoring program that would contribute to future investigations of the impacts of climate change on marine systems and dependant industries. Australia's Integrated Marine Observing System would be well placed to take a leadership role in establishing greater industry involvement and maintaining this program.

Keywords: climate change impacts, fisheries adaptation, risk assessment, research priorities, marine ecosystems, fisheries management, southern rock lobster, abalone, blue grenadier, snapper.

2. Background

South-eastern Australia has been identified as a global hotspot for marine climate change (Hobday and Pecl 2014) and Governments of the five jurisdictions within the region have been proactive in establishing a formal collaborative structure (SEAP) to facilitate effective adaption of fisheries to potential impacts. 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 east Australia. Species selected as case studies in the proposed 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.

Ensuring that the fisheries of South-eastern Australia adapt effectively to climate change will require the development of management systems that will allow negative impacts to be mitigated and opportunities that arise to be seized. We 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, as specified in the National Climate Change Action Plan and by the Australian Fisheries Management Forum and SEAP, is being provided by working groups that include fisheries scientists, marine ecologists, oceanographers and climate change scientists from State and Commonwealth research agencies and universities throughout south east Australia. The scientific working groups will identify the: (1) likely effects of climate change on the biology/ecology of the four case study species; (2) implications for current stock assessment systems, harvest strategies and management frameworks; and (3) options for addressing these limitations.

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 (DEPI 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.

3. Need

Climate change is expected to alter physical and chemical oceanographic conditions and processes around Australia. The influence that these changes could have on the distribution and abundance of various marine species is poorly understood. 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. A risk-based approach will help to ensure the development of policies that allow industry to minimise adverse effects by optimising adaptation responses (e.g. by providing flexible management arrangements) and seizing opportunities as they arise (e.g. for species where productivity increases).

The need for this project has been identified in the SEAP Program Plan. A project to inform fisheries adaptation to climate change for high-risk commercial fisheries is needed in the south east region because:

- It is an international 'hotspot' for marine climate change, which is currently displaying signs of perturbation and where further shifts, shrinkages and expansions of ecosystems and species distributions are expected;

- It produces >50% of Australia's seafood and is home to 60% of the Australian population;

- A formal risk assessment identified fisheries species at highest risk from climate changes are also those with highest economic importance to the region (Pecl et al 2011);

- Its fisheries are managed by five separate jurisdictions whose adaption responses will need to be well coordinated if negative impacts are to be reduced effectively and opportunities that arise are to be seized.

4. Introduction

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 east 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 (Last et al 2010), major distributional shifts have been recorded in barrens-forming sea urchins (Ling et al 2009), bivalves and gastropods (Pitt et al 2010), and major declines in rock lobster recruitment have also been related to ocean warming and changing circulation patterns (Pecl et al 2009).

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 and timely adaptive actions, could be reduced (Madin et al 2012). Fisheries provide significant social and economic benefits globally, and early warning of changes in resource quality and/or availability is required to minimise social implications (e.g. as a function of changes in resource allocation) and societal costs (e.g. income redistribution and government restructuring) (Hobday and Pecl 2014). Already there is strong evidence that climate change is impacting our fisheries on a time scale that is relevant to *current* fisheries management and strategic planning (Plagányi et al 2011). 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 (Norman-López et al 2011). 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 (Pecl et al 2011).

Table 1. A *selection* of the strategies and actions highlighted by the National Adaptation Plan for Fisheries (2010) for guiding adaptation to climate change considered in this project.

Actions	STRATEGY	lead responsibility
	Improving the resilience of fishing operations to climate change	
1.1	*Incorporate climate change considerations in fisheries sector planning and management processes, and fishing operations.*	Fishers and research providers
1.2	*Identify and address barriers to adapting fisheries operations to climate change, such as:* * legislative, policy and management barriers and other fisheries-related factors, including fisher motivations and knowledge of climate change	Fishers, governments and research providers
	Strategy: Improving understanding and awareness of climate change impacts on fisheries	
1.3	*Deliver a research, development and extension (RD&E) program that coordinates and targets investment to address fisheries climate change issues, and aims to:* * encompass physical, biological, economic and social factors as appropriate * capture synergies across fisheries, jurisdictions, regions and beyond, in order to maximise returns and avoid duplication * bring together multiple investors to help identify such synergies and maximise leverage opportunities * encourage end-user input throughout the process, to ensure that RD&E is appropriately targeted, prioritised, communicated and applied * bring together expertise from multiple sources and disciplines * encourage sharing of data, methodologies and results * operationalise and extend results, and encourage uptake to maximise returns.	Research providers, fishers and governments
1.4	*Identify, prioritise and undertake integrated (environmental, economic and social) vulnerability and opportunity assessments at appropriate scales, which aim to:* * assess habitats, species and communities within a risk-management framework * inform policy, management and decision making * identify and prioritise data-collection and analysis needs	Research providers, fishers and governments
1.6	*Provide climate change information for fisheries that is relevant, understandable and easily accessible:* * ensure that researchers, fisheries managers and policy makers understand fishers' information needs * communicate the outcomes of climate change RD&E to help realise the benefits of research and inform decisions * engage fishers at national, regional and fishery levels as appropriate * raise awareness and attract fisheries stakeholder buy-in and leadership on climate change, e.g. through communicating and showcasing fisher initiatives in response to climate change	Fishers, research providers and governments
	Management and policy frameworks that are informed, agile and consistent	
1.10	*Ensure fisheries management strategies account for climate change. Management strategies should:* * be collaborative and allow flexibility for adaptation * consider biophysical and socio-economic factors (for fishers and communities), including understanding fisher motivations now, and in response to likely climate-driven changes * incorporate an ecosystem based fisheries management approach * allow for shifting 'baseline' assumptions, appropriate to new climatic conditions * consider the suitability and effectiveness of spatial and other management arrangements, now and in the future	Governments, fishers

According to the National Adaptation Plan for Fisheries (2010), "The most effective role for government in assisting the fisheries sectors to adapt to climate change is to continue supporting targeted research and development. This will provide information to make sound decisions on climate change and its impacts, and allow fishers to adapt their operations as they deem necessary. Governments should also aim to ensure that management and legal frameworks are sufficiently flexible to accommodate required changes to fishery operations, such as spatial or species shifts in the fishery and adjusting input restrictions, provided such changes are compatible with other management objectives". The major goal of this project was to identify sensible planned adaptation actions and to highlight major barriers to adaptation. In doing so, we carefully considered the strategies identified by the National Adaptation Plan for Fisheries (2010) as being appropriate strategies for guiding effective adaptation to climate change for fisheries (Table 1).

The south-eastern Australia region is suitable as a case study to develop methods for identifying key climate change issues and establishing a prioritised framework for addressing adaptation as it involves a suite of the complex factors that are likely to be encountered in other global regions. Ocean warming over recent decades has been considerable (Holbrook and Bindoff 1997, Ridgway 2007), and the oceanography of the region is complex, with changes in the physical environment likely to be heterogeneous within the region (e.g. different between the eastern and southern coasts). Fisheries in south-eastern Australia are based on a wide range of species and involve a diversity of fishing methods; fisheries resources are utilised by commercial, recreational and indigenous sectors leading to complex social considerations associated with resource access and equity. There are five marine jurisdictions within the region (four States and the Commonwealth) with different environmental and fisheries management legislation and systems; consequently, jurisdictional and political issues may complicate adaption. The ultimate focus of the broader SEAP program is to prepare governments and industry for climate change through the identification of clear adaptation pathways. While there will be a number of species-specific and population-level responses as a function of climate change, three recurring scenarios associated with changes in distribution and abundance which could require management or industry responses are evident:

- A predicted decline in resource abundance through declines in recruitment or productivity.
- Shifts in resource distribution at both small spatial scales (between fishing communities) and larger scales (over jurisdictional boundaries).
- A predicted increase in resource abundance through increased recruitment (any life history stage) or productivity.

Resource managers require knowledge of the types of adaptive responses that can be applied in the three cases above, across a variety of management systems.

5. Objectives

This report is the output of a two year project focussing on four case study fisheries across south east Australia – abalone, blue grenadier, snapper and southern rock lobster. The objectives of the project are to:

1. Identify likely key effects of climate change on four major fisheries species in SE Australia (rock lobster, abalone, snapper and blue grenadier), 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 the four species and their habitats to ensure that they are suitable for measuring the likely impacts of climate change and other drivers.

6. Methods

GENERAL APPROACH

To achieve the project objectives, we utilised a wide variety of qualitative, semi-quantitative and quantitative methods. These methodological elements contributed to the project outcomes as described in Figure 1 and Table 2. The elements are linked and all contribute to the development of future scenarios for the four fishery case studies and ultimately the generation of potential adaptation options to address specific climate challenges.

We have taken a mixed-methods approach to utilise and synthesise all available data and knowledge sources for each fishery. Our understanding of both the climate challenges and the available adaptation options to address these is embedded within the context of a systems view of each fishery. Our efforts to undertake a highly participatory approach with industry and management throughout all phases of the project is a function of this broader systems view and our aim to incorporate all available forms of knowledge of the fishery system.

The approaches utilised and developed in this project explicitly target the fishery systems of each case study across a range of levels, e.g. the operational framework of the harvest strategy and stock assessment components, the fishery management and the governance of the fishery (Figure 2). Climate change can intersect with the broader fishery system at any one of these levels. Moreover, adaptation planning can be relevant to and be implemented across any one of those levels of the fishery system.

Please note that references for each scientific working group case study, and the social and economic species profiles are at the end of each case study/species profile; all other references cited in the text are available at Appendix 5.

Text box 1: Multiple approaches to thinking about adaptation options

Adaptation in the broad sense can be considered as a deliberate process of change in anticipation of or reaction to external stimuli or stress. Adaptation involves the interaction of a range of social, economic, cultural, policy and ecological factors.

There can be varying goals of adaptation, e.g. to:

- Reduce exposure
- Reduce sensitivity
- Manage impacts or
- Increase adaptive capacity

Adaptive capacity is how well the system is equipped to adjust to climate change to reduce potential damage, to take advantage of opportunities, or to cope with the consequences.

Adaptation can be:

- ***Autonomous***: Changes that are expected to occur spontaneously in reactive response to the effects of climate change, without any government intervention occurring. Can occur without any interaction with management.

- ***Business as mostly usual:*** May involver larger changes than usual but involves no changes to existing management and operational arrangements.

- ***Incremental/intentional***: Involves minor changes to existing management and operational arrangements.

- ***Transformative***: Involves radical shift in resource management and utilisation.

Adaptation can also be considered in the context of being reactive or anticipatory (Adger et al. 2005). Reactive adaptation is adaptation that takes place in response to the consequences of a particular event, whilst anticipatory adaptation involves deliberate planned actions taken as part of a strategic response to climate change.

'Adaption pathways' (see Stafford Smith et al. 2011) map out what the timing of appropriate adaptation actions may be, based on the combination of lead time required to develop and implement a particular response and the consequence period of that response after introduction (e.g. altering jurisdictional boundaries across the south east may have a long lead time and a long consequence period, whereas revising a performance indicator may have a short lead time and potentially a short consequence period). This approach would allow a balanced combination of considering management responses that can be introduced now, through to medium and longer-term responses that might be required at later stages.

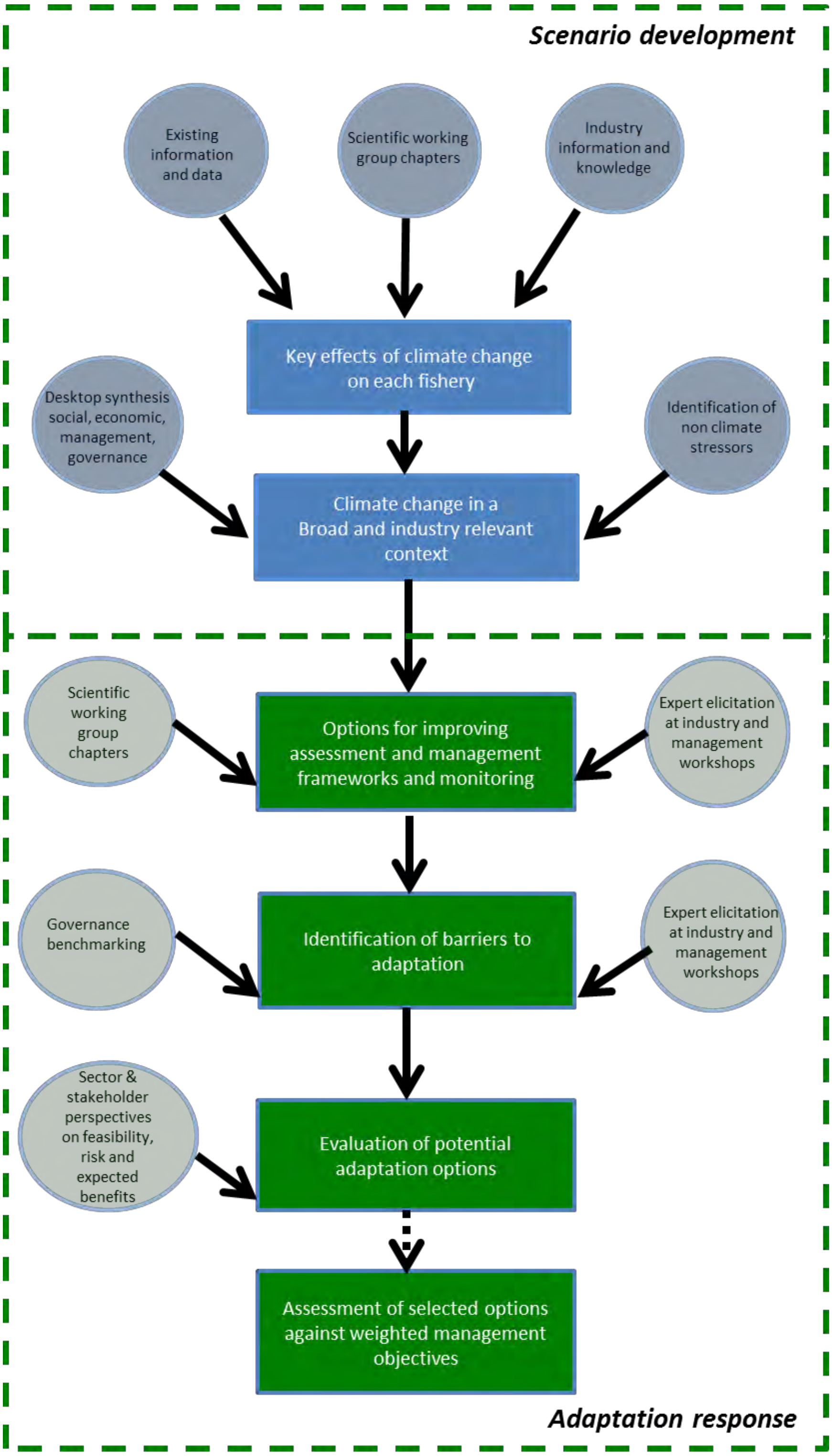

Figure 1. Project linkages for each of the project components. Dotted arrow to 'assessment of selected options against weighted management objectives' indicates a component outside the scope of this particular project, but is a sensible next step which could be conducted within a management strategy evaluation (MSE) framework.

Table 2. Methods for each objective and formal outputs relevant to each objective, for the southern rock lobster, abalone, snapper and blue grenadier fisheries in south east Australia.

	Objective	Methods	Output beyond the final report
1	Identify likely key effects of climate change on each species particularly where these effects may impact the harvest strategies.	➢ Elicitation of industry observations at participatory workshops ➢ Case study chapters	Paper 1: Linnane et al Paper 2: Briceño et al Paper 3: Mayfield et al Paper 4: Tuck et al Paper 5: Hamer et al Paper 6: Fowler et al Paper 7: Gardner et al
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).	➢ Case study chapters	Paper 1: Linnane et al Paper 2: Briceño et al Paper 3: Mayfield et al Paper 4: Tuck et al Paper 5: Hamer et al Paper 6: Fowler et al Paper 7: Gardner et al
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).	➢ Identify potential adaptation options and barriers to adaptation ➢ Identify key non-climate stressors to the fisheries (expert elicitation at workshops) ➢ Desktop synthesis of main social & economic components of the fisheries, and management and governance systems ➢ Governance benchmarking for effective fisheries management ➢ Development of conceptual scenarios (science input & workshops) ➢ Expert elicitation of anticipated risk, benefit and feasibility of suggested options	Paper 8 : Pecl et al Paper 9: Ogier et al Appendix 3 Appendix 4
4	Identify improvements to current monitoring systems for the four species and their habitats to ensure that they are suitable for measuring the likely impacts of climate change and other drivers.	➢ Case study chapters	

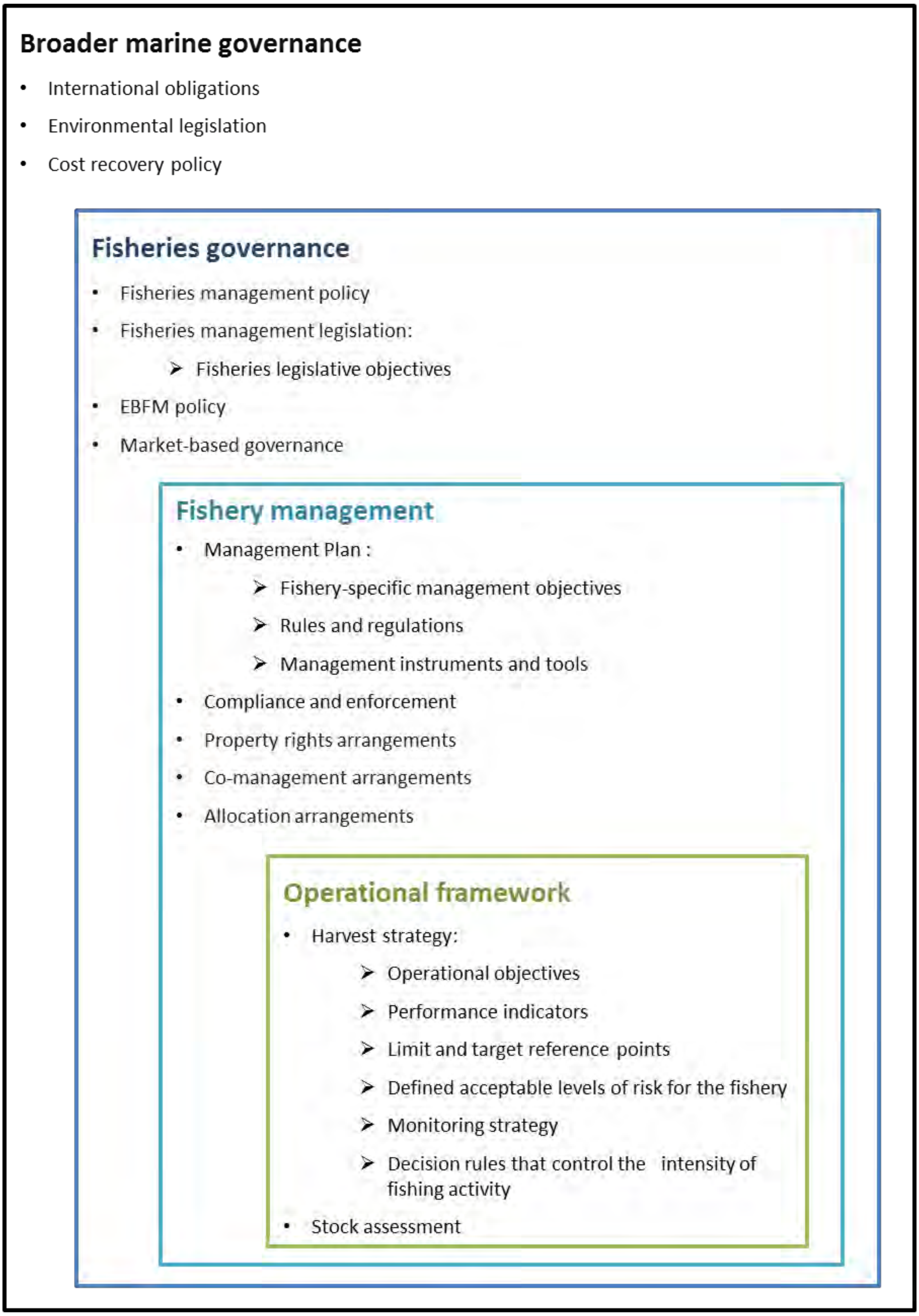

Figure 2. An overview of the potential points where changes in climate can be relevant to the governance, management or operational frameworks of a fishery system, via either impacts of climate change, barriers to adaptation or possible intervention points where adaptation options could be implemented. The fishery sub-system is embedded within the broader marine system.

6.1 INDUSTRY OBSERVATIONS OF OCEANOGRAPHIC, ECOSYSTEM OR FISHERY CHANGES

Fishers spend a large amount time out on the water and over time acquire extensive knowledge of the marine environment. We sought to increase our knowledge of changes that are occurring in the marine environment in south east Australia through seeking observational information from commercial and recreational fishers associated with the snapper, abalone, rock lobster and blue grenadier fisheries. Combining industry observations with scientific data and analyses gives a more complete understanding of current changes in the fisheries and broader environment.

A large two day workshop (see Appendix 2) was held on March 15 and 16 2012 in Melbourne. This was attended by 40 fishery managers, industry representatives (commercial and recreational) and researchers from across the south eastern Australia. This workshop provided an opportunity to solicit from stakeholders any observations, possibility related to climate, that were either specific to their operations and fishery or the ecosystem in general.

6.2 IDENTIFICATION OF NON-CLIMATE STRESSORS FOR EACH FISHERY

It is recognised that healthy fish stocks managed in an ecologically sustainable manner will generally be better placed to withstand increased environmental stresses, including those arising from climate change. Similarly, efficient and profitable commercial operators in economically healthy fisheries will generally have greater financial scope to adapt to changed conditions.

In order to facilitate and assist industry and management to adapting to climate change it is important for researchers to understand where climate change adaptation currently fits within industry and management priorities and planning. Identifying the existing stressors assists industry, management and researchers to identify links between the challenges faced today and the expected problems that climate change will bring in the future. This is critically important when developing and implementing effective and efficient adaptation strategies that will provide the greatest net benefit to the particular fishery under consideration.

During the 2012 workshop, a session was dedicated to understanding the stressors currently being experienced by individual fisheries and the industry as a whole. Fishery stressors were also identified during the desktop analysis (see 6.3) component of this project and are also described within the species profiles in Appendix 3 of this report. The results of the two methods have been combined for the purpose of this section and are reported within each case study chapter.

6.3 DESKTOP SYNTHESIS OF THE MAIN SOCIAL AND ECONOMIC COMPONENTS OF THE FISHERIES, AND THE RESPECTIVE MANAGEMENT AND GOVERNANCE SYSTEMS OF EACH JURISDICTION

A desktop analysis of the main ecological impacts of climate change, and key social and economic components of the fishery, including a description of the management systems and governance across the jurisdictions, was completed for each species case study.. Development of potential adaptation options requires knowledge of the social, economic, management and governance systems and constraints of each fishery. The details of these elements are provided in Appendix 3.

6.4 IDENTIFYING POTENTIAL CHANGES

Researchers in each jurisdiction assembled the fishery and ecological data for each case study species. Following meetings of the scientific working groups, the core project team for each species examined the historical environment-biology relationships (e.g. rock lobster recruitment and temperature). Particular attention was given to changes that may impact the productivity of each species. The scientific working group also assessed the capacity of current stock assessment procedures and harvest strategies (e.g. fisheries models, performance measures, decision rules) to respond to likely climate change scenarios (e.g. assumptions of temporal stability in temperature-influenced parameters such growth and recruitment). In conjunction with the industry and management representatives, the scientific working group then identified approaches to addressing any weaknesses that may be identified (e.g. potential changes to performance measures to remove or account for consistent bias).

Each scientific working group examined how climate change may intersect with the specific management tools and structures for each fishery. For example, the influence of climate on input and output controls and technical measures (e.g. size limits) were examined for each species.

6.5 IDENTIFYING POTENTIAL ADAPTATION OPTIONS AND BARRIERS TO ADAPTATION.

We used a 'mixed methods' approach (see Kalaugher et al 2012) to highlight potential directions for developing adaptation options and identifying likely barriers to adaptation, via both 'top-down' (e.g. Governance benchmarking) and 'bottom-up' (e.g. exploration of conceptual scenarios with industry representatives) approaches.

A key element to our approach was a large workshop in 2012 followed by a series of fishery-specific workshops in 2013 (Appendix 2) that provided the forums for generating important feedback from managers and industry, and communication between and within case study groups. This regular feedback process allowed us to develop and evaluate sensible adaptation strategies that are more likely to be seen as legitimate, credible and salient by both industry and resource managers.

6.5.1 GOVERNANCE BENCHMARKING FOR EFFECTIVE FISHERIES MANAGEMENT

Good fisheries governance is essential for effective climate change adaptation. Benchmarking governance systems against best practice in the case study fisheries allowed identification of barriers to adaptation, and helped shape fishery level adaptation strategies.

Governance is defined by the Productivity Commission (2011) as "the use of institutions, structures of authority and other bodies to establish policies and rules, to allocate resources for implementation, and to coordinate and control the resulting activities." Governance is a broad ranging concept, including processes for incorporating various types of knowledge into decision making, regulations that dictate the composition of management advisory groups, and the constitutional rules that underpin the allocation of responsibility for management across the various levels of government. While varying in detail and emphasis, there is strong agreement about what constitutes good governance. At the highest level for example, it is generally agreed that well governed systems are characterised by accountability, transparency, flexibility, appropriate incentives, coordination, participation, and are adequately resourced. Nevertheless, no single governance system will be appropriate in all situations.

Climate change adaptation occurs within the context of, and interacts with the system of governance. Adaptation requires organisational and institutional capacities, as well as the ability to generate and support actions built on strong governance principles (Productivity Commission 2011). While a strong governance system can support adaptation, poor governance may inhibit or act as a barrier to all phases of the adaptation process. It may, for example, prevent the timely identification of emerging issues and understanding of important problems, fail to support planning, implementation, monitoring and evaluation of adaptations (Moser and Ekstrom 2010).

Addressing barriers to climate change adaptation involves continual assessment of governance arrangements. Good governance is generally described in terms of a set of desirable attributes or principles, with weaknesses arising when these attributes are not fully embedded, and operational in a system. Benchmarking existing governance against the set of desirable attributes provides a basis for identifying strengths and for monitoring improvements. It is also a way of identifying governance related barriers to adaptation.

In this exercise we benchmarked each of the eleven south eastern Australian fisheries against a set of desirable governance attributes. Our list, comprising 43 attributes, was based on Grafton (2006) in which two Australian fisheries were benchmarked against 22 attributes relating broadly to the areas of accountability; transparency; incentives; risk assessment and management; and adaptability (Table 3). Following a review of some recent governance literature, we extend this list to include 21 others, particularly in the areas of fisheries planning processes and knowledge-systems. This assessment includes six areas: accountability; planning; transparency; incentives; adaptability; and knowledge. Fisheries benchmarking was conducted by asking key individuals in each of the eleven fisheries to complete an online form in which attributes were assessed as being:

- Fully in place and always/mostly operational
- Fully in place and sometimes operational
- Fully in place and rarely/never operational
- Partially in place and always/mostly operational
- Partially in place and sometimes operational
- Partially in place and rarely/never operational
- Not in place but importance recognized and working towards it
- Not in place but importance recognized but not working towards it
- Not in place and importance not recognized

Table 3. Governance attributes relating to accountability; transparency; incentives; adaptability and knowledge

Governance area	Attribute
Accountability (AC)	• Rights and responsibilities of all parties clearly defined • Mechanisms to ensure operational accountability • Independent fishery report cards and/or accreditation • Biological performance indicators • Economic, social and community performance indicators • Ecosystem performance indicators • Inter-agency and inter-jurisdictional roles and responsibilities clearly defined
Planning (P)	• Inclusive and collaborative planning process • Planning occurs across the entire fishery value chain • Planning is forward-looking and strategic • Planning includes risk assessment and evaluation • Goals and objectives of fishery management clearly defined
Transparency (T)	• Non-confidential data easily accessible • Open and publically recorded decision-making processes • Clear processes for making trade-offs between conflicting objectives
Incentives (I)	• Incentives fully aligned with goals and objectives • Secure and durable individual or community harvesting or area fishing rights • Competitive and well-developed market for fishing rights • Monitoring and enforcement of fishing rights • Monitoring and enforcement of other regulations, including input controls • Incentives to avoid negative externalities, including habitat damage and by-catch • Monitoring of negative externalities • Incentives to minimise compliance costs • Incentives to minimise management costs • Mechanisms to ensure re-investment of some economic rent in fishery
Adaptability (AD)	• Adaptive and responsive decision-making • In-season adjustment to management possible • Limit and target reference points used and regularly reviewed • Range of operational fisheries management tools available • Management is at appropriate temporal and spatial scales • Flexibility to manage range shifting species • Ability and preparedness to effect change in management
Knowledge (K)	• Systematic use of localized fisher and community knowledge • Decision systems integrate ecological, social and economic knowledge • Management based on 'best' science • Research provides timely, robust and useable science

(Adapted from Grafton et al 2006)

6.5.2 CONCEPTUAL SCENARIOS TO IDENTIFY ADAPTATION OPTIONS AND BARRIERS

To determine likely responses to plausible climate change scenarios we followed a similar approach taken in the vulnerability to climate change assessment of the east coast Tasmanian Rock Lobster Fishery (Pecl et al 2009) by involving key stakeholders in a workshop. Conceptual scenarios were used to generate an understanding of what capacity the respective industry sectors have to adjust autonomously to the main impacts of climate change in each of the four fishery systems. These scenarios helped identify potential adaptation options and the key barriers to those actions.

Workshop participants were presented with a range of potential climate change impacts prepared by the case study leaders and workshop facilitators for each of the four species. These 'fishery scenarios' were largely generated from the species profiles prepared in the recent biological risk assessment (Pecl et al 2011), combined with known information on likely physical changes for the south east region of Australia (e.g. projected changes to current systems), the potential impact of likely future trends in key external stressors (e.g. fuel prices) and the perceptions of industry on recent changes in the fishery. Participants then provided likely autonomous adaptation responses, other possible adaptation actions and what the critical barriers may be to implementing these actions. Participants at the workshops were also presented with information on key ecological interactions and uncertainties and potential barriers to change. Managers and industry then proposed a range of ideas for management changes to address these challenges. Explicitly, industry and management were asked to identify:

- Potential climate change impacts;
- Autonomous adaptation responses;
- Possible [planned] adaptation options; and
- Barriers to adaptation

Workshop participants were challenged to think outside the normal realms of fisheries management responses to problems. 'Blue sky' thinking is what will be required to find new and innovative adaptation pathways to unknown and unpredictable to fisheries. Scenarios were specific to each fishery and were based on predicted changes to environmental variables such as water temperature, ocean currents and rainfall. Whilst the consequences of these actions on abundance, distribution and phenology are not fully understood, for the purpose of the exercise it was assumed that abundance would either go up or down as a consequence.

6.6 EVALUATE OPTIONS FOR ADJUSTING MANAGEMENT ARRANGEMENTS TO REDUCE NEGATIVE IMPACTS AND MAXIMISE UPTAKE OF OPPORTUNITIES & IDENTIFY BARRIERS TO ADAPTATION

Preliminary adaptation options identified in the March 2012 workshop were reviewed and revised by case study leaders in preparation for the second round of stakeholder workshops held throughout 2013. In order to ensure adequate attendance and participation, the project team in conjunction with the case study leaders, hosted the workshops largely around existing meetings for each of the fisheries. The aim of the second round of workshops was to evaluate options for adjusting management arrangements for each case study fishery to reduce negative impacts and maximise uptake of opportunities that climate change may provide. At these workshops the revised adaptation options were furthered refined and analysed using a characterisation matrix which identified the key characteristics of the adaptation options being evaluated (Table 4). Specific options were linked to specific climate challenges for each fishery.

The purpose of the characterisation was to identify characteristics which needed to be considered in the evaluation of the perceived risks, benefits and feasibility of each option, and in decision-making processes for fisheries more broadly (Table 5). Characteristics were identified by the scientific working group on the basis of an extensive review of literature and included the implications of each option on the fishery system as a whole (i.e. the interaction of adaptation options with other management strategies) as well as temporal and spatial scales of implementation processes and benefits. The revised adaptation options and draft characterisation tables were circulated to participants prior to the second round of participatory workshops held for each fishery for feedback, and then finalised at the workshops. Both the final set of specific adaptation options for each fishery and the characterisation of those options are included in the respective case study chapters.

Semi-quantitative evaluation of the final list of potential adaptation options was undertaken by participants in the second round of stakeholder workshops by scoring the anticipated performance/outcome of an adaptation option against a pre-determined set of normative criteria and related indicators. Candidate criteria and indicators were identified on the basis of the review of literature and then selected and refined for the fishery-specific context at a case study leader's meeting in August 2013.

For the purposes of this report the authors have presented the analysis and discussion on a selection of adaptation options for each fishery, rather than for all of those identified. Adaptation options were selected in consultation with case study leaders and based on a number of factors including: selecting a range of adaptation types (e.g. autonomous, transformative), ability to compare like with like across fisheries, stakeholder preferences and number of survey responses. Analysis of the level of consensus between all respondents within and between sectors, as well as collectively, was undertaken by determining the percentage of scores for an adaption option and criterion in each evaluation class. The following categories of consensus were used (after Lemieux and Scott 2011): High =70% of responses in one evaluation class or 80% in two adjacent classes (i.e. "low" and "very low"); Medium = 60% of responses in one evaluation class or 70% in two adjacent classes; Low = 50% of responses in one evaluation class or 60% in two adjacent classes; and, None = Less than 60% of responses in two adjacent evaluation classes.

Table 4: Characterisation matrix used to identify the key characteristics of possible adaptation options

CHARACTERISTIC		TYPOLOGY / SCORE
Adaption Type		Autonomous Business-As-(Mostly)-Usual Incremental Transformative
Implementation	Scale of application	National State Zone Sub-zone
	Jurisdiction/s	
	Significance of difference between jurisdictions	Low, Medium, High
	Lead time to implementation	<1 year, 1-5 years, >5 years
	Additional cost	Nil, Low, Medium, High
	Who pays	Industry Government Consumers Post-Harvest Local communities
	Level of controversy	Low, Medium, High
Benefits	Primary beneficiary	Fishers Fishery Fish Stock Ecosystem
	Scale of benefit	National State Zone Sub-zone
	Consequence period after implementation	<1 year, 1-5 years, >5 years
	Addresses other climate challenges	List other challenges
Barriers		Individual barriers listed

Workshop participants collectively discussed then prioritised a sub-set of potential adaptation options for evaluation. The selected options were subsequently evaluated by individual participants by selecting a score of 1 - 5 for each indicator, where 1 = Less Feasible/Low Risk/Low Expected benefits and 5 = More Feasible/High Risk/High Expected benefits (Table 5). Results were then collated and analysed by averaging the scores given by respondents for a given option for each indicator. Scores of all workshop participants and of respondents of a specific sector (i.e. fishing industry, managing agencies) were determined to generate both a combined average score and an average sector score for each criterion. It should be noted that representatives from the recreational sectors were not present at these workshops as the workshops were built around pre-planned co-management or research meetings which typically do not involve recreational representatives.

A review of the survey responses from each of the workshops identified a number of gaps in the survey responses from across the sectors. This was not unexpected given the large volume of potential adaptation options identified for each fishery. Where significant gaps existed participants were emailed or contacted by telephone in an effort to obtain a more complete and informative data set. Responses of "N/A" were treated as a non-score for the purposes of analysis. If more than one third of responses for a given indicator were N/A then the "Consensus" level was deemed to be "Unsatisfactory". Evaluation classes were developed for interpretation of the results (Table 6) and the results for each option for each fishery were then plotted for comparison.

For the purposes of this report the authors have presented the analysis and discussion on a selection of adaptation options for each fishery, rather than for all of those identified. Adaptation options were selected in consultation with case study leaders and based on a number of factors including: selecting a range of adaptation types (e.g. autonomous, transformative), ability to compare like with like across fisheries, stakeholder preferences and number of survey responses. Analysis of the level of consensus between all respondents within and between sectors, as well as collectively, was undertaken by determining the percentage of scores for an adaption option and criterion in each evaluation class. The following categories of consensus were used (after Lemieux and Scott 2011): High =70% of responses in one evaluation class or 80% in two adjacent classes (i.e. "low" and "very low"); Medium = 60% of responses in one evaluation class or 70% in two adjacent classes; Low = 50% of responses in one evaluation class or 60% in two adjacent classes; and, None = Less than 60% of responses in two adjacent evaluation classes.

For the purposes of this report the authors have analysed a selection of adaptation options for each fishery, rather than analysing all of the potential adaptation options identified. The options selected were chosen in consultation with case study leaders and based on a number of factors including: need to present a range of adaptation types (e.g. autonomous, transformative etc.), ability to compare like with like across fisheries, stakeholder interest/preference and the number of survey responses received. It is important to note that the adaptation options analysed and discussed here are only a selection of the potential adaptation options available. By conducting further analysis on these options we are not commenting on the suitability of one adaptation over another. The comprehensive list of adaptation options are detailed in the fishery characterisation tables in section 4 (Evaluate potential adaptation options) of each species-specific results chapter.

Table 5. The three major evaluation criteria selected were: Feasibility, Risk and Expected benefits. A Likert scale scoring system was used to score indicators for each criterion.

CRITERIA							
1. Feasibility	**Low score=less feasible**		**High score=more feasible**			**Not Applicable**	**Comments**
(low score = less feasible)	**1**	**2**	**3**	**4**	**5**		
1.1 Cost of implementation **(high cost is less**							
1.2 Ongoing cost **(high cost is less feasible)**							
1.3 Legal and procedural barriers							
1.4 Social and political barriers							
1.5 Need for additional skills, knowledge and expertise							
2. Risk	**Low score=low risk**		**High score=high risk**			**Not Applicable**	**Comments**
(low score = low risk)	**1**	**2**	**3**	**4**	**5**		
2.1 Likelihood of failing to address climate challenge							
2.2 Likelihood of negative impact of action on biological sustainability of fish stock							
2.3 Likelihood of negative impact on wider ecosystem							
2.4 Likelihood of reduced economic sustainability of the fishery							
2.5 Likelihood of reduced fisher profit							
2.6 Likelihood of reduced employment							
2.7 Likelihood of reduced social license to operate							
2.8 Likelihood of limiting other adaptation options							
2. Expected benefits	**Low score=low benefit**		**High score=high benefit**			**Not Applicable**	**Comments**
(low score = low benefit)	**1**	**2**	**3**	**4**	**5**		
3.1 Level of benefit to biological sustainability of fish stock							
3.2 Level of benefit to wider ecosystem							
3.3 Level of benefit to economic sustainability of fishery							
3.4 Level of benefit to fisher profit							
3.5 Level of benefit to employment							
3.6 Level of benefit to overall fisheries management							
3.7 Persistence of benefit after implementation							

Table 6. Evaluation classes for each range of scores

CRITERION	SCORE RANGE	EVALUATION CLASS
Feasibility	0.1 – 1.0	Negligible feasibility
	1.1 – 2.0	Very low feasibility
	2.1 – 3.0	Low feasibility
	3.1 - 4.0	Moderate feasibility
	4.1 – 5.0	High feasibility
Risk	0.1 – 1.0	No risk
	1.1 – 2.0	Very low risk
	2.1 – 3.0	Low risk
	3.1 - 4.0	Moderate risk
	4.1 – 5.0	High risk
Expected benefit	0.1 – 1.0	No expected benefit
	1.1 – 2.0	Very low expected benefit
	2.1 – 3.0	Low expected benefit
	3.1 - 4.0	Moderate expected benefit
	4.1 – 5.0	High expected benefit

7. General Results

This chapter reports on findings that were not specific to a particular case study.

7.1 INDUSTRY OBSERVED OCEANOGRAPHIC, ECOSYSTEM OR FISHERY CHANGES

Fisher's knowledge is being recognised as an important and often integral component of the knowledge need to understand fisheries and marine ecosystems (Haggan et. al. 2007). Fishers rely on the sea for their livelihoods and, like most practitioners, they attempt to understand their working environment so as to ensure a productive and profitable livelihood. Knowledge can be gained through a series of types such as historical knowledge passed down from father to son or from skipper to deckhand. Knowledge can also be shared by peers, primarily informally through meetings on wharfs or local fishing associations. Finally, this acquired knowledge can then be tested, validated and increased through personal observations. More recently there has been a growing use of "citizen science" as a way of tapping into the knowledge of individuals and communities (Silvertown 2009) (Figure 3). This rapid increase in citizen science programs not only demonstrates their usefulness but also the increased recognition of the difficulty in maintaining broad-scale monitoring programs (Bates et al 2014).

However, interpretation of mechanisms behind observations can be variable. In a recent study by Nursey-Bray et al (2012), fisher's observations of recent changes in the marine environment were plentiful whereas when asked whether they "believed" in climate change, most of the same fishers were sure that it was not occurring and/or just a conspiracy to keep scientists employed. This was despite the fact that most of the fisheries observations were associated with abundance, distribution and phenology changes consistent with the much publicised footprint of warming waters associated with the climate change signal in this region. Despite their denial, fisher's observations have proven valuable in demonstrating the broad and often complex changes that are occurring in the marine environment. In this section we sought to increase our knowledge of changes that are occurring in the marine environment in south east Australia through seeking observational information from commercial and recreational fishers associated with the snapper, abalone, rock lobster and blue grenadier fisheries. Observations from commercial and recreational fishers covered a range of issues that were either specific to their operations and fishery or more general reflecting ecosystem impacts (Table 7). In Table 7 we have combined information which may have come from different sources. For example, both the abalone and rock lobster commercial fishers were aware that recruitment of lobsters had declined.

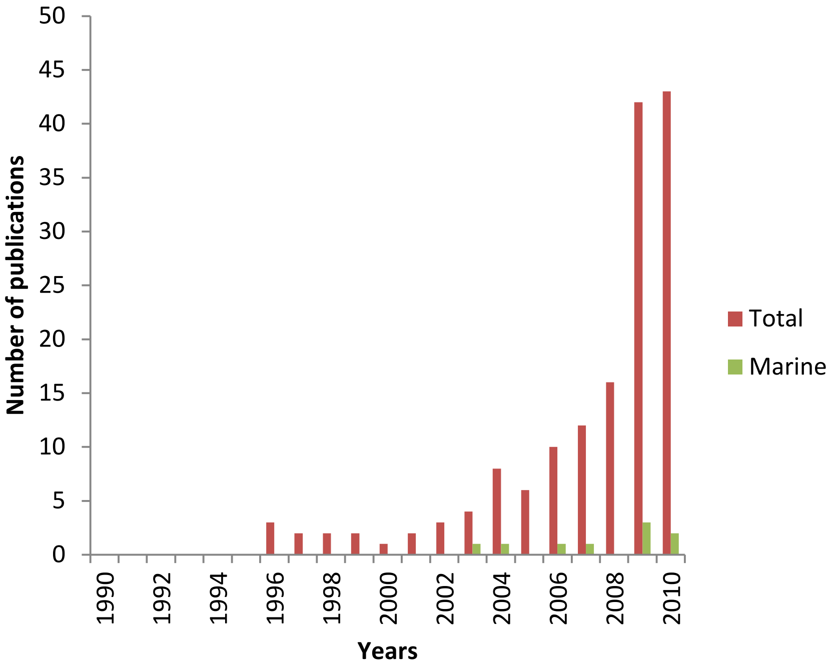

Figure 3. Number of publications using citizen science as a keyword published since 1990 (from Bates et al unpub data)

Of the 26 observations reported nearly 40% were observations not familiar to researchers indicating the potential benefit of fisher's knowledge in expanding scientific knowledge. While most of the impacts were related to the increased strength and penetration of the East Australian Current – the dominant climate signal in this region, several others were related to seasonal winds, rainfall and upwelling. While the majority of observations (70%) could be linked to climate change or variability, fishers also reported observations potentially linked to climate change, but which are currently uncertain (15%) and would involve more detailed research to confirm, and others related to changes in abundance that is considered to reflect trends in populations after release from harvesting (i.e. marine mammals).

Table 7. List of observations provided by fishers and their potential link to climate change.

Fishery	Observation	Possible climate signal	Known to research team
Abalone	1. Drought conditions have allowed better access (to launch boats)	Reduced rainfall	No
Physical	2. Cold water events (increased (magnitude and rate) upwelling in early 2000s)	Increased upwelling due to increased onshore winds. Predicted impact of climate change	Yes
Ecosystem	2a. Increased krill	Cooler water due to upwelling	Yes
Ecosystem	2b. More [paper] nautilus [shells]	Uncertain	No
Abalone	2c. Good catches following upwelling	Cooler waters and increased productivity during upwelling may have led to improved juvenile survival	No
Abalone	3. Recent wet years have improved population abundance – theory=land seepage into coastal regions increases productivity	Uncertain	No
Ecosystem	4. Increase in whale sightings	Increased upwelling = increased food	No
Ecosystem	5. Increased in great white shark sightings and earlier in year	Phenology change	No
Abalone	6. Warm water events in Tasmania have resulted in abalone mortalities	Suspect a combination of temperature and other factors such as still conditions for a number of days.	Yes
Ecosystem	7. Decrease in kelp (primarily *Macrocystsis*)	East Coast has lost nearly 90% of kelp forests – suggested due to increasing temperatures and low nutrients.	Yes
Abalone	8. Recent colder years have resulted in increased recruitment and catches	Negative correlation between water temperature and catchability of abalone during winter/spring	Yes
Abalone	9. 2011 Storm event resulted in lack of a winter spike in the fishery	Uncertain	No
Abalone	10. Increased *Centrostephanus* (sea urchin) barrens has resulted in concentrated fishing effort in smaller areas	*Centrostephanus* is a range extending species facilitated by the East Australian Current.	Yes
Recreational	11. More abundant Bluefin tuna and marlin	Increased abundance due to warming waters. Increased reporting's on REDMAP	Yes
Physical	12. Colder later in winter and warmer longer in summer	Phenology changes associated with timing of EAC	Yes
Ecosystem	12.a More red algae	Uncertain	Yes
Recreational	13. King George Whiting, Snapper and Prawns more abundant then previously seen on East Coast	All recognised as range extending species either following currents or larvae (e.g. Prawns) being distributed by EAC	Yes
Ecosystem	14. *Macrocystis* decline and change in condition (paler in colour and brittle)	Considered to be negatively impacted by warmer temperatures	Yes
Ecosystem	15. Mangrove plant recorded for first time on east coast	Considered to be distributed by EAC and onshore winds	No

Scalefish	16. Substantial decreases in jack mackerel on east coast	Declining nutrients and warming waters lead to decrease in krill condition and abundance and krill is main prey of jack mackerel	Yes
Ecosystem	17. Increased seal populations – also causing increased damage to mutton bird habitats in haul out regions	Assumed to be associated with release from hunting and not climate change response.	Yes
Scalefish and recreational	18. Recent increase in striped and bastard trumpeter catches	Both species have periodic recruitment and there has been observed a recent recruitment event. Uncertain of any climate change impact	Yes
Blue-eye trevalla	19. Increased seal, orca and short finned pilot whale numbers with resultant increased damage to harvested species	Assumed to be a result of populations recovering from previous harvesting activities	Yes
Snapper	20. Both blue swimmer crabs and snapper distributions have changed. Found lower in South Australian Gulfs – Spencer Gulf.	Upper regions considered to be too warm and salty due to increasing temperature	No
Snapper	21. Increased reports of white sharks – considered to be following snapper schools	Snapper is a major dietary item of white sharks. Uncertain of whether observations are linked to abundance changes or distributional shifts. No climate signal currently reported.	No
Ecosystem/ Commercial/ Recreational	22. Increased blue-green algae concentrations caused closure of commercial and recreational fishing in Gippsland lakes. Adjacent school and eastern king prawn fisheries also closed.	2011 had very high summer water temperatures. Increased harmful algal blooms are considered a result of warming waters and predicted to increase under global warming scenarios.	Yes

7.2 CONCEPTUAL SCENARIOS TO IDENTIFY ADAPTATION OPTIONS AND BARRIERS

Whilst the potential impacts of climate change are specific to each species, and occur at different scales within regions, the likely impacts can be broadly summarised as either reducing or increasing abundance, or resulting in distribution shifts (contraction or expansion). Not surprisingly therefore, the adaptation strategies and barriers to adaptation identified through the March 2012 conceptual scenario workshop exercise were relatively consistent across the four species, noting that for some fisheries very specific threats and potential impacts elicited quite specific adaptation responses. For the purpose of this report a summary of both the key autonomous (Table 8) and possible planned (Table 9) adaptation strategies has been prepared.

Table 8. Summary of the key autonomous adaptations to predicted climate change impacts

Impact	Autonomous fisher adaptation	Autonomous fishery management adaptation
Changes in abundance (either absolute or seasonally)	Diversify operations (target other species)	Control catch (TAC) and/or effort
	Shift operation	Adjust size limits
	Adopt technology (new gear, bigger/smaller vessels)	Finer spatial management
Shift in distribution	Shift area of operation	Control catch (TAC) and/or effort
		Adjust size limits
		Finer spatial management

Table 9. Summary of the key possible adaptation strategies to predicted climate impacts

Impact	Possible adaptation strategies to climate change impacts
Changes in abundance (either absolute or seasonally)	Stock enhancement
	Habitat enhancement (e.g. artificial reefs)
	Habitat protection (e.g. maintain freshwater flows, sediment traps)
	Remove barriers to flexible fishing operations provided it does not compromise sustainability objectives (e.g. remove/reduce close seasons, remove gear restrictions)
Shift in distribution	Remove barriers to flexible fishing operations provided it does not compromise sustainability objectives (e.g. remove/reduce close seasons, remove gear restrictions)

The barriers identified to adaptation relate to both autonomous adaptation and possible planned adaptation actions. The following key barriers were identified:

1. Increased costs and/or loss of revenue
2. Increased research and monitoring to address knowledge gaps (additional costs)
3. Protection of existing access rights
4. Differential capacities to adapt between jurisdictions or sectors resulting in shifts in relative resource allocation
5. Jurisdictional boundaries prevent management across the entire distribution of stocks
6. Significant legislative changes may be required in some cases
7. Decision making undertaken within environment of increased uncertainty
8. Lack of stakeholder trust/support for tough decisions

All the potential climate change impacts are described in the adaptation action tables for each species in the respective species chapters.

8. Abalone

BACKGROUND

Abalone are gastropod molluscs that are among the most important of global invertebrate fisheries with typically small, but high value, catches occurring worldwide (Leiva and Castilla 2001, Prince 2003, Mayfield et al 2012). Australian abalone production is globally significant, with these fisheries providing about 60% of world abalone production in 2008 (Cook and Gordon 2010).

The Australian abalone stocks have been commercially fished for ~50 years (Prince and Shepherd 1992, Mayfield et al 2012) with harvests occurring across the five southern States of New South Wales (NSW), Tasmania (Tas), Victoria (Vic), South Australia (SA) and Western Australia (WA). The largest fishery is in Tas (~2,100 $t.yr^{-1}$). Abalone are found in high-energy rocky reef habitats and are hand-harvested by divers. Fishing typically occurs as single day fishing trips, using trailer vessels up to 8m. In remote regions of Tasmania, catch is transferred to wet wells on 'mother boats', where they are held and transported back to port over several days (Tarbath and Gardner 2011). The product is exported live, chilled, frozen (collectively ~60%) or canned (~40%), primarily to China, Japan and Taiwan (Skirtun et al 2011). Abalone fishing is also a popular recreational activity in all southern States.

Fishery management is independent across States, but regulations are comparable and include limited entry, annual total allowable commercial catches (TACCs), minimum legal lengths (MLL; varies among species and States), compliance programs and some degree of spatial management (Prince et al 2008, Mayfield et al 2012). Catches are dominated by blacklip abalone (*Haliotis rubra*; 82%; hereafter referred to as blacklip) and greenlip abalone (*H. laevigata*; 15%; hereafter referred to as greenlip; Mayfield et al 2012). The remainder comprises *H. roei* and *H. conicopora* for which harvests are small and confined to WA (Mayfield et al 2012). This case study considers only greenlip and blacklip.

A number of non-climate stressors need to be taken into account when considering implications of climate change for abalone fisheries. For example, large reductions in adult biomass in Western Victoria due to Abalone Virus Ganglioneuritis (AVG) may increase potential sensitivity to future reductions in productivity resulting from climate change. Illegal fishing is also widespread for abalone and also has potential to exacerbate effects in reductions in future recruitment. Reduced profitability through market issues and competition from aquaculture may also impact on capacity to adapt to climate change impacts.

1. ***Identify likely key effects of climate change particularly where these effects may impact the harvest strategy for this species.***

a. *What are the historical relationships between key oceanographic variables and population dynamics?*

Estimates of size at maturity from sites across Tasmania and South Australia for blacklip populations were obtained from IMAS and SARDI, respectively. Spatially replicated blacklip growth increment data were only available for Tasmania and were obtained from IMAS. These data were used to provide estimates of L_∞ (Von Bertalanffy growth model) and L_{95} (inverse logistic growth model; Haddon et al 2008). No useable data were available for greenlip. SST data were derived from the Pathfinder sensors on the NOAA satellites, and provided by CSIRO (Paper 3). Summer SST was obtained from the 4-month period from December to March. There was an inverse relationship between size at maturity and summer SST (Figure 4). Thus, at warmer summer SSTs, the size at maturity estimates were smaller than those at cooler summer water temperatures. Relationships between summer SST and both L_∞ and L_{95} were less clear. However, there was a general tendency for these metrics to be larger at cool to moderate summer water temperatures (<17°C), and smaller in areas with higher summer SST values (Paper 3).

- Increased water temperatures likely to result in smaller maximum lengths and smaller size at maturity estimates for blacklip.
- No data were available to assess these relationships for greenlip.

b. *What are the historical relationships between key oceanographic variables and distribution?*

Both blacklip and greenlip occupy reefs with wide-ranging estimates for most oceanographic variables (Table 10, Paper 3), indicating a broad tolerance of a range of environmental conditions. For example, both species occupy reefs with a summer SST from 15-23°C, a summer maximum SST of up to 26°C and up to a summer degree heating day value of 320°C. In contrast, greenlip were less tolerant of cold winter SST levels (no greenlip production <11°C) than blacklip. Both species occupied reefs with similar ranges in salinity (34-37.6‰) and pH (8-8.1).

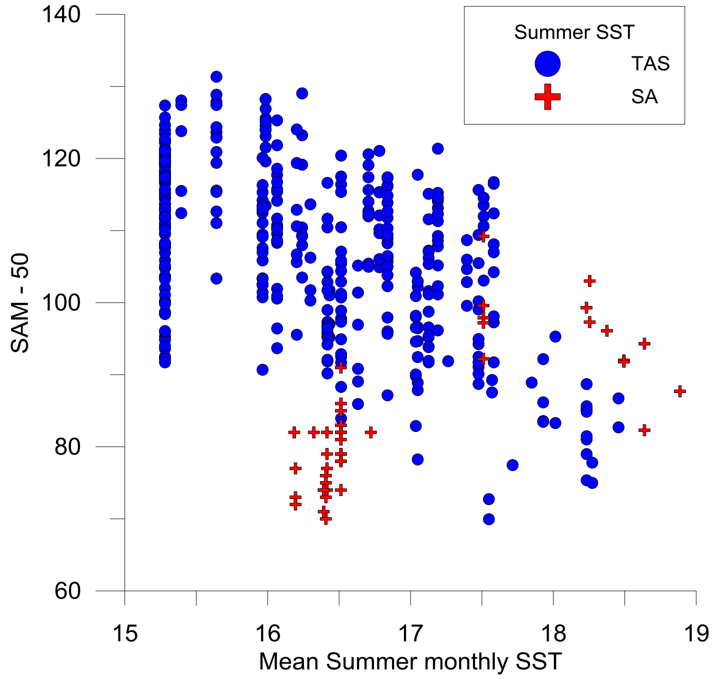

Figure 4. Relationship between SST and size at maturity for blacklip abalone.

Table 10. Environmental variables of abalone spatial management units.

Environmental variable	Unit	No. of spatial units	Mean	StdDev	SD-CV (%)	SE	SE-CV (%)	Max	Min	Range
Tidal flow	$m.s^{-1}$	149	0.09	0.11	123.60	0.01	10.13	0.57	0	0.57
Summer degree heating days	°C	150	61.27	70.01	114.27	5.72	9.33	319.52	0	319.52
Summer degree cooling days	°C	150	39.59	42.58	107.54	3.48	8.78	179.51	0	179.51
Winter wave energy	J	150	51.28	44.91	87.57	3.67	7.15	188.89	0	188.69
chl a	mg.m -3	148	0.65	0.47	72.20	0.04	5.93	4.03	0.26	3.77
Winter degree cooling days	°C	150	243.25	96.29	39.59	7.86	3.23	498.80	13.87	484.93
SST range	°C	150	6.65	2.17	32.63	0.18	2.66	12.78	3.01	9.77
Winter SST	°C	150	14.05	1.62	11.54	0.13	0.94	18.49	9.87	8.63
Summer maximum SST	°C	150	19.72	2.13	10.81	0.17	0.88	26.20	16.03	10.17
Summer SST	°C	150	18.38	1.60	8.69	0.13	0.71	23.00	15.28	7.71
Salinity	‰	145	35.56	0.53	1.48	0.04	0.12	37.59	34.03	3.55
pH	-	129	8.06	0.03	0.37	0.00	0.03	8.11	8.01	0.10

High catches of blacklip have typically been associated with low greenlip catches, and the converse, demonstrating a limited overlap in geographic distribution of the productive fishing grounds for these two species (Paper 3). Productive blacklip stocks have a broader geographic distribution than those of greenlip: (1) blacklip catches have been reported from a greater proportion (93%) of the spatial units when compared with greenlip (69%; Paper 3) and (2) blacklip catches span a broader latitudinal range (12°; 32 – 44°) than those for greenlip (10°; 32 – 41°; Paper 3). In contrast, greenlip catches (33°; 115 – 148°) encompassed a broader longitudinal range than those for blacklip (18°; 133 – 151°), reflective of the long south-facing coastline (Paper 3).

> - Both species occupy reefs with wide-ranging estimates for most oceanographic variables, indicating a broad tolerance of a range of environmental conditions.
> - Productive fishing grounds for greenlip and blacklip have a limited spatial overlap.

c. *What are the historical relationships between key oceanographic variables and productivity?*

There were several strong relationships between blacklip production and key oceanographic variables (Paper 2). Notably, warmer water temperatures during summer were typically associated with lower blacklip catches. Spatial units with low SST ranges, lower salinity levels and slower tidal flow rates also typically had higher blacklip catches. Some relationships between blacklip catches and oceanographic variables were less clear (e.g. winter SST, winter degree cooling days, pH and ChlA).

Catch data also suggests that there is a relationship between blacklip catches and both the length and strength of summer (high catches typically obtained from those spatial units with short, cool summers) rather than winter intensity or duration.

There were, however, several exceptions to this pattern because blacklip catches were frequently highly variable within narrow ranges of the 12 oceanographic variables considered. For example, for summer SST values between 15 and 16.5°C, blacklip catch ranged from 5.4 to 386.7 $t.yr^{-1}$ (Paper 3). Similarly, the large blacklip catches from area 24 in Vic (274.6 $t.yr^{-1}$, 3rd highest value across the 150 spatial units), located at the eastern end of that State, were associated with substantially warmer summer water temperatures than observed in spatial units yielding similar catches (Paper 3). These exceptions indicate that other variables not considered in this study (e.g. habitat complexity, food quality and quantity) are also likely to strongly influence production.

Relationships between greenlip catches and the oceanographic variables considered in this study were less clear than those for blacklip, in part because substantial greenlip catches from two spatial units, Tiparra Reef in SA (96.2 $t.yr^{-1}$) and Augusta in WA (51.9 $t.yr^{-1}$; Paper 3), strongly influenced these relationships. Outside of these spatial units, greenlip catches generally declined with increasing summer degree heating days and increasing winter degree cooling days (Paper 3).

In addition, larger greenlip catches tend to have been obtained from those spatial units 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 (Paper 3). Thus, greenlip catches have been smallest in spatial units with intensive and lengthy summers and winters.

- Large blacklip catches typically obtained from areas with short, cool summers, although several exceptions were identified.
- General trend of larger greenlip catches from areas with relatively stable water temperatures with a low incidence of high summer, cold summer and cold winter temperatures, although relationship less clear than for blacklip.

d. How might larval dispersal be altered by changes in climatic conditions, and what might be the implications of any changes for larval survival?

Larval development of haliotids is strongly influenced by temperature, with a shortening of time to competency with increasing water temperature. For blacklip and greenlip, at 12C larval development is expected to take around 12 days, whereas at 20C, larval development may be as short as 4 days (Grubert and Ritar 2004). The primary outcome of increased temperatures associated with climate change is a shortening of the pelagic phase, which is expected to have two consequences for recruitment processes. Firstly, a shorter pelagic phase is likely to result in lower rates of larval mortality simply through a reduction in exposure risk. Secondly, there may be a potential reduction in the spatial scales of connectivity, as a consequence of reduced time for dispersal, increasing the level of self-recruitment, and decreasing the connectivity between distant populations. For blacklip abalone where connectivity on the East Coast of Tasmania is already highly localised, this change is not likely to be important for the fisheries ecology of blacklip abalone. For greenlip abalone however, where larval dispersal is much greater (Miller, Mundy et al in prep), temperature driven changes in the pelagic phase may be more significant.

The impacts of ocean acidification on abalone larval development are less clear. (Byrne et al 2011) found elevated temperature and lower pH negatively affected larval development in *Haliotis cocchoradiata*. (Crim et al 2011) also found negative effects of lowered pH on larval development of *H. katschatkana*, although of those larvae surviving to the later larval stages, the proportion metamorphosing was not different to ambient pH conditions.

- Increased water temperatures likely to reduce larval development period, resulting in increased survival and decreased dispersal for both blacklip and greenlip abalone
- Acidification may negatively affect the development of larvae, if they are unable to adapt to changes in pH.

e. *What are the key ecosystem/ecological/habitat relationships, and how may these alter under a changing climate?*

The key ecosystem, ecological and habitat relationships for blacklip and greenlip are habitat structure, competition, predation and the availability of suitable habitat for larval settlement. Marine species' distributions are strongly influenced by the environment (Russell et al 2012). Consequently, a changing climate is likely to impact on the distribution and productivity abalone stocks because of (1) range shifts, altered recruitment and altered growth rates of competitors and predators that may also (2) alter habitats (Johnson et al 2005, Thresher et al 2007, Pecl et al 2009, Pitt et al 2010, Last et al 2011, Pecl et al 2011). While future changes are difficult to predict, the impact of climate change on these ecological relationships is already evident. For example, in south east Australia, the East Australia Current has strengthened (Ridgway 2007), water temperature has risen 1.5 °C since the 1950's (Hobday et al 2008), pelagic fish communities have altered (McLeod et al 2012), giant kelp *(Macrocystis pyrifera)* distribution has contracted 95% since 1940 (Johnson et al 2011) and range expansion of the long-spined sea urchin *Centrostephanus rodgersii* from New South Wales to Victoria and Tasmania has altered benthic habitats through barrens formation (Andrew et al 1998, Ling 2008, Johnson et al 2011). It is likely that these trends will continue, and possibly magnify, over the next 50 years as the climate continues to warm. In addition, increased acidification is likely to reduce the availability of crustose coralline substrates for larval settlement and early development (Doney 2006, Cooley 2012). Collectively, these would substantially impact recruitment and productivity.

- Range shifts, altered recruitment and altered growth rates of competitors and predators likely to influence abalone production, in part through altered habitats
- Increased acidification could reduce the availability of crustose coralline substrates for larval settlement and early development.

f. *To what extent may climate change, through an altered physical environment, influence access to current or future fishing grounds? Consider swell, winds, storm events, wave height.*

- Not undertaken within this project

g. *To what extent might climate change influence stocks/fisheries? Consider both slow trends and potential for extreme events or 'surprises'.*

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 key ways: (1) the gradual increase in water temperature and ocean acidification; (2) increased frequency and magnitude of extreme events (e.g. marine heat waves; Pearce et al 2011); and (3) indirectly via climate-driven alterations to ecosystem dynamics.

The projected environmental data in ~2060 across the spatial extent of the Australian abalone fisheries will be in most cases, substantially different to those observed historically (Paper 3). Key differences were increases in (1) mean summer temperature (increase: 2.8°C), mean winter temperature (increase: 3.5°C) and mean summer maximum (increase: 2.3°C) SSTs; (2) lower estimates of summer and winter degree cooling days; and (3) a decrease in pH (mean decrease: 0.18). These differences were clearly evident in the MDS plots (Paper 3), which show little overlap between the historic and projected environmental conditions across spatial units, especially for greenlip. Predicted changes in summer SST were highly variable among spatial units, and un-related to historic catch.

The predicted summer SST values in ~2060 were inversely related to historic blacklip production Paper 3). Thus, those areas that have produced the highest blacklip catches are predicted to remain among those with the lowest summer SST values. In contrast, for greenlip, those areas from which most of the historic catch has been obtained are predicted to be the warmest in ~2060. GLM models for projecting blacklip catches were statistically significant, but had small pseudo r^2 values, indicating that the proportion of variance explained by these models was low (range: 6% – 11%) and, consequently, their predictive power limited. Nevertheless, all seven models tested projected lower blacklip catches in 2060 (range: 10% to 58%; Figure 5). There was also substantial variability in projected catch reductions among spatial units (range: 5.7 – 46.4%), but no significant relationship between the predicted proportional reduction and historic annual catch ($r = 0.25$, $P > 0.05$). No estimates of future greenlip catches were made because the pseudo r^2 values were low (<0.05) and, consequently, none of the fitted GLM models were statistically significant ($P > 0.2$). Thus, for blacklip, it appears more likely that there will be a negative rather than a positive effect of climate change on total production – and with these changes being spatially variable. Whilst the mechanisms underpinning these changes are poorly understood, the gradual environmental changes are likely to impact production through changes in growth rates (slower) and a smaller maximum size (smaller). Uncertainties over physiological optimum growth rates however, may see growth rate increases in the cooler abalone fisheries where summer temperatures often do not reach the physiological optimum for growth and reproduction. For greenlip, the long-term effects of climate change are considerably more difficult to determine, and it is not yet clear if or how this species will be affected. Notably, the highest catches are already harvested from reefs with the highest SST and salinity values across the extent of the fisheries (Paper 3).

For both species, there is also the likelihood that increased temperatures will result in elevated disease expression, notably bacterial infections, AVG and Perkinsus. Hygiene, stocking rates and handling practices in processing facilities may need to be tightened in areas where temperatures are predicted to rise considerably above current temperature ranges. Most Tasmanian live export processors routinely hold animals at 12.5°C, thus for this phase of the harvest and export process, warming related issues may be negated, albeit at a higher operational cost.

An increase in both the magnitude and frequency of extreme events, such as marine heat waves, are likely to have substantially greater, short-term impacts on abalone stocks and the fisheries. For example, in 2010, an increase in water temperature resulted in mortality of blacklip abalone in one of the most important fishing grounds for this species in Australia, the Actaeons in Tasmania. Additionally, a rapid increase in SST to >26°C following two months of elevated water temperatures off WA in the summer of 2010/11 resulted in very high levels of mortality in *H. roei* over an extended area to the north of the Murchison River (Pearce et al 2011). Subsequent surveys by commercial fishers failed to locate any live abalone and the area is closed to harvest. More recently, in SA, elevated water temperatures were considered to be the cause of a widespread mortality of blacklip abalone, with estimates of stock loss exceeding 50% in some locations (Government of South Australia 2013). Consequently, despite being classified as "lightly fished" (Mayfield et al 2013), the TACC in the Southern Zone was not increased for the 2013/14 season. If temperature related mortality events of these magnitudes continue to occur they will almost certainly result in catch reductions. Should the frequency and severity increase, as predicted, those reductions in catch could be rapid and substantial.

In addition to the direct effect of climate change, there may also be several indirect impacts on production. These include range expansion of competitors/predators (see above), resulting in altered habitats, and a potential reduction in the quality of the abalone product. The latter includes increased challenges in handling and transporting abalone for the live market, and the proportion of large greenlip suitable for export in a frozen form. It is also possible that the nearshore wind and wave environment could alter substantially. If, for example, the frequency and duration of calm-weather periods reduced (calm weather required for diving in shallow water to harvest abalone) this may make harvesting the allocated TACCs challenging.

- Determining the extent to which climate change may influence the Australian abalone stocks is challenging.
- For blacklip, the most likely outcome will be a reduction in total production – but with these changes being variable across space, less clear for greenlip.
- The Australian abalone fisheries are also likely to be negatively impacted by an increased frequency and magnitude of extreme events (e.g. marine heat waves)

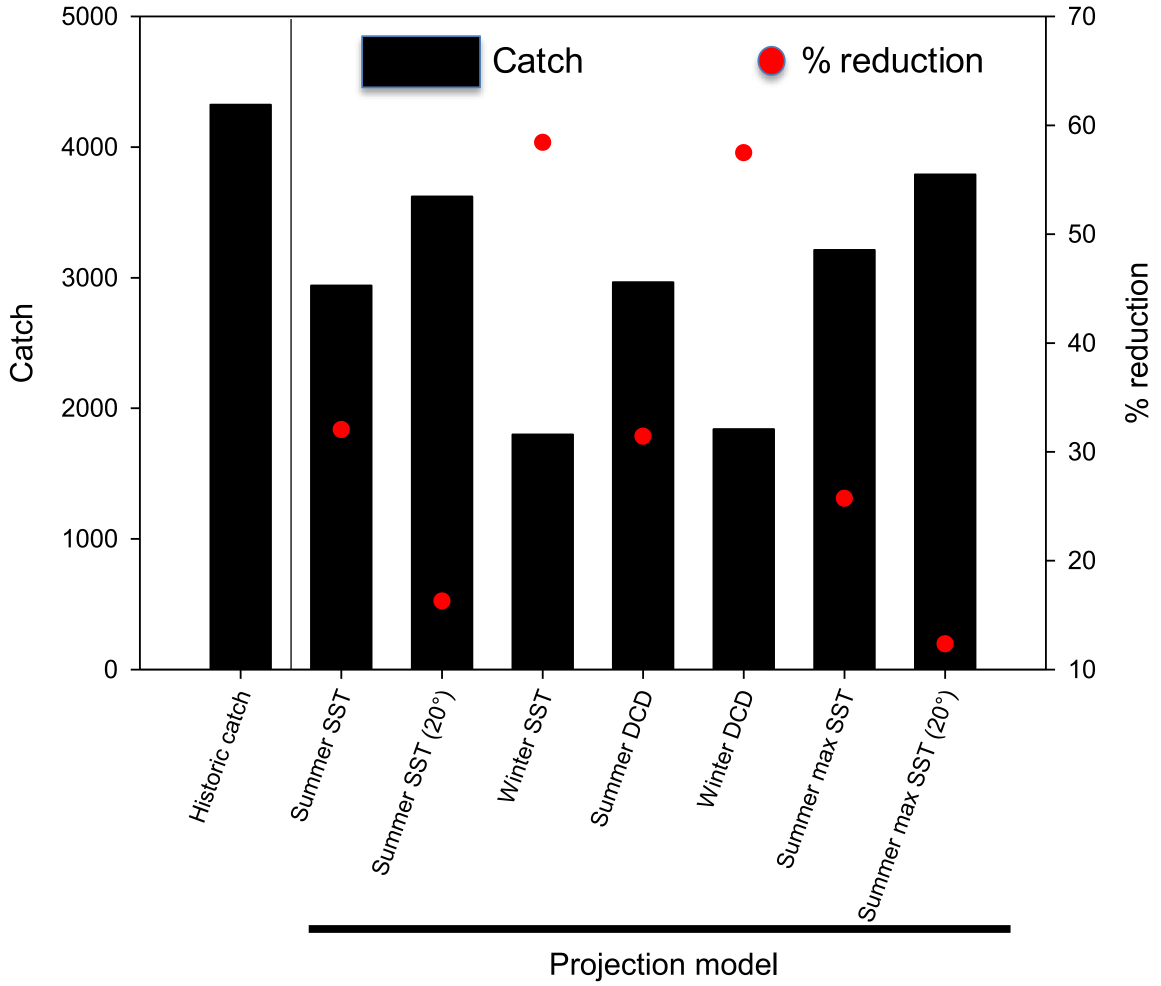

Figure 5. Catch projection model based on predicted environmental variables in 2060.

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).***

Reasonably good biological data (e.g. age/size, growth and reproduction) are available for abalone in all jurisdictions. However, patterns of growth and recruitment are highly variable over a range of spatial and temporal scales. Ongoing programs to monitor spatial and temporal variability in these parameters are limited due to high costs. These factors limit the use of stock assessment models to produce indicators of stock status. Fisheries data are collected and analysed at relatively fine spatial scales in most jurisdictions. Fishery-independent surveys are conducted in some jurisdictions but are expensive and necessarily limited in scope. The limitations of empirical measures traditionally used to assess abalone stock status (i.e. CPUE, size structure of the commercial catches, density estimates from fishery-independent surveys) are widely acknowledged. These limitations also constrain existing capacity to detect changes in abundance and productivity resulting from climate change. Recent attempts to integrate multiple empirical measures to provide a single measure of stock status have met with some success (Stobart et al 2013). Current research projects investigating the development of new indicators that utilize high resolution spatial data from commercial fishing appear to provide an opportunity to greatly improve the robustness of abalone stock assessments. If successful these new measures will dramatically increase our capacity to detect future alterations in biomass and productivity resulting from climate change. Reference points and decision rules for the Australian abalone fisheries are currently being established and the potential impacts of climate change are being considered as part of this process. Fisheries are managed using TACs and minimum size limits that in some cases vary over relatively fine spatial scales.

a. Does additional data needed to be collected to understand the cause and scale of changes? (e.g. is spatial resolution of data adequate to detect changes in distribution or changes in timing or location of spawning etc?)

Four sets of additional data are required to understand and respond to climate-induced changes. These are *in situ* water temperature monitoring, and sampling periodically to monitor changes in growth rates, size at maturity and abundance. These should be undertaken in key fishing grounds and the utility of SST as a mechanism to expand these finding more broadly investigated. The additional data should be integrated with existing data sets and the spatial scales of assessment and management reconsidered. This should include consideration of the need for spatially-explicit minimum legal lengths and catch caps to ensure these reflect any changes in population dynamics and productivity that may occur through climate change.

In addition, it would be useful to (1) evaluate the projected changes to the nearshore wind and wave environment from model outputs to identify the need for structural adjustments in the fishing fleet, (2) determine the responsiveness of existing harvest strategies using MSE, and (3) monitor product quality (e.g. rejection rate in harvests for live export). The first of these should include a review of legislative arrangements, particularly with respect to their flexibility/adaptability if needed.

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

b. Will current measures of stock status remain appropriate?

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; (Mundy 2012)) are likely to provide valuable additions to these.

> ➢ No changes required to current measures/practices for assessing stock status.

c. Will reference points need to be changed?

Reference points for the Australian abalone fisheries are currently being established with the potential impacts of climate change in mind. Two harvest strategies are being developed and/or implemented, including substantial revision and evaluation of reference points. Reference points that explicitly relate to catch as a performance measure will need to be modified to allow for possible changes in productivity associated with climate change.

> ➢ Catch related reference points may need to be revised to account for reduced productivity associated with climate change.

d. Do model assumptions need to change (e.g. constant growth rates)

Length/age structured models are not used in Australia for assessment of abalone stocks. However, MSE simulations do rely on growth information, but can easily be updated and or modified to test specific hypotheses relating to temperature driven changes in growth.

> ➢ Models easily adjusted to test or incorporate temporal changes due to warming.

e. Do decision rules need to change (e.g. do TACs at different abundance levels need to be reduced to reflect decreases in recruitment?)

As with the reference points, decision rules for abalone fisheries are in a formative stage in most states. Decisions rules that explicitly include catch as a performance measure will need to be modified to allow for possible changes in productivity associated with climate change.

> ➢ Minor modifications to reference points will be required in some circumstances as a consequence of climate change.

f. Is coordination among jurisdictions adequate to address potential changes?

There are strong industry links across jurisdictions through two peak bodies – (Abalone Council of Australia (ACA) and Abalone Association Australasia (AAA)) – that can provide over-arching guidance for industry. No formal structures exist specifically for coordination and cooperation between researchers and managers. However, annual Marine and fisheries conferences can provide a regular forum for scientific interchange, although funding restrictions can prevent researchers from attending regularly. At a high level there is interaction among heads of management agencies, but there are few opportunities for managers to interact on any issues including climate change.

- Adequate industry coordination among and across jurisdictions to address potential changes as a consequence of climate change.
- Annual research conferences provide a forum for researcher interaction.
- Few opportunities exist for managers to interact.

3. Identify climate change impacts, adaptation options and barriers

Table 11 lists the autonomous and possible planned adaptation actions that were elicited from stakeholders in response to the potential climate change impacts presented at the March 2012 workshop. Stakeholders also identified likely barriers to implementing any possible planned adaptation actions.

Table 11. Adaptation options and potential barriers to implementing possible adaptation options for abalone

POTENTIAL IMPACT	AUTONOMOUS ADAPTATION	POSSIBLE ADAPTATION ACTIONS	BARRIERS
Changes to weather patterns influencing access to fishing grounds; spatial shifts in fishing effort/catch	1. Prioritise fishing options 2. Mobilise fleet in good weather 3. Increase coordination & cooperation amongst catching sector 4. Increase number of Mother boats	1. Increase number of licences 2. Increase number of divers/license 3. Manage to increase biomass 4. Carry quota over years quota transfers 5. Move divers among zones	1. Legislation limiting entry to fishery Economic viability of divers 2. Cost of implementation 3. Knowledge 4. Management inertia 5. Licence conditions/regulations
Abalone range shifts; within and among zones	1. Divers move within zone 2. Accept lower catch 3. Accept lower CPUE	1. Implement spatial management Reduce TACC 2. Stock enhancement through selective breeding	1. Cost 2. Ownership and equity in enhanced stock 3. Knowledge
Range shift of predators/ competitors/habitat modifiers (e.g. *Centrostephanus*)	1. Accept lower CPUE Accept lower TACC 2. Undertake industry based cull programs (*Centrostephanus*) 3. Diversify into urchin harvesting	1. Fishery & product development (e.g. urchin roe from *Centrostephanus*) 2. Revise access rights	1. Cost 2. Knowledge
Changes in the prevalence of disease	1. Accept lower CPUE 2. Alter handling practices to minimise stress on animals harvested 3. Fish only when conditions are suitable	1. Close fishing grounds during high risk periods 2. Spatial management 3. Implement biosecurity protocols 4. Stock enhancement - selective breeding for disease resistance, thermal tolerance?	1. Cost 2. Knowledge
Changes in productivity -Impacts on reproductive biology & growth from changing water temperatures and water chemistry; - Changes in spatial or temporal variation in recruitment - Changes in spatial and temporal variation in growth	1. Alter TACC 2. Accept lower CPUE 3. Finer-scale spatial assessment 4. Periodic review of key biological parameters (growth, size at maturity) 5. Temporal closures to protect spawning Spatial management 6. Amend size limits	1. Spatial assessment 2. Spatial management 3. Alternate output controls	1. Cost 2. Knowledge

The governance benchmarking exercise also identified a number of potential barriers to adaptation for the abalone fisheries in each jurisdiction (Table 12). Governance for abalone fisheries needs to be improved in some jurisdictions. Of the 47 individual barriers that were identified across all four of the case study species and all jurisdictions, 23 of those were identified within the NSW abalone fishery alone. Of the 42 attributes across the governance areas of Acountability (AC), Planning (P), Transparency (T), Incentives (I), Adaptability (AD) and Knowledge (K), the abalone fishery in NSW only recorded 'partially in place and always/mostly operational' for six attributes. The goals and objectives of fishery management are not clearly defined in abalone fisheries of NSW, Tasmania and Victoria. Additionally, 'incentives were not fully aligned with goals and objectives' in NSW, South Australia and Victoria. Several potential barriers to adaptation were also identified in the 'Accountability' section of the benchmarking exercise. For example, 'independent fishery report cards and/or accreditation' is only 'partially in place and rarely/never operational' in South Australia. In the Tasmanian abalone fishery 'economic, social and community performance indicators' are 'not in place and importance not recognised.

Table 12. Summary of barriers to adaptation related to fisheries governance attributes for the abalone fisheries. Accountability (AC), Planning (P), Incentives (I), Adaptability (AD) and Knowledge (K).

Jurisdiction	Summary of barriers
New South Wales	Potential barriers were highlighted for 23 attributes. These are outlined in appendix 4
South Australia	• Independent fishery report cards and/or accreditation (AC) • Planning occurs across the entire fishery value chain (P) • Incentives fully aligned with goals and objectives (I) • Mechanisms to ensure re-investment of some economic rent in fishery (I) • Flexibility to manage range shifting species (AD)
Tasmania	• Economic, social and community performance indicators (AC) • Ecosystem performance indicators (AC) • Planning includes risk assessment and evaluation (P) • Incentives to avoid negative externalities, including habitat damage and by-catch (I) • Monitoring of negative externalities (I)
Victoria	• Clear processes for making trade-offs between conflicting objectives (T) • Flexibility to manage range shifting species (AD)

Prior to evaluating potential adaptation options, the revised adaptation options were furthered refined and analysed using a characterisation matrix which identified the key characteristics of the adaptation options being considered for further evaluation (Table 13). This was considered an important step to map out implications, interactions with other management strategies and issues of temporal and spatial scales.

4. Evaluate potential adaptation options

We assessed two of the eight climate challenges identified for the abalone fishery; (1) mortality events from thermal shock and (7) altered weather patterns. In regard to mortality events through thermal shock we examined the adaptation options of: reducing the TACC (by up to 40%) and bringing the harvest forward when forecast (i.e. when heat event is forecast, divers can forward harvest their quota to catch fish that would otherwise die in the predicted mortality event). When combining all sectors, both adaptation options were ranked similarly, however a 'high' feasibility ranking was given to reducing the TACC, whereas accelerating the harvest was ranked as 'moderate' (Table 14, Figure 5).

When looking at the sector responses to both adaptation options, they were reasonably consistent, with some notable differences. Industry ranked both adaptation options as a 'moderate' risk, whereas management and research considered the risk to be either 'low' or 'very low'. Whilst the consensus rankings were relatively strong for the option of reducing the TACC, over all sectors combined the consensus on both the feasibility and risk of brining the harvest forward were both 'low' (Table 14, Figure 5).

In addressing the climate challenge of altered weather patterns we assessed six identified adaptation options. All adaptation options were ranked similarly when all responses were combined, with none of the options being ranked above 'low' in terms of benefit (Figure 6). When looking at each option, the different sectors were reasonably consistent with the rankings for risk and benefit, with the majority of difference being in the feasibility scoring. The biggest differences were between industry and the other sectors, with industry tending to rank the feasibility of adaptation options as 'very low' to 'low'. These differences are clearly demonstrated in Fleet Mobilisation (7a), Increased use of mother boats (7b) and greater flexibility in quota transfers (7e) (Table 14, Figure 6).

For most of the adaptation options assessed for the abalone fishery, industry ranked benefit and feasibility lower than that of management and research. It may well be that those industry members who participated are relatively conservative and/or sceptical of the ability to implement management changes. In cases such as this it would be worthwhile further investigating where the main differences lie between the stakeholder groups by analysing the individual criteria scored for feasibility, risk and benefit, which this process allows you to do.

Table 13. Abalone: final list of suggested potential adaptation options, and a characterisation of each option.

ABALONE			IMPLEMENATION CHARACTERISTICS							BENEFIT CHARACTERISTICS				
Challenge No. Option No.	CLIMATE CHALLENGE (includes potential impact/s) POTENTIAL ADAPTATION OPTIONS	ADAPTATION TYPE	SCALE OF APPLICATION	JURISDICTION/S	SIGNIFICANCE OF DIFFERENCE BETWEEN JURISDICTIONS	LEAD TIME TO IMPLEMENTATION	ADDITIONAL COST	WHO PAYS	LEVEL OF CONTROVERSY	PRIMARY BENEFICIARY	SCALE OF BENEFIT	CONSEQUENCE PERIOD (once implemented)	ADDRESSES OTHER CLIMATE CHALLENGES?	BARRIERS
		Autonomous, Business-As-(Mostly)-Usual, Incremental, Transformative	National, State, Zone, Sub-zone	Name which jurisdictions (i.e. TAS, VIC, SA, C'Wealth)	Low,Medium,High	<1 year,1-5 years,>5 years	Nil,Low,Medium,High	Industry, Government, Consumers, Post-Harvest, Local communities	Low,Medium,High	Fishers,Fishery,Fish Stock,Ecosystem	National, State, Zone, Sub-zone	<1 year,1-5 years,>5 years	Name which ones	
1	**Mortality from thermal shock (extreme events) 1. Locally (e.g. Actaeon Is. 2010) 2. Regionally (e.g. SA SZ 2013)**													
1a	Reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	Zone	State/Zone	Low	<1 year	Nil	Variable among States	Medium	Fish Stock	Zone	1-5 years		Cost
1b	Spatial management - catch controls	Incremental	Sub-zone	State/Zone	High	1-5 years	Medium	Variable among States	High	Fish Stock	Sub-zone	1-5 years		Knowledge
1c	When forecast, bring harvest forward	Transformative	Sub-zone	State/Zone	High	1-5 years	Medium	Variable among States	High	Fishers	Sub-zone	1-5 years		Legislation
1d	Closed season (within annual season)	Incremental	Zone	State/Zone	Medium	1-5 years	Low	Variable among States	High	Fish Stock	Zone	1-5 years		Management Inertia
1e	Stock enhancement - selective breeding for thermal resistance	Transformative	Sub-zone	National	High	>5 years	High	Variable among States	High	Fish Stock	Sub-zone	>5 years		
2	**Reduced productivity 1. Locally (e.g. Tas blocks 11-13; Vic Area 24) 2. Regionally (e.g. SA CZ, SZ)**													
2a	Reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	Zone	State/Zone	Low	<1 year	Nil	Variable among States	Medium	Fish Stock	Zone	1-5 years		Cost
2b	Spatial management - catch controls	Incremental	Sub-zone	State/Zone	High	1-5 years	Medium	Variable among States	High	Fish Stock	Sub-zone	1-5 years		Legislation
2c	Review Harvest strategy	Business-As-(Mostly)-Usual	State	State	Medium	1-5 years	Low	Variable among States	Medium	Fish Stock	Sub-zone	1-5 years		Management Inertia
2d	Stock enhancement - selective breeding for thermal resistance	Transformative	Sub-zone	National	High	>5 years	High	Variable among States	High	Fish Stock	Sub-zone	>5 years		
2e	Translocation	Transformative	Sub-zone	State/Zone	High	>5 years	High	Variable among States	High	Fish Stock	Sub-zone	>5 years		
3	**Biological changes 1. Changes in size at maturity 2. Changes in growth rate, max size and weight 3. Changed time period from size at maturity to MLL 4. Spatial and/or temporal recruitment changes**													
3a	Periodic review of biological parameters	Business-As-(Mostly)-Usual	Sub-zone	State	Low	1-5 years	Medium	Variable among States	Low	Fish Stock	Sub-zone	1-5 years		Cost
3b	Spatial management - variable MLLs and catch controls	Incremental	Sub-zone	State/Zone	High	1-5 years	Medium	Variable among States	High	Fish Stock	Sub-zone	1-5 years		Knowledge
3c	Review Harvest strategy	Business-As-(Mostly)-Usual	State	State	Medium	1-5 years	Low	Variable among States	Medium	Fish Stock	Sub-zone	1-5 years		Legislation
3d	Reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	Zone	State/Zone	Low	<1 year	Nil	Variable among States	Medium	Fish Stock	Zone	1-5 years		Management Inertia
3e	Closed season (within annual season)	Incremental	Zone	State/Zone	Medium	1-5 years	Low	Variable among States	High	Fish Stock	Zone	1-5 years		
4	**Disease expression 1. Perkinsus 2. AVG 3. 3. Algal blooms**													

4a	Design comprehensive biosecurity system	Incremental	State	National	Low	1-5 years	Medium	Variable among States	Low	Fish Stock	State	<1 year		Knowledge
4b	Stock enhancement - selective breeding for disease resistance	Transformative	Sub-zone	National	High	>5 years	High	Variable among States	High	Fish Stock	Sub-zone	>5 years		Legislation
4c	Closed season (within annual season)	Incremental	Zone	State/Zone	Medium	1-5 years	Low	Variable among States	High	Fish Stock	Zone	1-5 years		
4d	Spatial management - variable MLLs and catch controls	Incremental	Sub-zone	State/Zone	High	1-5 years	Medium	Variable among States	High	Fish Stock	Sub-zone	1-5 years		Management Inertia
4e	Reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	Zone	State/Zone	Low	<1 year	Nil	Variable among States	Medium	Fish Stock	Zone	1-5 years		
5	**Product quality** **1. Changed product characteristics**													
5a	Alter handling practices, including timing of fishing	Incremental	State	State	Medium	1-5 years	Low	Variable among States	Low	Fishers	State	<1 year		Cost
5b	Vary/develop alternate products/markets for greenlip and blacklip	Incremental	State	State/Zone	Medium	1-5 years	Low	Variable among States	Low	Fishery	State	<1 year		Knowledge
5c	Closed season (within annual season)	Transformative	National	National	Medium	>5 years	Medium	Variable among States	Medium	Fishers	State	1-5 years		Need to modify existing marketing systems
6	**Altered habitats** **1. Changed abundance of predators/competitors** **2. Changed abundance of preferred algal species**													
6a	Undertake competitor/predator kills	Transformative	Zone	State/Zone	Medium	1-5 years	High	Variable among States	High	Fish Stock	Sub-zone	1-5 years		Cost
6b	Fishery & product development (e.g. urchin (Centrostephanus))	Transformative	Zone	State/Zone	Medium	1-5 years	Medium	Variable among States	High	Fish Stock	Sub-zone	1-5 years		Knowledge
6c	Reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	Zone	State	Low	<1 year	Nil	Variable among States	Medium	Fish Stock	Zone	1-5 years		Management Inertia
6d	Spatial management - catch controls	Incremental	Sub-zone	State/Zone	High	1-5 years	Medium	Variable among States	High	Fish Stock	Sub-zone	1-5 years		
6e	Review Harvest strategy	Business-As-(Mostly)-Usual	State	State	Medium	1-5 years	Low	Variable among States	Medium	Fish Stock	Sub-zone	1-5 years		
6f	Habitat enhancement	Transformative	Sub-zone	State	High	>5 years	High	Variable among States	High	Fishers	Sub-zone	>5 years		
6g	Closed season (within annual season)	Incremental	Zone	State/Zone	Medium	1-5 years	Low	Variable among States	High	Fish Stock	Zone	1-5 years		
7	**Altered weather patterns** **1. Changes to wind/swell patterns (eg: west coast of Tas and southern zone SA)**													
7a	Prioritise fishing trips including fleet mobilisation	Incremental	Zone	State/Zone	Low	1-5 years	Low	Variable among States	Low	Fishers	Zone	<1 year		Existing legislation (limited entry, licence conditions, regulations)
7b	Increase use of mother boats	Incremental	Zone	State/Zone	Medium	1-5 years	Low	Variable among States	Medium	Fishers	Zone	<1 year		Economic viability of licences/divers
7c	Change number of divers	Transformative	Zone	State/Zone	Medium	1-5 years	Low	Variable among States	High	Fishers	Zone	<1 year		Implementation cost
7d	Stop fishing to increase biomass (raise CPUE)	Transformative	Zone	State/Zone	Medium	>5 years	Medium	Variable among States	High	Fishers	Zone	1-5 years		Management inertia
7e	Carry quota across years	Transformative	State	State/Zone	Medium	1-5 years	Medium	Variable among States	High	Fishers	Zone	1-5 years		
7f	Flexibility in quota transfers	Incremental	State	State	Medium	1-5 years	Low	Variable among States	Low	Fishers	Zone	<1 year		
8	**Acidification** **1. Changed larval development**													
8a	Reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	Zone	State/Zone	Low	<1 year	Nil	Variable among States	Medium	Fish Stock	Zone	1-5 years		
8b	Spatial management - variable MLLs and catch controls	Incremental	Sub-zone	State/Zone	High	1-5 years	Medium	Variable among States	High	Fish Stock	Sub-zone	1-5 years		
8c	Review Harvest strategy	Business-As-(Mostly)-Usual	State	State	Medium	1-5 years	Low	Variable among States	Medium	Fish Stock	Sub-zone	1-5 years		

Table 14. Average scores and consensus level by sector for assessed adaptation options for the abalone fishery.

Climate Challenge	Adaptation Option	Sector	Feasibility		Risk		Benefit		No. respondents
			Average	Consensus	Average	Consensus	Average	Consensus	
Mortality event through thermal shock (extreme event)	1a. Reduce the TACC by up to 40%	Industry	Moderate	High	Moderate	High	Low	Low	3
		Management	Moderate	Low	Low	High	Moderate	High	3
		Research	High	High	Low	High	Low	High	3
		All sectors combined	High	High	Low	High	Low	High	9
	1c. Bring harvest forward when forecast	Industry	Low	Medium	Moderate	Medium	Low	High	4
		Management	Moderate	Medium	Very low	High	Moderate	Low	3
		Research	Moderate	Low	Low	High	Low	High	3
		All sectors combined	Moderate	Low	Low	Medium	Low	High	10
Altered weather patterns	7a. Fleet mobilisation - prioritising fishing trips/areas	Industry	Low	Medium	Low	High	Low	Medium	4
		Management	Moderate	High	Low	High	Low	High	3
		Research	High	High	Very low	High	Moderate	High	3
		All sectors combined	Moderate	High	Very low	High	Low	High	10
	7b. Increase use of mother boats	Industry	Very low	Medium	Low	High	Low	Medium	4
		Management	Moderate	Low	Low	High	Low	High	3
		Research	Moderate	High	Low	High	Low	High	4
		All sectors combined	Low	Low	Low	High	Low	High	11
	7c. Change number of divers	Industry	Low	High	Low	High	Low	Medium	4
		Management	Low	High	Low	High	Low	High	3
		Research	Moderate	High	Very low	High	Low	High	3
		All sectors combined	Low	High	Low	High	Low	High	10
	7d.Stop fishing to increase biomass & CPUE	Industry	Low	High	Moderate	High	Low	High	3
		Management	Very low	High	Low	Low	Low	High	2
		Research	Low	High	Low	High	Low	High	2
		All sectors combined	Low	High	Low	High	Low	High	7
	7e. Carry-over quota	Industry	Low	Low	Low	High	Low	Low	4

		Management	Moderate	High	Low	High	Moderate	High	3
		Research	Moderate	High	Low	High	Moderate	High	5
		All sectors combined	Moderate	Medium	Low	High	Low	High	12
	7f. Greater flexibility in quota transfers	Industry	Low	High	Low	Medium	Low	High	3
		Management	High	High	Very low	High	Low	High	2
		Research	Moderate	High	Low	High	Low	High	2
		All sectors combined	Moderate	High	Low	High	Low	High	7

5. *Identify improvements to current monitoring systems to ensure that they are suitable for measuring the likely impacts of climate change and other drivers (and see section 2a)*

There are several key improvements that could be implemented in terms of monitoring relevant to the abalone fisheries in south east Australia, for example:

- Continue to monitor and assesss abalone stocks at small spatial scales relevant to their biology. This process is largely underway across Australia;
- Identify sentinel sites for in situ water temperature monitoring so that relationships between SST and bottom temperature in near-shore waters can continue to be evaluated;
- Undertake periodic (for example 5-yearly) sampling at key sites where water temperatures change to monitor for changes in size at maturity and/or growth rates;
- Develop a reporting card for divers to record anomalous events (e.g. urchin sightings).

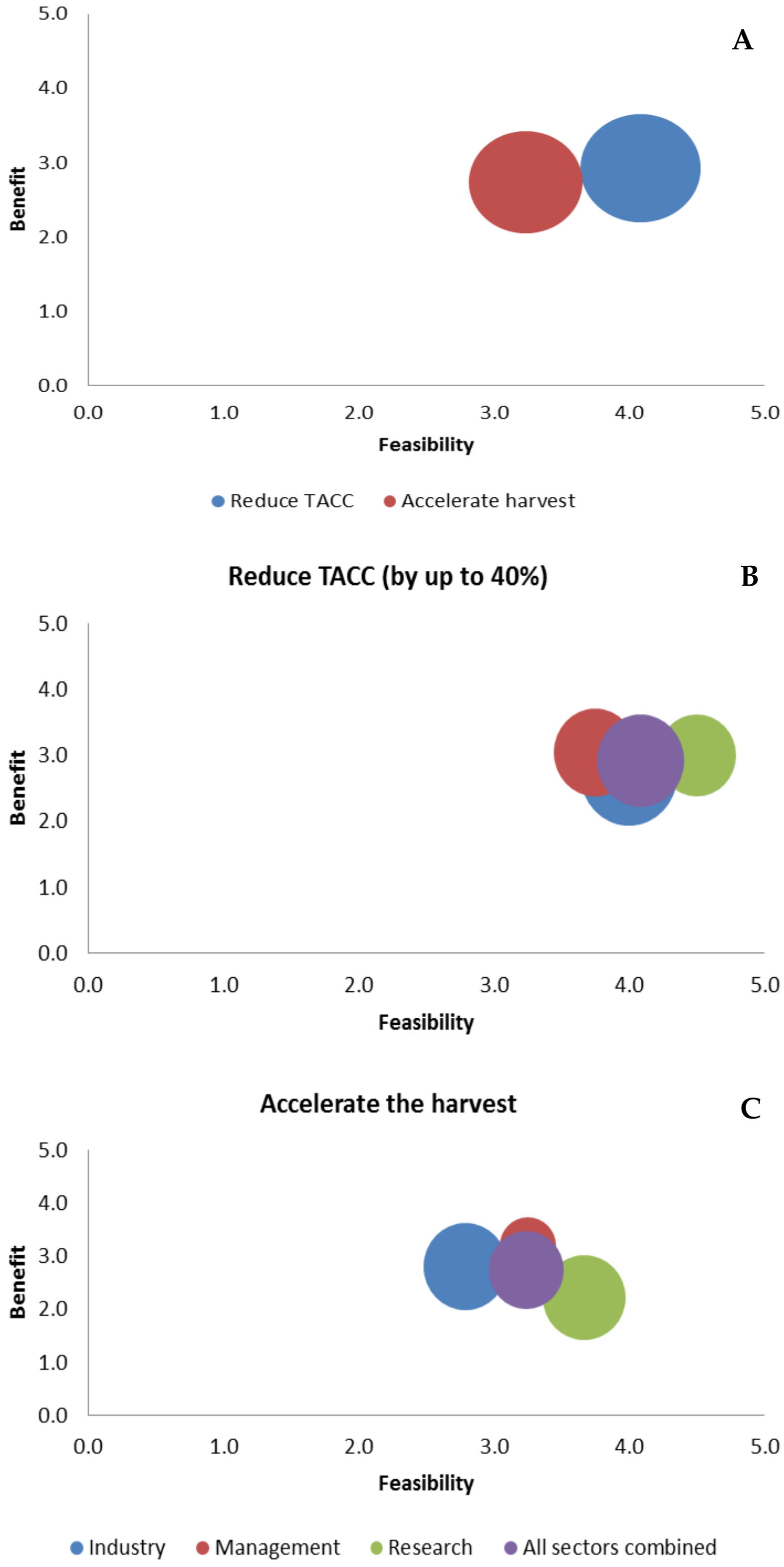

Figure 5. Abalone: Evaluation of options to address the climate challenge of mortality from thermal shock. (A) Evaluation of each option by all sectors combined, (B) evaluation of reducing TACC and (C) accelerating the harvest by each sector.

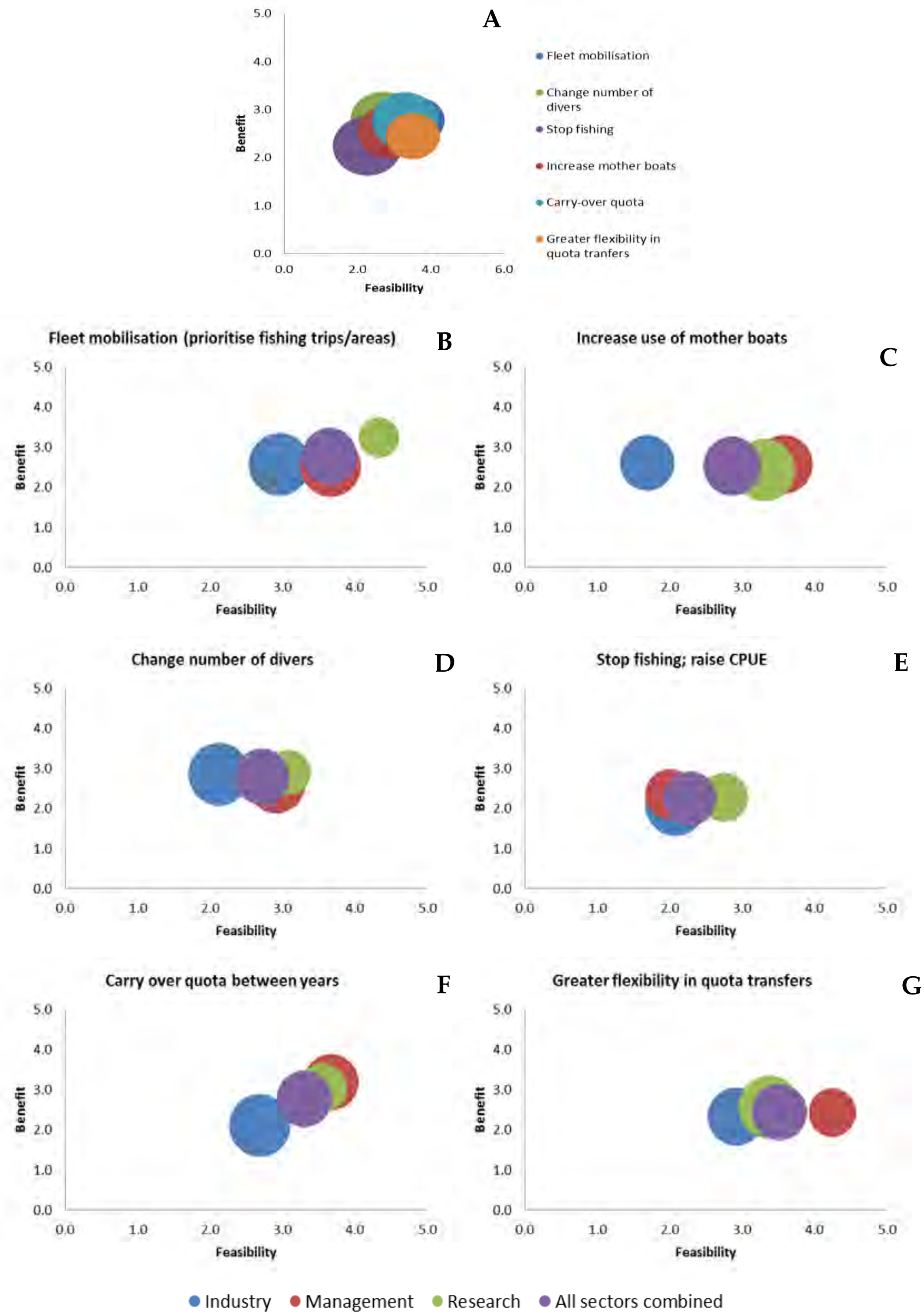

Figure 6. Abalone: Evaluation of options to address the climate challenge of altered weather patterns. (A) Evaluation of each option by all sectors combined, (B) evaluation of fleet mobilisation (prioritise fishing trips/areas), (C) increase use of mother boats, (D) change number of divers, (E) stop fishing; raise CPUE, (F) carry over quota between years, (G) greater flexibility in quota transfers.

REFERENCES

Andrew, N.L., Worthington, D.G., Brett, P.A., Bently, N., Chick, R.C., & Blount, C. (1998). Interactions between the abalone fishery and sea urchins in New South Wales. NSW Fisheries Research Institute P.O. Box 21, Cronulla, NSW, 2230 Australia.

Byrne, M., Ho, M., Wong, E., Soars, N.A., Selvakumaraswamy, P., Shepard-Brennand, H., Dworjanyn, S.A., & Davis, A. R. (2011). Unshelled abalone and corrupted urchins: development of marine calcifiers in a changing ocean. *Proceedings of the Royal Society B-Biological Sciences* 278, 2376-2383.

Cook, P.A., & Gordon, H.R. (2010). World abalone supply, markets, and pricing. *Journal of Shellfish Research* 29, 569-571.

Cooley, S.R., Lucey, N., Kite-Powell, H., & Doney, S.C. (2012). Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow. *Fish and Fisheries* 13, 182-215.

Crim, R.N., Sunday, J.M., & Harley, C.D.G. (2011). Elevated seawater CO2 concentrations impair larval development and reduce larval survival in endangered northern abalone (*Haliotis kamtschatkana*). *Journal of Experimental Marine Biology and Ecology* 400, 272-277.

Doney, S.C. (2006). The dangers of ocean acidification. *Scientific American* 294, 58-65.

Government of South Australia (2013). Fish and dolphin mortalities in South Australia March-April 2013. 75pp. http://www.pir.sa.gov.au/fishmortalities

Grubert, M.A., & Ritar, A.J. (2004). The effect of temperature on the embryonic and larval development of blacklip (*Haliotis rubra*) and greenlip (*H. laevigata*) abalone. *Invertebrate Reproduction & Development* 45,197-203.

Haddon, M., Mundy, C. & Tarbath, D. (2008). Using an inverse-logistic model to describe growth increments of blacklip abalone (*Haliotis rubra*) in Tasmania. *Fishery Bulletin* 106, 58-71.

Johnson, C.R., Banks, S.C., Barrett, N.S., Cazassus, F., Dunstan, P.K., Edgar, G.J., Frusher, S.D., Gardner, C., Haddon, M., Helidoniotis, F., Hill, K.L., Holbrook, N.J., Hosie, G.W., Last, P.R., Ling, S.D., Melbourne-Thomas, J., Miller, K., Pecl, G.T., Richardson, A.J., Ridgway, K.R., Rintoul, S.R., Ritz, D.A., Ross, D.J., Sanderson, J.C., Shepherd, S.A., Slotvvinski, A., Swadling, K.M., & Taw, N. (2011). Climate change cascades: Shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. *Journal of Experimental Marine Biology and Ecology* 400, 17-32.

Johnson, C.R., Ling, S., Ross, D.J., Shepherd, S.A., & Miller, K. (2005). Establishment of the long-spined sea urchin (*Centrostephanus rodgersii*) in Tasmania: first assessment of potential threats to fisheries. Project Report. School of Zoology and Tasmanian Aquaculture and Fisheries Institute, Hobart, Tasmania.

Last, P.R., White, W.T., Gledhill, D.C., Hobday, A.J., Brown, R., Edgar, G.J., & Pecl, G. (2011). Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. *Global Ecology and Biogeography* 20, 58-72.

Leiva, G.E., & Castilla, J.C. (2001). A review of the world marine gastropod fishery: evolution of catches, management and the Chilean experience. *Reviews in Fish Biology and Fisheries* 11, 283-300.

Ling, S. (2008). Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. *Oecologia* 156, 883-894.

Mayfield, S., Mundy, C., Gorfine, H., Hart, A.M., & Worthington, D. (2012). Fifty Years of Sustained Production from the Australian Abalone Fisheries. *Reviews in Fisheries Science* 20, 220-250.

Mayfield, S., Hogg, A., & Burch, P. (2013). Southern Zone Abalone Fishery (*Haliotis rubra* and *H. laevigata*). Fishery assessment report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000552-4. SARDI Research Report Series No. 694. 54pp.

McLeod, D.J., Hobday, A.J., Lyle, J.M., & Welsford, D.C. (2012). A prey-related shift in the abundance of small pelagic fish in eastern Tasmania? *Ices Journal of Marine Science* 69, 953-960.

Mundy, C. (2012). Using GPS techology to improve fishery-dependent data collection in abalone fisheries. Institute for Marine and Antarctic Studies, Hobart, Tasmania.

Pearce, A., Lenanton, R., Jackson, G., Moore, J., Feng, M., & Gaughan, D. (2011). The “marine heat wave” off Western Australia during the summer of 2010/11. pp. 40 pp. Department of Fisheries, Perth, Western Australia.

Pecl, G., Frusher, S., Gardner, C., Haward, M., Hobday, A., Jennings, S., Nursey-Bray, M., Punt, A., Revill, H., & van Putten, I. (2009). The east coast Tasmanian rock lobster fishery – vulnerability to climate change impacts and adaptation response options (Executive summary) Report to the Department of Climate Change, Australia.

Pecl G.T., 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., & Stoklosa R. (2011). Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia. Fisheries Research and Development Corporation, Project 2009/070.

Pitt, N.R., Poloczanska, E.S., & Hobday, A.J. (2010). Climate-driven range changes in Tasmanian intertidal fauna. *Marine and Freshwater Research* 61, 963-970.

Prince, J. (2003). The barefoot ecologist goes fishing. *Fish and Fisheries* 4, 359-371.

Prince, J.D., Peeters, H., Gorfine, H., & Day, R.W. (2008). The novel use of harvest policies and rapid visual assessment to manage spatially complex abalone resources (*Genus Haliotis*). *Fisheries Research* 94, 330-338.

Prince, J.D., & Shepherd, S.A. (1992). Australian abalone fisheries and their management. Abalone of the world: biology, fisheries and culture. *Proceedings of the 1st International Symposium on Abalone* 407-426.

Ridgway, K.R. (2007). Long-term trend and decadal variability of the southward penetration of the East Australian Current. *Geophysical Research Letters* 34, L13613.

Russell, B.D., Connell, S.D., Mellin, C., Brook, B.W., Burnell, O.W., & Fordham, D.A. (2012). Predicting the Distribution of Commercially Important Invertebrate Stocks under Future Climate. *Plos One* 7.

Stobart, B., Mayfield, S. & McGarvey, R. (2013). Maximum Yield or Minimum Risk: Using Biological Data to Optimize Harvest Strategies in a Southern Australian Molluscan Fishery. *Journal of Shellfish Research* 32(3), 899-909

Skirtun, M., Sahlqvist, P., Curtotti, R., & Hobsbawn, P. (2011). Australian Fisheries Statistics 2011. 113 p.

Tarbath, D., & Gardner, C. (2011). Tasmanian Abalone Fishery - 2010. Insitute for Marine and Antarctic Studies, Hobart.

Thresher, R.E., Koslow, J.A., Morison, A.K., & Smith, D.C. (2007). Depth-mediated reversal of the effects of climate change on long-term growth rates of exploited marine fish. *Proceedings of the National Academy of Sciences of the United States of America* 104, 7461-7465.

9. Blue grenadier

Blue grenadier (*Macruronus novaezelandiae*) supports the most valuable commercial fishery in the Southern and Eastern Scalefish and Shark Fishery (SESSF). The fishery landed market value is approximately $12–$14 million AUD (www.abareconomics.com) (ABARE 2008). Blue grenadier are found from southern New South Wales around southern Australia to Western Australia, including the coast of Tasmania, however, most of the catch is taken from around Tasmania and off eastern Bass Strait. Blue grenadier are typically targeted along the shelf slope at depths between 300 and 600 m, but can occur to depths of at least 1000 m (Kuo and Tanaka 1984, Smith 1994, Smith 2000). The species is caught by demersal trawling and the annual TAC has ranged between approximately 4300 to 5200 tonnes between 2008 and 2012, and as much as 10,000 tonnes between 1994 and 2002 (http://www.afma.gov.au/home/afma-archives/historical-total-allowable-catch-and-effort/).

The fishery is divided into a summer (non-spawning) fishery, where blue grenadier are caught in mixed bags with other fish stocks by small scale "wet" boats, and a winter (spawning) fishery that is focused off western Tasmania where a factory vessel and some smaller wet boats target large winter spawning aggregations. The west Tasmanian winter fishery accounts for the majority of the annual catch. The fishery is currently managed under a single stock model with a Global TAC. The fishery is highly recruitment driven with short periods of marked strong cohorts (year-classes) interspersed with extended periods of poor recruitment. Current estimates of the strongest year-classes over the last 30 years are 1979, 1987, 1994 and 2003 (Tuck et al 2011).

Blue grenadier is a moderately long-lived species with a maximum age of about 25 years. Age at maturity is approximately 4 years for males and 5 years for females (length at 50% maturity for males and females is 57cm and 64cm respectively (Russell 2009, Russell and Smith 2006). There is evidence that availability to the gear on the spawning ground off western Tasmania differs by sex, with a higher proportion of smaller males being caught than females. This is most likely due to the arrival of males on the spawning ground at a smaller size (and younger age) than females. Spawning occurs predominantly off western Tasmania in winter (the peak spawning period is between June and August) (Bruce et al 2001, Bulman et al 1999, Gunn et al 1989, Russell 2009, Thresher et al 1988). Variation in spawning period noted by Gunn et al (1989) may occur due to inter-annual differences in the development of coastal currents and water temperature patterns around Tasmania, with spawning thought to begin when the sea surface temperature drops below 14˚C (Gunn et al 1989). Eggs are buoyant and larval stages are most abundant over the shelf in depths between 20 to 90 m (Thresher et al 1988).

Spawning aggregations can be quite concentrated within the canyons of the slope habitat found off western Tasmania or spread north-south along the slope. Adults disperse following the spawning season and while fish are found throughout the south-east slope region of Australia during the non-spawning season, their range and distribution patterns are not well defined. Spawning fish have recently been caught off the east coast of Australia and larvae from a likely eastern spawning area have been previously described by Bruce et al (2001). Further, recent otolith studies suggest population sub-structure may occur in southern Australian waters, despite low genetic variation (Hamer et al 2012).

The stock assessment for blue grenadier is an age- and sex-structured model coded in Stock Synthesis (Methot and Wetzel 2013). Data inputs include the mass of catch and discards, length and age-at-length data from the spawning and non-spawning fishery, fishery catch rate indices (from 1986), acoustic estimates of spawning biomass (from 2003 to 2010) and an egg survey (1994-1995), both off western Tasmania.

The blue grenadier fishery depends on infrequent but large recruitment pulses that can support fishery production for many years. Changes to either the average magnitude and/or frequency of these strong year classes would have a major impact on the fishery. Recruitment pulses are driven by inter-annual variation in spawning success that is thought to be related to variation in the survival rates of early life stages (i.e. larvae or small juveniles, first few months of life). Little is known about the processes influencing survival of larvae and small juveniles, but earlier studies suggest that climatic factors are likely to be important (Thresher et al 1992, Bull and Livingston 2001). Climate change may alter current recruitment dynamics and/or average magnitude, therefore it is important that the harvest strategy for this fishery can deal with a variety of possible recruitment scenarios and continue to recommend appropriate catch levels that will prevent stock collapse.

The vulnerability of blue grenadier to climate change impacts may be increased by reductions in biomass resulting from inappropriate harvest regulation, historical overfishing and ongoing high fishing pressure. The apparent dependence of the major fishery region on one spawning ground on the west coast of Tasmania also increases vulnerability of this fishery. The west coast spawning ground occurs in a climate change hotspot region and is also isolated from major ports. Economic pressures associated with rising costs, particularly fuel, and stagnating prices may also reduce opportunities for adapting fishing practices to climate change impacts.

1. *Identify likely key effects of climate change particularly where these effects may impact the harvest strategy for this species*

a. *What are the historical relationships between oceanographic/climatic variables and population dynamics?*

The key driver of the population dynamics of blue grenadier around southern Australia is highly variable recruitment (herein termed 'year-class-strength', YCS) (Figure 7). Recent age composition data also shows that the same strong year-classes dominate the fishery catches off western Tasmania, eastern Bass Strait and the Great Australian Bight (Hamer et al 2012, Russell

2009). Broad-scale environmental/climatic factors are therefore likely to be involved in influencing blue grenadier population dynamics.

This case study focussed on the major western Tasmanian fishery and spawning region. Earlier studies of this region, and of the blue grenadier (or 'hoki') population off western New Zealand, have suggested a link between larval growth and survival and autumn to spring weather patterns (Bull and Livingston 2001). For the western Tasmania area, in particular, it was suggested that the frequency and intensity of storms influences transport of seagrass detritus from inshore waters to the larval growing areas on the shelf and that this seagrass detritus, through microbial decomposition, is important for supporting increased abundance of larval prey, and therefore increased growth and survival of young larvae (Thresher et al 1992). For the period 1973-2008, we found a positive relationship between mean autumn wind strength in the year of spawning (i.e. birth year) and an index of blue grenadier YCS (e.g. log transformed year-class-strength) derived from the fishery stock assessment model (Paper 4). Interestingly, the positive relationship between autumn wind strength and the YCS index was consistent beyond 1982, but actually switched to negative prior to 1982.

Another climate related oceanographic process that may influence survival of blue-grenadier early life-stages off western Tasmania is vertical water column mixing, which is higher with increased wind strength and wave action. Vertical mixing, indicated by the depth of the mixed layer (MLD), brings deeper more nutrient rich water to the surface illuminated layers resulting in increased plankton production, and ultimately more planktonic food for growing blue grenadier larvae. We found that mean maximum July-November MLD had a moderate to strong positive relationship with YCS (Paper 4). The MLD data were only available from 1994, and were correlated with SST.

We also found a negative relationship between YCS and mean sea surface temperature (SST) over the west Tasmanian spawning region during July-November (i.e. the spawning and larval development period) as well as over an annual period. Sea surface temperature data from satellite remote sensing measurements were available from 1994, and air temp data from the Marrawah climate station in north western Tasmania from prior to 1970. We use the strong relationship between Marrawah air temperature and the available SST data to create an SST time series extending from 1973-2008. Over this period, SST variation explained 40% and 50% of the variation in YCS for the July-November and annual time series respectively (Paper 4). Other environmental variables that were related to YCS included the annual mean Southern Oscillation Index (SOI), which had a moderate negative relationship with YCS (Paper 4).

Overall the results suggest that windy autumns (conducive to greater vertical water column mixing and nutrient supply to surface waters just prior to spawning) and colder winter to spring periods (characteristic of negative SOI conditions) are conducive to higher YCS of blue grenadier off western Tasmania.

- Fishery characterised by highly variable recruitment.
- Recruitment success linked with windy periods during autumn, prompting greater vertical mixing and cooler winter-spring SSTs.

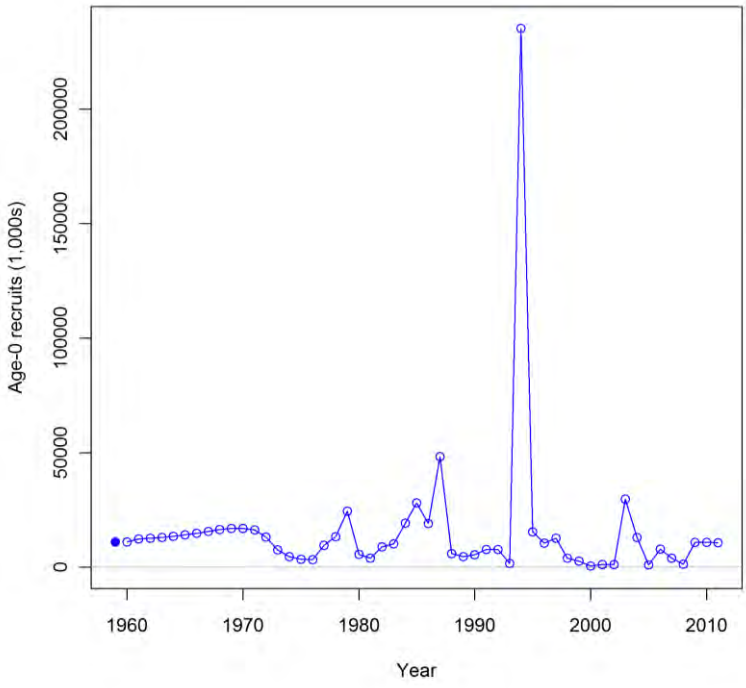

Figure 7. Estimated Age-0 recruits of blue grenadier from the assessment model of Tuck (2011).

b. What are the historical relationships between key oceanographic variables and distribution?

Blue grenadier adults are found in deeper waters on the shelf slope and off the shelf. The smaller juveniles and larval stages occur more commonly over the shelf and in inshore waters, with small juveniles often being found in southern Tasmanian bays/estuaries. There is limited understanding of the advantages and process that have promoted the aggregative spawning behaviour off western Tasmania. It is likely that the aggregative behaviour somehow relates to suitable habitat and environmental features, including prey availability, for survival of young, and or bathymetric/habitat features that provide landmarks for aggregation and/or high food supply for spawning adults. While the canyon habitats of the shelf slope are attractive for blue grenadier spawning aggregations, it remains unclear whether this is purely a habitat effect or related to the influence of the canyon bathymetry on oceanographics and feeding success.

One oceanographic feature that relates to timing of blue grenadier spawning is the MLD (mixed layer depth) which reaches its maximum depth in winter/spring off western Tasmania. It is likely that winter spawning has evolved to match the seasonal timing of the MLD maximum, which is conducive to higher plankton productivity and prey availability for larvae.

The major oceanographic feature of the spawning region off west Tasmania is the Zeehan Current. The Zeehan Current is a north-south surface current, predominant on the shelf, that reaches its maximum in the winter when blue grenadier spawn (Cresswell 2000). This current delivers warmer surface waters to the shelf region off western Tasmania in winter. While the direct role of the Zeehan Current in influencing larval survival and spawning aggregation behaviour, and therefore distribution, of blue grenadier is unclear, it does appear to play a role in larval dispersal away from the spawning areas (Thresher 1988, Bruce et al 2001) and may have implications for larval survival. The negative relationship between SST and YCS may be related to the influence of the Zeehan Current in transporting larvae south and away from the west coast of Tasmania.

In relation to water temperature regimes, the adults appear to spend most of their lives at temperatures below about 12 ˚C, typical of water depths below 300 m, although they do migrate up to surface waters to feed at night which indicates they can tolerate short periods of exposure to warmer water. Patchell et al (1987) suggests that adults can be found in water temperature ranging from 4—20 ˚C. Deep ocean waters show much less temperature variation than surface waters, and suitable deep cool water temperatures can be found in many areas around the Australian shelf slope that do not appear to harbour significant blue grenadier populations. Therefore, it can be hypothesised that distribution may be more influence by the surface water temperature tolerances of eggs, larvae and small juveniles, and/or by other oceanographic, prey distribution or habitat features important for adults.

There is a lack of knowledge around the distribution and ecology of the early juvenile life-stages surrounding Tasmania (i.e. < 20 cm length). There have been no studies on temperature tolerances of eggs, larvae and small juveniles against which to assess implications of surface water warming on future distributions. Projection models for the deeper waters where adults occur are currently unreliable. These areas of uncertainty require further study to inform predictions of how spatial distribution of blue grenadier might change in response to long-term climate change.

- Wide spread distribution of adults throughout south east Australia in deeper waters on the shelf slope and off the shelf.
- Key oceanographic variables such as SST, mixed layer depth/wind strength and Zeehan current may influence distribution and production through effects on spawning, larval survival and recruitment success.
- Major knowledge gaps surrounding distribution and ecology of small juveniles.

c. What are the historical relationships between key oceanographic variables and productivity?

Productivity of a fish stock is a combination of juvenile recruitment (i.e. population replenishment), mortality and growth rates, and potentially changes to migratory dynamics and distribution. While recruitment dynamics may be influenced by changes to wind patterns/strength and SST (discussed previously), the overall impact of climate change on production is difficult to predict because climate projection models cannot provide data on temporal/inter-annual dynamics (i.e. changes in the frequency of conditions conducive to strong YCS) and only provide average conditions with associated uncertainty. Clearly if SST becomes unsuitable for blue grenadier larvae around the Tasmanian shelf, fishery production will decline greatly. Growth is known to be variable in blue grenadier (Whitten 2012), however, this variability is likely to be related to a combination of density dependent and environmental factors. There is currently no information on the relationship between oceanographic variables and growth or mortality rates, and this could be an area for further study using archived otolith collections to develop time series of growth chronologies.

- Potential negative effects on recruitment and therefore productivity.
- Relationship between oceanographic variables and other factors influencing productivity such as growth, mortality and migration largely unknown.

d. How might larval dispersal be altered by changes in climatic conditions, and what might be the implications of any changes for larval survival?

This case study used larval dispersal modelling to investigate inter-annual variation in dispersal patterns from the west Tasmanian spawning area, and explore the hypothesis that higher rates of inshore dispersal of larvae to 'more productive' shelf waters is conducive to higher survival rates and subsequent higher YCS. The study used the dispersal model BRAN2p1_Bluelink ReANalysis version 2.1. The results of dispersal model runs of simulated larvae showed that larval dispersal patterns depended greatly on the depth at which the propagules dispersed. Propagules that were programmed to be released over the known spawning ground and time, and move between depths consistent with previous information about the depth distribution of eggs (surface) and larvae (50 m depth), displayed highly variable dispersal over the 50 day (blue grenadier larval development period) dispersal period from year to year. To test the hypothesis that dispersal of larvae to inshore shelf waters was an important process for increased survival and higher YCS we compared, for the 1994 – 2005 period (i.e. period of available model data), the number of propagules that ended their 50 day dispersal period in 'optimal larval/nursery habitat'; defined as: a) shelf waters shallow than the 200 m isobath, and b) shelf waters shallower than the 200 m isobath and north of Port Davey.

For both scenarios the number of propagules that ended their dispersal period in the optimal habitats as defined above was positively related to YCS, however, the relationship was strongest for scenario b), suggesting that higher dispersal to, and retention of, larvae over the shelf and closer to the spawning area was conducive to higher YCS. While results are preliminary, and are influenced by the exceptionally strong 1994 year class, they do suggest that larval dispersal is an important process influencing blue grenadier recruitment dynamics, and that this process warrants further study.

In relation to how changes in climatic conditions might influence dispersal patterns and larval survival, oceanographic projection models that can provide depth stratified ocean currents for future periods (i.e. 2063-2073) are only just beginning to be produced, and were not available to the current study. As these future ocean current projections become available, studies can be instigated to further model how larval dispersal patterns might change under realistic climate change scenarios, particularly in relation to on-shelf versus off-shelf transport, and the amount and extent of southerly dispersal.

- Larval dispersal appears to be an important component of recruitment success.
- How dispersal patterns might change in relation to climate change is unknown, oceanographic projection models currently being developed may provide a useful tool for better understanding.

e. What are the key ecosystem/ecological/habitat relationships, and how may these alter under a changing climate?

The key ecosystem/ecological/habitat relationships that should be focussed on are those that relate to the larval and early juvenile life-stages that typically occur in the surface waters (<100 m depth). While understanding of ecological processes that influence the survival and dynamics of these early life stages is limited, the mass aggregation of adult blue grenadier off western Tasmania has no doubt evolved under selective pressure to provide habitat conditions that maximise the survival of their offspring. The processes that influence larval prey availability and dispersal patterns are the likely keys to understanding much of the inter-annual variation in YCS, and this case study, along with the earlier work of Thresher et al (1988) point to the role of autumn/winter storm events to drive both vertical water column mixing and supply of seagrass detritus to promote increased productivity of the pelagic food web off western Tasmania. Projections of future wind conditions for western Tasmania under climate change scenarios suggest that average autumn wind strengths are unlikely to change by more or less than 2% over the 50 year projection period (2063-2073) and therefore have only a minor if any effect on average YCS.

The greatest risk to this fishery in the long-term appears to be the predicted warming of the surface waters. While developed (i.e. capable of active swimming and buoyancy control) larval stages can alter their vertical position in the water column to find suitable water temperatures, the availability and composition of the prey resource at deeper (cooler) depths may not be suitable for high survival rates, and/or may be more highly variable than in the surface waters, adding another factor to the already complex and uncertain process of recruitment variation. Irrespective of behavioural responses of developed larvae, the positive buoyancy of eggs, and poor behavioural ability of newly hatched larvae, will see them exposed to surface waters for the first week to 10 days of life, and this may be the critical bottleneck in determining the long-term suitability of the west Tasmanian slope as a spawning and larval growing area.

> ➢ Of the predicted changes, increased SST poses greatest risk, through potential negative impacts on egg/larval development and survival.

f. To what extent may climate change, through an altered physical environment, influence access to current or future fishing grounds? Consider swell, winds, storm events, wave height.

Given that the catch off western Tasmania, and the largest catch component of the fishery overall, is currently taken by a large factory trawler, the changes in wind conditions predicted would have no impact on the ability of such a vessel to access the aggregation areas off western Tasmania in the future. For the smaller 'wet boats', the changes in wind strengths under the higher emission scenarios and the upper end of predictions may have implications for their ability to access the western Tasmania aggregations (i.e. lower frequency of suitable weather windows), but the level of impacts is uncertain.

> ➢ Current vessels considered capable of operating under predicted altered conditions.

g. What extent might climate change influence stocks/fisheries? Consider both slow trends and potential for extreme events or 'surprises'. Develop 'scenarios' for developing and evaluating adaptation responses in the workshops (a scenario is an evidence-based plausible future for the fishery, given likely climate change – i.e. the sum of a-f above).

Considering the potential impacts of a warming SST on suitability of the west Tasmanian region as a spawning and larval rearing habitat, the likely influence on the blue grenadier stock would be a slow decline in average recruitment and potentially a more variable recruitment dynamic, with longer periods between high recruitments. Overtime, the fishery production off western Tasmania would be predicted to become much more sporadic and on average lower than current if the SST forecasts eventuate and the early life stages cannot adapt to the new conditions.

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).***

Good biological data (e.g. age, growth and reproduction) are available for blue grenadier. The existing fishery (otolith - length/age) sampling program provides an opportunity to monitor changes in growth and recruitment over time. Limitations of current knowledge of juvenile distribution and ecology restrict understanding of the process(es) that drive recruitment variation and the development of methods and spatial sampling design for monitoring pre-recruit abundance. High quality fishery catch and effort, and compositional data are used as inputs to a modern stock assessment model that underpins the formal harvest strategy that is used to establish TACs.

a. *Does additional data needed to be collected to understand the cause and scale of changes? (e.g. is spatial resolution of data adequate to detect changes in distribution or changes in timing or location of spawning etc?)*

A clear impediment to predicting climate change impacts on the blue grenadier fishery is an understanding of the response of egg and larvae survival, abnormal development and growth rates to temperatures above 14˚C. Furthermore, understanding the time series of spawning behavior and spawning depth, in relation to environmental cues (in particular water column temperature profiles), would be useful. Collection of more frequent temperature/depth profiles for specific depths and locations off western and southern Tasmania would be useful to provide additional calibration data to support the development of improved predictive models of temperature/depth profiles. Improvements to the vertical and horizontal spatial resolution of dispersal models would also be valuable, particularly in the slope and shelf regions. There would be opportunities for industry to assist with some of these data collection activities (e.g. water temperature data, spawning behavior/condition etc.)

- Data on egg and larval responses to increased water temperatures are important.
- Temperature/depth profile data beneficial to understanding spawning aggregation behavior, recruitment variation and relationships to environmental variables and to help develop and calibrate predictive models of vertical temperature profiles.

b. *Will current measures of stock status remain appropriate?*

The Australian harvest strategy uses a tier-based system of assessments and corresponding harvest control rules (Smith et al 2008), whereby stocks are assigned to each tier level according to the quantity and quality of data available to assess the stock. Blue grenadier is considered a Tier 1 stock, as it has considerable data of high quality, and a robust quantitative stock assessment to estimate stock size and depletion (Tuck et al 2011). The stock status metric is the derived spawning biomass from the stock assessment relative to its pre-fishery equilibrium spawning biomass, and the current estimate of spawning biomass is considered reliable. As such, the current stock assessment provides the best opportunity to estimate stock status, and therefore the best opportunity to track any changes in biomass that may have occurred through climate-induced influences on demography.

- Current measures of stock status appropriate for for monitoring of future change in biomass.

c. *Will reference points need to be changed?*

The harvest strategy for blue grenadier is based around biomass target and limit reference points, where the target is the biomass that produces maximum economic yield (MEY) (Smith et al 2008). The limit reference point, B_{LIM}, is half of the biomass that corresponds to maximum sustainable yield (MSY). If scientifically justifiable estimates of these values are not available, proxies can be used and in the case of blue grenadier, B_{MSY} = 40% of the unexploited biomass, B_{MEY} = 48% of the unexploited biomass, and B_{LIM} = 20% of the unexploited biomass. The harvest strategy states that the stock should be maintained, on average, at B_{MEY}, and the stock should stay above the limit reference point at least 90% of the time (DAFF 2007). We consider that this harvest strategy and associated reference points are robust and precautionary enough to manage the fishery under the predicted climate change scenarios.

We tested the harvest strategy under different scenarios that included significant changes in the recruitment dynamics of blue grenadier using a management strategy evaluation (MSE) tool (Paper 4). Results from the MSE simulations showed that the harvest strategy was robust to substantial changes in the recruitment dynamics of blue grenadier. Extreme episodic recruitment events (long periods of poor recruitment) caused major fluctuations in key fishery indicators, such as catch and variation in catch, and the spawning biomass. However, as the harvest strategy is based on a fishing mortality rate, if the stock is estimated to be below 35% of the unexploited biomass, the assigned fishing mortality is gradually reduced (until zero at 20% of the unexploited biomass), the fishery is able to respond to long periods of poor recruitment and maintain the stock biomass. While a reasonable outcome for stock conservation, the economic impact of considerable years of minimal catch was beyond the scope of this modeling exercise, but should be considered in any analysis of potential impacts of climate-induced changes to blue grenadier stock/fishery dynamics.

- Current harvest strategy and associated reference points are robust and precautionary.

d. Do model assumptions need to change (e.g. constant growth rates)

There are numerous assumptions relating to model parameterisation and stock structure that are needed for any fishery stock assessment. These include the parameters that define natural mortality, growth, breeding biology, proportion spawning, spatial structure, fleet characteristics, and gear selectivity, among others. The parameters used in the current blue grenadier stock assessments have been taken from biological studies (eg. proportion spawning, size at maturity; Russell and Smith, 2006), and from meta-analysis of similar stocks (e.g. steepness; Francis (2009)), or are estimated directly within the model using fishery data (e.g. natural mortality, growth, selectivity) (Tuck et al 2011).

It is possible that blue grenadier growth, mortality or other parameters might be affected by changes in surrounding environmental conditions (e.g. water temperature, prey availability). While this was not considered specifically in this work, the key assumptions used in the stock assessment model are reviewed and agreed upon annually by fishery and biology experts prior to their implementation. This allows the opportunity for observed or inferred changes to a parameter to be incorporated within the model on a regular basis.

- Key model assumptions reviewed annually to ensure parameters reflect most up to date information

e. Do decision rules need to change (e.g. do TACs at different abundance levels need to be reduced to reflect decreases in recruitment?)

The current decision rule for translating biomass estimates into TACs for blue grenadier is based on the Tier 1 assessment and associated control rule (Smith et al 2008). The estimated biomass is used as an input to a control rule which produces a fishing mortality rate and consequent recommended biological catch (RBC). The TAC is the RBC less any estimated discards. The fishing mortality rate (and RBC) reduces as the estimated spawning biomass decreases below 35% of the unexploited biomass. The decision rule allows precaution, as once the estimated spawning biomass drops below the limit reference point (20% of unexploited biomass), then no commercial fishing is permitted. This harvest strategy, along with the TAC decision rule, was tested in the MSE, and found to be robust to changes in recruitment dynamics.

- Existing harvest control rules considered appropriate and robust to changes in recruitment dynamics.

f. Is coordination among jurisdictions adequate to address potential changes?

The Australian blue grenadier fishery of the SESSF is a solely Commonwealth managed fishery. The Australian Fishery Management Authority (AFMA) is responsible for its management (assessment and TAC setting). There are no substantial catches of, or resource sharing with, State, or International jurisdictions for this fishery, so multi-jurisdictional management/policy challenges are not relevant for this fishery.

- Single jurisdiction fishery with little or no cross jurisdictional interactions.

3. Identify climate change impacts, adaptation options and barriers

Table 15 lists the autonomous and possible planned adaptation actions that were elicited from stakeholders in response to the potential climate change impacts presented at the March 2012 workshop. Stakeholders also identified likely barriers to implementing any possible planned adaptation actions.

Table 15. Adaptation options and potential barriers for implementing possible adaptation options for blue grenadier.

POTENTIAL IMPACT	AUTONOMOUS ADAPTATION	POSSIBLE ADAPTATION ACTIONS	BARRIERS
Changes in location (depth or area), intensity of spawning aggregation.	1. Increase search effort, follow fish 2. Use a larger number of smaller vessel to increase spatial coverage and efficiency (finding & catching fish) 3. Alter/optimise available window to target highest density periods	1. Alter fishing/quota season dates 2. Remove restrictions on trawl depths 3. Increase fishery independent research (migratory dynamics and distributions)	1. Cost 2. Impact on existing rights and seasons 3. MPAs and fisheries closures 4. Knowledge
Reduced recruitment overall, or changes in the frequency of major recruitment events which may lead to lower average productivity.	1. Reduce TAC 2. Reduce effort 3. Adapt gear to minimise impact on juveniles	1. Look for alternative species 2. Lease in more quota (as an individual) 3. Improve efficiency and or product value to increase profit margin	1. Limited options for diversifying 2. Limited quota 3. Knowledge
Changes to adult aggregation and spawning depths increased interactions with bycatch and protected species/habitats	1. Fish deeper/shallower 2. Fish less to reduce interactions	1. Look for alternative species 2. Gear changes to mitigate interactions	1. Spatial/depth closures to trawling 2. Increased restrictions to mitigate and monitor protected species interactions
Elevated temperatures may shift timing and or durations of annual spawning migrations	1. Optimise fishing operations accordingly to target highest density periods 2. Change target species	1. Gear technology to maximise catches during shorter peak availability periods. 2. Changes to quota year	1. Costs 2. Impacts on other quota and non-quota species 3. Knowledge
Reduced availability	1. Shift fishing effort to other species 2. Consolidate and expand quota holdings to maintain operation	1. Economic assessment to determine other opportunities 2. Improve efficiency and or product value to increase profit margin	1. Costs of changing type of operation 2. Availability & costs of quota for Grenadier and other species

The governance benchmarking exercise identified very few potential barriers to adaptation for the blue grenadier fishery (see Appendix 4). Governance for blue grenadier fisheries could be improved, however, the blue grenadier fishery performed most strongly across all the attribute areas compared with the other case study fisheries. The goals and objectives of fishery management were classed as being clearly defined, however clear processes for making trade-offs between conflicting objectives were only 'partially in place and sometimes operational'. Several potential barriers to adaptation were also identified in the 'Adaptability' section of the benchmarking exercise where both 'range of operational fisheries management tools' and 'ability and preparedness to effect change in management' were evaluated as only 'partially in place and sometimes operational'. Biological KPIs are monitored and reported annually.

Prior to evaluating potential adaptation options, the revised adaptation options were furthered refined and analysed using a characterisation matrix which identified the key characteristics of the adaptation options being considered for further evaluation (Table 16). This was considered an important step to map out implications, interactions with other management strategies and issues of temporal and spatial scales.

4. *Evaluate potential adaptation options*

For blue grenadier we examined four different adaptation options. Three options were designed to address the climate risk of Reduced productivity and availability (Climate challenge 1), and the remaining one was to address the risk of Reduced and altered temporal and spatial distribution of the spawning aggregations (Climate challenge 2).

For reduced productivity we assessed; (1a) reducing the TACC (by up to 40%), (1f) spatial or temporal closures to protect juveniles and (1g) a two-year quota period. Reducing the TACC ranked highest ('high') in terms of feasibility when all sectors were combined, whilst in terms of benefit, reducing the TACC and spatial or temporal closures both ranked ('moderate') above the option of a two-year quota period ('low') (Table 17, Figure 8).

The adaptation option of shifting the fishing fleet to a higher number of smaller vessels (as opposed to the large freezer trawlers currently used) was the only adaptation option assessed to address the risk of changes to spawning biomass. This was clearly not a favoured option by any sector and received 'low' or 'very low' rankings by all sectors for feasibility and benefit (Table 17, Figure 9).

Interestingly consensus was 'high' for feasibility, risk and benefit for each of the adaptation options assessed. However it should be noted that sample sizes were small for this fishery particularly for industry and management (Table 17).

When looking at the results for the blue grenadier fishery, the most striking outcome is the level of consensus within and between the stakeholder groups. This could be explained by the low sample size, or it could also be related to the fact that this fishery is the only single jurisdiction/sector fishery examined within this study. Therefore the issues being faced by the industry are not differentiated by jurisdiction or sector. This fishery is also confined to a small number of large operators who take the vast majority of the TACC so the demographics of the fishery are not as diverse as some larger fisheries and therefore it appears the opinions regarding management change are also quite similar.

Table 16. Blue grenadier: final list of suggested potential adaptation options, and a characterisation of each option.

BLUE GRENADIER			2. CHARACTERISING IMPLEMENTATION							3. CHARACTERISING BENEFITS				
Challenge No. Option No.	**CLIMATE CHALLENGE (includes potential impact/s)** POTENTIAL ADAPTATION OPTIONS	**1. ADAPTATION TYPE**	2.1 SCALE OF APPLICATION	2.2 JURISDICTION/S IN WHICH IMPLEMENTED	2.3 SIGNIFICANCE OF DIFFERENCE BETWEEN JURISDICTIONS	2.4 LEAD TIME TO IMPLEMENTATION	2.5 ADDITIONAL COST (relative to "do nothing")	2.6 WHO PAYS	2.7 LEVEL OF CONTROVERSY EXPECTED	3.1 PRIMARY BENEFICIARY	3.2 SCALE OF BENEFIT	3.3 CONSEQUENCE PERIOD (when benefits are expected)	3.4 ADDRESSES OTHER CLIMATE CHALLENGES?	**BARRIERS (list any not already identified)**
		Autonomous, Business-As-(Mostly)-Usual, Incremental, Transformative	National, State, Zone, Sub-zone	Name which jurisdictions (i.e. TAS, VIC, SA, C'Wealth)	Low,Medium, High	<1 year,1-5 years,>5 years	Nil,Low, Medium, High	Industry, Government, Consumers, Post-Harvest, Local communities	Low,Medium,High	Fishers,Fishery,Fish Stock,Ecosystem	National, State, Zone, Sub-zone	<1 year,1-5 years,>5 years	Name which ones	
1	**Changed productivity and/or availability** **1. Smaller than anticipated SSB** **2. Changes in recruitment (magnitude, frequency)**													
1a	Reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	National	Commonwealth	Low	<1 year	Low	Industry	Medium	Fish Stock	National	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Sound assessment needed
1b	Reduce effort	Incremental	National	Commonwealth	Low	1-5 years	Low	Industry	Medium	Fish Stock	National	1-5 years	May lead to greater profitability of ind operators	Sound assessment needed
1c	Adapt gear to reduce impact on juveniles	Incremental	National	Commonwealth	Low	1-5 years	Medium	Industry	Low	Fish Stock	National	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Sound assessment needed
1d	Improve larval survival	Transformative	National	Commonwealth	Low	>5 years	High	Government	High	Fish Stock	National	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Technological
1e	Harvest alternative sp	Incremental	National	Commonwealth	Low	1-5 years	Medium	Industry	Medium	Fish Stock	National	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Markets and gear changes
1f	Temporal or spatial closure for juveniles	Incremental	National	Commonwealth	Low	1-5 years	Low	Government	Medium	Fish Stock	National	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Depends if closure impacts other fisheries
1g	Extend quota period (eg if not economical to take quota per year then can take larger quota every second yr)	Incremental	National	Commonwealth	Low	<1 year	Low	Government	Low	Fishers	National	1-5 years	May lead to greater profitability of ind operators	
2	**Spawning Biomass Changes** **1. Changes in timing of spawning** **2. Changes in density (spread of SSB)** **3. Changes in location (depth/area)**													
2a	Improved fish finding technology	Incremental	National	Commonwealth	Low	1-5 years	Low	Industry	Low	Fishery	National	>5 years	May lead to greater profitability of ind operators	Technological
2b	More smaller vessels to find fish	Transformative	National	Commonwealth	Low	1-5 years	High	Industry	Low	Fishery	National	>5 years	May lead to greater profitability of ind operators	Cost
2c	Shift timing/location of operations	Incremental	National	Commonwealth	Low	<1 year	Medium	Industry	Low	Fishery	National	>5 years	May lead to greater profitability of ind operators	
2d	Spatial management/assessment	Incremental	National	Commonwealth	Low	1-5 years	Medium	Government	Low	Fish Stock	National	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Data availability

3	**Biological changes** **1. Changes in size at maturity** **2. Changes in growth**													
3a	Periodic review of biological parameters	Incremental	National	Commonwealth	Low	1-5 years	Medium	Government	Low	Fish Stock	National	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost of research
3b	Adapt assessment accordingly	Incremental	National	Commonwealth	Low	1-5 years	Low	Government	Low	Fish Stock	National	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost of research
4	**Disease expression**													
4a	Design comprehensive biosecurity system	Transformative	National	Commonwealth	Low	1-5 years	Medium	Government	Low	Fishery	National	>5 years	May lead to greater profitability of ind operators	Knowledge
5	**Product quality** **1. Changed product characteristics**													
5a	Alter handling practices, including timing of fishing	Business-As-(Mostly)-Usual	National	Commonwealth	Low	<1 year	Low	Industry	Low	Fishery	National	<1 year	May lead to greater profitability of ind operators	Operational
5b	Develop alternate products/markets	Incremental		Commonwealth	Low	1-5 years	Medium	Industry	Low	Fishers	National	>5 years	May lead to greater profitability of ind operators	Co-operation between parties
6	**Altered habitats** **1. Changed abundance of predators/competitors/prey**													
6a	Periodic review of biological parameters	Incremental	National	Commonwealth	Low	1-5 years	Medium	Government	Low	Fish Stock	National	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost of research
6b	Adapt assessment accordingly	Incremental	National	Commonwealth	Low	1-5 years	Low	Government	Low	Fish Stock	National	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost of research
6c	Reduce/increase TACC	Business-As-(Mostly)-Usual	National	Commonwealth	Low	<1 year	Low	Industry	Medium	Fish Stock	National	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Sound assessment needed
6d	Review Harvest strategy	Incremental	National	Commonwealth	Low	1-5 years	Medium	Government	Low	Fish Stock	National	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost of research
7	**Altered weather patterns**													
7a	Change frequency/duration of trips	Incremental	National	Commonwealth	Low	<1 year	Medium	Industry	Low	Fishers	National	<1 year	May lead to greater profitability of ind operators	Operational costs

Table 17. Average scores and consensus level by sector for assessed adaptation options for the blue grenadier fishery.

Climate Challenge	Adaptation Option	Sector	Feasibility		Risk		Benefit		No. respondents
			Average	Consensus	Average	Consensus	Average	Consensus	
Reduced productivity	1a. Reduce TACC by up to 40%	Industry	Moderate	High	Low	High	Moderate	High	3
		Management	High	High	Low	High	Moderate	High	2
		Research	High	High	Low	High	Moderate	High	7
		All sectors combined	High	High	Low	High	Moderate	High	12
	1f. Spatial or temporal closures for juveniles	Industry	Low	High	Low	High	Moderate	High	3
		Management	Moderate	High	Very low	High	Low	High	1
		Research	Low	High	Low	High	Moderate	High	5
		All sectors combined	Moderate	High	Low	High	Moderate	High	9
	1g. 2yr quota period	Industry	Moderate	High	Low	High	Moderate	High	3
		Management	Moderate	High	Moderate	High	Very low	High	1
		Research	Moderate	High	Low	High	Low	High	6
		All sectors combined	Moderate	High	Low	High	Low	High	10
Spawning biomass changes	2b. Shift to more smaller vessels	Industry	Low	High	Moderate	High	Low	High	3
		Management	Low	High	High	High	Very low	High	1
		Research	Low	High	Low	High	Low	High	6
		All sectors combined	Low	High	Moderate	High	Very low	High	10

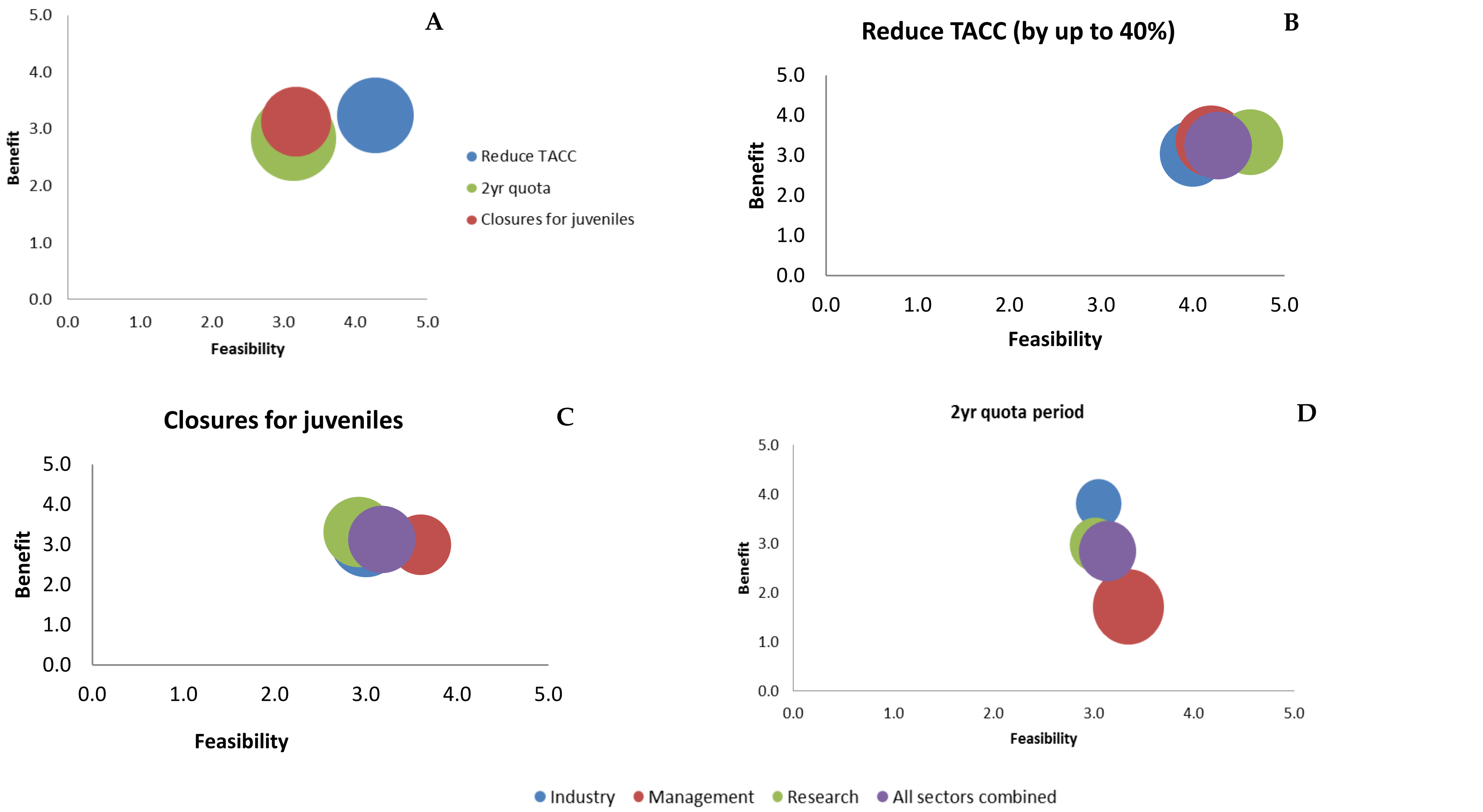

Figure 8. Blue grenadier: Evaluation options to address the climate challenge of reduced productivity and availability. (A) Evaluation of each option by all sectors combined. (B) Evaluation of reducing TACC, (C) closures for juveniles and (D) two years quota period.

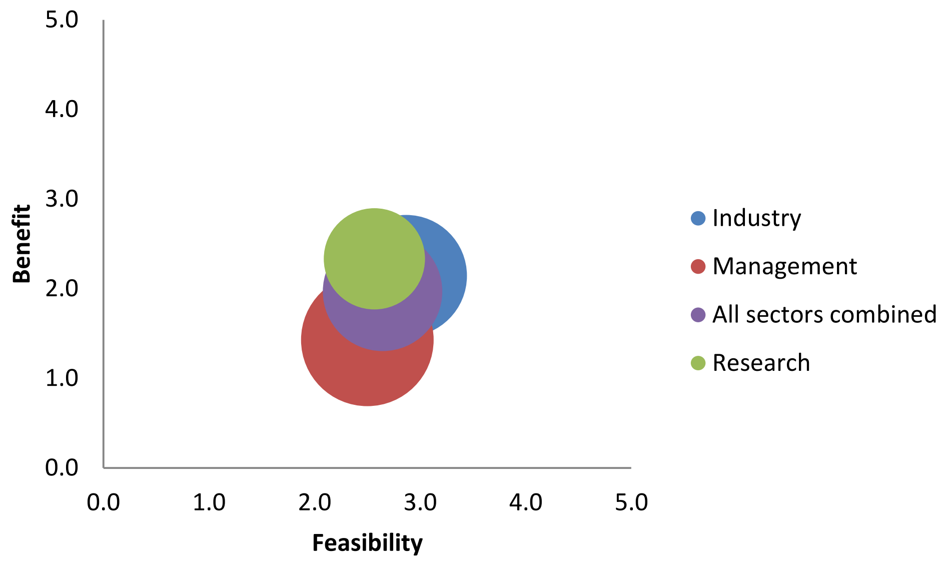

Figure 9. Blue grenadier: evaluation of options to address reduced & altered spawning biomass. Evaluation of the adaptation option shifting to smaller vessels.

5. *Identify improvements to current monitoring systems to ensure that they are suitable for measuring the likely impacts of climate change and other drivers*

There are several key improvements that could be implemented in terms of monitoring relevant to the blue grenadier fisheries in south east Australia, for example:

- Increase collection of water temperature depth profiles to help improve water temperature depth profile forecasting models.
- Improve monitoring of reproductive aggregation behaviour by collecting time series of reproductive condition of fish in trawl shots (i.e. macroscopic assessments), with associated data on depth of capture, water temperature at depth of capture and surface, sex ratio, date, time location etc.
- Improve modelling of larval dispersal, particularly the spatial resolution and ability to investigate realistic future climate change scenarios of larval dispersal.
- Use of otoliths to study how climate regime changes might relate to/influence growth rate variation and implications for assessment modelling.
- Collect data on juvenile abundance to validate model YCS estimates, improve understanding of juvenile ecology and distribution.
- Conduct controlled studies of egg and larval temperature tolerances.

REFERENCES

ABARE (2008). Australian Fisheries Statistics. ABARE and FRDC, Canberra.

Bruce, B.D., Condie, S.A., & Sutton, C.A. (2001). Larval distribution of blue grenadier (*Macruronus novaezelandiae* Hector) in south-eastern Australia: further evidence for a second spawning area. *Marine and Freshwater Research* 52, 603-610.

Bull, B., & Livingston, M.E. (2001). Links between climate variation and year class strength of New Zealand hoki (*Macruronus novaezelandiae*): An update. *New Zealand Journal of Marine and Freshwater Research* 35, 871-880.

Bulman, C.M., Koslow, J.A., & Haskard, K.A. (1999). Estimation of the spawning stock biomass of blue grenadier (*Macruronus novaezelandiae*) off western Tasmania based upon the annual egg production method. *Marine and Freshwater Research* 50, 197-207.

DAFF (2007). Commonwealth Fisheries Harvest Strategy. Policy and Guidelines. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, Australia, 63 pp. http://www.daff.gov.au/data/assets/pdf file/0004/397264/HSP-and-Guidelines.pdf.

Francis, R.I.C.C. (2009). Assessment of hoki (*Macruronus novaezelandiae*) in 2008. New Zealand Fisheries Assessment Report 2009/7. February 2009.

Gunn, J.S., Bruce, B.D., Furlani, D.M., Thresher, R.E., & Blaber, S.J.M. (1989). Timing and location of spawning of blue grenadier, *Macruronus novaezelandiae* (Teleostei: Merlucciidae) in Australian coastal waters. *Australian Journal of Marine and Freshwater Research* 40, 97-112.

Hamer, P.A., Kemp, J., Roberston, S., & Hindell, J.S. (2012). Multiple otolith techniques aid stock discrimination of a broadly distributed deepwater fishery species, blue grenadier, *Macruronus novaezelandiae*. *Fisheries Research* 113, 21-34.

Kuo, C.-L., & Tanaka, S. (1984). Distribution and migration of hoki *Macruronus novaezelandidae* (Hector) in waters around New Zealand. *Bulletin of the Japanese Society for the Science of Fish* 50, 391-396.

Methot, R.D.J., & Wetzel, C.R. (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* 142, 86-99.

Patchell, G.J., Allen, M.S., & Dreadon, D.J. (1987). Egg and larval development of the New Zealand hoki *Macruronus novaezelandiae*. *New Zealand Journal of Marine and Freshwater Research* 21, 301-313.

Russell, S. (2009). Reproductive biology and spawning dynamics of blue grenadier (*Macruronus novaezelandiae*). PHD Thesis, University of Tasmania.

Russell, S., & Smith, D.C. (2006). Spawning and reproductive biology of blue grenadier in south-eastern Australia and the winter spawning aggregation off western Tasmania. Final report, FRDC 2000/201. Canberra.

Smith, A.D.M., Smith, D.C., Tuck, G.N., Klaer, N., Punt, A.E., Knuckey, I., Prince, J., Morison, A., Kloser, R., Haddon, M., Wayte, S., Day, J., Fay, G., Pribac, F., Fuller, M., Taylor, B., & Little, L.R. (2008). Experience in implementing harvest strategies in Australia's south-eastern fisheries. *Fisheries Research* 94, 373-379.

Smith, A.D.M. (1994). Blue grenadier, *Macruronus novaezelandiae*. In The South East Fishery. (Ed. RDJ Tilzey)(Bureau of Resource Sciences: Canberra).

Smith, D.C. (2000). Blue Grenadier 1995, Stock Assessment Report, South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Thresher, R.E., Bruce, B.D., Furlani, D.M., & Gunn, J.S. (1988). Distribution, advection and growth of larvae of the southern temperate gadoid, *Macruronus novaezelandiae* (Teleostei: Merlucciidae), in Australian coastal waters. *Fisheries Bulletin* 87, 17-28.

Thresher, R.E., Nichols, P.D., Gunn, J.S., Bruce, B.D., and Furlani, D.M. (1992) Seagrass detritus as the basis of a coastal planktonic food chain. *Limnology and Oceanography* 37, 1754-1758.

Tuck, G.N., Whitten, A., & Punt, A.E. (2011). Stock assessment of blue grenadier based on *Macruronus novaezelandiae* based on data up to 2010. CSIRO, Hobart.

Whitten, A.R. (2012). Variable Growth Effects in Fish Stocks: Evidence, Modelling, and Implications for Management. PhD Thesis, University of Melbourne.

10. Snapper

Snapper, *Chrysophrys auratus*, is a large, long-lived, demersal finfish species that is abundant throughout the coastal waters of Australasia. The species has a broad Australian distribution that includes the coastal waters of the southern two thirds of the continent, including southwards from the mid-coast of Western Australia, the southern continental coastline and north coast of Tasmania, and the east coast up as far as north Queensland (Kailola et al 1993, Jackson et al 2012). Throughout this distribution, snapper occupy a diversity of coastal habitats including bays, inlets, gulfs and open marine waters to the edge of the continental shelf to a depth of at least 200 m. Consequently, across the different places, the various life history stages of snapper are exposed to a range of environmental conditions.

This project relates to the south eastern region of Australia which supports three different snapper stocks. The Eastern Stock extends from Wilson's Promontory in eastern Victoria (Vic) up the coast of New South Wales (NSW), and Queensland (Qld). The Western Victorian stock is thought to extend from Wilson's Promontory westward into South Australian (SA) waters adjacent to the mouth of the Murray River. This stock includes the important Port Phillip Bay (PPB) fishery. The South Australian stock extends westwards from the Murray mouth into Western Australian waters and includes the populations of Spencer Gulf and Gulf St. Vincent.

Snapper can live up to at least 40 years of age in Australian waters (Norriss and Crisafulli 2010). They are serial batch spawners that reach sexual maturity at 3 – 5 years of age and 25 – 35 cm length (Francis and Pankhurst 1988, Coutin et al 2003). The timing of reproductive activity varies with latitude, presumably in response to water temperature regimes (Sheaves 2006, Wakefield 2006). During the reproductive season, highly-fecund adult snapper form spawning aggregations that produce massive numbers of small, spherical, buoyant eggs. The fertilised eggs hatch after <1 – 2 days of development releasing small, undeveloped larvae of 1.5 – 2.5 mm length. The eggs and larvae are pelagic and free-floating, forming part of the planktonic community and so are subject to passive transport by currents. The larvae take approximately 20-30 days to attain settlement-competency before settling into nursery areas in bays, gulfs and estuaries that support either bare, flat muddy habitat or seagrass meadows.

Recruitment of 0+ (less the age 1 year) snapper into nursery areas in South Australia and Victoria demonstrates significant inter-annual variation, which ultimately drives the population dynamics and variation in fishable biomass and fishery productivity (Figure 10) (Fowler and McGlennon 2011). This variability is thought to relate to inter-annual variation in survivorship of snapper larvae (Zeldis et al 2005, Murphy et al 2012, 2013). The populations of snapper in NSW and Qld do not demonstrate such high recruitment variability, which may be linked to the broad distribution of spawning in oceanic coastal waters, and the fact that juvenile recruitment occurs in a large number of different inshore bays and estuaries.

Significant recreational and commercial fisheries for snapper are found in each of SA, Vic, NSW, WA and Qld. These various State-based fisheries are managed independently of each other, which is problematic for assessment and management when stocks straddle jurisdictional boundaries (i.e. the Eastern stock straddles QLD, NSW and Vic, and the Victorian western stock straddles Vic and SA). In the different commercial fisheries, snapper are targeted with different gear types including handlines, longlines, fish traps and demersal trawls. Also, the relative contributions of the commercial and recreational sectors to total catch differ amongst jurisdictions, with the commercial sector making the dominant contribution in SA and NSW, whilst the recreational sector dominates catches in Qld and Vic.

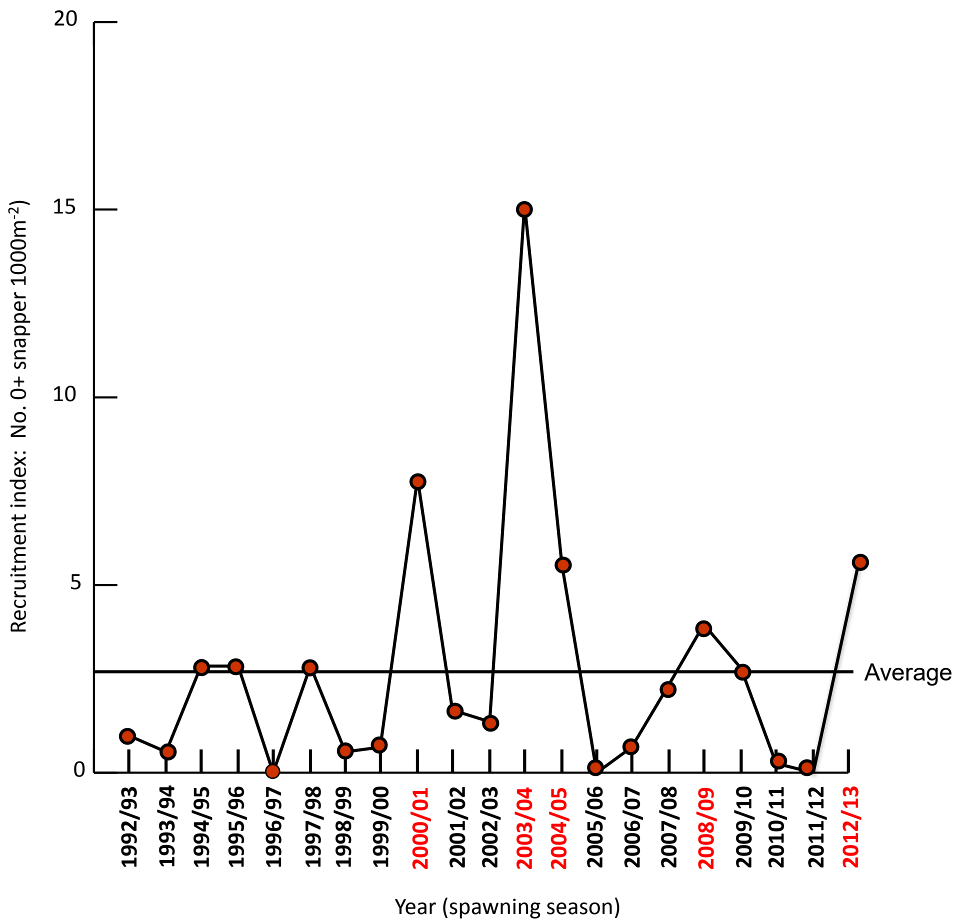

Figure 10. Port Phillip Bay 0+ age annual recruitment index, 1992/93–2012/13.

Reductions in biomass resulting from inappropriate high levels of fishing pressure by recreational and commercial fishers has the potential to increase susceptibility to future climate-induced impacts on recruitment and productivity. Targeting of spawning aggregations has the potential to reduce future spawning success. Competition and conflict between sectors (commercial and recreational) may create barriers that reduce capacity or feasibility for individual sectors to adapt to climate change.

1. ***Identify likely key effects of climate change particularly where these effects may impact the harvest strategy for this species.***

a. *What are the historical relationships between key oceanographic variables and population dynamics?*

In SA and Vic, population dynamics of snapper are driven predominantly by inter-annual variation in recruitment of the 0+ life stages (i.e. new born fish less than 6 month of age) into the demersal populations. Such variation in recruitment relates to the variable survivorship of the larval stages (i.e. first few weeks of life) (Zeldis et al 2005, Murphy et al 2013). There are several environmental factors thought to influence larval survivorship. Firstly, there is the physical influence of SST on larval physiology and growth rates. Larval survivorship is related to growth since higher growth rates are associated with shorter pre-settlement durations, which mean that larvae are exposed for shorter periods to the high predation risk in the plankton (Houde 1987).

Snapper larval survivorship is also influenced by plankton productivity and lower trophic relationships, either directly through starvation or indirectly through reduced growth and physical condition leading to higher predation rates. Snapper larvae are more abundant when their preferred prey, i.e. copepod nauplii and copepodites are also more abundant (Zeldis et al 2005, Murphy et al 2013). Prey availability depends on the input of nutrients to the planktonic environment which then promotes phytoplankton and zooplankton productivity. The timing of the phytoplankton blooms, to produce suitable prey availability for zooplankton (i.e. the food of the larval snapper), importantly needs to coincide with the optimal water temperature conditions for spawning and larval survivorship of 18 - 22°C (this study).

The degree of overlap between the periods of maximum prey availability and this optimum temperature window is likely to be an important influence on the probability of survival of the snapper larvae and ultimately whether recruitment of a new year class will be weak or strong. While inter-annual and long-term water temperature variability can reflect broader geographic climate variation, the sources of nutrients to support plankton productivity vary between places, and therefore the environmental drivers of recruitment variation can vary at local scales. For example, in Port Phillip Bay nutrient supply depends mostly on freshwater inflow from the Yarra River, whilst for the SA’s gulfs nutrients are brought from the continental shelf with inflowing currents during the cooler months of the year (Middleton et al 2013). Inter-annual recruitment variation of small juvenile snapper is therefore not highly correlated between Port Phillip Bay and SA’s Gulfs, and it is clear that there is no simple environmental/climatic relationship with snapper recruitment success that is consistent across a broad geographic range.

> - Population dynamics strongly driven by inter-annual variation in recruitment.
> - Interactions between SST dynamics and plankton productivity thought to affect recruitment success; however there is no simple environmental/climatic relationship that is consistent across the broad geographic range.

b. What are the historical relationships between key oceanographic variables and distribution?

Snapper have a broad distribution and occupy a diversity of coastal habitats including bays, inlets, gulfs and open marine waters to the edge of the continental shelf to a depth of at least 200 m. Consequently, across the different places, the various life history stages of snapper are exposed to a range of environmental and oceanographic conditions such as SST, salinity, turbidity and pH. Whilst older snapper exhibit broad environmental tolerances, geographic distribution of snapper seems strongly limited to regions where the eggs and larvae can survive, and so therefore successful reproduction can occur. These regions are characterised by significant periods of the year (i.e. months) with SST between 18 - 22°C. The timing of seasonal reproductive activity of snapper varies in a systematic way with latitude, i.e. the peak spawning times for populations at low latitudes (warmer climates) is during winter, whereas for higher latitudes (cooler climates) it is during summer. This latitudinal variation in the timing of spawning timing means that the environmental conditions when the eggs and larvae are delivered into the pelagic environment at the different latitudes are relatively consistent. This study showed that the peak spawning times across the entire range of the species tend to occur when the SSTs are in the range of 18 - 22°C, which are the optimal conditions for survival of the eggs and larvae as demonstrated in controlled laboratory/aquaculture environments.

In the future, as SST regimes on the east coast change and the East Australian current extends to Tasmania, the spatial and temporal opportunities (i.e. availability of the optimal temperature window) for survivorship of eggs and larvae will change. In the waters of south east Qld and northern NSW the predicted increased SSTs due to climate change will severely reduce or likely eliminate the spatial and temporal occurrence of the optimal temperature conditions for survivorship of the early life history stages. However, in the waters of southern NSW, eastern Vic and northern and eastern Tasmania there will be either increased opportunity for egg and larval survivorship or changes to the timing of the optimal periods. This will provide opportunity for successful spawning at different times and the southward movement of the distribution of snapper. Further, although not specifically examined in this study, the southerly flow of the East Australian Current is predicted to increase under climate change (Hobday and Lough 2011). This could result in increased transport of larvae southward from spawning areas along the NSW coast into eastern Bass Strait and northern Tasmania away from their traditional nursery areas in the NSW and eastern Victorian estuaries. The fate of the larvae that do not encounter suitable nursery habitat is unclear, but would be predicted to be high mortality.

Higher predicted summer SSTs in SA's northern gulfs could compromise the survivorship of the eggs and larvae. Since the nursery areas are located close to the spawning grounds, there may be limited opportunity for increased spawning activity in the southern gulfs to replace recruitment previously derived from spawning in the northern gulfs. Therefore, if the snapper in the northern gulfs do not modify their behaviour with respect to the timing and locations of spawning then there could be serious consequences for the distribution and abundance in these important spawning areas.

In Port Phillip Bay, the key spawning area for Victoria's Western snapper stock (Hamer et al 2011), successful spawning of snapper predominantly occurs in the 18-22˚C temperature range, similar to other areas in south eastern Australia. There are no long-term temperature projections for Port Phillip Bay due to constraints with SST forecast modelling of small water bodies. However, applying forecast models for the adjacent ocean waters of Bass Strait suggest (Note: Port Phillip Bay is warmer than Bass Strait in the summer) that the optimal 18-22 ˚C spawning window would be similar overall in the 50-year forecast period, but would on average occur earlier and be consistently split into two periods; November-December and March – May, with water temperature in January and February being consistently >22 ˚C. The ability of snapper in a specific region to adapt their spawning behaviour to two distinct windows of optimal temperature, one when temperature and day length were increasing and the other when they were decreasing is unclear. However the fact that snapper spawn in Queensland when day length and temperature are decreasing, suggests that such behaviour is physiologically possible. The average success of spawning and the dynamics of recruitment may then relate to how a shift in spawning timing overlaps with optimal periods of planktonic prey availability for the larval stages.

- Across distribution, snapper are exposed to and tolerate a wide range of environmental and oceanographic conditions.
- Spawning success is limited to regions where the eggs and larvae can survive characterised by prolonged periods with SST between 18 - 22°C.
- Predicted changes in SST and the EAC flow provide new opportunities in southern NSW, eastern Vic & northern Tas, but negative effects in other regions in southern QLD and northern NSW where SST is predicted to rise above optimum temperature for spawning & larval survival.

c. What are the historical relationships between key oceanographic variables and productivity?

Fishery productivity for snapper in SA and Vic is driven by variable population dynamics, linked to inter-annual variation in recruitment. Variable recruitment determines the number and ages of strong year classes that contribute to a snapper population at any one time. Therefore, fishery productivity is ultimately largely dependent on the inter-annual variability in survivorship of the early life stage, particularly the larvae. It appears that interactions between SST regimes and plankton prey dynamics are important influences on snapper larval survival and recruitment success in the SA gulfs and Port Phillip Bay. Plankton prey dynamics are not simply linked to easily measured oceanographic variables, but depend on multiple and variable factors depending on each region. While higher temperatures may benefit larval growth and recruitment in some areas (i.e. SA Gulfs), these benefits may be overwhelmed by changes in rainfall regimes and nutrient supply dynamics (i.e. Port Phillip Bay). Predicting productivity of snapper fisheries from oceanographic variables alone does not appear feasible and more complex biophysical models incorporating interactions between oceanography, physical and chemical conditions, and planktonic prey production (trophodynamics) will be required.

- Productivity mostly influenced by variable survivorship during the early life stages.
- Determining simple and consistent empirical relationships between productivity and oceanographic variables does not appear feasible. Biophysical models incorporating interactions between oceanography and planktonic prey production (trophodynamics) will likely be required.

d. How might larval dispersal be altered by changes in climatic conditions, and what might be the implications of any changes for larval survival?

Due to climate change, the East Australian Current is predicted to strengthen and project further southwards, as far south as southern Tasmania (Hobday and Lough 2011). Furthermore, the marine waters of south east Australia are predicted to experience the greatest degree of warming, relative to all coastal Australian waters (Hobday and Lough 2011). Both changes will have consequences for the survivorship and transport of snapper larvae in eastern Australian coastal waters.

As described earlier, the optimal SST range for the survivorship and production of viable snapper eggs and larvae is clearly 18-22°C. Projected SSTs for the years of 2063 to 2073 indicate that the timing and duration of SSTs will change considerably compared to those from 1994 to 2012. In the future, for both southern Queensland and northern NSW at no time during the year will SST fall below 22°C, suggesting no opportunity for successful spawning of snapper based on their current biology. This would contribute to a major reduction in distribution and abundance of snapper in this region. For central and southern NSW and also for the coastal areas of eastern and western Victoria as well as the northern and eastern waters of Tasmania, the water temperature regimes will change, increasing the periods of the year during which the SST will fall in the range of 18-22°C. This will provide greater opportunity for survivorship of the early life history stages of snapper, and therefore enhance the opportunity for establishing and then building up self-recruiting, permanent adult populations.

For SA and western Victoria, the main spawning grounds and nursery areas are located in the northern parts of Gulf St Vincent and Spencer Gulf, and Port Phillip Bay, respectively. At present, spawning occurs in these regions each summer between November and January with the peak in December corresponding to an average SST of 19-22°C. However, the projected SSTs for these regions are considerably higher, exceeding the optimal range of 18-22°C for prolonged periods during summer months. For the SA gulfs, projected increases in summer water temperatures may remove the northern Gulfs as suitable spawning areas during the current spring/summer spawning season. This may well have a negative, if not catastrophic effect, on recruitment success for snapper in these regions. This is potentially significant for the populations of the whole State, since these regions support the most significant nursery areas. For Phillip Bay, the impact of increases in temperature on spawning success and recruitment will depend on whether snapper can split their spawning season across two distinct windows of optimal temperature (Nov-Dec, and March-May).

- Predicted temperature increases likely to create adverse conditions for spawning/larval survivorship in southern QLD, northern NSW, Port Phillip Bay (Vic) and SA gulfs.
- Predicted SSTs through central and southern NSW, Victoria (excluding Port Phillip Bay) as well as the northern and eastern waters of Tasmania will increase the period of optimal spawning conditions facilitating southern range extension and consolidation.

e. What are the key ecosystem/ecological/habitat relationships, and how may these alter under a changing climate?

Snapper have an extremely broad range and occupy a diversity of habitat types. They are a schooling species with a generalist carnivorous diet that includes crustaceans, molluscs, polychaetes and demersal fishes (Winstanley 1983). In SA Gulfs, macro-crustaceans such as blue swimmer crabs (*Portunus sp.*) commonly constitute a significant part of their diet when available (Lloyd 2010). Snapper is a top-down predator and has the potential to significantly modify the community structure of the habitat that it occupies or any new ecosystem that it might colonise. As a consequence of climate change, the abundances of predators or competitors of snapper may increase. This could produce a sustained decrease in productivity of the snapper populations. However, there is also the possibility of an increase in the abundance of the prey species of snapper, as is occurring with the range extension of blue swimmer crabs into SA's southern gulfs. In such situations, there could be a sustained increase in the productivity of snapper populations. Ecosystem models are required to further explore this issue. However, development of such models is limited by poor or out dated information on trophic ecology of snapper, particularly, in areas such a Port Phillip Bay that have seen major changes in benthic prey communities over the last few decades.

- Abundance and distribution changes to predators, competitors and prey will be key ecosystem factors affecting snapper. These may be positive or negative and are likely to vary across distribution.

f. To what extent may climate change, through an altered physical environment, influence access to current or future fishing grounds? Consider swell, winds, storm events, wave height.

Specific projection modelling of physical parameters such as swell, winds, storm events and wave heights were not undertaken as part of this project. The only readily available information against which to make some assessment about altered weather impacts on access to fishing grounds is the average modelled wind projections provided at http://www.climatechangeinaustralia.com.au/. However, these cover broad regional zones and are not specific enough for major fishing areas such the SA Gulfs and Port Phillip Bay. Given that the major fishing grounds in Vic and SA are in relatively sheltered bay/gulf waters, long-term climate impacts on access to the fishing grounds are expected to be minimal, however, for the NSW and Queensland ocean fisheries the impact could be greater.

- Current projected changes to weather patterns are not considered specific enough to predict impacts on access to open coastal water fishing areas, although the impacts are likely to be limited for sheltered water fisheries in the SA gulfs and Port Phillip Bay.

g. To what extent might climate change influence stocks/fisheries? Consider both slow trends and potential for extreme events or 'surprises'. Develop 'scenarios' for developing and evaluating adaptation responses in the workshops (a scenario is an evidence-based plausible future for the fishery, given likely climate change – i.e. the sum of a-f above).

Consideration of the effects of climate change on snapper populations has identified two potential significant effects. Based on model projections done by CSIRO for the years of 2063-

2073, SST regimes will generally become warmer in the future. In some northern regions this is likely to reduce the opportunity for successful spawning and recruitment, but in some southern regions the opportunities will increase. Our analysis leads us to predict lower recruitment rates and overall fishery productivity in Queensland and northern NSW, but increased opportunity for successful spawning and recruitment southward from central NSW to eastern Victorian waters as well as northern and eastern Tasmania.

There is also concern for Port Philip Bay and northern gulf waters in SA where SST is predicted to rise above the current optimal window of 18 - 22˚C for greater periods of time during the current spring/summer. It's predicted that, in these areas there will be a longer period of sub-optimal SST during mid-summer, but potentially a longer window of optimal spawning temperature into autumn. Overall, the net change in the period of 18-22 ˚C each year may be small, but separated more evenly across two discrete time windows, i.e. late spring/early summer and late summer autumn. If snapper do not adapt their migratory habitats to stay in the bay longer and shift spawning to periods associated with both increasing and decreasing day length and temperature trends, then future high summer SST may have a major negative impact on recruitment and overall fishery productivity.

- Climate change predicted to reduce optimal conditions for spawning and larval survival in warmer areas and provide increased opportunities in south eastern Australia, particularly northern and eastern Tasmania.
- Climate change likely to alter existing recruitment variability due to changes in SSTs and nutrient supply dynamics which are not currently well understood.

A second possible effect of climate change for snapper populations is increased variability in recruitment of 0+ fish into the demersal populations. Such variability is driven by survivorship of the larvae. Because high recruitment success (larval survival) depends on the favourable interaction/overlap of the optimal temperature window with periods of high larval prey availability, changes to the temporal dynamics of both SST and nutrient inputs will influence the frequency of high and low recruitment events. The effects of climate change on the dynamics of this key interaction are not clear and present a major uncertainty in predicting climate change impacts on the bay/gulf spawning snapper stocks of Victoria and SA. The main nutrient source to Port Phillip Bay is the Yarra River, which depends on rainfall to drive nutrient discharge into the bay, which in general is predicted to decrease. The source of nutrients to the SA gulfs is a mixture of terrestrial point source and inputs from adjacent ocean waters. The sources of such nutrients to the coastal waters of NSW, QLD and eastern Victoria where snapper larvae occur will be a mixture of coastal draining rivers and up-welled nutrients from deeper waters. The effects of climate change on nutrient supply dynamics and amounts primary and secondary production across snapper spawning areas are difficult to predict and are not specifically dealt with by current projection modelling tools. Current understanding of nutrient supply – planktonic food chain linkages and dynamics is poor.

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).***

Good biological data (e.g. age, growth and reproduction) are available for snapper in most jurisdictions. Catch sampling and fishery catch and effort data currently collected from most fisheries provide a cost effective basis for monitoring temporal changes in rates of growth and patterns of inter-annual variability in recruitment and production. There is an ongoing (since 1993) fishery independent pre-recruit monitoring program for the western Victorian stock. Stock assessment models have been developed for SA and QLD fisheries and are in development for the Victorian western stock. There is a need to improve stock assessments and biomass estimates by developing fishery independent approaches that are not influenced by changes in regulation/management and or fishing behaviour/gear. There is a clear need to better monitor catches by the recreational (including charter) sector across the range. Development of harvest strategies and performance measures that involve recreational and commercial sectors and their objectives will be critical to facilitating appropriate harvest management decisions in a changing climate. Harvest management needs to take account of socio-economic as well as biological sustainability objectives, and there is clear need to develop performance measures and monitoring approaches for social and economic objectives. Finally, competition for snapper will increase in some areas, which may lead to barriers to adaption by each sector. Formal resource sharing frameworks will be required to facilitate adaptation within and across sectors.

a. *Do additional data needed to be collected to understand the cause and scale of changes? (e.g. is spatial resolution of data adequate to detect changes in distribution or changes in timing or location of spawning etc?)*

Data on commercial catch, recreational catch, as well as sizes and ages of captured snapper are collected in each of the four mainland states, although not necessarily consistently across years. Where a stock straddles state boundaries, the data are not collected in a coordinated way between states. This is an issue for the southern QLD - northern NSW regions where a more integrated cross-jurisdictional monitoring and assessment program is warranted. In the cases of SA and Vic, these data appear to be sufficient to undertake appropriate stock assessments. Furthermore, it appears that sufficient data already exist to undertake a cross-jurisdictional stock assessment for the eastern stock, although that has never been undertaken in the past (Jackson et al 2012). Therefore, it would appear that sufficient data are currently being recorded to detect shifts in patterns of distribution, productivity and abundance of snapper throughout its range in south east Australia, although more collaboration with regards to monitoring and assessment across jurisdictions that share stock is recommended. However, there is a clear risk that core monitoring programs will be cut to meet Government cost savings in some States and this would have severe implications for detecting longer-term, climate-related trends in fisheries production. Further, monitoring would have to be introduced to detect predicted increases in abundance in Tasmanian waters. Such monitoring/or research would be required to establish whether breeding populations had become established and were sufficiently large to support a commercial and more widely promoted and valuable recreational fishery in this region.

At present, regular collection and assessment of data relating to nutrient supply dynamics and recruitment is not undertaken as the relationship is poorly understood. Determining the key drivers behind recruitment variability would be a pre-requisite for monitoring the effects of climate change on these variables and the consequential impacts on stock productivity.

- Sufficient data being recorded to detect shifts in patterns of distribution, productivity and abundance of snapper throughout its current range.
- New monitoring required to determine whether breeding populations become established in Tasmania.
- Additional work required to understand recruitment variability.

b. Will current measures of stock status remain appropriate?

Daily fisheries data (effort, catch, etc) are used to develop direct indicators of stock status (e.g. CPUE) in some jurisdictions (e.g. NSW) and as inputs to stock assessment models elsewhere (SA, Vic). A FRDC project is in place to develop a fishery-independent measure of absolute abundance for snapper in South Australia. Formal harvest strategies with performance indicators, reference points and decision rules have not been established for snapper, but are subject of new FRDC project for the western Victorian stock.

The status for each of the various Australian stocks of snapper was recently established based on the classification system used in the recent national stock status report (Flood et al 2012). It is anticipated that this classification system will continue to be used by the various jurisdictions in the future and that the existing data underpinning these classifications will continue to be appropriate and collected.

c. Will reference points need to be changed?

South Australia has numerous reference points that are applied to commercial fishery statistics and biological parameters that are primarily derived from the stock assessment model. The reference points are appropriate for detecting both quick, short-term changes and slow, chronic changes. As such, the performance indicators and trigger reference points should not need enhancement for picking up changes associated with climate change. Reference points have not been determined and implemented within formal harvest strategies or for other purposes in Victoria, NSW or Queensland. Decisions to change input controls typically result from consultative forums that may or may not be informed by Management Strategy Evaluations.

d. Do model assumptions need to change (e.g. constant growth rates)

Currently in eastern Australia, only SA and QLD use a quantitative fishery assessment model to inform stock assessments for their snapper fisheries. Victoria is in the process of developing such a model for the western stock. These models are used to inform management options but are not linked to formal harvest strategies with pre-defined control rules, as is the case in the larger Commonwealth fisheries (i.e. blue grenadier). The South Australian model is a sophisticated one that is based on integrating commercial and recreational fishery statistics with data on population structure (age and length composition) from market sampling. This model should be sufficiently robust to identify changes in biomass as a consequence of declining recruitment or growth parameters, which could result from climate change. Although, biomass estimates need validation by independent methods due to the impacts of recent changes in management of fishery dependant monitoring data. A new FRDC project is trialling egg surveys/daily egg production method as an approach to independently estimate spawning biomass and SA gulfs. The model already accommodates different regional growth functions. At present, in SA a stock assessment is undertaken every three years as part of which new data collected since the last assessment are added to historical datasets for consideration in the model whilst appropriate software updates are made as necessary. As such, at this time, changes can be made to growth models and other biological parameters if required.

- SA & QLD have quantitative models, Vic in process of developing one.
- Existing data collection sufficient to inform need for any model assumptions to be altered.

e. Do decision rules need to change (e.g. do TACs at different abundance levels need to be reduced to reflect decreases in recruitment?)

Existing management frameworks/decision making processes are considered to be sufficiently adaptive such that they could cope with changes to stock abundance resulting from climate change. Importantly however, none of the snapper fisheries in southern and eastern Australia are managed with formal harvest control rules, whether it is through a TACC or other effort and/or catch controls. This presents a risk to the ability to rapidly determine and effectively implement any harvest management changes should the fishery assessment data point to the need for such changes.

> - Existing management frameworks considered sufficiently adaptive to respond to changes.
> - Lack of formal agreed harvest strategies presents a risk to timely identification and implementation of harvest management changes should they be required.

f. Is coordination among jurisdictions adequate to address potential changes?

The Eastern Stock was recently assigned an 'undefined' status because no stock assessment has been conducted across its whole geographic range (Jackson et al 2012). That report also identified that a formal cross-jurisdictional stock assessment was required as a matter of urgency. Given the likelihood of significant changes in the distribution and abundance of the populations of the Eastern Stock, it would be highly beneficial to implement single, cross-jurisdictional assessment and management across its entire range from Queensland to Tasmania. Furthermore, the recent significant catches that have come from the south east region of SA may have originated from PPB in Victoria. This hypothesis is currently being tested in FRDC Project 2012/020. If supported, it may indicate the need for cooperative fishery management and stock assessment for the Western stock between Vic and SA.

> - Greater collaboration considered important to better understand stock status, particularly for the Eastern Stock.
> - More collaborative assessment and management may be required between SA & Vic if current research indicates shared stocks.

3. Identify climate change impacts, adaptation options and barriers

Table 18 lists the autonomous and possible planned adaptation actions that were elicited from stakeholders in response to the potential climate change impacts presented at the March 2012 workshop. Stakeholders also identified likely barriers to implementing any possible planned adaptation actions.

The governance benchmarking exercise also identified a number of potential barriers to adaptation for the snapper fisheries in each jurisdiction (Table 19). Governance for snapper fisheries needs to be improved in some jurisdictions. For example half the 'Planning' and 'Accountability' attributes were not in place in Victoria. Clear processes for making trade-offs between conflicting objectives were not in place in Victoria and only partially in place in South Australia. Clear and equitable processes to deal with interactions or conflicts among user groups could also be introduced or improved in both jurisdictions. Several potential barriers to adaptation were also identified in the 'Incentives' section of the benchmarking exercise for South Australia. For example, seven of the ten attributes in this category were 'not in place and importance not recognised', including 'incentives fully aligned with goals and objectives' and 'monitoring of negative externalities'. Annual monitoring of biological KPIs occurs in South Australia but, while monitoring is sufficient, the establishment of formal KPIs is required in Victoria. Economic, social and/or community performance indicators could be improved in South Australia, and are currently not in place at all in Victoria or NSW.

Table 18. Adaptation options and barriers for snapper.

POTENTIAL IMPACT	AUTONOMOUS ADAPTATION	POSSIBLE ADAPTATION ACTIONS	BARRIERS
Larval dispersal and range shift southward with increased EAC & SST. – abundance decrease in southernQLD & Northern NSW; - abundance increase in north and eastern TAS (and possibly eastern & central VIC)	1. Shift fishing operations to areas of high abundance, including across jurisdictions 2. Change target species 3. Increase/reduce targeted effort and or catch	1. Implement single jurisdictional responsibility across the range of the stock 2. Increase monitoring to track increase in abundance and to assess if & when abundance is suitable to develop new regional commercial fisheries (e.g. TAS)	1. Increased fuel costs 2. Increased travel 3. Negative impacts on other species 4. Existing jurisdictional arrangements are complex, any changes will be difficult and affect access rights 5. Differential uptake of opportunities will affect catch shares between sectors
Loss of larvae from suitable estuarine nurseries through currents and or increased temperatures (abundance decrease NSW, QLD)	1. Change target species 2. Reduce targeted effort and or catch	1. Undertake stocking of areas negatively impacted 2. Maintain capacity for commercial effort to shift according to fluctuations in abundance	1. Stocking is costly and unproven and in some cases is not supported by Government policy 2. Disease & genetic risks 3. Impacts on other species
Decreased estuarine productivity (habitat loss) due to storm surges and reduced freshwater flows	1. Change target species 2. Reduce targeted effort and or catch	1. Maintain capacity for commercial effort to shift according to fluctuations in abundance 2. Stocking 3. Habitat protection (silt traps, flow controls, rock walls). 4. Habitat enhancement (artificial reefs) 5. Catchment management improvements (e.g. reduce water extracted for irrigation)	1. As above for Loss of larvae – abundance decrease 2. Difficult to evaluate 3. Potential for negative impacts on other processes and or species
Introduced species & pollution may negatively impact important habitat	1. Change target species 2. Reduce targeted effort and or catch	1. Stocking 2. Mitigate impacts of introduced species through control methods	1. As above for Loss of larvae – abundance decrease 2. Expensive and likely to be on-going and expensive
Increased productivity due to increases in prey species due to changing environment and processes.	1. Increase catch/effort according to harvest strategy or assessment outcomes.	1. Undertake a review of management strategy, particularly if prey species are also commercially important species	1. Consideration of impacts on access rights and catch shares.
Greater survival and retention of older snapper further south (TAS) with potential for locally derived recruitment.	1. Fishers target snapper as part of existing operations	1. Prohibit snapper fishing to maximise opportunity of self-sustaining and viable population to develop. 2. Implement independent monitoring to determine extent and potential of new fishery.	1. Differential uptake of opportunities will affect catch shares between sectors (allocation) 2. Independent monitoring is expensive
Periods of high water temperatures (e.g. SA gulfs) could cause larval mortality and affect recruitment	1. Decreased abundance-conservative harvest strategy	1. Stocking and enhancement	1. Costs 2. Probability of success is low
Possible increase in fishing pressure on snapper if other species decline (e.g. sand flathead)	1. Build decision rules into harvest strategies that account for effort shifts.	1. Restrict ability for the transfer of effort across species	1. Ability to transfer effort across species is considered important climate change adaptation tool

Table 19. Summary of barriers to adaptation related to fisheries governance attributes for snapper. Accountability (AC), Planning (P), Incentives (I), Adaptability (AD) and Knowledge (K).

Jurisdiction	Summary of barriers
South Australia	• Planning occurs across the entire fishery value chain (P) • Incentives fully aligned with goals and objectives (I) • Secure and durable individual or community harvesting or area fishing rights (I) • Competitive and well-developed market for fishing rights (I) • Monitoring and enforcement of fishing rights (I) • Incentives to avoid negative externalities, including habitat damage and by-catch (I) • Monitoring of negative externalities (I) • Mechanisms to ensure re-investment of some economic rent in fishery (I)
Victoria	• Mechanisms to ensure re-investment of some economic rent in fishery (I)

4. Evaluate potential adaptation options

Prior to evaluating potential adaptation options, the revised adaptation options were furthered refined and analysed using a characterisation matrix which identified the key characteristics of the adaptation options being considered for further evaluation (Table 20). This was considered an important step to map out implications, interactions with other management strategies and issues of temporal and spatial scales.

Four adaptation options all addressing the climate challenge of reduced productivity and availability were assessed for the snapper fishery. The four adaptation options assessed were: (1a) reducing effort through spatial closures, (1b) reducing effort through temporal closures, (1e) change seasonal fishing activities/methods, and (1f) implement single cross-jurisdictional management across the stock range. Clearly the highest ranked adaptation option in terms of benefit was to implement single cross-jurisdictional management, being ranked as either 'high' or 'moderate' by all sectors. However this option was also ranked the lowest in terms of feasibility, being scored as 'very low' by all sectors (Table 21, Figure 11). The adaptation option with the next highest benefit was to change seasonal fishing activities/methods, which was ranked as 'moderate' by both industry and management, however as with single cross-jurisdictional management this feasibility was ranked as either 'low' or 'very low' by all sectors (Table 21, Figure 11). Consensus levels varied across the different adaptation options and also within sectors (Table 21).

Results for the snapper fishery were varied in terms of how the different sectors perceived the benefits of the different adaptation options. However there was generally good consistency regarding the feasibility of the options. The snapper fishery is perhaps the most diverse fishery across the south east Australian region. The large numbers of commercial and recreational fishers that participate in this fishery would ideally necessitate a larger number of survey respondents from the various jurisdictions and also from the recreational sector.

Table 20. Snapper final list of suggested potential adaptation options, and a characterisation of each option

SNAPPER			2. CHARACTERISING IMPLEMENTATION							3. CHARACTERISING BENEFITS				
Challenge No. Option No.	**CLIMATE CHALLENGE (includes potential impact/s)** POTENTIAL ADAPTATION OPTIONS	**1. ADAPTATION TYPE**	2.1 SCALE OF APPLICATION	2.2 JURISDICTION/S IN WHICH IMPLEMENTED	2.3 SIGNIFICANCE OF DIFFERENCE BETWEEN JURISDICTIONS	2.4 LEAD TIME TO IMPLEMENTATION	2.5 ADDITIONAL COST (relative to "do nothing")	2.6 WHO PAYS	2.7 LEVEL OF CONTROVERSY EXPECTED	3.1 PRIMARY BENEFICIARY	3.2 SCALE OF BENEFIT	3.3 CONSEQUENCE PERIOD (when benefits are expected)	3.4 ADDRESSES OTHER CLIMATE CHALLENGES?	**BARRIERS (list any not already identified)**
		Autonomous, Business-As-(Mostly)-Usual, Incremental, Transformative	National, State, Zone, Sub-zone	Name which jurisdictions (i.e. TAS, VIC, SA, C'Wealth)	Low,Medium,High	<1 year,1-5 years,>5 years	Nil,Low, Medium,High	Industry, Government, Consumers, Post-Harvest, Local communities	Low,Medium,High	Fishers,Fishery,Fish Stock,Ecosystem	National, State, Zone, Sub-zone	<1 year,1-5 years,>5 years	Name which ones	
1	**Reduced productivity and availability** **1. Northward extension of distribution is reduced** **2. Timing of peak local abundance changes (local & regional)** **3. Negative effects on recruitment**													
1a	Reduce targeted effort through spatial closures (local)	Business-As-(Mostly)-Usual	State	SA,VIC,NSW	Medium	1-5 years	Low	Industry	Medium	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
1b	Reduce targeted effort through temporal closures (regional)	Business-As-(Mostly)-Usual	State	SA,VIC,NSW	Medium	1-5 years	Low	Industry	Medium	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
1c	Shift fishing operations (regional)	Incremental	State	SA,VIC,NSW	Medium	1-5 years	Low	Industry	Medium	Fishers	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Conflict over access
1d	Change target species (local)	Business-As-(Mostly)-Usual	State	SA,VIC,NSW	Medium	1-5 years	Low	Industry	Medium	Fishers	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Conflict over access
1e	Change seasonal fishing activities/methods	Incremental	State	SA,VIC,NSW	Medium	<1 year	Low	Industry	Medium	Fishers	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Conflict over access
1f	Implement single cross-jurisdictional management/access arrangements across stock range (i.e. east stock shared b/w QLD, NSW, Vic, Tas)	Transformative	State	SA,VIC,NSW ,TAS	High	>5 years	High	Government	High	Fish Stock	State	>5 years	Other influences that alter productivity regionally (eg changes in growth, recruitment etc.)	Political and or industry will
1g	Revise restrictions (size, bag, gear limits)	Business-As-(Mostly)-Usual	State	SA,VIC,NSW ,TAS	Low	1-5 years	Low	Government	Medium	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
1h	Stocking of nursery areas	Transformative	State	SA,VIC,NSW	High	>5 years	High	Government	High	Fish Stock	State	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Political and or industry will
2	**Increased productivity and availablility** **1. Southward shift in distribution - Tasmania**													
2a	Initiate research/monitoring program: Find out the origin of the new fishery - life history/movement/ecological impact, abundance research	Incremental	State	TAS	Low	1-5 years	Medium	Government	Low	Fishery	State	1-5 years	Better understanding of climate drivers	Time frame

2b	Developmental fishery plan/fishery expansion plan	Business-As-(Mostly)-Usual	State	TAS	Low	1-5 years	Low	Government	Low	Fishers	State	1-5 years	na	Knowledge gaps
2c	Establish new fishery	Transformative	State	TAS	Low	>5 years	Medium	Government	Medium	Fishery	State	>5 years	Declines in other target species	Determining access rights
2d	Implement restrictions (size/bag/gear etc)	Incremental	State	TAS	Low	1-5 years	Low	Government	Low	Fish Stock	State	1-5 years	na	Knowledge gaps
2e	Implement single cross-jurisdictional management/access arrangements across stock range (i.e. east stock shared b/w QLD, NSW, Vic, Tas)	Transformative	State	SA,VIC,NSW,TAS	High	>5 years	High	Government	High	Fish Stock	State	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Political and or industry will
3	**Altered habitats** **1. Changed abundance of predators/competitors/prey**													
3a	Reduce fishing effort on snapper	Business-As-(Mostly)-Usual	State	SA,VIC,NSW,TAS	Medium	1-5 years	Low	Industry	Medium	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
3b	Shift fishing effort to other species	Business-As-(Mostly)-Usual	State	SA,VIC,NSW,TAS	Medium	1-5 years	Low	Industry	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Conflict over access
3c	Alter fishing activities/methods	Incremental	State	SA,VIC,NSW,TAS	Medium	1-5 years	Low	Industry	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Conflict over access
3d	Stocking of nursery areas	Transformative	State	SA,VIC,NSW,TAS	High	>5 years	High	Government	High	Fishery	State	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Feasibility
3e	Review management (harvest) of prey species	Incremental	State	SA,VIC,NSW,TAS	Medium	1-5 years	Low	Government	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
3f	Implement control measures on pest species/new competitors	Incremental	State	SA,VIC,NSW,TAS	Medium	1-5 years	High	Government	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost, practicality
4	**Declines in other associated target species** **1. Increased targeting of snapper**													
4a	Reduce fishing effort on snapper	Business-As-(Mostly)-Usual	State	SA,VIC,NSW	Medium	1-5 years	Low	Industry	Medium	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
4b	Restrict transfer of effort to snapper	Business-As-(Mostly)-Usual	State	SA,VIC,NSW	Medium	1-5 years	Medium	Industry	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Conflict over access
5	**Altered weather patterns** **1. Reduction in freshwater flows, reducing recruitment** **2. Local population decline**													
5a	Stocking of nursery areas	Transformative	State	SA,VIC,NSW	Medium	>5 years	High	Government	High	Fishery	State	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Feasibility
5b	Reduce fishing effort on snapper	Business-As-(Mostly)-Usual	State	SA,VIC,NSW	Medium	<1 year	Low	Industry	Medium	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
5c	Shift fishing effort across species	Business-As-(Mostly)-Usual	State	SA,VIC,NSW	Medium	<1 year	Low	Industry	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Conflict over access

Table 21. Average scores and consensus level by sector for assessed adaptation options for the snapper fishery.

Climate Challenge	Adaptation Option	Sector	Feasibility		Risk		Benefit		No. respondents
			Average	**Consensus**	**Average**	**Consensus**	**Average**	**Consensus**	
Reduced productivity and availability	1a. Reduce effort through spatial closures	Industry	Low	High	Moderate	Low	Low	High	3
		Management	Moderate	High	Low	High	Low	Low	2
		Research	Low	Medium	Moderate	Medium	Low	Medium	4
		All sectors combined	Moderate	Low	Moderate	Low	Low	Medium	9
	1b. Reduce effort though temporal closures	Industry	Low	Low	Moderate	High	Moderate	Medium	3
		Management	Moderate	Low	Low	High	Low	Low	2
		Research	Moderate	Medium	Low	Medium	Moderate	Medium	4
		All sectors combined	Moderate	Low	Low	Medium	Low	Low	9
	1e. Change seasonal fishing activities/methods	Industry	Low	High	Low	High	Moderate	High	3
		Management	Low	High	Low	High	Moderate	High	2
		Research	Very low	High	Low	Medium	Low	Medium	4
		All sectors combined	Low	High	Low	Medium	Moderate	Medium	9
	1f. Implement single cross-jurisdictional management arrangements across stock range	Industry	Very low	High	Low	Low	Moderate	Low	3
		Management	Very low	High	Low	Low	High	High	2
		Research	Very low	Medium	Very low	High	High	Medium	4
		All sectors combined	Very low	High	Low	Low	High	Medium	9

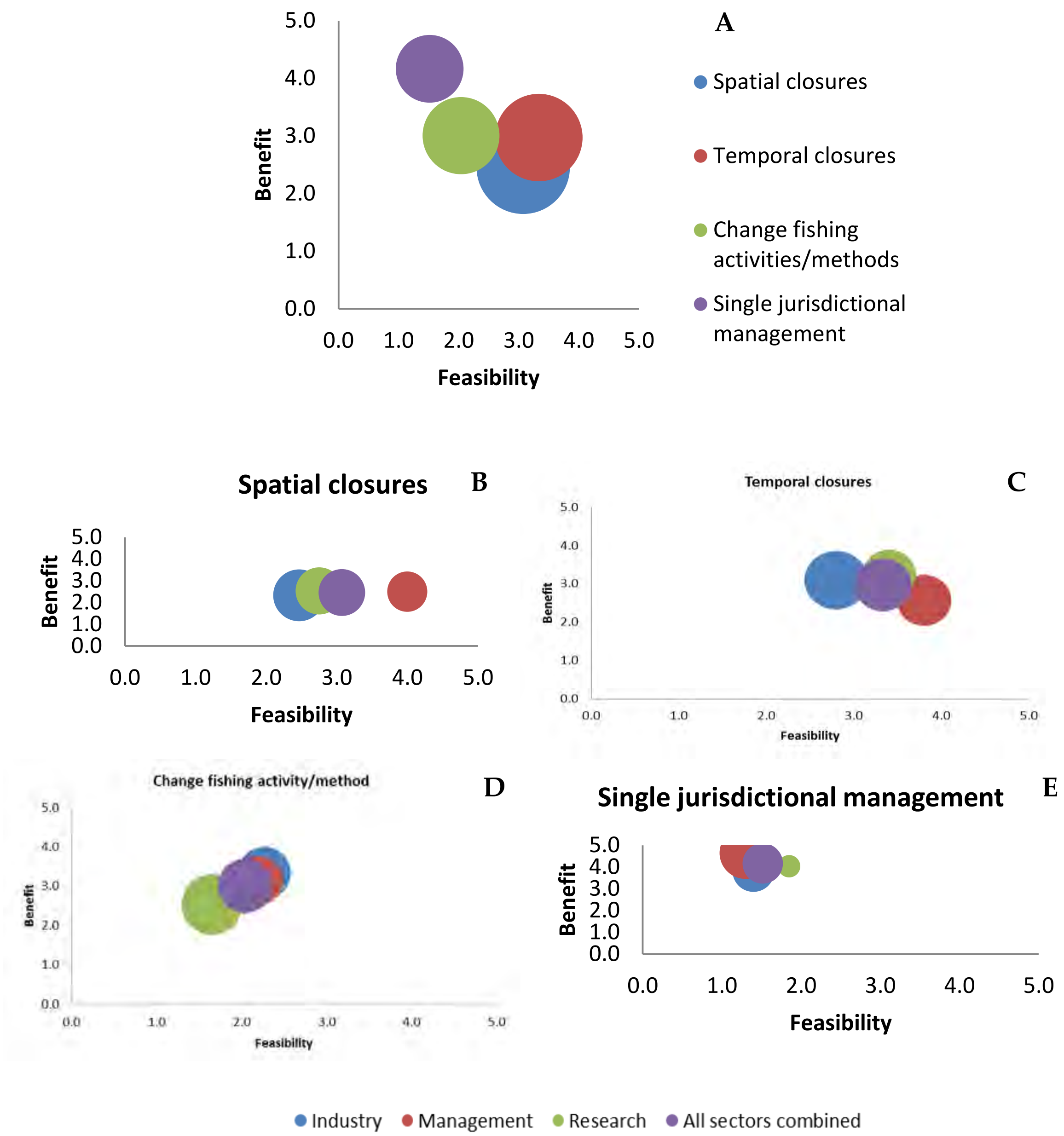

Figure 11. Snapper: evaluation of options to address the climate challenge of reduced productivity and availability. (A) Evaluation of each option by all sectors combined, (B) evaluation of spatial closures, (C) temporal closures, (D) changing fishing activity/method, (E) single jurisdictional management.

5. *Identify improvements to current monitoring systems to ensure that they are suitable for measuring the likely impacts of climate change and other drivers*

There are several key improvements that could be implemented in terms of monitoring relevant to the snapper fisheries in south east Australia, for example:

- Improved water temperature forecasting models for nearshore coastal waters including shallow bays, in particular Port Phillip Bay and the South Australian gulfs.
- Monitoring of nutrient, phytoplankton, zooplankton dynamics in key spawning areas to inform improved modelling of climate implications for larval feeding success, growth and survival and their influence on juvenile recruitment.
- Reporting of commercial fishery catches at a finer spatial scale to identify changes in patterns of distribution and abundance.
- Improved monitoring of spawning behaviour, particularly in coastal waters of QLD, NSW and eastern Vic.
- Improve modelling of larval dispersal, particularly the spatial resolution and ability to investigate realistic future climate change scenarios of larval dispersal down the east coast of Australia and Tasmania.
- Monitoring for reproductive activity, larval stages and juvenile recruitment in Tasmanian waters.
- Monitoring of adult movement/stock structure to detect changes in range and or stock boundaries

REFERENCES

Coutin, P.C., Cashmore, S., & Sivkumuran, K.P. (2003). Assessment of the snapper fishery in Victoria. Final Report to FRDC (Project No. 1997/128). 205 p.

Flood, M., Stobutzki, I., Andrews, J., Begg, G., Fletcher, W., Gardner, C., Kemp, J., Moore, A., O'Brien A., Quinn, R., Roach, J., Rowling, K., Sainsbury, K., Saunders, T., Ward, T. & Winning, M. (eds) (2012). Status of key Australian fish stocks reports 2012, Fisheries Research and Development Corporation, Canberra.

Fowler, A.J., McGlennon, D. (2011). Variation in productivity of a key snapper, *Chrysophrys auratus*, fishery related to recruitment and fleet dynamics. *Fisheries Management and Ecology* 18, 411-423.

Francis, M.P., & Pankhurst, N.W. (1988). Juvenile sex inversion in the New Zealand Snapper *Chrysophrys auratus* (Bloch and Schneider, 1801) (Sparidae). *Australian Journal of Marine and Freshwater research* 39, 625-631.

Hamer, P.A., Acevedo, S., Jenkins, G.P., & Newman, A. (2011). Connectivity of a large embayment and coastal fishery: spawning aggregations in one bay source local and broad-scale fishery replenishment. *Journal of Fish Biology* 78, 1090–1109.

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

Houde, E.D. (1987). Fish early life history dynamics and recruitment variability. *American Fisheries Society Symposium* 2, 17-29.

Jackson, G., Fowler, A., Holmes, B., Kemp, J., & Stewart, J. (2012). Snapper *Pagrus auratus* in M. Flood, I. Stobutzki, J. Andrews, G. Begg, W. Fletcher, C. Gardner, J. Kemp, A. Moore, A. O'Brien, R. Quinn, J. Roach, K. Rowling, K. Sainsbury, T. Saunders, T. Ward & M. Winning (eds), Status of key Australian fish stocks reports 2012, Fisheries Research and Development Corporation, Canberra, 344-354.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A., & Grieve, C. (1993). Australian Fisheries Resources. Bureau of Resource Sciences and the Fisheries Research and Development Corporation Canberra Australia. Imprint Limited, Brisbane.

Lloyd, M. (2010). Spatial variation in growth of snapper (*Chrysophrys auratus*) in South Australian gulf waters: an investigation of diet as a contributing factor. Honours thesis – Adelaide University 66 p.

Middleton, J.F. (2013). PIRSA Initiative II: carrying capacity of Spencer Gulf: hydrodynamic and geochemical measurement modelling and performance monitoring. Final Report to FRDC (Project No. 2009/046). South Australian Research and Development Institute (Aquatic sciences), Adelaide. SARDI Publication No. F2013/00000-1. SARDI Research Report Series No. xxx. xxx pp.

Murphy, H.M., Jenkins, G.P., Hamer, P.A., & Swearer, S.E. (2012). Interannual variation in larval survival of snapper (*Chrysophrys auratus*, Sparidae) is linked to diet breadth and prey availability. *Canadian Journal of Fisheries and Aquatic Sciences* 69, 1340-1351.

Murphy, H.M., Jenkins, G.P., Hamer, P.A., & Swearer, S.E. (2013). Interannual variation in larval abundance and growth in snapper, *Chrysophrys auratus* Sparidae, is related to prey availability and temperature. *Marine Ecology Progress Series* (in press).

Norriss, J.V., & Crisafulli, B. (2010). Longevity in Australian snapper *Pagrus auratus* (Sparidae). *Journal of the Royal Society of Western Australia* 93, 129-132.

Sheaves, M. (2006). Is the timing of s[awning in sparid fishes a response to sea temperature regimes? *Coral Reefs* 25, 655-669.

Wakefield, C.B. (2006). Latitudinal and temporal comparisons of the reproductive biology and growth of snapper, *Pagrus auratus* (Sparidae), in Western Australia. PhD thesis, Centre for Fish and Fisheries Research, Murdoch University, Perth, Western Australia.

Winstanley, R.H. (1983). The food of snapper, *Chrysophrys auratus*, in Port Phillip Bay, Victoria. Department of Conservation, Forests and Lands, Fisheries and Wildlife Service. Commercial Fisheries Report No. 10. Melbourne.

Zeldis J.R., Oldman J., Ballara S., & Richards L.A. (2005). Physical fluxes, pelagic ecosystem structure, and larval fish survival in Hauraki Gulf, New Zealand. *Canadian Journal of Fisheries and Aquatic Sciences* 62, 593-610.

11. Southern rock lobster

Southern Rock Lobster *Jasus edwardsii* (Hutton 1994) are distributed around southern mainland Australia, Tasmania and New Zealand in a wide range of different marine communities. Across this range they require rocky reef, which provides protective cover in structurally complex crevice or ledge formations. However they will also forage across sand and silty habitats. Juveniles (<30 mm carapace length, CL) are typically solitary whereas larger individuals (30-70 mm CL) and adults cohabit in systems known as "dens" (MacDiarmid 1994). As would be expected from an animal that lives across a wide range of habitats and at different depths, southern rock lobster do not have a specialised diet and consume both plants and animals. However, they are primarily carnivorous of slow moving benthic invertebrate prey such as sea urchins or crabs (Redd et al 2008, Guest et al 2009).

The southern rock lobster resource supports important commercial and recreational fisheries across the States of South Australia, Victoria and Tasmania. The total annual catch is approximately 3000 tonnes with an estimated gross commercial value of ~AUS$200 million (ABARES 2012). Fishing has involved the use of baited pots since the late 1800's in most jurisdictions and these are set individually overnight and hauled at first light (Harrison 1995). All three fisheries are managed under management plans that have been separately developed under State legislation within each jurisdiction. Despite this, the management tools utilised are broadly similar across each region, which means that adaption to climate change can be done in a similar manner across the wider region. Management tools include input controls such as limited entry to the fishery, gear limitations and spatial or temporal closures, as well as output controls in the form of minimum legal sizes and total allowable commercial catches (TACCs). Collectively, these have been successful at ensuring that harvest level are controlled so that the species is currently assessed as being sustainably managed (ABARES 2012).

Southern Rock Lobster have a complex lifecycle that begins with annual mating from April to June. Males deposit a spermatophore on the female sternal plate before external fertilisation of eggs on extrusion. Females brood over the remainder of the winter period until larvae hatch in early spring (September/October; MacDiarmid 1988) and develop through a brief (10-14 days) nauplius period before entering into an extended planktonic phyllosoma phase. Phyllosoma larvae have been found down to depths of >300 m, tens to hundreds of kilometres offshore (Booth et al 1991, Booth and Phillips 1994). They develop through a series of eleven stages over 12-23 months before metamorphosing into puerulus near the continental shelf break (Booth et al 1991). A short-lived (ca. 3-4 weeks) non-feeding stage, puerulus actively settle onto reef habitat in depths from 200 m to the intertidal zone (Phillips and McWilliam 2009). Puerulus settlement occurs throughout the year but highest levels tend to be observed during the winter months of June, July and August (Cohen and Gardner 2007, Linnane et al 2010).

Southern rock lobster fisheries tend to have large variations in recruitment from year to year, which affects fishery production and is of particular interest in the context of climate change. This is because the success of different cohorts is influenced by changes in oceanic conditions during the long larval stage. The importance of changes in recruitment to performance of the fishery has motivated several research projects on puerulus settlement across all three States since the early 1970s (Lewis 1977a and b) and eventually the development of annual indices of settlement in the early 1990s (Kennedy 1991, Prescott et al 1998). Initially, research was driven by the twin aims of understanding both long-term settlement trends and the biology of early life history. More recently, the focus has changed to examining the use of quantified puerulus settlement indices (PSIs) as indicators of future recruitment to the fishable biomass (Gardner et al 2001, Booth et al 2004, Linnane et al 2013).

Over the past decade, catch rates have decreased in all of the major rock lobster fisheries in south-eastern Australia, which in turn, has translated to reductions in TACCs (Linnane et al 2010). Reductions in recruitment to the fishable biomass, as a result of low puerulus settlement levels, appear to be the primary driver underpinning the decline. Significantly, the decline has occurred simultaneously across a number of jurisdictions which points towards large-scale environmental influences. Settlement of puerulus has subsequently recovered in some areas but this recent history highlights the vulnerability of lobster fisheries to change in recruitment. While specific environmental factors remain largely unknown, climate change can potentially affect recruitment by altering patterns of larval dispersal and survival.

Recent reductions in biomass and egg production across south-eastern Australia may increase susceptibility to future climate change impacts. Competition between commercial and recreational sectors may impede capacity to adapt.

- Southern Rock Lobster are fished across south-eastern Australia and are highly valued by both commercial and recreational fisheries.
- Juveniles and adults live on rocky reef in a wide range of different marine communities.
- Climate change can potentially affect recruitment by altering patterns of larval dispersal and survival.

1. *Implications of climate change for productivity of Southern Rock Lobster fisheries*

Patterns in production of other rock lobster fisheries and Southern Rock Lobster in particular show that the fishery is primarily vulnerable to two factors: changes in levels of recruitment; and management decisions on catch setting, in particular, responsiveness to changes in recruitment (Linnane et al 2010, Phillips et al 2010).

For this reason, analyses of the relationship between environmental process and the rock lobster fishery focussed on the potential for climate change to alter fishery recruitment and the ability of management systems to respond. Links between environmental processes and settlement was examined using data on catch rates of the first benthic stage or puerulus from monitoring programs across all jurisdictions. These monitoring programs have been conducted since the early 1990s using identical equipment across the range (Figure 12 and Figure 13).

Programs to monitor lobster settlement have been established in many other fisheries and in some cases the data collected has been used to examine the environmental processes affecting settlement (Phillips 1995, Ndjaula and Grobler 2002, Vega Velazquez et al 2003). Extensive work has been done in this area on Western Rock Lobster *Panulirus cygnus*, in part because the fishery is highly valued but also because there were clear environmental signals from the strong influence of the Leeuwin current (Phillips 1981, Pearce and Phillips 1988, Caputi and Brown 1993, Caputi et al 2001). Examining environmental processes affecting Southern Rock Lobster production is more complicated because of the larger geographical distribution and because the current systems are more complex with convergence of different water masses, especially in the southeast. As a result, fewer studies linking environmental variables to settlement have been undertaken on Southern Rock Lobster.

In one of the few successful attempts to examine environmental drivers of Southern Rock Lobster recruitment, catch rates in puerulus monitoring sites off South Australia were contrasted with wind strength data across the region. That suggested that storm events were an important influence of settlement in this part of the fishery (Linnane et al 2010). Attempts to examine wider patterns across the fishery have been superficial and failed to identify important environmental processes (Bruce et al 2000).

The research conducted for this project is the first attempt to examine environmental drivers of Southern Rock Lobster recruitment across the range of the South –eastern Australian fishery and across all available environmental data including wind, current and wave strength in addition to oceanic indices such as the Eastern Australian Current index (EACI) and the Southern Oscillation Index (SOI).

- Settlement of larval rock lobster (puerulus) indicator of recruitment.
- Few detailed studies linking successful recruitment to environmental variables.

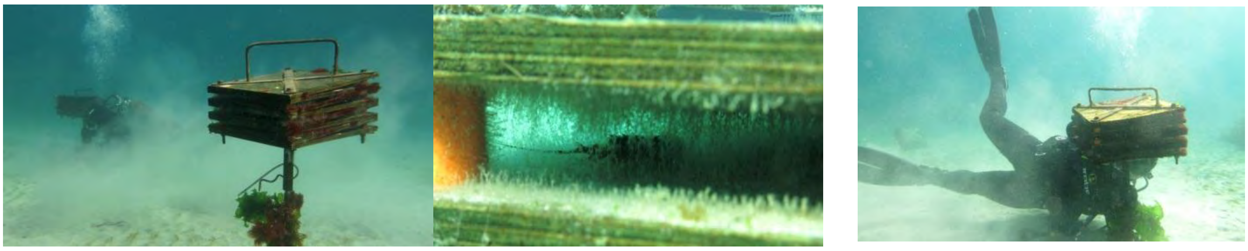

Figure 12. Settling-stage southern rock lobsters or puerulus are monitored using collectors made from sheets of plywood which mimic natural reef (left). Puerulus encounter these when swimming in from ocean waters and reside in the crevices (middle). The collectors are serviced monthly by research teams who count newly settled puerulus to provide an index of puerulus abundance.

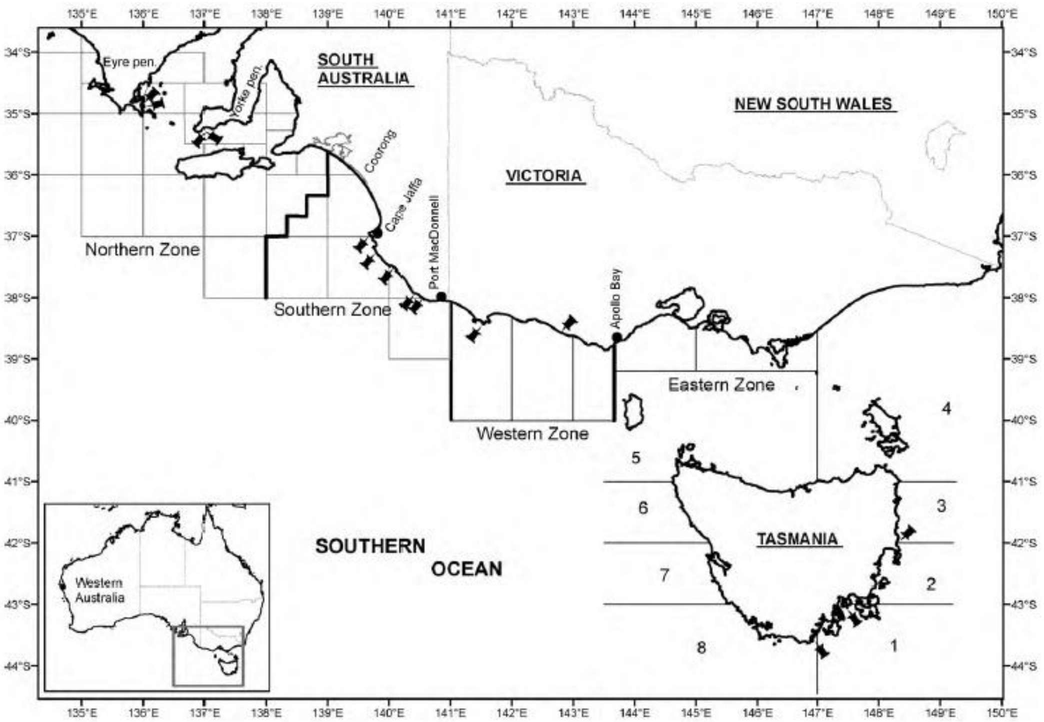

Figure 13. Puerulus settlement monitoring sites (pins) used to examine the effect of environmental processes on puerulus settlement in South Australia, Victoria and Tasmania.

METHODS

The effect of key oceanographic variables on recruitment of Southern Rock Lobster was examined by first determining broad regional patterns in settlement through time. That is, the common patterns in settlement along broad areas of the Australian coast were determined by statistical techniques to identify groupings between different puerulus monitoring sites. This involved the use of a technique termed Dynamic Factor Analysis, which is especially designed for time series data and indicates whether there is a common underlying pattern (Zivot and Wang 2006).

Prior to analysis, the puerulus data series required statistical modification to enable model fitting to occur. This was to overcome issues such as cycles in timing of settlement created by seasonal patterns in settlement, which tends to be higher in winter. In this example, the statistical removal of the natural seasonal cycle in settlement enable the effect of temperature to be examined without becoming biased by the yearly pattern of cold winter temperatures and strength of puerulus settlement.

Models of puerulus catch rates versus environmental variables were then explored in two stages:

- on a monthly basis, which was intended to explore processes that affected recruitment success immediately prior to settling, such as transport from ocean waters across the continental shelf to coastal reef;
- on an annual basis, which was intended to explore processes that affected larval survival during the long oceanic development phase.

Models were fitted using the following available variables, most of which could be expected to vary as a consequence of climate change: egg production (mature biomass), wind variables (speed, speed of vector component v and u, stress of component v and u, stress along and cross shore), current strength, wave variables (height, direction and period), the Eastern Australian Current index (EACI), the Southern Oscillation Index (SOI), the Southern Annular Mode (SAM), and the Dipole Mode Index (DMI). Environmental data on wind and temperature were sourced from different regions along the range of the fishery to enable the spatial differences in processes to be examined (Figure 14). Model fitting explored different lags for each of these variables, bounded by the two-year period of larval development (Bruce et al 2000).

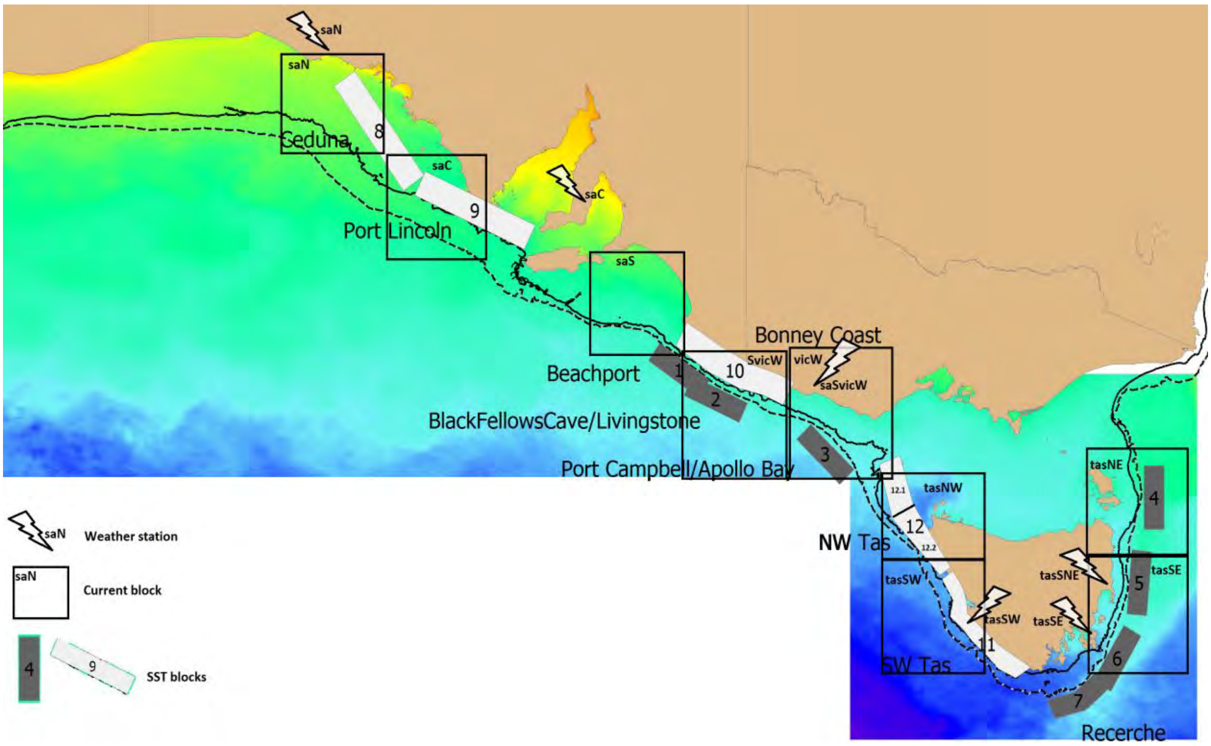

Figure 14. Regions used for environmental data. Water temperature and wind blocks are numbered 1 to 12 and run approximately parallel with the coast with grey cells in offshore areas and white cells for inshore (on-shelf) areas. Larger unfilled cells were used for sourcing current strength data.

RESULTS

In general, models were able to identify probable environmental drivers of puerulus settlement, although in most cases, a large proportion of the observed variation was not explained. In other words, there are clearly other processes affecting puerulus settlement that we were not able to explore or identify with data currently available. Examples of other factors that we could not consider but could be important to recruitment strength were: (i) predator and prey abundance in oceanic waters; and (ii) processes affecting the initial transport of larvae over the first few weeks of larval life, from inshore reef where they hatch, to the offshore oceanic waters where most of the larval development occurs. Nonetheless, common patterns between environmental processes and puerulus settlement were observed which provides insight into possible changes that could occur as a result of climate change.

Trends in puerulus settlement were statistically consistent across broad regions of the fishery. Four different groupings of collector sites were established which involved pooling Southern South Australia and Western Victoria (either with and without the Port Campbell site) and pooling Victoria and Tasmania (with either the Apollo Bay or Port Campbell sites in Victoria) (Figure 15). This was an important result because it provides confidence that the puerulus monitoring data reflects broad trends in settlement across the region, rather than data noise from a single site.

The observation that puerulus catch data had similar patterns across broad areas was also an important step for understanding possible climate change impacts. This was because it showed that the entire fishery did not have similar patterns, rather, the fishery could be broadly split into two uncorrelated regions, which were: (i) South Australia and Western Victoria; and (ii) Victoria and Tasmania (there was some overlap with Victorian sites between groupings). This is not to suggest that there are different stocks but it does show that climate change effects maybe different between these regions.

SHORT-TERM DRIVERS OF PUERULUS SETTLEMENT

The analysis of monthly puerulus catch data was relevant to examining the final period of larval development where they swim or are transported from oceanic waters across the continental shelf to inshore reef (or puerulus monitoring sites).

None of the environmental variables examined were able to explain the strength of monthly puerulus settlement when lagged over a period of three months. Several were weakly statistically significant but these appeared to be spurious statistical results caused by the large number of analyses, for example, where wind strength lagged by 5 months was statistically significant but not at any other period closer to the actual settlement period.

The absence of any apparent effect of environmental factors on settlement strength in the period immediately prior to settlement suggested that the effect of climate change is more likely to be important during the oceanic larval development phase rather than the final period of transport across the continental shelf

- Climate change effects more likely to impact recruitment during the larval development phase.

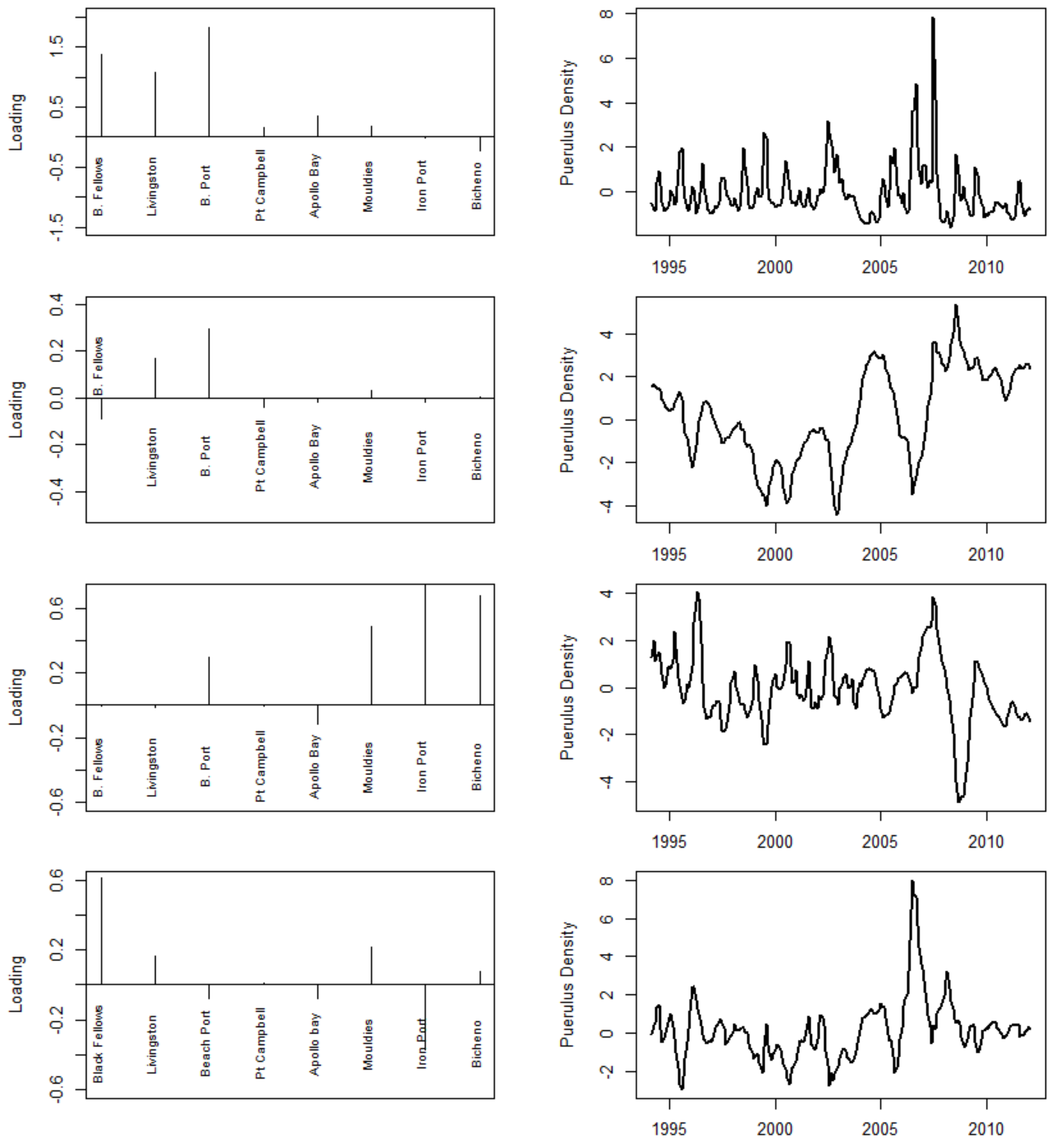

Figure 15. Grouping of puerulus monitoring sites by similarity in the settlement time series (left column) and the underlying signal in settlement from each of the four groupings (right column). This illustrates that patterns in settlement were broadly consistent across wider areas of the fishery with these groupings tending to be either western (SA and western Vic) or eastern (Vic and Tasmania). These also illustrate that this fishery is exposed to large extremes in settlement strength.

DRIVERS OF PUERULUS SETTLEMENT DURING THE OCEANIC LARVAL DEVELOPMENT PHASE

The effect of longer-term environmental patterns on the strength of puerulus settlement was examined by pooling all puerulus data for 12 months periods (April to March) to provide a measure of the overall strength of annual settlement. Several environmental processes were found to significantly affect the settlement patterns for each spatial grouping of puerulus data. Factors that appeared to have had greatest influence are shown in Table 22 although none of these individually explained more than 20% of the variation.

Table 22. Environmental factors having a significant effect on the strength of annual puerulus settlement by region. Only the three most significant factors are shown in descending order of effect size, which excludes factors where there was a statistically significant but weak effect. Colour codes are groupings of factor type with effect direction indicated in parentheses (e.g. "+" indicates a positive effect from egg production with higher egg production appearing to result in higher settlement). Temporal lags indicated by T1 and T2, which equate to environmental factors in year of settlement (T1) or the previous year (T2).

Region	Effect 1	Effect 2	Effect 3
SZ SA, WZ Vic[1]	Eggs EZ Vic (+)	Rainfall T1 (+)	Temp (+)
SZ SA, WZ Vic[2]	Eggs WZ Vic (+)	Current T2 (+)	Current T1 (+)
Vic/Tas[3]	Eggs SW Tas (+)	Eggs NE Tas (+)	Current T2 (-)
Vic/Tas[4]	Current T1 (+)	Current T2 (+)	Rainfall T1 (+)

[1]Sites aggregated here were B.Fellows Cave, Livingston, B. Port, P. Campbell, Apollo Bay

[2] Sites aggregated here were B.Fellows Cave, Livingston, B. Port, Apollo Bay

[3] Sites aggregated here were Apollo Bay, Mouldies, Bicheno

[4] Sites aggregated here were P. Campbell, Mouldies, Bicheno

Several noteworthy patterns emerged from the analysis of annual puerulus settlement (Table 23). The first was that there was evidence that levels of egg production were affecting future recruitment. While there is clearly a link between egg production and recruitment, quantifying this link was unexpected because it indicates some level of stock –recruitment relationship, not previously identified, at levels of egg production seen over the last two decades. Egg production had varied through this period, but only modestly, so there was low power in the analysis yet this still appeared to affect settlement. Thus, the result is noteworthy and suggests that management targeting higher levels of egg production may provide a modest benefit to fishery production. In the context of climate change adaption, this implies one strategy to ensure future production is within the control of the managers, which is to manage the stock to higher levels of egg production. Egg production explained less than 16% of variation in settlement, so higher egg production may assist productivity but recruitment will be expected to remain variable and influenced by factors outside the control of management.

Current strength in oceanic waters offshore was also consistently associated with change in settlement strength, with stronger settlement occurring after stronger current flows (with one exception for Victoria and Tasmania at the weaker third tier effect level). Current strength is influenced by climate change, so this result indicates a process by which climate change may influence future settlement. Using this information to forecast the effect is, however, problematic. This is because the current strength effect varied between regions in a complex manner. For example, the effect was sensitive to whether Tasmanian puerulus data was grouped with Victorian data from Port Campbell versus data from Apollo Bay.

Rainfall explained only a minor part of the variation in puerulus settlement and less than egg production but appeared to explain some of the variation in settlement strength. These results were not only of interest in terms of where settlement strength was explained by environmental factors but also for those factors where there was no apparent effect. These were wind variables, wave variables, the Eastern Australian Current index (EACI), the Southern Oscillation Index (SOI), the Southern Annular Mode (SAM), and the Dipole Mode Index (DMI). This is presumably in part because several of these variables are partially correlated, for example the EACI will be correlated with current strength data for smaller oceanic areas. However, the absence of any statistically significant effect from indices such as the EACI, SOI, SAM and DMI illustrates that forecasting the effect of climate change on future recruitment requires an understanding of regional processes rather than information on the scale of these indices.

- No correlation between puerulus settlement and broad scale indices such as EACI, SOI, SAM & DMI.
- Egg production and current strength linked to recruitment and puerulus settlement

Table 23. Environmental factors having a significant effect on the strength of annual puerulus settlement for individual sites (excluding site where no patterns were apparent). Only the three most significant factors are shown in descending order of effect size, which excludes factors where there was a statistically significant but weak effect. Colour codes are groupings of factor type with effect direction indicated in parentheses (e.g. "+" indicates a positive effect from egg production with higher egg production appearing to result in higher settlement). Two different explanatory models were found for two sites (Beach Port and Mouldies Hole).

Site	Effect 1	Effect 2	Effect 3
B.Fellows Cave	Current Sth SA (+)	Wind W Bass St. (-)	Wind SW Tas (+)
Livingston	Wind Inshore Bonney (-)	Wind Offshore Bonney (+)	Eggs SA NZ (-)
B. Port (1)	Temp Inshore Bonney (-)	Temp Inshore Ceduna (-)	Wind Offshore Bonney (-)
B. Port (2)	Current Sth SA (+)	Current Nth SA (-)	Rain Nth SA (-)
P. Campbell	Wind Inshore Bonney (-)	Wind Offshore Bonney (+)	Temp W Vic (+)
Apollo Bay	Temp (+)	Wind W Bass St. (-)	Wind Inshore Bonney (-)
Bicheno	Wave height (-)	Wave period (-)	Wind (-)
Mouldies (1)	Wind W Bass St. (-)	Temp SW Tas (+)	
Mouldies (2)	Current SW Tas (-)	Wind W Bass St. (-)	Temp NW Tas (-)

CONCLUSIONS OF ANALYSES OF THE EFFECT OF ENVIRONMENTAL PROCESSES ON RECRUITMENT

The study examined the effects of environmental variables on Southern Rock Lobster 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 (up to 2 years). 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 beyond emphasizing that puerulus settlement is highly variable between years, that it is influenced by a complex set of environmental factors, and that this exposes fisheries to risk resulting from climate change.

- A number of environmental variables impacted on settlement, but these varied regionally.
- Difficult to predict impact of climate change, however puerulus settlement is influenced by a complex set of environmental factors that expose the fishery to risks resulting from climate change.

2. Implications of climate change drive ecosystem changes for Southern Rock Lobster fisheries

Climate change will be expected to affect coastal ecosystems and thus Southern Rock Lobster Fisheries through interactions with predator, prey, and habitat forming species such as kelp. The complex nature of these interactions makes predicting trends difficult, especially with a species such as rock lobster that occupy a wide range of habitats across a very large geographic range. However, there have been some changes in coastal systems apparently associated with climate change that are of interest.

The predation of urchins by lobster is of interest because of changes in grazing patterns of urchins when released from predation by lobster (Arana 1987, Andrew and MacDiarmid 1991, Shears and Babcock 2003). The loss of the macroalgal canopy from grazing appears to have surprisingly little effect on biodiversity off eastern Tasmania EDGAR, although more extensive grazing of reef results in barren areas with substantially reduced productivity and biodiversity (Pederson and Johnson 2006, Ling and Johnson 2008, Ling et al 2009). Rock lobster predation of urchins also appears to mitigate climate change driven range-expansion of the long-spined urchin off eastern Australia, which forms barrens when at high density (Ling et al 2009). The ability to handle and eat urchins appears to increase with lobster size (Mayfield et al 2001, Ling et al 2009). This currently has a modest risk of impact on SRL fisheries with around 20 tonnes of the Victorian Eastern Zone commercial quota taken from the affected depth range (6% of the total Victorian catch) and around 50 tonnes from eastern Tasmania (5% of the total Tasmanian catch).

Change in rates of octopus predation of lobsters in pots is also of concern in the context of climate change. Research on temporal and spatial patterns of predation has had mixed conclusions with apparently clear seasonal trends in South Australia (Brock and Ward 2004), while there were no apparent trends in Tasmania (Harrington et al 2006). Although no seasonal trends were apparent in Tasmania, there are indications that mortality from octopus could be higher in years with higher average water temperature, suggesting vulnerability from climate change (Pecl et al 2009). Octopus predation in lobster pots can compound problems of low recruitment because predation risk increases as stocks decline and catch rates fall (Hunter et al 2005). This is because octopus are more capable of successfully killing lobsters in pots when fewer lobsters were present (Hunter et al 2005).

Octopus mortality in lobster pots is routinely monitored as part of compulsory log-book data and this will enable trends to be monitored. Fine scale recording has been in place in Tasmania since 2009. This has not been used to examine environmental linkages with predation but does illustrate that predation rates are highly variable between years and across broad regions although similar trends are commonly seen over smaller scales in the order of ~50 km (Figure 16).

- Climate change impacts likely to affect rock lobster predator/prey relations ships.
- Increased rock lobster mortality through octopus predation has been identified during years with higher average water temperatures.

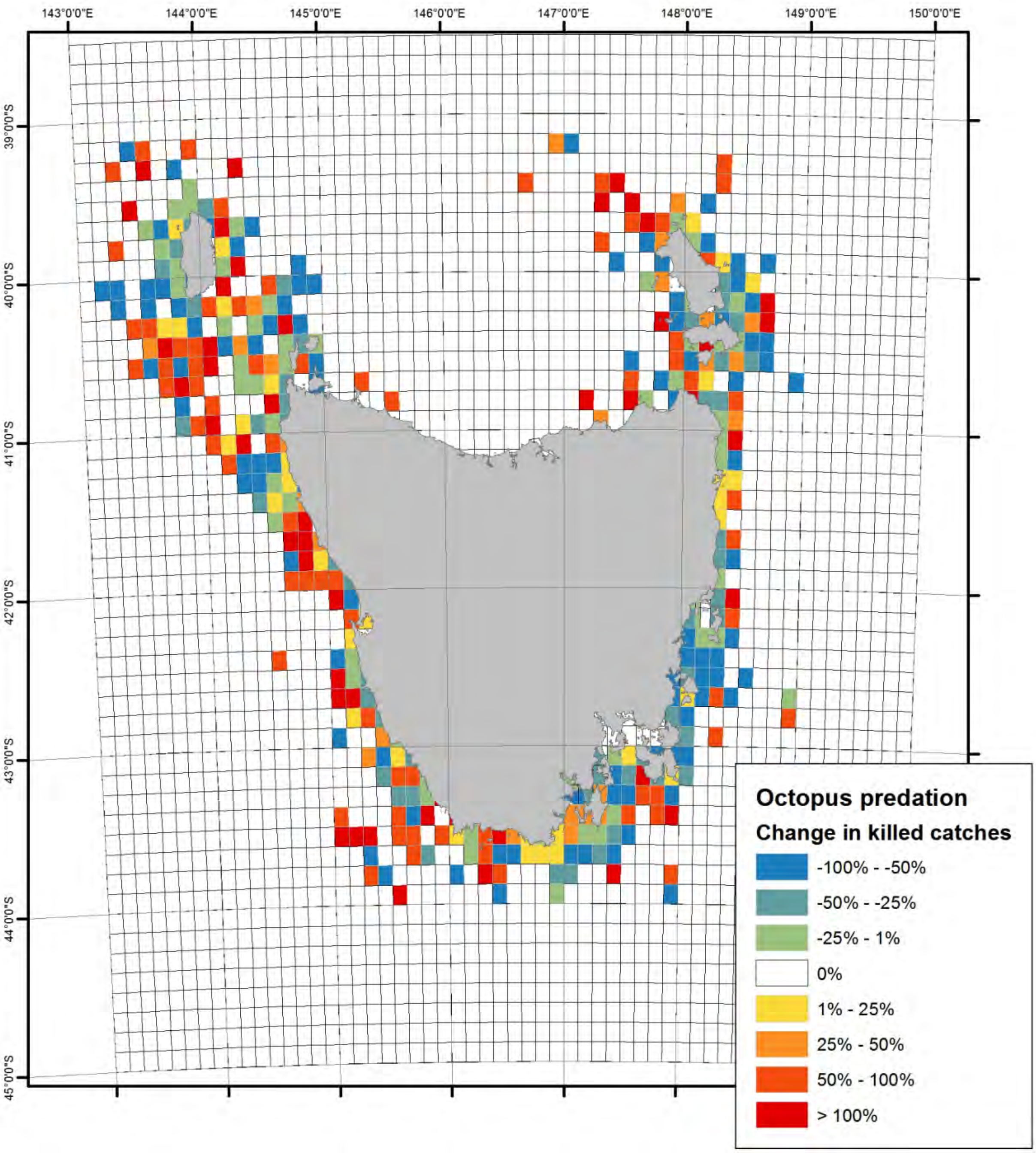

Figure 16. Change in rates of octopus predation of lobsters in traps between 2009/10 and 2012/13. Data is recorded in 1/8 degree blocks. This preliminary data suggests that there are consistent patterns across small spatial scales of ½ degree but not across the wider fishery (Paper 2).

3. Robust fishery management in the face of uncertain recruitment through climate change

INTRODUCTION

The outcome of climate change on Southern Rock Lobster fisheries is not only a function of the biological and ecological changes that may occur but also the management system and responsiveness of catch setting. Management systems for Southern Rock Lobster fisheries in Australia were tested over the last decade with all jurisdictions experiencing periods of low recruitment that extended for longer than had been seen since at least 1970 (Linnane et al 2010, Hartmann et al 2013). The timing of these events and thus the environmental cause were not consistent across all jurisdictions however it exposed consistent problems with management decision-making. This was that future recruitment was expected to vary within ranges similar to what had been seen in the past (Hartmann et al 2013). It also became apparent that catches were managed with little room for error so that when recruitment fell, declines in catch rates followed rapidly. Subsequent cuts to the quota were required and implemented but not before catch rates and profitability had fallen to low levels (Hartmann et al 2013). The decline in recruitment was evident in low puerulus settlement from the early 2000s, subsequent low recruitment to the observable undersize stock and ultimately low commercial catch rates from the late 2000s onwards. Figure 17 shows this pattern of decline in catches of puerulus at Tasmanian monitoring sites. SRL fisheries in other states had similar periods of decline although timing of these events varied.

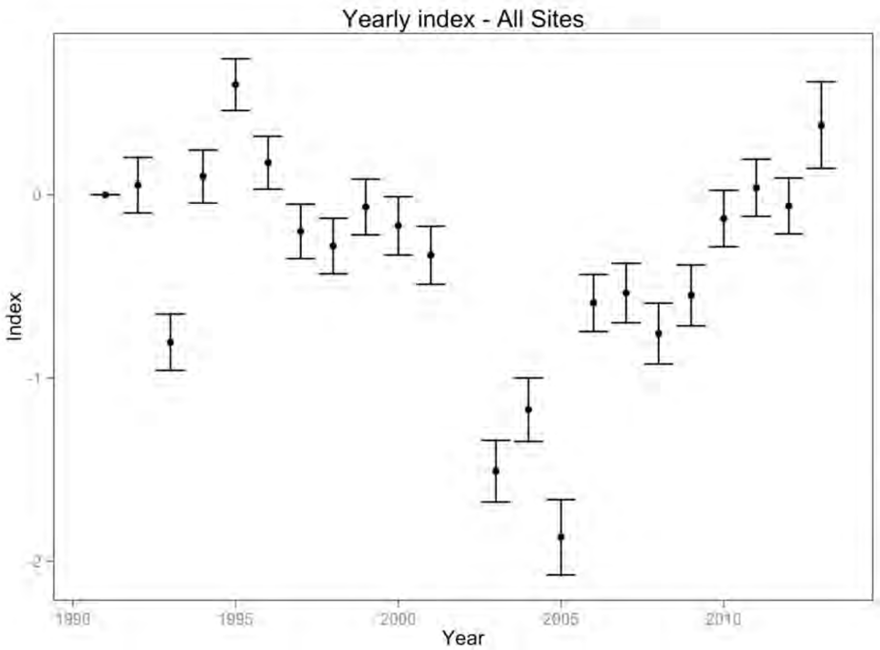

Figure 17. Catches of puerulus at Tasmanian monitoring sites declined during the 2000s in Tasmania, indicative of below average settlement across the wider coast.

This sequence of events in each SRL fishery raised concerns that future recruitment to SRL stocks would continue at below average levels, for example due to a phase shift in recruitment triggered by climate change. More recent puerulus settlement has been above average in Tasmania but below average in South Australia (Hartmann et al 2013, Linnane et al 2013). This pattern reinforces conclusions from the analyses of environmental drivers of settlement, are complex in Southern Rock Lobster but the risk of unexpected changes exists and should be managed.

Uncertainty about future recruitment into the fishery is further complicated by the fact that there are varying time-lags between settlement and recruitment. Consequently, it is essential to identify management strategies that deliver positive outcomes across a wide range of future recruitment scenarios. Such management strategies should ideally produce these outcomes regardless of what future recruitment holds. Simulations of Southern Rock Lobster fisheries under different management settings show that such strategies exist and can be achieved by the use of target performance indicators that sacrifice some economic yield in favour of greater inter-annual stability and resilience to periods of low recruitment.

METHODS

Current assessment practice

The relationship between egg production in Southern Rock Lobster (which can be estimated reasonably well) and subsequent recruitment to the stock is poorly understood. Consequently, the Southern Rock Lobster bio-economic model (Punt and Kennedy 1997, Punt et al 2012, Punt et al 2013) does not contain a stock-recruitment relationship. Instead, the best estimate of variation and magnitude of future recruitment is from past observations of recruitment - as estimated by the stock assessment model.

Whilst recruitment changes from year to year, the likely range of recruitment may be relatively constant through time, that is, a stationary process. In this case, future recruitment should be reliably estimated using all historic recruitment estimates. This was the assumption made in Tasmania until the 2009/2010 assessment, when it became clear that greater consideration should be given to unexpected events such as prolonged low recruitment events. There was also concern that recruitment patterns may have fundamentally changed, perhaps as a result of climate change and for this reason, recruitment estimates from 2000 onwards only are now used in that assessment process (although we note that subsequent above-average settlement is not consistent with a fundamental shift in settlement patterns, (Hartmann et al 2013)). South Australian and Victorian assessments continue to assume long-term recruitment averages into the future although South Australia places less weight on model projections in their decision-making process (Punt et al 2012, Punt et al 2013).

Robustness Exploration

The projection model (Hartmann et al 2013) was used to project the Tasmanian and South Australian fisheries under different harvest levels and with a range of future recruitment scenarios. For each combination of harvest level (TACC) and recruitment scenario, 500 bootstrap replicates were performed. All model settings and parameters apart from the TACC and recruitment were those used in the 2012/2013 stock assessments conducted in each state.

Since predictions of possible future recruitment reductions are unavailable, historic variability in recruitment was used to estimate future potential recruitment reductions. This was achieved by dividing the available recruitment estimates into groups of seven years. This includes groups with years of good recruitment and groups with poor recruitment (e.g. in Tasmania the recent 2000-2006 low). For each seven year period, a model projection was run that assumed recruitment from 2013 onwards would be as it was during that seven year period. Thus the most pessimistic projection assumes that all future recruitment will be at a level equal to the worst seven year period.

Fishery projections were then carried out for each seven year period at a broad range of possible TACCs and the value of the fishery under each management strategy was calculated in terms of the Net Present Value (NPV; Gardner et al 2013).

RESULTS

Tasmania

The value of the Tasmanian rock lobster fishery as a function of hypothetical future TACCs is shown in Figure 18. Each line corresponds to a different recruitment scenario. The solid black line corresponds to the assumptions used by the current stock assessment process and indicates that 1000 t would maximise the value of the fishery, a point that is commonly referred to as the maximum economic yield (MEY). Importantly, TACCs in the range of 800-1160t give 90% of MEY, so a broad range of management options achieve a reasonably good economic outcome.

The black dashed line in Figure 18 corresponds to the full range of available recruitment estimates. With this assumption, a higher TACC of approximately 1100 t would maximise economic yield. Consequently the shift from using long term recruitment estimates to more values resulted in a reduction of 100 t in the TAC corresponding to MEY and a 6% reduction in MEY (the difference in the height of the two heavy line curves).

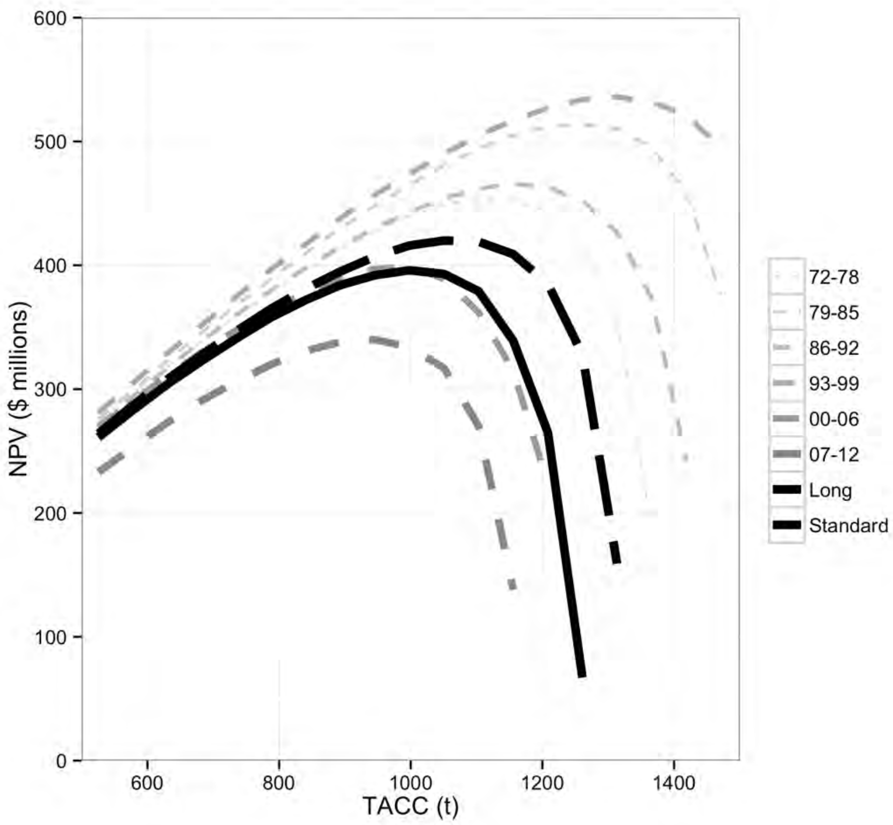

Figure 18. The economic yield of the Tasmanian southern rock lobster fishery expressed as net present value (NPV; y axis) in relation to the TACC for alternate recruitment assumptions. The "Long" recruitment scenario uses recruitment from 1965-2000, the "Standard" scenario uses 2000-2010 as used in the 12/13 stock assessment and the other scenarios use the years indicated. Under the standard recruitment scenario (solid line), the value of the fishery is maximized with a TACC of 1000t. TACCs below 1050t are robust to recruitment variation as indicated by similar economic yields regardless of the pattern in recruitment.

The other lines in Figure 18 correspond to different historic periods of recruitment. These were considered in order to explore the sensitivity of optimal management to natural recruitment variability and long term temporal trends. TACCs below around 950 tonnes are less sensitive to the recruitment scenario. This is seen by smaller gaps between each curve to the left hand side of the plot. The TACC corresponding to the peak of each of the economic yield curves in Figure 18 varied as a consequence of different productivity. The peak or MEY for each recruitment series is shown in Figure 19. The optimal TACC varied from 950 to 1300t with pre-2000 recruitment scenarios corresponding to higher TACCs. The lower recruitment periods included in recruitment series from more recent years result in lower economic yield. There has been speculation that this is a downward trend linked to climate change but there is insufficient data here to draw that conclusion. However, what is clear is that economic yield is highly sensitive to recruitment and targeting MEY implies the fishery will have highly variable economic yield.

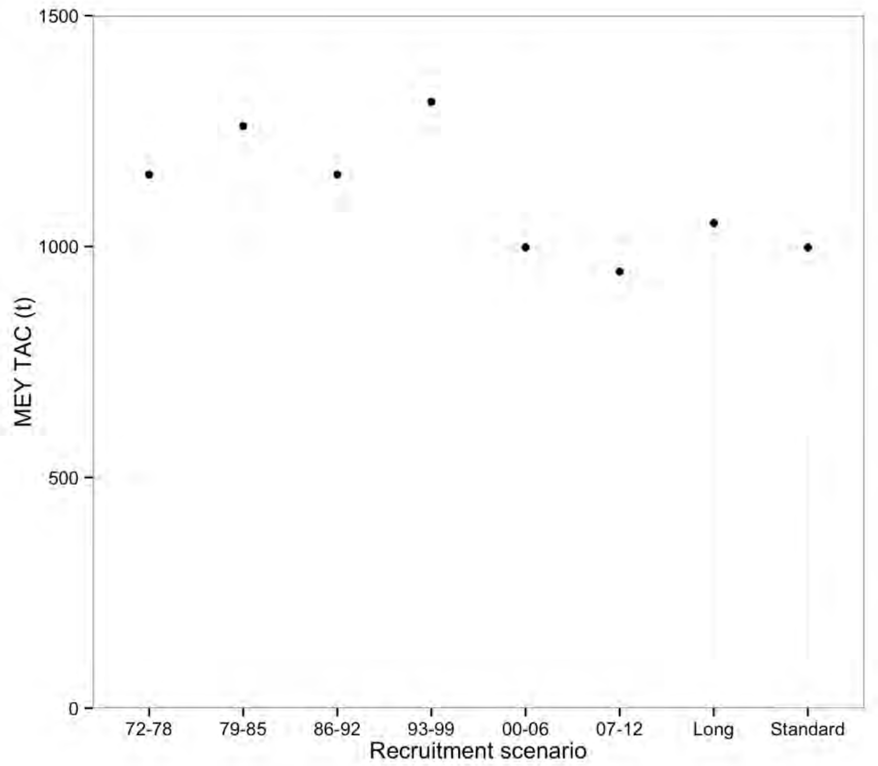

Figure 19. The optimal TACC (corresponding to MEY) for each of the recruitment scenarios that were considered. The "Long" recruitment scenario uses recruitment from 1965-2000, the "Standard" scenario uses 2000-2010 as used in the 12/13 stock assessment and the other scenarios use the years indicated.

South Australia

The same analysis of economic yield curves under different historical recruitment curves was also conducted for the Southern Zone of South Australia which has well developed fishery modelling capability (Punt et al 2012). This reinforced conclusions from the Tasmanian analysis with economic yield sensitive to recruitment as expected. The shape of the economic yield curves differed from those in Tasmania which is partially due to differences in population dynamics but also different cost structures with shorter fishing seasons and higher pot limits in South Australia.

The implications of this analysis for adaption to climate change were also consistent with analyses from Tasmania. TACCs below 1200t did not maximise economic yield, however, they provided reasonable economic yield and dramatically reduced the risk and volatility in economic yield created by recruitment variation.

Maintaining commercial catches in this fishery below 1200 tonnes implies foregone economic yield during periods of high recruitment although this could conceivably be managed by short term increases in TACC. This would be a different approach to that applied in the recent history of this fishery where catches tend to have been set at high levels (eg TACC from 2003 to 2007 was 1900 tonnes; Linnane et al 2013) and reduced when catch rate declines were apparent. This exposed the fishery to greater loss of economic yield through low catch rates than would occur with more conservative TACCs consistently below 1200 t. A system more robust to climate change would maintain generally low catches to provide for high catch rates, with short periods of higher TACCs above 1200 t when exceptional recruitment was apparent.

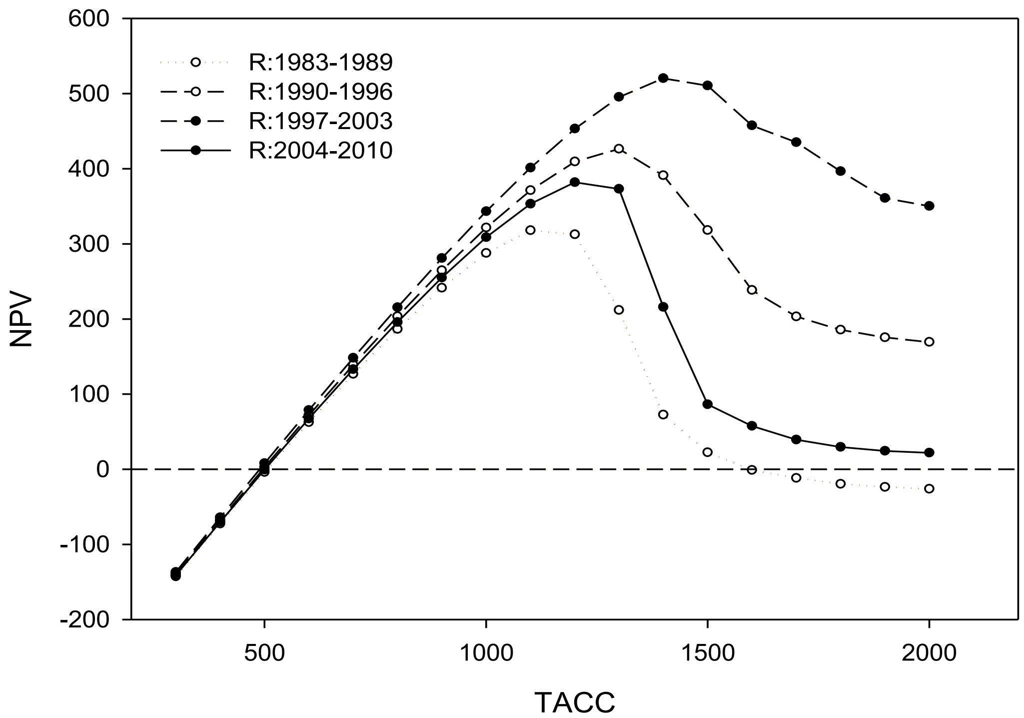

Figure 20. The net present value (NPV) of the South Australian Southern Zone SRL fishery (y axis) as a function of the TACC for a range of recruitment assumptions, as indicated in the legend. TACCs below 1200t are robust to variation in recruitment.

DISCUSSION

Economic yield curves from southern rock lobster fisheries (e.g. Figure 20) tend to have a flat peak, which implies there are a wide spectrum of TACCs that provide similar economic outcomes for fixed set of other management controls (size limits, seasons, pot limits etc.). When alternative assumptions about recruitment are considered, there is overlap between the relatively flat peaks of these curves. This allows us to identify robust management strategies that provide economic outcomes within some percentage of the optimum across all alternative assumptions.

Adopting an identified robust management strategy would avoid the need to rapidly respond to future recruitment changes as expected with climate change and would substantially reduce the possibility of depleting the population to the levels that recently occurred in southern rock lobster.

The weakest point in this analysis is the extent of the future recruitment changes that have been considered. It is possible that climate change could drastically reduce recruitment below the lowest historic period (e.g. through changing ocean currents or acidification). Our most pessimistic scenario considers what would happen if the worst seven year period of recruitment was representative of all future recruitment. Given the variability in historic recruitment and duration of the time series, this worst seven-year period is quite extreme and we believe it unlikely that future average recruitment would fall below this value. Indeed if it does, this extreme situation would dramatically change the fishery in ways not considered here. As such, it seems inappropriate and unnecessary to put in place a TACC that is robust to such extreme situations. Nonetheless, our general conclusion of greater resilience and minor loss of economic yield from more conservative TACCs holds regardless of exact future recruitment patterns.

In Tasmania the 12/13 TACC of 1103t is robust across most recruitment scenarios except the most pessimistic and most recent scenario (2007-2012). Note that this scenario is incomplete, covering only six years and recruitment estimates for the most recent years (particularly 2011 onwards) are imprecise until further data is collected. Consequently, this may present an overly pessimistic recruitment scenario. However, to provide a positive outcome, a TACC reduction of just 50 t to 1050t is sufficient.

The South Australian Southern Zone TACC is currently set at 1250t. This corresponds to the peak of the most recent poor recruitment period considered (2004-2010) and is robust across the other scenarios.

Results from modelling of southern rock lobster fisheries under alternate recruitment scenarios show that the tools are in place to respond to climate change but require two actions to assist adaption. The first is that ongoing data collection for model inputs is required, especially information on stock abundance, recruitment (undersize monitoring and / or puerulus data), and economic information on business costs and market prices for different grades. The second required action is for extension of model outputs into management decision-making as there tends to be industry resistance to application of model based information. The use of models in management decision-making is important because it counters the typical human trait of assuming that higher catch is good for economic yield and business. The model outputs produced here illustrate that long run economic yield and business stability in the face of climate change is promoted by lower TACCs – a result that is counter-intuitive.

- Adoption of a robust and more conservative management process would avoid the need for rapid responses to future recruitment changes that are expected with climate change. In addition it would substantially reduce the possibility of depleting the population during periods of low recuitment

4. *The implications of change in productivity on setting of management reference points*

Australian fisheries management generally relies on the application of harvest strategies, which have been defined as "*a framework that specifies the pre-determined management actions in a fishery for defined species (at the stock or management unit level) necessary to achieve the agreed ecological, economic and/or social management objectives in a fishery*" (Sloan et al 2014).

Harvest strategies involve defining reference points for the fishery that provide targets for the optimal state of the fishery (target reference points; TRP) and also limit reference points (LRP) that are used to define situations where strong management changes are required. southern rock lobster fisheries incorporate a range of different reference points that vary by jurisdiction, however, they consistently involve the use of catch rate or CPUE (in addition to other measures such as biomass) with this indicator frequently used as the most important reference point in decision making (Hartmann et al 2013, Linnane et al 2013). This is because CPUE is used to target MEY, which tends to require lower harvest rates than reference points associated with sustainability (eg egg production) or ecosystem function (eg total biomass) (Hartmann et al 2013).

The responses of the stock to changes in patterns of recruitment were explored in previous sections. Analyses of puerulus settlement showed that recruitment may vary with climate change. Modelling of economic outcomes from the fishery showed that this would affect economic yield and also the optimal level of catch, which is the aim of quota setting. This leads to the question of whether the current fishery management is vulnerable to use of existing harvest strategies? Do the reference points selected to guide management remain useful if recruitment changes or do they force sub-optimal decisions on quota setting? To illustrate, quota decisions in the Tasmanian SRL fishery are mainly driven by the following TRP:

Catch rate = 1.4 kg/potlift state-wide as a proxy for MEY, with a target probability of 70%, by 2020 (Hartmann et al 2013).

This TRP drives management decisions so that the catch rate will equal around 1.4 kg / potlift by around 2020. But is this a suitable target if recruitment changes?

To determine whether this TRP was vulnerable to climate change, model based projections of the fishery were run for TACCs that resulted in the maximum economic yield (MEY) from the fishery, but for different recruitment scenarios (as predicted with climate change). These correspond to the optimal TACCs illustrated in Figure 19. Projections were for 10 years ahead from present and used to determine the catch rate TRP that would be applied to target MEY.

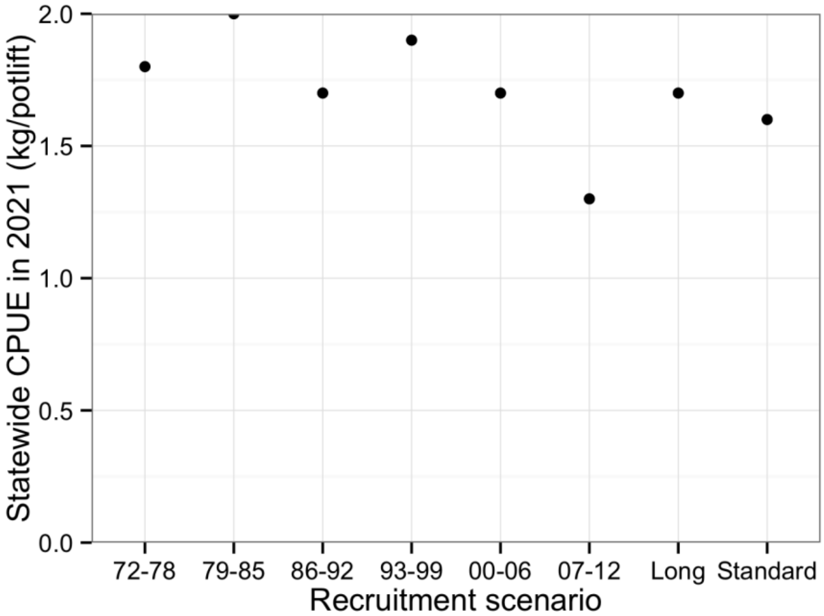

Figure 21. Statewide catch rate (kg/potlift, CPUE) after ten years with quota set to target MEY under different recruitment scenarios. These recruitment scenarios are the same as explored in the previous section.

These catch rates thus represent the ideal CPUE target reference point if management were to target MEY. Lowest recruitment was observed in the 2007-2012 series and targeting MEY under this situation would involve a lower CPUE target.

Results from projections of the fishery with the TACC set to target MEY and with different levels of recruitment show that the CPUE target reference point varies with recruitment (Figure 21). These results indicate that if recruitment falls as a consequence of climate change, then the CPUE target reference points for southern rock lobster fisheries will tend to aim too high. That is, they will promote TACCs that are lower than the levels that deliver MEY, and biomass will be maintained at higher levels than that which delivers MEY.

This result suggests some capacity for autonomous adaption to climate change. Maintaining catches at low levels to meet higher CPUE targets in the face of falling recruitment is a conservative outcome and far preferable to the risk of catches being set too high. Lower catches result in accumulation of stock and reduced volatility in economic yield. Lobsters are long lived and if it appears that stock levels are higher (or catches are lower) than is optimal, then there is scope to increase catches in later years.

> - Maintaining existing target reference points under climate change scenarios (e.g. reduced recruitment) may lead to TACCs that are below levels that would deliver MEY. Reference points may therefore need reviewing.

5. *Adaptation options and barriers*

Table 24 lists the autonomous and possible planned adaptation actions that were elicited from stakeholders in response to the potential climate change impacts presented at the March 2012 workshop. Stakeholders also identified likely barriers to implementing any possible planned adaptation actions.

Table 24. Adaptation options and barriers for the southern rock lobster

POTENTIAL IMPACT	AUTONOMOUS ADAPTATION	POSSIBLE ADAPTATION ACTIONS	BARRIERS
Change in the distribution of the fishery (e.g. from change in settlement patterns or change in distribution of habitat/predation)	1. Move to larger vessels fishing more of the quota 2. Shift focus on other species (e.g. scalefish species)	1. Implement finer spatial management	1. Existing access rights strongly protected – a 're-allocation' will be controversial Need good quality and timely data to support adaptive fishing operations.
Increased predation within pots within increased abundance of predators (e.g. octopus)	1. Modify set time - avoid moving - change soak time/location	1. Allow for target octopus fishery in conjunction with RL fishing 2. Account for dead animals to measure changes in predation	1. Gear use limited to rock lobster pots. 2. Access to octopus not limited to RL fishers 3. Difficult to measure dead animals 4. Limited knowledge on behaviour
Increase in post-release predation (e.g. leatherjackets, seals)	1. Modify gear for in water release 2. Modify "on deck" release 3. Code of conduct Night time release	1. Retain 'discarded' animals 2. Gear technology investment	1. Increase in time to release animals 2. Limited capacity 3. Cannot keep undersize 4. Selling 'discarded' product may decrease value of product

Change in absolute productivity of stocks – increase or decrease (e.g. through change in settlement, growth, mortality)	1. Increase or decrease TAC in response to increase/decrease in productivity	1. Change size limits 2. Stock enhancement 3. Closures 4. Translocations	1. Potential economic losses 2. Increased uncertainty with decision making
Change in variation in productivity between years (i.e. the peaks and the troughs of good / bad years become more pronounced)	1. Apply greater precaution to harvest strategy (manage to trough drop) 2. Diversify business		1. Lack of data 2. Lack of trust and industry support for management decisions
Increase/decrease in suitable fishing days due to weather	1. Maximise the good days 2. Access unused licenses Shorter trips/fewer trips 3. Better utilisation of forecasts and technology	1. Allow multiple licences on boats 2. Increase vessel size bigger boat 3. Reduce input controls (e.g. pot limits)	1. Require significant legislative changes
Warm water mortality events on-board	1. Land dead lobster and explore markets 2. Refrigerate/cool water 3. Process at sea 4. Choose cold-water ports		1. Live market superior 2. Loss of value Compliance
Reduced catchability resulting from upwelling events	1. Adjust assessment due to CPUE changes and set TAC accordingly	1. Change fishing method (e.g. dive)	1. Knowledge gaps on fish behaviour at low temperature 2. Ability to discern a decrease in abundance Vs. decrease in catchability 3. New method require significant legislative changes and raise a host of other issues
Reduced synchronicity of moulting	1. Flexible closed season 2. Remove closed seasons and have continuous supply 3. Alter/control spatial effort across the fishery	1. Develop holding technology	1. Costs of holding live fish and developing new technology 2. Increase in soft fish in market can lower process 3. Diverse opinions regarding closed season
Shifts in seasonal catchability	1. Flexible closed season 2. Alter fishing effort to maximise returns either during high price periods or high catchability	1. Develop holding technology	1. Costs of holding live fish and developing new technology

The governance benchmarking exercise also identified a number of potential barriers to adaptation for the southern rock lobster fisheries in each jurisdiction (Table 25). Governance for southern rock lobster fisheries performed strongly in many jurisdictions, however, clear areas of potential improvement were identified in all regions. For example ecosystem, economic, social and community performance indicators were not in place in Victoria and South Australia had ecosystem indicators that were regarded as only 'partially in place and sometimes operational'. The goals and objectives of fishery management were not clearly defined in Tasmania, and 'clear processes for making trade-offs between conflicting objectives' were only partially in place and sometimes operational in South Australia and Tasmania and not in place at all in Victoria. Additionally, several potential barriers to adaptation were identified for South Australia and Tasmania in the 'Incentives' attributes.

Table 25. Summary of barriers to adaptation related to fisheries governance attributes for southern rock lobster. Accountability (AC), Planning (P), Incentives (I), Adaptability (AD) and Knowledge (K).

Jurisdiction	Summary of barriers
South Australia	• No major barriers identified
Tasmania	• Goals and objectives of fishery management clearly defined (P) • Plan includes process to monitor outcomes, values and pressures (P) • Incentives to avoid negative externalities, including habitat damage and by-catch (I)
Victoria	• Clear & equitable processes to deal with interactions or conflicts among user groups (T)

Prior to evaluating potential adaptation options, the revised adaptation options were furthered refined and analysed using a characterisation matrix which identified the key characteristics of the adaptation options being considered for further evaluation (Table 26). This was considered an important step to map out implications, interactions with other management strategies and issues of temporal and spatial scales.

6. Evaluate potential adaptation options

We assessed two of the five climate challenges identified for the rock lobster fishery; (1) reduced productivity, and (3) altered ecosystem - increased octopus predation.

For reduced productivity we examined three of the six adaptation options identified: reduce the TACC (by up to 40%), translocation and stock enhancement. All three options were ranked quite similarly when all sectors are combined, with all options scoring ‘moderate’ for benefit (Table 27, Figure 22) however, in terms of feasibility, reducing the TACC was ranked ‘moderate’ with the other options both ranked ‘low’ (Table 27, Figure 22). When looking at the adaptation option of reducing the TACC, both management and research ranked the benefit as ‘moderate’ whilst industry ranked it as ‘low’. Conversely for both translocation and stock enhancement, research and management considered the benefit to be ‘low’, whilst industry considered the benefit to be ‘high’ and ‘moderate’ respectively (Table 27, Figure 22).

When addressing the issue of increased octopus-induced mortality, we examined two adaptation options; increasing the take of octopus (either through dedicated targeting or retention of bycatch) or the using spatial and temporal closures to avoid areas of high predation during particular times. Of the two, spatial closures were ranked as having a higher benefit (Table 25, Figure 23). Consensus levels regarding the feasibility and benefit of spatial closures were generally ‘high’ for all sectors and for all sectors combined (Table 27).

One of the most interesting results for the rock lobster fishery was the differences in perceived benefits between the commercial sector and both management and research in regard to translocation and stock enhancement. It appears that industry believes that both of these adaptation options would provide a moderate to high benefit, whereas management and research perceive the benefits as low. This is a potential area of conflict for future decision making processes and may identify some fundamental differences between sectors and the way they perceive risks and benefits.

7. Future Monitoring

To assist adaption to climate change, ongoing data collection for model inputs is essential, especially in relation to spatial estimates of stock abundance and recruitment (undersize monitoring and / or puerulus data). In addition, improved economic data are required such as specific information on business costs and market prices for different lobster grades.

Table 26. Rock Lobster: final list of suggested potential adaptation options, and a characterisation of each option.

SOUTHERN ROCK LOBSTER			2. CHARACTERISING IMPLEMENTATION							3. CHARACTERISING BENEFITS				
Challenge No. Option No.	CLIMATE CHALLENGE (includes potential impact/s) POTENTIAL ADAPTATION OPTIONS	1. ADAPTATION TYPE	2.1 SCALE OF APPLICATION	2.2 JURISDICTION/S IN WHICH IMPLEMENTED	2.3 SIGNIFICANCE OF DIFFERENCE BETWEEN JURISDICTIONS	2.4 LEAD TIME TO IMPLEMENTATION	2.5 ADDITIONAL COST (relative to "do nothing")	2.6 WHO PAYS	2.7 LEVEL OF CONTROVERSY EXPECTED	3.1 PRIMARY BENEFICIARY	3.2 SCALE OF BENEFIT	3.3 CONSEQUENCE PERIOD (when benefits are expected)	3.4 ADDRESSES OTHER CLIMATE CHALLENGES?	BARRIERS (list any not already identified)
		Autonomous, Business-As-(Mostly)-Usual, Incremental, Transformative	National, State, Zone, Sub-zone	Name which jurisdictions (i.e. TAS, VIC, SA, C'Wealth)	Low,Medium,High	<1 year,1-5 years,>5 years	Nil,Low,Medium,High	Industry, Government, Consumers, Post-Harvest, Local communities	Low,Medium,High	Fishers,Fishery,Fish Stock,Ecosystem	National, State, Zone, Sub-zone	<1 year,1-5 years,>5 years	Name which ones	
1	**Change in productivity, increase or decrease** **1. Negative effects on** **2. Timing of peak local**													
1a	Change/reduce TACC (by for example 30-40%)	Business-As-(Mostly)-Usual	State	SA, VIC, TAS	Low	<1 year	Low	Industry	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
1b	Adjust size limits	Incremental	State	SA, VIC, TAS	Low	1-5 years	Low	Industry	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
1c	Seasonal/spatial closures	Business-As-(Mostly)-Usual	State	SA, VIC, TAS	Low	<1 year	Low	Industry	Low	Fish Stock	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
1d	Alter sector allocations (ie. Reduce recreational share of resource)	Incremental	State	SA, VIC, TAS	Medium	1-5 years	Medium	Industry	High	Fishers	State	1-5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Stakeholder suport, political will
1e	Translocations	Transformative	State	SA, VIC, TAS	Medium	1-5 years	High	Industry	Medium	Fishery	State	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost
1f	Stock enhancement	Transformative	State	SA, VIC, TAS	Medium	>5 years	High	Government	High	Fishery	State	>5 years	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	Cost, feasibility
2	**Biological Changes** **1. Change in distribution** **2. Changes to timing & synchronicity of moulting**													
2a	Finer spatial scale management	Incremental	Zone	SA, VIC, TAS	Medium	1-5 years	Medium	Industry	Low	Fishery	State	>5 years	May lead to greater profitability of ind operators	

2b	Seasonal/spatial closures	Business-As-(Mostly)-Usual	State	SA, VIC, TAS	Medium	<1 year	Low	Industry	Low	Fishery	State	>5 years	May lead to greater profitability of ind operators	
2c	Processor setting limits	Incremental	State	SA, VIC, TAS	Medium	1-5 years	Low	Industry	Low	Fishery	State	>5 years	May lead to greater profitability of ind operators	
2d	Develop holding technology (land based)	Incremental	State	SA, VIC, TAS	Low	1-5 years	High	Industry	Low	Fishery	State	>5 years	May lead to greater profitability of ind operators	
3	**Altered ecosystem** **1. Increase in octopus predation (abundance)** **2. Increased predation/mortality (post release)** **3. Increase in on-board mortality through increases water temp**													
3a	Update estimates of natural mortality in fishery models	Business-As-(Mostly)-Usual	State	SA, VIC, TAS	Medium	1-5 years	Low	Government	Low	Fishery	State	1-5 years	Understanding biological changes in fishery	Operational
3b	Increase the take of octopus (bycatch/dedicated targetting)	Incremental	State	SA, VIC, TAS	Medium	1-5 years	Low	Industry	Low	Fish Stock	State	1-5 years	May lead to greater profitability of ind operators	Feasibility, market demand
3c	Retain discarded species	Incremental	State	SA, VIC, TAS	Low	<1 year	Low	Industry	Low	Fishery	State	1-5 years	May lead to greater profitability of ind operators	Operational
3d	Spatial and temporal closures	Business-As-(Mostly)-Usual	Zone	SA, VIC, TAS	Medium	1-5 years	Low	Industry	Low	Fish Stock	State	1-5 years	May lead to greater profitability of ind operators	Knowledge gaps
3e	Gear technology investment	Autonomous	State	SA, VIC, TAS	Low	1-5 years	Medium	Industry	Low	Fishers	State	1-5 years	May lead to greater profitability of ind operators	Operational
4	**Disease expression** **1. Increased frequency/intensity of toxic algal blooms**													
4a	Early detection & monitoring	Incremental	State	SA, VIC, TAS	Medium	<1 year	Medium	Industry	Low	Fishery	State	<1 year	May lead to greater profitability of ind operators	Cost
4b	Spatial/temporal closures	Business-As-(Mostly)-Usual	State	SA, VIC, TAS	Medium	<1 year	Low	Industry	Low	Fishery	State	<1 year	Other influences that may have reduced productivity (eg changes in growth, recruitment etc.)	
5	**Altered weather patterns** **1. Increase/decrease in suitable fishing days due to weather**													
5a	Allow multiple licences on boats	Incremental	State	SA, TAS	Medium	1-5 years	Low	Government	Medium	Fishers	State	>5 years	May lead to greater profitability of ind operators	Legislative
5b	Increase pot limits	Incremental	State	SA, TAS	Low	1-5 years	Low	Government	Medium	Fishers	State	>5 years	May lead to greater profitability of ind operators	Legislative
5c	Increase vessel size	Autonomous	State	SA, TAS	Medium	1-5 years	Medium	Industry	Low	Fishers	State	>5 years	May lead to greater profitability of ind operators	Cost

Table 27. Average scores and consensus level by sector for assessed adaptation options for the southern rock lobster fishery.

Climate Challenge	Adaptation Option	Sector	Feasibility		Risk		Benefit		No. respondents
			Average	Consensus	Average	Consensus	Average	Consensus	
Reduced productivity	1a. Reduce TACC by up to 40%	Industry	Moderate	Medium	Low	Medium	Low	High	7
		Management	Moderate	High	Low	High	Moderate	High	4
		Research	Low	High	Very low	Medium	Moderate	High	6
		All sectors combined	Moderate	High	Low	Medium	Moderate	Medium	17
	Translocation	Industry	Low	High	High	High	High	Low	3
		Management	Low	High	Low	High	Low	High	1
		Research	Low	Medium	Low	Medium	Low	Low	3
		All sectors combined	Low	Medium	Moderate	High	Low	Medium	7
	Stock enhancement	Industry	Moderate	High	Very low	High	Moderate	High	5
		Management	Very low	High	Moderate	Medium	Low	Medium	4
		Research	Low	Low	Low	Low	Low	Low	6
		All sectors combined	Low	High	Low	Medium	Moderate	Medium	15
Altered ecosystem - Increased octopus predation	Increase take of octopus	Industry	Moderate	None	Moderate	None	Low	None	7
		Management	Moderate	High	Low	Medium	Low	Medium	4
		Research	Moderate	High	Low	High	Moderate	High	3
		All sectors combined	Moderate	Medium	Low	Medium	Low	Medium	14
	Spatial and temporal closures	Industry	Moderate	High	Moderate	Low	Moderate	High	5
		Management	Moderate	Low	Low	High	Moderate	High	3
		Research	Moderate	High	Very low	High	Moderate	High	3
		All sectors combined	Moderate	High	Low	High	Moderate	High	11

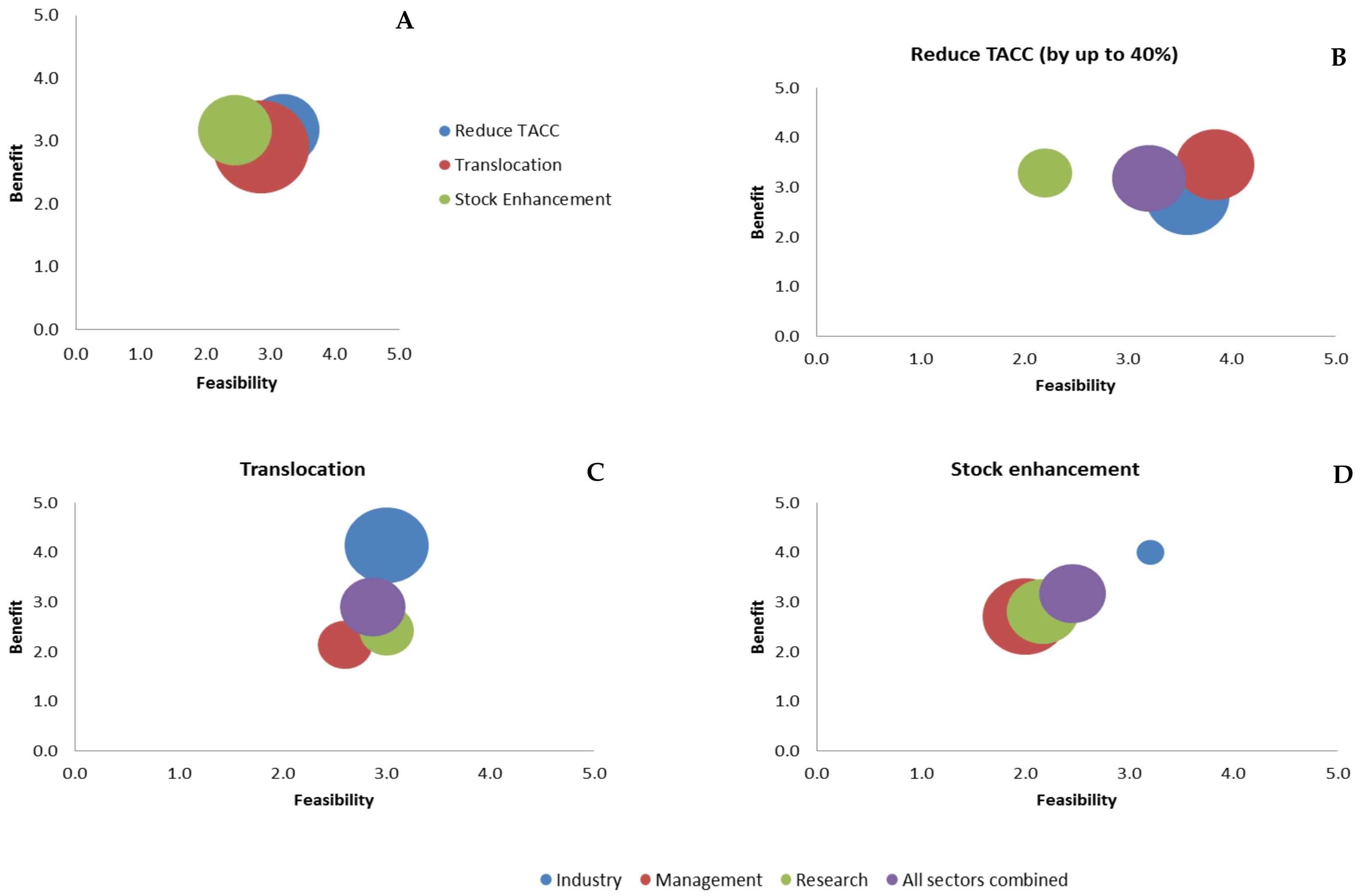

Figure 22. Southern rock lobster: Evaluation of options to address the climate challenge of reduced productivity. (A) Evaluation of each option by all sectors combined, (B) evaluation of reducing TACC, (C) translocation, (D) stock enhancement.

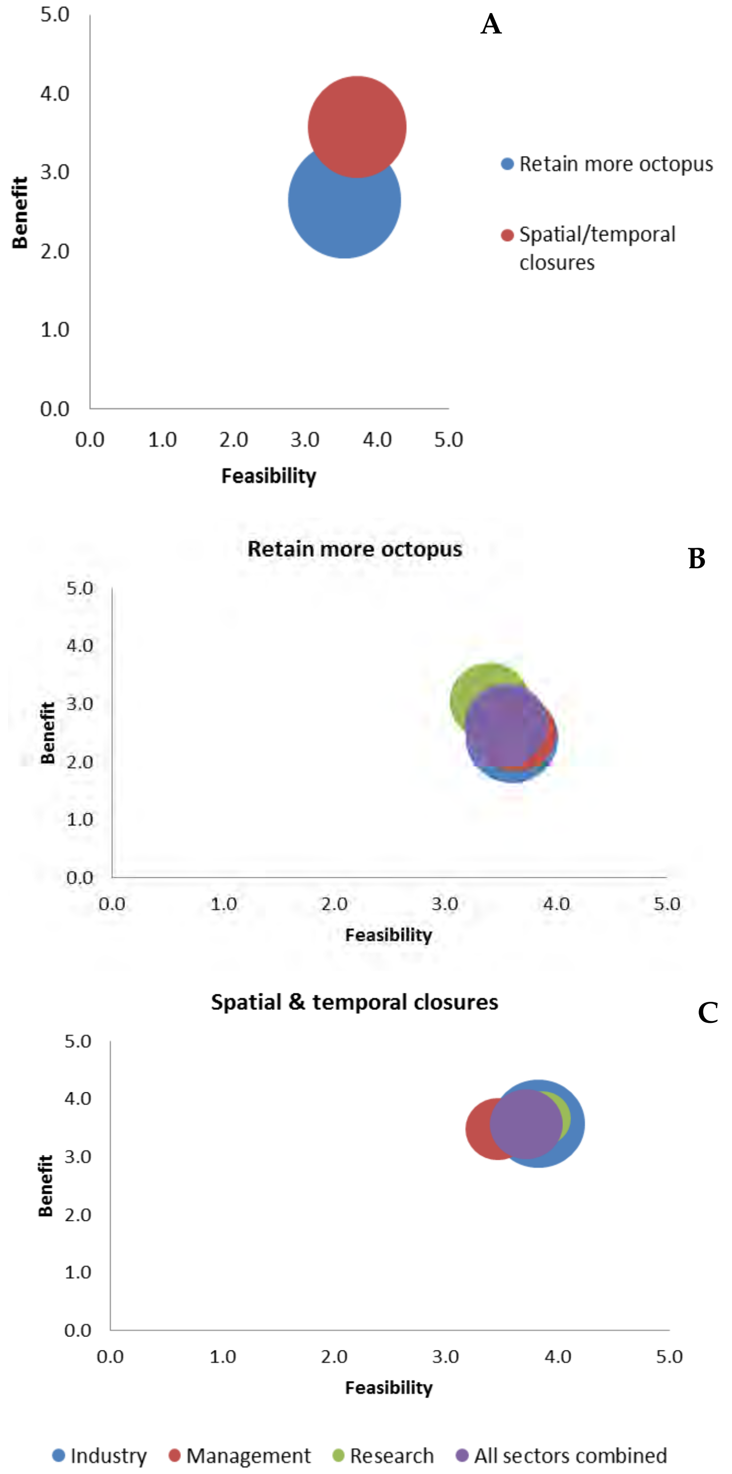

Figure 23. Southern rock lobster: Evaluation of options to address the climate challenge of an altered ecosystem, increased octopus predation. (A) Evaluation of each option by all sectors combined, (B) evaluation of retaining more octopus, (C) spatial and temporal closures.

REFERENCES

ABARES, Australian fisheries statistics (2011). In: A.B.o.A.a.R.E.a. Sciences (Ed.), Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, ACT., 2012.

Andrew, N.L., & MacDiarmid, A.B. (1991). Interrelations between sea urchins and spiny lobsters in northeastern New Zealand. *Marine Ecology Progress Series* 211-222.

Arana, P. (1987). Historical perspective and projections of the fisheries activity in the Archipelago of Juan Fernandez, Chile. 319-353.

Booth, J., & Phillips, B. (1994) Early life history of spiny lobster. *Crustaceana* 66, 271-294.

Booth, J.D., Carruthers, A.D., Bolt, C.D., & Stewart, R.A. (1991). Measuring depth of settlement in the red rock lobster, *Jasus edwardsii. New Zealand Journal of Marine & Freshwater Research* 25, 123-132.

Booth, J.D., Forman, J.S., Stotter, D.R., & McKenzie, A. (2004). Settlement indices for 2002 for the red rock lobster (*Jasus edwardsii*). *National Institute of Water & Atmospheric Research* 37.

Brock, D.J., & Ward, T.M. (2004). Maori octopus (*Octopus maorum*) bycatch and southern rock lobster (*Jasus edwardsii*) mortality in the South Australian rock lobster fishery. *Fishery Bulletin* 102, 430-440.

Bruce, B., Bradford, R., Griffin, D., Gardner, C., & Young, J. (2000). A synthesis of existing data on larval rock lobster distribution in southern Australia. FRDC Final Report 96/107. CSIRO, Hobart, Australia, 57 p.

Caputi, N., & Brown, R.S. (1993). The effect of environment on puerulus settlement of the western rock lobster (*Panulirus cygnus*) in Western Australia. *Fisheries Oceanography* 2, 1-10.

Caputi, N., Chubb, C., & Pearce, A. (2001). Environmental effects on recruitment of the western rock lobster, *Panulirus Cygnus*. CSIRO Publishing 1167-1174.

Cohen, P.J., & Gardner, C. (2007). Regional patterns in puerulus catches from eastern and western Tasmania. *Journal of Crustacean Biology* 27, 592-596.

Gardner, C., Frusher, S.D., Kennedy, R.B., Cawthorn, A. (2001). Relationship between settlement of southern rock lobster puerulus *Jasus edwardsii* and recruitment to the fishery in Tasmania, Australia. *Marine and Freshwater Research* 52, 1271-1275.

Gardner, C., Larkin, S., & Seijo, J.C. (2013). Systems to Maximize Economic Benefits from Lobster Fisheries, in: B. Phillips (Ed.) Lobsters: Biology, Management Aquaculture and Fisheries, Wiley-Blackwell. 113-132 p.

Guest, M.A., Frusher, S.D., Nichols, P.D., Johnson, C.R., & Wheatley, K.E. (2009). Trophic effects of fishing southern rock lobster *Jasus edwardsii* shown by combined fatty acid and stable isotope analyses. *Marine Ecology Progress Series* 388, 169-184.

Harrington, J.J., Semmens, J.M., Gardner, C., & Frusher, S.D. (2006). Predation of trap caught southern rock lobsters (*Jasus edwardsii*) in Tasmanian waters by the Maori octopus (*Octopus maorum*): spatial and temporal trends. *Fisheries Research* 77, 10-16.

Harrison, A. (1995). The development and management of the Tasmanian Rock Lobster fishery 1803-1985.

Hartmann, K., Gardner, C., & Hobday, D. (2013). Tasmanian Rock Lobster Fishery 2011/12. IMAS Fishery Assessment Report, University of Tasmania, Hobart, Tasmania.

Hunter, C.M., Haddon, M., & Sainsbury, K.J. (2005). Use of fishery-dependent data for the evaluation of depensation: case study involving the predation of rock lobster (*Jasus edwardsii*) by octopus (*Octopus maorum*). *New Zealand Journal of Marine and Freshwater Research* 39, 455-469.

Kennedy, R.B., Wallner, B., & Phillips, B.F. (1991). Preliminary investigations of puerulus settlement of the rock lobster *Jasus novaehollandiae* in southern Australia. *Revista Investigaciones Marinas* 12, 76-82.

Lewis, R.K. (1977)a. Rock Lobster puerulus settlement in the South East. SAFIC 9-11.

Lewis, R.K. (1977)b. Studies on the puerulus and post-puerulus stages of southern rock lobster (*Jasus novaehollandiae* Holthuis) in the south-easternregion of South Australia, in: B.F. Phillips, J.S. Cobb (Eds.) Workshop on Lobster and Rock Lobster Ecology and Physiology, CSIRO, Division of Fisheries and Oceanography, Perth, 36 p.

Ling, S.D., & Johnson, C.R. (2008). Population dynamics of an ecologically important range-extender: kelp beds versus sea urchin barrens. *Marine Ecology Progress Series* 374, 113-125.

Ling, S.D., Johnson, C.R., Ridgway, K., Hobday, A.J. & Haddon, M., (2009). Climate-driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. *Global Change Biology* 15, 719-731.

Linnane, A., Gardner, C., Hobday, D., Punt, A., McGarvey, R., Feenstra, J., Matthews, J., & Green, B. (2010). Evidence of large-scale spatial declines in recruitment patterns of southern rock lobster *Jasus edwardsii*, across south-eastern Australia. *Fisheries Research* (Amsterdam) 105, 163-171.

Linnane, A., James, C., Middleton, J., Hawthorne, P., & Hoare, M. (2010). Impact of wind stress anomalies on the seasonal pattern of southern rock lobster (*Jasus edwardsii*) settlement in South Australia. *Fisheries Oceanography* 19, 290-300.

Linnane, A., McGarvey, R., Feenstra, J. & Hawthorne, P., (2013). Southern zone rock lobster (*Jasus edwardsii*) fishery 2011/12: fishery assessment report to PIRSA Fisheries and Aquaculture. SARDI Fishery Assessment Reports, SARDI Aquatic Sciences, Adelaide, South Australia, 2013.

Linnane, A., McGarvey, R., Gardner, C., Walker, T.I., Matthews, J., Green, B.S., & Punt, A.E. (2013). Large-scale patterns in puerulus settlement and links to fishery recruitment in the southern rock lobster (*Jasus edwardsii*), across south-eastern Australia. *ICES* doi.10.1093/icesjms/fst176.

MacDiarmid, A.B. (1988). Experimental confirmation of external fertilisation in the southern temperate rock lobster *Jasus edwardsii* (Hutton) (Decapoda: Palinuridae*). Journal of Experimental Marine Biology and Ecology* 277-285.

MacDiarmid, A.B. (1994). Cohabitation in the spiny lobster *Jasus edwardsii* (Hutton, 1875). *Crustaceana* 341-355.

Mayfield, S., de Beer, E., & Branch, G.M. (2001). Prey preference and the consumption of sea urchins and juvenile abalone by captive rock lobsters (*Jasus lalandii*). *Marine & Freshwater Research* 52, 773-780.

Ndjaula, C.A.F. & Grobler (2002). Namibian lobster (*Jasus lalandii*) recruitment: Settlement in the Luderitz lagoon in relation to environmental parameters.

Pearce, A.F., & Phillips, B.F. (1988). ENSO events, the Leeuwin Current, and larval recruitment of the western rock lobster. *I C E S Journal of Marine Science* 45, 13-21.

Pecl, G., Frusher, S., Gardner, C., Haward, M., Hobday, A., Jennings, S., Nursey-Bray, M., Punt, A., Revill, H., & van Putten, I. (2009). The east coast Tasmanian rock lobster fishery – vulnerability to climate change impacts and adaptation response options. Report to the Department of Climate Change, Australia, University of Tasmania.

Pederson, H.G., & Johnson, C.R. (2006). Predation of the sea urchin Heliocidaris erythrogramma by rock lobsters (*Jasus edwardsii*) in no-take marine reserves. *Journal of Experimental Marine Biology and Ecology* 336, 120-134.

Phillips, B.F. (1981). The circulation of the southeastern Indian Ocean and the planktonic life of the western rock lobster. Oceanography and marine biology: an annual review 1981.

Phillips, B.F. (1995). Oceanic processes, puerulus recruitment, prediction and management of the Western Rock lobster *Panulirus Cygnus*. *Revista cubana de investigaciones pesqueras* 19, 27-32.

Phillips, B.F., & McWilliam, P.S. (2009). Spiny lobster development: where does successful metamorphosis to the puerulus occur? a review. *Reviews in Fish Biology and Fisheries* 19, 193-215.

Phillips, B.F., Melville-Smith, R., Linnane, A., Gardner, C., Walker, T.I., & Liggins, G. (2010). Are the spiny lobster fisheries in Australia sustainable? *Journal of the Marine Biological Association of India* 52, 139-161.

Prescott, J., McGarvey, R., Jones, A., Ferguson, G., Casement, D., Xiao, Y., & McShane, P. (1998). Southern Zone Rock Lobster, in: Southern Australian Fisheries Assessment Series, South Australian Research and Develoment Institute.

Punt, A.E., & Kennedy, R.B. (1997). Population modelling of Tasmanian rock lobster, *Jasus edwardsii*, resources. *Marine and Freshwater Research* 48, 967-980.

Punt, A.E., McGarvey, R., Linnane, A., Phillips, J., Triantafillos, L., & Feenstra, J. (2012). Evaluating empirical decision rules for southern rock lobster fisheries: A South Australian example. *Fisheries Research* (Amsterdam) 115-116, 60-71.

Punt, A.E., Trinnie, F., Walker, T.I., McGarvey, R., Feenstra, J., Linnane, A., & Hartmann, K. (2013). The performance of a management procedure for rock lobsters, *Jasus edwardsii*, off western Victoria, Australia in the face of non-stationary dynamics. *Fisheries Research* (Amsterdam) 137, 116-128.

Redd, K.S., Jarman, S.N., Frusher, S.D., & Johnson, C.R. (2008). A molecular approach to identify prey of the southern rock lobster. *Bulletin of Entomological Research* 98 233-238.

Shears, N.T., & Babcock, R.C. (2003). Continuing trophic cascade effects after 25 years of no-take marine reserve protection. *Marine Ecology Progress Series* 246, 1-16.

Sloan, S.R., Smith, A.D.M., Gardner, C., Crosthwaite, K., Triantafillos, L., Jeffries, B., & Kimber, N. (2014). National Guidelines to Develop Fishery Harvest Strategies., in: FRDC Report – Project 2010/061. Fisheries Research Report, Primary Industries and Regions, South Australia., SARDI.

Vega Velazquez, A., Gomez Rojo, C., Del Valle Manriquez, A., & Ayala Murillo, R. (2003). Recruitment of puerulus of red lobster *Panulirus interruptus* and its relationship with environmental factors in the northwest coast noroccidental of South Baja California.

Zivot, E., & Wang, J. (2006). Modeling Financial Time Series with S-PLUS, Second Edition ed., Springer.

12. Discussion

LIKELY KEY EFFECTS OF CLIMATE CHANGE

The results of this project suggest that the overall effects of climate change on the four case study species are likely to be negative. Increased inter-annual variability in recruitment may reduce the future productivity of both the snapper and blue grenadier fisheries in the southeast region. Increased recruitment variability as a consequence of climate change was also the main impact identified for southern rock lobster. The future productivity of abalone fisheries in the southeast will also be impacted by climate change through a combination of slower growth rates and increased frequency of mortality events. The notable exception to this generally negative outlook is the potential for a self-recruiting snapper population to be established off Tasmania.

The projected increase in water temperature was the main environmental factor associated with these predicted negative impacts. This result probably reflects, at least in part, 1) the strong capacity of existing models to predict future water temperatures compared to other environmental variables (e.g. rainfall) and 2) the extensive data available on the relationships between temperature and biological parameters (e.g. growth rates) compared to other physical variables (e.g. pH). However, this finding also reinforces the serious implications for Australia's fisheries of the rapid increases in water temperature that have already been recorded and are predicted to continue in several locations in south-eastern Australia (Hobday and Pecl 2014). Importantly, extreme temperature events are also predicted to increase in severity and frequency (Oliver et al 2014).

Future productivity of South Australia's large snapper fishery may be reduced because future water temperatures in key spawning areas in the two gulfs are predicted to exceed the upper thermal limit for successful recruitment. Similarly, future productivity of the blue grenadier component of the Commonwealth South East Fishery may be reduced if the negative correlation between recruitment strength and sea surface temperature during the spawning and larval development period (i.e. July-November) continues into the future. Furthermore, recent mortalities of blacklip abalone caused by extreme "hot water" events during summer, which have been estimated to reduce abalone abundance by approximately 30% in some areas (e.g. SA Southern Zone), demonstrate how rapidly fisheries can be affected by climate change impacts, particularly for reasonably sessile species that are not able to migrate to more favourable conditions.

Factors other than water temperature were identified as potentially important drivers of future change for several species. In several fisheries, the relative influence of different factors varied among regions. For example, range expansions of the long-spined sea urchin *Centrostephanus rodgersii)* have reduced stocks and catches of blacklip abalone in some areas of Tasmania and Victoria but have not been recorded in some other regions (e.g. South Australia). Similarly, in Victoria's Port Phillip Bay, river flow, associated nutrient regimes and plankton dynamics have all been shown to have a greater influence on larval survival rates and juvenile recruitment of snapper than water temperature, which is the dominant driver of recruitment success elsewhere. Factors affecting settlement of pureulus of southern rock lobster also varied regionally, with egg production being important in some zones in Victoria and South Australia and wind strength being dominant in others.

Some of our findings matched industry observations of environmental and biological changes in the marine ecosystems off south-eastern Australia. For example, members of the abalone industry also considered that summer mortalities were caused by extreme hot water events, low water temperatures were associated with high abalone productivity and the expansion of urchin barrens had significantly reduced abalone catches in some areas. However, industry members were often reluctant to attribute these variations to the impacts of human-induced climate change.

Stakeholders identified that a range of non-climate stressors are currently impacting on the operational, economic and social viability of their businesses and have the potential to increase the sensitivity of stocks/fisheries to climate change. For example, reductions in biomass caused by fishing and other non-climate related effects (e.g. abalone virus) were identified as potentially increasing the sensitivity of several fisheries to future predicted reductions in recruitment and productivity resulting from climate change. Similarly, loss of access to key fishing grounds through implementation of marine parks/reserves was identified as potentially increasing impacts of climate impacts in parts of the fishery outside the existing or proposed closed areas.

For all species the explanatory strength of variables was generally weak, suggesting that factors affecting key processes underlying fisheries production are complex. Predictions of future change presented in this report should be treated with caution. We recommend that results should only be considered as indicative of the type of impacts that may occur and used as a basis for identifying and evaluating potential adaptation options (as we have done here).

SUITABILITY OF CURRENT STOCK ASSESSMENT AND MANAGEMENT FRAMEWORKS

Data available to inform stock assessment and management of abalone, blue grenadier, snapper and southern rock lobster vary between jurisdictions. Key biological data (e.g. age/size, growth and reproduction) are available for all species. However, assessment of the implications of climate change for most species would be enhanced by more detailed information of spatial and temporal patterns of variability for these key parameters. Few ongoing programs are in place to evaluate the current (typically implicit) assumption that biological parameters (e.g. growth, recruitment, natural mortality) are static over time or fluctuate around a stable equilibrium, mainly due to the high costs associated with ongoing assessment of these parameters.

Economic data have been collected for all South Australian fisheries for over a decade but are sparse or non-existent for most species in other jurisdictions. The economic implications of climate change cannot be evaluated for most of the case study species because of the lack data available to undertake the associated assessments. Economic data are also needed to inform the development of management frameworks that aim to optimize the economic performance of fisheries. It should be noted that bio-economic modelling undertaken for southern rock lobster suggests that harvest strategies that aim to improve economic performance by reduced fishing costs and maximising prices also tend to maintain biomass at levels likely to improve resilience to climate-induced future reductions in productivity.

Daily fisheries data (effort, catch, etc) are available in most situations but data accuracy is poorly understood and spatial resolution is highly variable (typically highest resolution in abalone fisheries). In all case study fisheries, these data are used as primary inputs for determining stock status. In some cases measures derived from fisheries data (CPUE, age/size structure) are used directly as indicators of stock status (e.g. abalone, snapper in Victoria). In other cases, these data are incorporated into fisheries models that produce outputs that are used as indicators of stock status (blue grenadier, snapper in South Australia and Queensland, southern rock lobster). The value of fisheries data for monitoring future changes in stock status associated with climate change would be enhanced by formal evaluations of data quality and potential refinements in the spatial scales over which data are collected and reported.

The limitations of empirical measures traditionally used to assess abalone stock status (i.e. CPUE, relative abundance, size structure of the commercial catch, density estimates from fishery-independent surveys) are widely acknowledged (Prince and Shepherd 1992, Shepherd and Rodda 2001, Stobart et al 2013, Tarbath and Gardner 2012). These limitations also impede our capacity to detect future changes in abundance and productivity resulting from climate change. Recent attempts to integrate multiple empirical measures to provide a single measure of status have met with some success (PIRSA 2012, Stobart et al 2013, Craig Mundy - IMAS unpublished data). Current research projects investigating the development of new indicators that utilize high resolution spatial data obtained from commercial fishing to provide better indicators of stock status appear to present an opportunity to greatly improve stock assessments of abalone (FRDC 2011/201 - *Implementing a spatial assessment and decision process to improve fishery management outcomes using geo-referenced diver data*). If successful, these new measures will dramatically increase our capacity to detect future alterations in biomass and productivity resulting from climate change.

Fishery-independent surveys of relative or absolute abundance are conducted in some jurisdictions for abalone and rock lobster (e.g. South Australia). A FRDC project is in place to develop a fishery-independent measure of absolute abundance for snapper. Fisheries-independent data (usually from surveys) are needed when fisheries-dependent measures, typically CPUE, do not provide a reliable index of relative abundance (e.g. snapper, abalone). Fisheries-independent measures of relative abundance can also be useful for testing the robustness of assessment models to assumptions that key biological parameters are stable over time or fluctuate around a stable equilibrium.

The extent to which integrated assessment models are used to determine stock status also varies widely among jurisdictions and species. Traditional stock assessment models have limited utility and are not widely used for stock assessment of abalone due to high levels of spatial variability in patterns of growth and recruitment. However, modern stock assessment models are in place for southern rock lobster, blue grenadier and snapper (South Australia and Queensland only). The rock lobster model has recently been expanded to include economic considerations. The blue grenadier model would be enhanced by incorporation of economic data, if and when these become available. The usefulness of outputs from current snapper models are limited by the unreliability of CPUE as an indicator of relative snapper abundance. The snapper model would be improved by incorporation of fishery-independent estimates of abundance such as those being developed in the current FRDC project (2014-019).

Management frameworks for the four case study species are highly variable. Abalone, blue grenadier and southern rock lobster are managed using TACs. In contrast, a range of input controls are the primary management tools for snapper and the nature of these controls vary between jurisdictions. Formal harvest strategies with performance indicators, reference points and decision rules are used for the management of abalone, blue grenadier and southern rock lobster in most jurisdictions. Again, however, decision making processes for snapper are less clearly defined and are generally determined by informal discussions among fisheries managers, scientists and industry.

ADAPTATION OPTIONS

Workshop outcomes reinforced the view that successful climate change adaptation will not be isolated from other fisheries management and business decisions. Adaptation options identified were largely comprised of traditional fishery management approaches (e.g. reducing TACCs). This finding is not surprising given that the impacts of climate are currently similar to other challenges to which fisheries management routinely adapts.

We identified a total of 104 adaptations to address potential challenges arising from climate change impacts. These adaptation options range from autonomous adjustments made by industry to major interventions that would require significant changes to legislation, management frameworks and fishing practices. Potential climate challenges identified here are by no means exhaustive. Unanticipated challenges that may require adaptations not been identified during this project are also likely.

Due to logistical constraints only a selection of the adaptation options were analysed for each fishery. The options evaluated were selected on the basis of a number of factors including: the need to analyse a range of adaptation types (e.g. autonomous, transformative etc.), the benefits of comparing similar options across fisheries, levels of stakeholder interest/preference and the number of survey responses received. We conducted these analyses to demonstrate how the model that we developed can be used to compare the feasibility, risks and benefits of a range of different adaptation options.

Reducing the TACC (by up to 40%) was generally evaluated as being a feasible and beneficial adaptation option for responding to lowered productivity of blue grenadier and southern rock lobster and a highly feasible option for addressing abalone mortality events caused by thermal shocks. Consensus among industry, management and government was relatively high regarding the feasibility of reducing the TACC (by up to 40%). Many of the other adaptation options for addressing lowered productivity were evaluated as having low feasibility or benefit. For example, establishing spatial or temporal closures to reduce fishing effort to address a decline in productivity or availability of snapper was evaluated as being of low benefit by most sectors.

For the abalone and rock lobster fisheries, industry tended to rank adaptation options differently to the other groups; with responses indicating a perception of lower feasibility for abalone adaptation options and lower perceived benefits from the options considered for southern rock lobster. For the snapper fishery, levels of consensus varied across the different adaptation options and within sectors. In contrast, responses for the blue grenadier fishery indicated a very high level of consensus among sectors for all adaption options considered. This finding could reflect the low sample sizes for blue grenadier but may also be explained by the fact this fishery is confined to a single jurisdiction and involves a smaller number of larger operators than the other fisheries.

Whilst we have not examined all the adaptation options that were identified for each fishery, the results of those that we did examine in detail provide useful insights that may assist future climate change adaptation planning and implementation. The adaptation actions evaluated in this report are the first step to developing adaptation pathways using a risk based approach. The preliminary results presented will need to be enhanced through further consultation with stakeholders to ensure the entire range of likely adaptation responses is captured. Most importantly, this methodology provides a framework which policy makers and fishery managers can use to undertake inclusive and comprehensive analyses of the benefits, feasibility and perceived risks associated a range of potential adaptations to climate change and other challenges.

BARRIERS TO ADAPTATION

During the initial workshops, industry members and other stakeholders identified several non-climate stressors that may limit the capacity of the fisheries of south-eastern Australian to adapt to climate change impacts. These included: 1) recent reductions in economic viability due to increasing fishing costs and stagnating prices; 2) limitations in resources available for fisheries management; 3) loss of access to key fishing grounds due to implementation of marine parks/reserves; and 4) competition with recreational fishers. The scenarios examined in the March

(2012) workshop also identified several major barriers to climate change adaptation, some of which were also identified in other parts of our study. These include:

1. Increased costs and/or loss of revenue, including additional costs of expanded research and monitoring programs to address knowledge gaps;
2. The need to protect existing access rights;
3. Jurisdictional boundaries that prevent integrated management across the entire distribution of stocks;
4. Varying capacity of different jurisdictions and sectors to adapt to changes in productivity or distribution;
5. Need for significant legislative changes to facilitate adaptation in some cases;
6. Difficulties of decision making in an environment of increased uncertainty
7. Lack of stakeholder trust/support for tough decisions that may be required

There is a high degree of variability between both species and jurisdictions regarding the attributes of the current governance systems that could promote sustainable and effective resource management and enhance resilience to climate change impacts and other stressors. Some fisheries were assessed as performing strongly across many of the attribute areas (e.g. blue grenadier) whereas others performed poorly. For example, of the 42 attributes across the governance areas of Acountability (AC), Planning (P), Transparency (T), Incentives (I), Adaptability (AD) and Knowledge (K), the abalone fishery in NSW only recorded 'partially in place and always/mostly operational' for six attributes. Similarly, more than half the 'Planning' and 'Accountability' attributes were not in place in the Victorian snapper fishery.

Overall, the main areas of weakness identified in our preliminary benchmarking exercise were attributes of governance associated with Planning, Incentives and Accountability. For example, the goals and objectives of fishery management are not clearly defined ('Planning' section of governance benchmarking) in several fisheries, including the NSW, Tasmania and Victorian abalone fisheries and the Tasmanian SRL fishery. In fisheries where the goals and objectives of fishery management were clearly defined, clear processes for making trade-offs between conflicting objectives were only 'partially in place and sometimes operational' (e.g. rock lobster in South Australia, blue grenadier).

Incentives were not fully aligned with goals and objectives of fishery management for most species and jurisdictions, including the abalone fisheries in NSW, South Australia and Victoria. In the South Australian snapper fishery, seven of the ten attributes in the 'Incentives' category were ‘not in place and importance not recognised’, including ‘incentives fully aligned with goals and objectives’ and ‘monitoring of negative externalities’.

Limited ‘Accountability’ was also identified as a significant potential barrier to adaptation. Biological performance indicators are in place for most fisheries considered, with NSW and Tasmanian abalone and Victorian snapper being the notable exceptions. Economic, social and/or community performance indicators could be improved in all fisheries considered. Ecological performance indicators are only in place for abalone in South Australia, blue grenadier, snapper in Victoria and SRL in Tasmania.

It is important to note that the results of this benchmarking are preliminary and reflect the views of key individuals with expertise in management and governance that participated in the workshops. Revision of the attributes and final benchmarking would ideally involve a wider group of experts. Due to the preliminary nature of the study, cross-jurisdictional and cross-species comparisons of governance attributes should be regarded as indicative only.

FUTURE MONITORING AND RESEARCH

Biological Key Performance Indicators (KPIs)are monitored and reported annually in abalone, blue grenadier and rock lobster. Annual monitoring of biological KPIs occurs for snapper in South Australia but the level of monitoring need to be improved in Victoria.

Although somewhat limited in many cases, current biological monitoring programs provide information that will be critical for measuring future climate change impacts. Many of these datasets that were used in the assessments of the potential impacts of climate change which were undertaken in the present study. Some current programs would ideally be expanded to explicitly collect data to monitor key parameters likely to be impacted by climate change. For example, a tagging program to assess spatial and temporal variability in abalone growth rates would be beneficial. However, the cost of conducting these programs is high and it is unlikely that either industry or government will fund major expansion in these programs in the foreseeable future. Individual fisheries/jurisdiction need to identify the key parameters that need to be measured to assess the impacts of climate change and assess whether there are cost effective options for collecting these data within the context of existing programs for monitoring fishery performance.

Valuable environmental data is already collected in some fisheries by attaching data loggers to vessels and gear (nets, pots, divers). This approach provides a cost effective option for monitoring environmental parameters on key fishing grounds during the fishing season. These data will be valuable for understanding potential future changes in key biological parameters in these fisheries. However, the acquisition and collation of these data is not currently undertaken within the context of an environmental monitoring program with broad strategic goals (e.g. regional environmental monitoring program).

Data provided by Australia's Integrated Marine Observing System (IMOS) was critical for many of the investigations carried out in this study. It is important that these data streams are maintained and available to assess future changes in environmental conditions. IMOS is also well placed to design and lead a monitoring program under which the Australian fishing industry could collect environmental data to inform future marine climate change studies.

13. Conclusions

- The overall effects of climate change on the four species considered in the present study appear likely to be negative, with future productivity likely to be reduced in most fisheries.
- Adaption options that help maintain biomasses at levels likely to enhance resilience to increased variability in recruitment success may need to be established in several fisheries.
- Results from bio-economic modelling of southern rock lobster suggest that biomass levels that provide resilience to climate change may also correspond to levels that also improve economic performance by reducing the costs of fishing through higher catch rates and enabling fishers to maximise prices through increases in product quality and improved marketing.
- Options available for addressing these climate induced changes (e.g. reduced TACCs, other actions to reduce fishing mortality) are similar to those used to address reductions in fish abundance and productivity caused by other factors.
- This project identified numerous opportunities for improving current governance systems to enhance future adaption of fisheries to climate change and other stressors. For example, formal Harvest Strategies with explicit Biological Performance Indicators, Reference Points and Decision (Harvest Control Rules) need to be established in several fisheries.
- In fisheries with formal Harvest Strategies, we are not aware of any examples where Reference Points and Decision Rules have been explicitly designed to provide resilience to climate change impacts. However, studies of rock lobster presented in this report could be used ensure that future Harvest Strategies achieve that objective.
- Few of the fisheries considered have ecological, economic or social Performance Indicators. Establishing economic Performance Indicators is a high priority and may assist fishing businesses/industries to adapt successfully to climate change. Economic data need to be collected to provide a basis for calculating economic Performance indicators.
- Performance Indicators should be monitored regularly so that fisheries can respond quickly to impacts caused by climate change or other factors.
- Individual fisheries/jurisdiction need to identify the key parameters that need to be measured to assess the impacts of climate change and assess whether there are cost effective options for collecting these data are in place or can be established.
- Future collection of environmental data by the fishing industry would ideally be undertaken within the context of an environmental monitoring program with broad strategic goals. IMOS is well placed to design and lead such a monitoring program.

14. Implications

- Future catches are likely to be lower than historical averages in most of the fisheries considered in the study.
- Implications for industry, recreational fishers and fishery-dependent communities will need to be assessed on a case by case basis.
- The profitability of some fisheries may potentially be retained by maintaining biomass at levels that provide opportunities to lower costs (e.g. higher catch rates) and maximise prices (e.g. taking high quality product at times when demand is high).
- There are opportunities to improve attributes of governance systems to enhance resilience to climate change impacts in many of the fisheries examined in this study. These opportunities include: defining goals and objectives for some fisheries; establishing formal harvest strategies; establishing economic performance indicators; and increasing the frequency of monitoring key performance indicators.
- There is an opportunity for the fishing industry to contribute to future investigations of the marine climate change impacts by participating in a strategic environmental monitoring program, potentially conducted under the leadership of IMOS.

15. Recommendations

- Individual jurisdictions/fisheries should evaluate existing governance frameworks with respect to provide resilience to climate change and other stressors, potentially using methods similar to those developed in this study.

- Formal Harvest Strategies that include performance indicators, reference points and decision rules (harvest control) rules should be established for fisheries where they are currently lacking.

- Ecological, economic, social and community performance indicators also need to be established in most fisheries. Importantly, transparent mechanisms for making trade-offs between competing objectives need to be developed.

- Harvest Strategies should be specifically designed to maintain future biomasses at levels likely to increase resilience to climate change.

- Ideally complimentary Harvest Strategies would be established across jurisdictions. The Australian Fisheries Management Forum (AFMF) provides a suitable platform for leading and facilitating the collaboration that will be required to achieve this ambitious goal. Abalone, snapper and southern rock lobster would provide suitable cases studies.

- Individual fisheries/jurisdictions need to identify the key parameters that need to be measured to assess the impacts of climate change and determine whether cost effective options for collecting these data are in place or can be established.

- AFMF should consider approaching IMOS to evaluate the opportunity for the fishing industry to contribute data to an environmental monitoring program that would enhance future investigations of the impacts of climate change on marine industries.

16. Extension and Adoption

- The workshop series conducted during project collectively involved a large number of stakeholders from across each of the fisheries and jurisdictions. These workshops were highly participatory, with significant input sought from industry and managers.

- Multiple presentations were made to fisheries managers and industry representatives during the course of the project, including Victorian DEPI (Melbourne), AFMF (Port Lincoln), the Australian Abalone Association (Melbourne), VRFish (Torquay), and the Tasmanian Recreational Research Advisory Group.

- The project PI was invited to give a keynote at the OceanWatch Australia conference, which allowed approximately 25 OceanWatch staff to become familiar with the project. This will facilitate broader industry communication about the aims of the project.

- Now that the project is near completion, the project team are currently negotiating with managers and stakeholders in each jurisdiction to attend meetings and deliver presentations on the project outcomes. This will include another presentation to AFMF. At these meetings, feedback will be sought on the content, language and format of the fishery-specific summaries (see below).

- The project PI's and case study leaders will work together with the respective industry representatives and managers to develop fishery-specific executive summaries. These will be similar in scope, scale and content to that prepared for the East Coast Rock Lobster Vulnerability Assessment (Pecl et al 2009), which was very well received by industry and the public.

17. Project materials developed

PEER REVIEWED PAPERS

Published or in press

1. 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* 71(3), 528-536.

Submitted

2. 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

3. Mayfield S, 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.

4. 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.

5. Hamer P and Tracey S. Potential impacts of climate change on blue grenadier recruitment and dispersal.

6. Fowler A and Hammer P et al Implications of climate change for snapper spawning behaviour and distribution in south-eastern Australia.

7. Gardner et al Environmental effects on rock lobster recruitment

8. 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.

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

Associated papers

10. Leith P, Pecl G, Ogier E, Hoshino E, Davidson J, and Haward M. (2014). Towards a diagnostic approach to climate adaptation for fisheries. *Climatic Change.* 122, (1-2) pp. 55-66.

11. Ogier E, Harward M, Davidson J, Fidelmon P, Pecl G, Hoshino E and Hobday A. (in review). Evaluating fisheries management frameworks for climate adaptation: Australian case studies

12. Frusher, Stewart; Metcalf, Sarah; van Putten, Ingrid; Marshall, Nadine; Tull, Malcolm; Holbrook, Neil; Jennings, Sarah; Hobday, Alistair; Haward, Marcus; Pecl, Gretta. (in review) From physics to folk via fish – connecting the socio-ecological system to understand the ramifications of climate change on coastal regional communities. Fisheries Oceanography.

13. Jennings S, Pascoe S, Hall-Aspland S, LeBouhellec B, Norman-Lopez A, Sullivan A, Pecl GT. (in review) Setting objectives for evaluating climate change adaptation actions – putting the horse before the cart. Fisheries Oceanography.

14. 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 (accepted pending minor changes). Rapid assessment of fisheries species sensitivity to climate change in south east Australia. Climatic Change.

15. Lim-Camacho et al (accepted pending minor changes) Climate change futures: supply chain scenarios for Australian seafood industries. Regional Environmental Change.

16. Hobday, A. J., R. H. Bustamante, A. Farmery, A. Fleming, S. Frusher, B. S. Green, L. Lim-Camacho, J. Innes, S. Jennings, A. Norman-Lopez, S. Pascoe, G. T. Pecl, E. E. Plaganyi, P. Schrobback, O. Thebaud, L. Thomas and E. I. van Putten (in press). Growth opportunities for marine fisheries and aquaculture industries in a changing climate. Applied climate change adaptation research. J. Palutikof, J. Barnett, S. L. Boulter and D. Rissik, Wiley.

17. Frusher S, Hobday AJ, Jennings SM, Pecl GT, Haward M, Nursey-Bray M, Holbrook N, van Putten I, Creighton C, D'Silva D (2014). History of adaptation research in a marine climate change hotspot – from anecdote to action in south-east Australia. *Reviews in Fish Biology and Fisheries* 24:593–611

CONFERENCE PRESENTATIONS

Keynotes/Plenaries

- January 2014, Washington DC, Pecl et al Managing Marine Fisheries in a Changing Climate, Building Climate Solutions Conference,

- December 2012, Melbourne, Pecl et al Keynote at the Australasian Mollusc Society Conference

- October 2011, Gold Coast, Pecl et al OceanWatch Australia Conference

Invited

- May 2014, Australian Abalone Association meeting. Mayfield et al

- July 2013, Tokyo, Pecl et al Japan-Australia Marine Science Workshop

- May 2013, St Petersburg Russia, Pecl et al, ICES/PICES workshop on shifting commercial stocks

- January 2013, Chile, Pecl et al, South Pacific Climate Change and Fisheries Symposium

- June 2012, Melbourne, Pecl, Gretta. NCCARF Marine Climate Change Panel, Climate Adaptation In Action,

- March 2012, Taipei, Pecl et al Climate Change Adaptation in Australian Fisheries. APEC International Symposium "Impacts and Adaptation to Climate Change on Fisheries and Aquaculture"

Conference (accepted submitted abstracts)

- July 2014, Darwin (ASFB). Hamer et al Snapper movement and migration in a warming world.

- January 2013, Chile, Briceno et al, ‘Modelling predator/prey interactions under a changing climate: implications for a key commercial fishery in Tasmania’.

Workshop input

- 3 September 2012, Hobart, ‘Evaluating Marine Governance Frameworks for Climate Adaptation’ workshop

Popular/Industry articles

- 20 Sept 2012: The Mercury, *Let's make Tasmania Great* Special Edition: feature article written by Gretta Pecl on marine climate change and industry in Tasmania 'Value in the deep'.
- SETFIA newsletter, August 2013. Written by Simon Boag

Other extension

- 26 June 2013. SEAP flyers at public film and talk event 'Tasmanian Seas Through Tasmanian Eyes'.
- 23 and 24 March 2013, Triabunna SeaFest, SEAP flyers on display at IMAS/Redmap stand.
- 23 March 2013, Torquay, Paul Hammer, presentation to VRFish at a workshop to Develop Marine Fisheries Policy in Victoria.
- 22 February 2013, update to the Derwent Estuary Program, SEAP and Redmap.
- 9 December 2012, Hobart, Dr Pecl gave a public talk at the Wooden Boat Festival 'Marine climate change and Tasmania's marine industries'
- 31st October 2012, Hobart, SEAP flyers and update to Recreational Research Advisory Group
- 28th October 2012, Hobart, Seafarers Festival, SEAP flyers on display at IMAS/Redmap stand
- RecFish Conference, Gold Coast, 17, 18 and 19th August 2012 – SEAP flyers on display at IMAS/Redmap stand

Preparing fisheries for climate change: Identifying adaptation options for four key fisheries in South Eastern Australia

WHAT'S THE ISSUE?

Water temperatures recorded off eastern Tasmania since the 1940s have shown that south-eastern Australia is one of the fastest warming regions globally and waters are expected to continue to warm at a rate 3.8 times the world average as the East Australian Current (EAC) increases in strength and pushes further south into SE Australia. Over the last 70 years water temperatures have risen to the extent that water temperatures off eastern Tasmania now are equivalent to those that existed off Eden in southern NSW in the 1940s. In other regions of SE Australia, such as the South Australian coast adjacent to the Victorian boarder, we are recording more frequent upwellings that bring substantially cooler waters to the surface during summer. These different changes in our coastal environment have differing impacts on species and habitats.

WHY IS THAT A PROBLEM?

Not surprisingly, as our coastal waters warm and coastal currents such as the EAC carry animals further south, animals that liked the warmer waters off NSW now find eastern Tasmania a more desirable home. For example, the sea urchin *Centrostephanus* that was common in eastern NSW, is now extending further and further down the east coast of Tasmania. Similarly many sub-tropical fish species are becoming more common in recreational catches in Victoria, South Australia and Tasmania.

In addition to sea urchins, these warming waters are altering the distribution and abundance of many species including species that are of commercial and recreational importance. These changes will affect the fishing industry, the communities that benefit from these industries and may require changes in management to ensure sustainable management of our marine resources for both current and future generations. Understanding the implications of climate change on marine industries in SE Australia is important as this region produces the majority of Australia's seafood.

WHAT ARE WE DOING?

This project follows on from recent research that considered over 25 key commercial and recreational species in SE Australia. From that project we identified 4 species – southern rock lobster, abalone, blue grenadier and snapper – as species which are either highly vulnerable to a changing climate or represent a situation that is commonly occurring. For example, snapper are extending their range and increasing their abundance in Tasmania and thus snapper are representative of a species undergoing changes in their distribution.

By working with recreational and commercial fishers and fisheries managers, scientists will bring all the existing information on these species and the environment in SE Australia to predict what changes are likely to occur, what adaptation options are possible and realistic, and how management may have to change to ensure that we can minimise adverse impacts and maximise opportunities as our marine resources respond to a changing climate.

Abalone............

- Low tolerance to temperature stress
- Reduction in habitat as a result of barrens-forming urchin
- Temperature may increase risk of disease

Blue grenadier

- Changes in temperature may impact timing or location of spawning
- Susceptible to over fishing due to a long life span

Snapper

- Recruitment is highly variable from year to year, region to region
- Population seems to be expanding further south
- Critically dependant on inshore benthic habitats as a nursery habitat for juveniles

Southern rock lobster

- Large scale decline in recruitment over last decade
- Poor knowledge of long larval phase
- Reduction in habitat as a result of barrens-forming urchin

CONTACTS:

GRETTA PECL, GRETTA.PECL@UTAS.EDU.AU, 03 6227 7277

TIM WARD, TIM.WARD@SA.GOV.AU, 08 8207 5433

This project is funded by FRDC and DAFF

Australian Government Department of Agriculture, Fisheries and Forestry · Australian Government Fisheries Research and Development Corporation · cl-nemo · State Government Victoria Department of Primary Industries · Government of South Australia Primary Industries and Regions SA · SARDI Research and Development · IMAS

Photos: Bruce Miller, IMAS and Redmap

SETFIA newsletter, August 2013. Written by Simon Boag

HOW DOES CLIMATE CHANGE AFFECT GRENADIER RECRUITMENT?

Strong Autumn winds + cold winter SST = high recruitment

Scientists believe that south east Australia is a climate change hot spot. Sea Surface Temperatures (SSTs) have increased by 0.6C globally but have risen 2.3C between 1880 and now and are forecast to increase another 2.5C by 2030. The pH in the SE has decreased by 30% (more acidic). There is some indication that autumn winds will get stronger. The area under Tasmania is complicated by currents and those at the surface do not match current sub-surface. This complicates water temperature. Work was completed on larval drift but was inconclusive. A scientific project tested the hypothesis that high winds increase the recruitment of blue grenadier off western Tasmania. They found that high autumn winds did bring about better recruitment. This *might* be due to displaced seagrass feeding invertebrates that larval blue grenadier feed on. The project also found an even stronger relationship with SST; low winter SSTs providing higher recruitments. No relationship was found with the southern oscillation index or rainfall. To some extent this explains the varying recruitment we see with blue grenadier. Industry has been catching a 2004 cohort for years and based on this year's reports from vessels this may be running out. Another strong cohort arrived in 2009 and at 4 years of age we are starting to see these as small fish in catches.

Appendix 1 - Project Contributors

Institute of Marine and Antarctic Studies (IMAS)

Dr Gretta Pecl co-led the project (together with Associate Professor Tim Ward, SARDI).

Mr Felipe Briceño

Associate Professor Stewart Frusher

Associate Professor Caleb Gardner

Dr Klaas Hartman

Dr Martin Marzloff

Dr Craig Mundy

Dr Sean Tracey

South Australian Research and Development Institute (SARDI) – Aquatic Sciences and Department of Primary Industries and Resources of South Australia (PIRSA)

Associate Professor Tim Ward co-led the project

Dr Tony Fowler

Dr Adrian Linnane

Dr Stephen Mayfield

CSIRO Marine and Atmospheric Research (CMAR)

Dr Alistair Hobday

Dr Geoff Tuck

Department of Environment and Primary Industry (DEPI) Victoria

Dr Paul Hamer

School of Economics and Finance, University of Tasmania

Dr Sarah Jennings

Dr Eriko Hoshino

Mr Bastien Le Bouhellec

Fish Focus Consulting

Andrew Sullivan, Director of Fish Focus Consulting

Other contributors

Many other individuals and organisations contributed their time and expertise towards the success of this collaborative project; their contributions are detailed in the acknowledgements.

Appendix 2 - Workshops

WORKSHOP 2012

- Invitation
- Agenda
- Attendee list

EXAMPLE INVITATION

Fisheries Aquaculture and Coasts Centre

Private Bag 49 Hobart
Tasmania 7001 Australia
Phone +61 3 6227 7277
Fax: +61 3 6227 8035
www.imas.utas.edu.au

Invitation to Attend South East Australia Program (SEAP) Fisheries Adaptation Project Workshop

When: March 15-16 2012, Where: Melbourne VICTORIA (Location TBA)

Dear Mark,
You are invited to attend the SEAP Fisheries Adaptation Workshop held in Melbourne March 15-16th 2012. The workshop is over two days with case study leaders for the fisheries involved (see below) meeting with industry and management on the first day, and the scientific working groups on the following day. You are invited to attend as a representative on March 15th.

Preparing fisheries for climate change: identifying adaptation options for four key fisheries in South Eastern Australia: project summary - South-eastern Australia has been identified as a global hotspot for marine climate change and Governments of the five jurisdictions within the region have been proactive in establishing a formal collaborative structure (SEAP) to facilitate effective adaption of fisheries in terms of responding constructively to potential impacts of climate change. Ensuring that the fisheries of South-eastern Australia adapt effectively to climate change will require the development of management systems that allow negative impacts to be mitigated and opportunities that arise to be seized. Industry and Management representatives for each case study, together with members of a scientific working group, will identify options for adjusting management arrangements to ensure that both the profitability of commercial fisheries and opportunities for participation in recreational fishing are enhanced.

Overall key objectives of this two year project are to:

1. Identify likely key effects of climate change on four major fisheries species in south east Australia
2. Identify options for improving assessment and management frameworks to ensure that they perform effectively under likely climate change scenarios
3. Evaluate options for adjusting management arrangements to reduce negative impacts and maximize uptake of opportunities that climate change may provide to commercial and recreational fisheries
4. Identify improvements to current monitoring systems proposed fisheries and their habitats to ensure that they are suitable for measuring the likely impacts of climate change and other drivers.

Fisheries case studies included in this project are:

- SOUTHERN ROCK LOBSTER (*Jasus edwardsii*) **(Case study Leaders: Caleb Gardner and Adrian Linnane)**
- ABALONE Greenlip (*Haliotis laevigata*) and Blacklip (*Haliotis rubra*) **(Case study leaders: Craig Mundy and Stephen Mayfield)**
- SNAPPER (*Pagrus auratus*) **(Case study leaders: Greg Jenkins and Anthony Fowler)**

- BLUE GRENADIER (*Macruronus novaezelandiae*) **(Case study leaders: Geoff Tuck and Paul Hamer)**

Please rsvp to Jemina.StuartSmith@utas.edu.au by February 27th noting:

1. ***If you require flights to Melbourne (note that we will reimburse your economy class air ticket from your capital city if it is booked by February 27th); and***
2. ***If you have any special dietary requirements***

Please contact Jemina.StuartSmith@utas.edu.au, Gretta.Pecl@utas.edu.au or Tim.Ward@sa.gov.au for more information.

Regards

Dr Gretta Pecl
Senior Research Fellow
Institute for Marine and Antarctic Studies
Fisheries, Aquaculture, Coasts Centre UTAS

Associate Professor Tim Ward
Science Leader, Fisheries Program
SARDI

A detailed agenda will be provided closer to the day; however, additional information is given below. Although you are invited to Day 1, we will provide the Day 2 objectives here for your information also.

OBJECTIVES FOR DAY 1 (March 15)

Attended by Industry and Management Representatives, Case Study Leaders

- 'Benchmarking for good fisheries governance' exercise (see short description below)
- Developing management objectives under a changing climate (see short description below)
- Discussion of potential regional approaches to management
- Establish broad indications of possible directions for adaptation options
- Collate industry perceptions regarding any observed oceanographic, ecosystem or fishery changes

OBJECTIVES FOR DAY 2 (March 16)

Attended by Case Study Leaders and Scientific Working Groups

Develop finalized scoping document for each case study, including timelines and itemised work packages:

- Define stakeholders requirements, project deliverables, roles and responsibilities
- Assess data and model requirements/availability
- Define climate change scenarios to be examined and climate change variables to be explicitly considered for each species

- Allocation of detailed work packages
- Consultation/engagement strategies:
    - With industry and management representatives
    - Other SEAP projects – Lyne et al and Fulton et al
    - Between the case studies

Governance benchmarking

Good fisheries governance is essential for effective climate change adaptation. Benchmarking governance systems against best practice in the case study fisheries will inform the fishery vulnerability assessments by identifying barriers to adaptation, and will help in shaping fishery level adaptation strategies. We have compiled a list of key governance attributes and, prior to the workshop, will conduct a preliminary, desk-top assessment for each of the case study fisheries. At the workshop we will be filling in any gaps and asking you to endorse the benchmarking assessments for each case study.

Fisheries management objectives

An important initial step in identifying climate change impacts and risks and for evaluating alternative management and governance adaptations is to develop a clear understanding of what values a fishery system is being managed for. In this project this involves identifying the objectives of fishery management and understanding how different groups of stakeholders weight them. This can help flag zones of conflict which may act as barriers to adoption and implementation of adaptation actions. We have developed a 'strawman' management objective hierarchy based on a review of legislation and management plans, and on previous work. At the workshop we will be asking you to refine the 'strawman' to reflect circumstances in each case study fishery. We will also be asking for your help in identifying people to be included in a survey which will subsequently determine the weights on objectives.

SOUTH EAST AUSTRALIA PROGRAM WORKSHOP - AGENDA

Melbourne VIC 15-16 March 2012

Day 1 March 15th Industry and Management Representatives and Case Study Leaders			
Time	**Topic**	**Speaker(s)**	**Room**
10:00	Welcome & SEAP adaptation project overview (including relationship to other projects)	Gretta Pecl	Plenary
10:15	Overview of climate change in the South-East	Alistair Hobday	Plenary
10.30	Climate change and our key species	Tim Ward	Plenary
11:00	Adaptation in the marine environment	Alistair Hobday	Plenary
11:20	*Discussion* Putting climate change into perspective: other key threats and issues across regions and fisheries	Andrew Sullivan	Plenary
11:50	*Discussion* Collating industry perceptions regarding observed oceanographic, ecosystem or fishery changes	Stewart Frusher	Plenary
12:30	*Lunch*		
13.15	Overview of the afternoon: 1/ Fishery Adaptation exercise and 2/ Establishing Fishery Management objectives	 Gretta Pecl Sarah Jennings	Plenary
13:45	Case study groups completing Fishery Adaptation & Fishery Management Objectives exercises	Case study leaders	Snapper (Plenary) Rock lobster (Rm 1) Abalone (Rm 2) Blue Grenadier (Rm 3)
14.45	*Afternoon tea*		
15:00	Continued from above	Case study leaders	(As above)
16:00	Workshop summary and discussion: Stakeholder requirements & expectations for this project	Tim Ward, Gretta Pecl & Sarah Jennings	Plenary
16:30	*Close*		

Note, in the afternoon session, two case studies groups will work on the *Establishing Fishery Management Objectives* exercise (with Sarah Jennings and Sean Pascoe) whilst two case study groups work on the *Fishery Adaptation* exercise (with Stewart Frusher/Tim Ward and Gretta Pecl/Alistair Hobday), and then these groups will swap.

Day 2 March 16th Scientific Working Groups and Case Study Leaders			
Time	**Topic**	**Speaker**	**Room**
10:00	Welcome & Project overview	Tim Ward and Gretta Pecl	Plenary
10.15	Adaptation in the marine environment	Alistair Hobday	Plenary
10:30	Summary of Day 1 Stakeholder requirements & expectations for this project	Tim Ward & Gretta Pecl	Plenary
11:00	Links with Beth Fulton's SEAP project: Climate change scenarios and assessing management strategies with Atlantis	Penny/ Fabio	Plenary
11.30	Discussion * • Define climate change scenarios to consider • Environmental data: availability, requirements and analyses required for the project	Alistair Hobday	Plenary
12:30	*Lunch*		
13:15	Finalise key deliverables and timelines: • Assess data and model availability • Detail of work to be conducted – essential and wish list • Allocation of work packages- roles, responsibilities and timelines • Consultation/engagement strategies	Case study leaders with Tim Ward, Stewart Frusher and Gretta Pecl	SRL & Abalone in Plenary Snapper in room 1 BG in room 2
15:00	*Afternoon tea*		
15:15	Session continued		
16:15	Workshop summary	Gretta Pecl & Tim Ward	

CASE STUDY LEADERS

Case leaders	Organisation	State	Group
Jenkins, Greg	DEPI VIC	VIC	Snapper
Fowler, Anthony	PIRSA-SARDI	SA	Snapper
Linnane, Adrian	PIRSA-SARDI	SA	Rock lobster
Gardner, Caleb	IMAS	TAS	Rock lobster
Tuck, Geoff	CSIRO	TAS	Blue Grenadier
Hamer, Paul	DEPI VIC	VIC	Blue Grenadier
Mundy, Craig	IMAS	TAS	Abalone
Mayfield, Stephen	PIRSA-SARDI	SA	Abalone

FINAL WORKSHOP ATTENDEE LIST

Name	Organisation	State	Group 1	Group 2	Role/area	Email
Mayfield, Stephen	SARDI	SA	Abalone		Case leader	Stephen.Mayfield@sa.gov.au
Woolford, Jonas	AIASA	SA	Abalone		Industry	jbw21@internode.on.net
Mundy, Craig	IMAS	TAS	Abalone		Case leader	Craig.Mundy@utas.edu.au
Pullen, Grant	DPIPWE	TAS	Abalone		Manager	Grant.Pullen@dpipwe.tas.gov.au
McKibben, Joey	ACA	TAS	Abalone		Industry	joeywmck@hotmail.com
Tudman, Michael	Aus Longline P/L	COM	Blue Grenadier		Industry	sw@australianlongline.com.au
Milic, Brad	AFMA	COM	Blue Grenadier		Management	Brad.Milic@afma.gov.au
Wayte, Sally	CSIRO	COM	Blue Grenadier		Science team	Sally.Wayte@csiro.au
Tuck, Geoff	CSIRO	TAS	Blue Grenadier		Case leader	Geoff.Tuck@csiro.au
Hamer, Paul	DPI VIC	VIC	Blue Grena	Snapper	Case leader	Paul.Hamer@dpi.vic.gov.au
Linnane, Adrian	PIRSA-SARDI	SA	Rock lobster		Case leader	Adrian.Linnane@sa.gov.au
Triantafillos, Lianos	PIRSA-SARDI	SA	Rock lobst	Abalone	Manager	lianos.triantafillos@sa.gov.au
Ward, Tim	PIRSA-SARDI	SA	Rock lobst	Abalone	Overall	Tim.Ward@sa.gov.au
Gardner, Caleb	IMAS	TAS	Rock lobster		Case leader	Caleb.Gardner@utas.edu.au
Treloggen, Rodney	TRLFA	TAS	Rock lobster		Industry	rocklobsterexo@bigpond.com.au
Revill, Hilary	DPIPWE	TAS	Rock lobster		Manager	Hilary.Revill@dpipwe.tas.gov.au
Frusher, Stewart	IMAS	TAS	Rock lobster		Other projects	Stewart.Frusher@utas.edu.au
Hartmann, Klaas	IMAS	TAS	Rock lobst	Abalone	Science team	Klaas.Hartmann@utas.edu.au
Pecl, Gretta	IMAS	TAS	Rock lobst	Snapper	Overall	Gretta.Pecl@utas.edu.au
Walker, Terry	DPI VIC	VIC	Rock lobster		Science team	Terry.Walker@dpi.vic.gov.au
Silberschneider, Veronica	DPI NSW	NSW	Snapper		Management	Veronica.Silberschneider@dpi.ns
Sumpton, Wayne	DEEDI	QLD	Snapper		Science team	Wayne.Sumpton@deedi.qld.gov.a
Fowler, Anthony	PIRSA-SARDI	SA	Snapper		Case leader	Anthony.Fowler@sa.gov.au
Besley, Michelle	PIRSA	SA	Snapper		Management	michelle.besley@sa.gov.au
Tracey, Sean	IMAS	TAS	Snapper	Blue Grena	Science team	Sean.Tracey@utas.edu.au
Jenkins, Greg	DPI VIC	VIC	Snapper		Case leader	greg.jenkins@dpi.vic.gov.au
Collins, Chris	VRfish	VIC	Snapper		Industry	christopher@vrfish.com.au
Lussier, Bill	DPI VIC	VIC	Snapper		Management	bill.lussier@dpi.vic.gov.au
Sullivan, Andrew	DPIPWE	TAS	Snapper		Management	Andrew.Sullivan@dpipwe.tas.gov.
Seaborn, Frances	DPIPWE	TAS	Snapper		Management	Frances.Seaborn@dpipwe.tas.gov
Pascoe, Sean	CSIRO	QLD	Other		Other projects	Sean.Pascoe@csiro.au
Hobday, Alistair	CSIRO	TAS	Other	Abalone	Overall	Alistair.Hobday@csiro.au
Jennings, Sarah	UTAS	TAS	Other		Overall	Sarah.Jennings@utas.edu.au
Stuart-Smith, Jemina	IMAS	TAS	Other		Overall	Jemina.StuartSmith@utas.edu.au
D'Silva, Dallas	DPI VIC	VIC	Other		Overall	Dallas.D'Silva@dpi.vic.gov.au
Boschetti, Fabio	CSIRO	WA	Other		Other projects	Fabio.Boschetti@csiro.au
Hall-Aspland, Sophie	UTAS	TAS	Other		Other projects	s_hallasp@hotmail.com
Johnson, Penny	CSIRO	TAS	Other		Other projects	penny.johnson@csiro.au
Hoshino, Eriko	UTAS	TAS	Other		Other projects	Eriko.Hoshino@utas.edu.au

WORKSHOP SERIES 2013

- Example invitation
- Example agenda
- Attendee lists

EXAMPLE INVITATION

Invitation to Attend South East Australia Program (SEAP) Fisheries Adaptation Project Workshop

When: 25 July 2013, Where: CSIRO in Hobart

Dear all,

As I am sure you are aware, the project FRDC 2009/070 "Preparing fisheries for climate change: identifying adaptation options for four key fisheries in South Eastern Australia" is well underway.

There are four components to the project:

1 Identify likely key effects of climate change, particularly where these effects may impact the harvest strategies for these species.

2 Identify options for improving assessment and management frameworks to ensure that they perform effectively under likely climate change scenarios.

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.

4 Identify improvements to current monitoring systems to ensure that they are suitable for measuring the likely impacts of climate change and other drivers.

Craig Mundy and I are the case study leaders of the abalone component and, having been working predominantly on objectives 1 and 2, are seeking input from you in relation to objective 3.
To do this, a workshop has been planned for 25 July 2013 at CSIRO in Hobart. To set the scene, we will present some of the results from objectives 1 and 2 to provide background for the discussion around objective 3:

a. *Identify possible impacts/opportunities*
b. *Assess potential for autonomous adaptations by fishers*
c. *Identify potential management and adaptation actions*
d. *Identify barriers to action and potential strategies to overcome these*
e. *For suggested changes/adaptation options assess:*
    i. *lead time to implement change*
    ii. *Consequence period*
    iii. *Likely benefit*
    iv. *Cost (to who, $, social, ecological?)*

Could you please advise by return email of your interest in attending this workshop. We will be able to assist with travel expenses.

Thanks and regards,
Steve & Craig

Dr Stephen Mayfield, Subprogram Leader: Molluscan Fisheries
SARDI Aquatic Sciences
Mobile: 0401 122 108

stephen.mayfield@sa.gov.au

AGENDA

South East Australia Program (SEAP)

Preparing fisheries for climate change: identifying adaptation options for four key fisheries in South Eastern Australia

DCC & FRDC – Marine Biodiversity and Fisheries Climate Change Project 2011/039

Cove Room, CSIRO Hobart, 25th July 2013

Chair: Dr Tim Ward

9:00	Welcome and introductions
9:15	Overview of project goals and objectives (Tim Ward)
9:30	Climate change in south east Australia (Alistair Hobday) (with time for questions/discussion after)
10:15	Morning tea
10:45	Potential effects of climate change on abalone and the abalone fishery (Stephen Mayfield) (with time for questions)
12:15	Lunch
13:00	Discussion of draft adaptation options (and their characterisation) to address key climate challenges (based on those developed largely by industry/management at workshop in March 2012) (Gretta Pecl)
13:45	Evaluation of options based on Feasibility, Risk and Benefit (Gretta)
15:00	Close

Please return your name tags to Gretta Pecl, thank you!

Attendees at 2013 industry and management evaluation of potential adaptation options workshop series

Project leaders meeting

22 July – Melbourne

Name	Representing	Juridiction
Tony Fowler	PIRSA- SARDI	South Australia
Paul Hamer	DEPI-Vic	Victoria
Sarah Jennings	UTAS	Tasmania
Adrian Linnane	SARDI	South Australia
Stephen Mayfield	SARDI	South Australia
Craig Mundy	IMAS	Tasmania
Emily Ogier	IMAS	Tasmania
Gretta Pecl	IMAS	Tasmania
Geoff Tuck	CSIRO	Tasmania

Abalone

25 July 2013 – Hobart

Name	Representing	Juridiction
Alistair Hobday	CSIRO	Tasmania
Zac Lewis	Fisheries Victoria	Victoria
Dean Lisson	Tasmania Abalone Council	Tasmania
Alice Marriott	Abalone Victoria	Victoria
Stephen Mayfield	SARDI	South Australia
Joey McKibben	Tasmania Abalone Council	Tasmania
Craig Mundy	IMAS	Tasmania
Gretta Pecl	IMAS	Tasmania
Bob Pennington	Abalone Industry Assoc S.A.	Tasmania
Lianos Triantafillos	PIRSA	South Australia
Tim Ward	SARDI	South Australia

Blue grenadier

29 July 2013 – Hobart

Name	Representing	Juridiction
Simon Boag	(South East Trawl Fishing industry Association)	
Ross Bromley	AFMA	
Josh Cahill	AFMA	
Claudio Castillo Jordan	IMAS	Tasmania
George Day	AFMA	
Stewart Frusher	IMAS	Tasmania
Paul Hamer	DEPI-Vic	Victoria
Alistair Hobday	CSIRO	Tasmania
Sandy Morison	RAG	
Jeff Moore		
Graeme Patchell	Sealord	
Gretta Pecl	IMAS	Tasmania
David Power	AFMA	
Les Scott	Australian longline Pty Ltd	
Sean Tracey	IMAS	Tasmania
Sally Wayte		

Snapper

29 August 2013 – Melbourne

Name	Representing	Juridiction
Michelle Besley	PIRSA Fisheries and Aquaculture SA	South Australia
Nathan Bicknell	Marine Fishers Association SA	South Australia
Tony Fowler	SARDI SA	South Australia
Franz Grasser	VRFish	Victoria
Paul Hamer	DEPI Vic	Victoria
Bill Lussier	DEPI Vic	Victoria
John Stewart	DPI NSW	New South Wales
Wayne Sumpton	DPI Qld	Queensland
Renee Vajtauer	Executive Director, Seafood Industry Victoria	Victoria
Tim Ward	SARDI SA	South Australia
Ross Winstanely	Retired fisheries scientist/manager	

Rock lobster

18 and 19 September – Adelaide

Name	Representing	Juridiction
Caleb Gardner	IMAS	Tasmania
Adrian Linnane	SARDI	South Australia
Justin Phillips		
Rodney Smith		
Lance Tyley		
Tim Ward	SARDI SA	South Australia

Abalone

11 November 2013 – Hobart

Name	Representing	Juridiction
Sam Andrew		
Matt Bradshaw	DPIPWE	Tasmania
Zac Lewis	Fisheries Victoria	Victoria
Dean Lisson	Tasmania Abalone Council	Tasmania
Alice Marriott		
Stephen Mayfield	SARDI	South Australia
Joey Mckibbon	Tasmania Abalone Council	Tasmania
Craig Mundy	IMAS	Tasmania
Bob Pennington	Abalone Industry Assoc S.A.	Tasmania
Greg Ryan	DPIPWE	
Lianos Triantafillos	PIRSA	South Australia
Tim Ward	SARDI	South Australia
Jonas Woolford		

Appendix 3 - Species and Fishery Profiles

Please note these species and fisheries profiles were produced March 2012 in preparation for the March 2012 workshop. They have not been updated since this time.

TABLE OF CONTENTS

3.1 Blacklip Abalone (BA), *Haliotis rubra* and Greenlip Abalone (GA), *Haliotis laevigata*

1. ECOLOGY

1.1 REPRODUCTION, LARVAL DEVELOPMENT, SETTLEMENT AND RECRUITMENT

Species within the *Haliotis* genus have similar life cycles (Figure 1.1; after Sloan and Breen 1988; McShane 1995). Abalone are broadcast spawners, releasing eggs and sperm into the water where fertilisation occurs (Grubert, Mundy et al 2005). The fertilised eggs disperse with the currents until they hatch into swimming pelagic lecithotrophic larvae, which then undergo a number of different developmental stages. Planktonic larval duration varies between 3 and 12 days depending on water temperature and species. Temperature appears to be an important cue for phenology, influencing the timing of spawning, rate of larval development and length of the pelagic phase (Sloan and Breen 1988). Peak settlement occurs in August for blacklip abalone (BA) (Keesing, Grove-Jones et al 1995; Nash, Sanderson et al 1995). Immediately after settlement, post-larval juveniles (spat) begin to graze on diatoms and other microalgae (Onitsuka, Kawamura et al 2007). During the first 4–6 weeks, juveniles occupy exposed rock surfaces and subsequently undergo a cryptic phase, inhabiting narrow crevices and fissures.

Aggregative behaviour / high densities of mature individuals are critical to successful egg fertilisation and maintaining sufficient levels of recruitment in abalone population (Dowling, Hall et al 2004): recruitment failures have been reported in South Australia (SA) at low densities (> 0.3 animals per m2; Babcock and Keesing 1999). However, abalone recruitment can vary independently from the number of spawners at high densities (McShane 1995). Recruitment variation at quite local spatial level is likely to be influenced by environmental conditions, density-dependence and habitat. In particular, crustose coralline algae habitat is key to settlement of abalone larvae and development of juveniles (Huggett, De Nys et al 2005).

Population genetics reveal low connectivity in abalone population: with low dispersal larvae, BA sub-populations are largely self-recruiting, with marked population subdivision at scales of 100 m. Dispersal of larvae at scales of tens of kilometres is rare, probably limited to once every few years (Temby, Miller et al 2007; Miller, Maynard et al 2009). Thus, recovery of depleted populations relies on larval recruits sourced at scales of tens of kilometres and may take many decades (Miller, Maynard et al 2009)

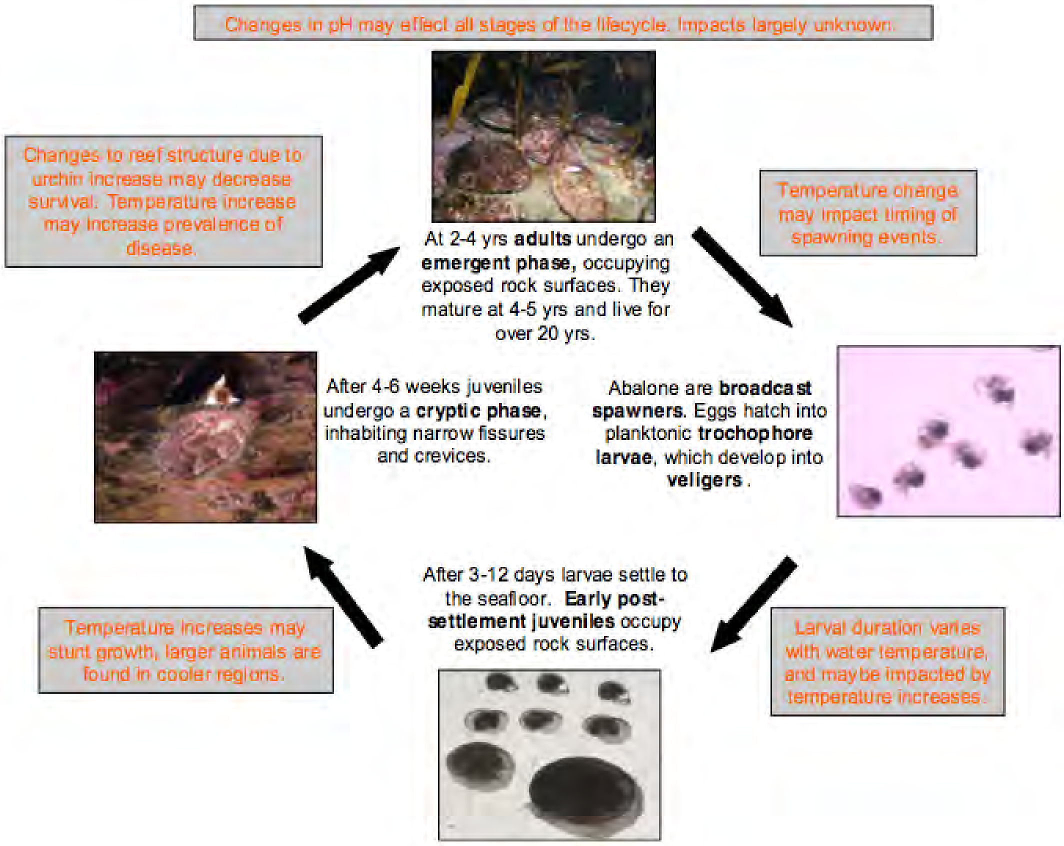

Figure 1. Summary of life cycle of *Haliotis* sp., and points of exposure to relevant climate change drivers or known impacts. Images are of blacklip abalone. Source: L. Lyall, A. Browne (IMAS).

1.2 ADULT PHYSIOLOGY

At 2–4 years of age, abalone emerge and (Figure 1), occupy open rock surfaces, which may coincide with sexual maturity (Prince, Peeters et al 2008). Note that size at maturity is highly heterogeneous in abalone population ranging for instance for BA from 75 to 120 mm in northern Tasmania alone (Tarbath and Officer 2003). Based on shell increment counts, Tasmanian BA can reach over 20 years of age (Tarbath and Officer 2003).

Growth rates in both BA and greenlip abalone (GA) vary considerably among regions (James 1981; Shepherd and Hearn 1983; Hutchinson, Gavine et al 2010). Maximum size and growth of BA in Tasmanian waters is inversely related to SST, with larger individuals occurring in the south of the state, which suggests that growth may be stunted at elevated temperatures (James 1981). Generally, abalone has reduced ability to cope with high temperature stress (Gilroy and Edwards 1998): BA has a lower thermal tolerance than GA: optimum growth temperature is 17°C and 18.3°C; 50% critical thermal maxima (when 50% of individuals were no longer attached to substrate) is 26.9°C and 27.5°C for BA and GA respectively. Although little is known about the potential impacts of ocean acidification (due to increasing CO_2 levels) on abalone, it may greatly impact their growth pattern, shell development, and survival as demonstrated for other marine calcifying organisms (Talmage and Gobler 2009).

KEY POINTS:

- High heterogeneity in physiology (growth and maximum size) between abalone sub-populations;
- Low tolerance to high temperature stress (critical thermal maxima in the high 20°C);
- Increasing temperature may retard growth and maximum size of individuals (optimal growth at 17 and 18.3°C for BA and GA respectively);
- Unknown effects of pH on shell formation and growth rate.

1.3 HABITAT AND SPECIES DISTRIBUTION

BA are distributed from northern NSW, around Tasmania, across SA and into southern WA (Figure 2). In contrast, GA are only found along the southern Australian coast from southern WA (Cape Naturalist) to Victoria (Corner Inlet), including northern Tasmania (Kailola, Williams et al 1993) (Figure 1.2). Adult emergent BA inhabit exposed rocky reef and boulder habitats up to 40 m deep (Williams, Craigie et al 2008; Strain and Johnson 2010; Rogers-Bennett, Allen et al 2011). GA are also found attached to low-lying reefs in open sandy environments. Manipulative experiments on Tasmanian rocky reefs have demonstrated the existence of a tight positive feedback between BA and its benthic habitat, crustose coralline algae (Strain and Johnson 2010): under canopies of macroalgae, rocks covered in pink coralline algae (non-geniculate coralline algae and other encrusting algal species) constitute an essential habitat and sources of food for adult abalone, as well as the metamorphosis of larvae and development of juveniles; Abalone grazing maintains pink encrusting algae by preventing their overgrowth by a brown benthos of sessile invertebrates and filamentous red algae (Strain and Johnson 2010). As this brown benthos develops, individuals avoid the overgrowth areas and abalone density declines (Strain and Johnson 2012).

KEY POINTS:

- Wide distribution as a complex meta-population across southern Australia from WA to NSW;
- Positive feedback between abalone population and their preferred habitat, i.e. encrusting coralline algae. Depletion of abalone population facilitates overgrowth of coralline algae by brown filamentous algae, on which abalone population declines.

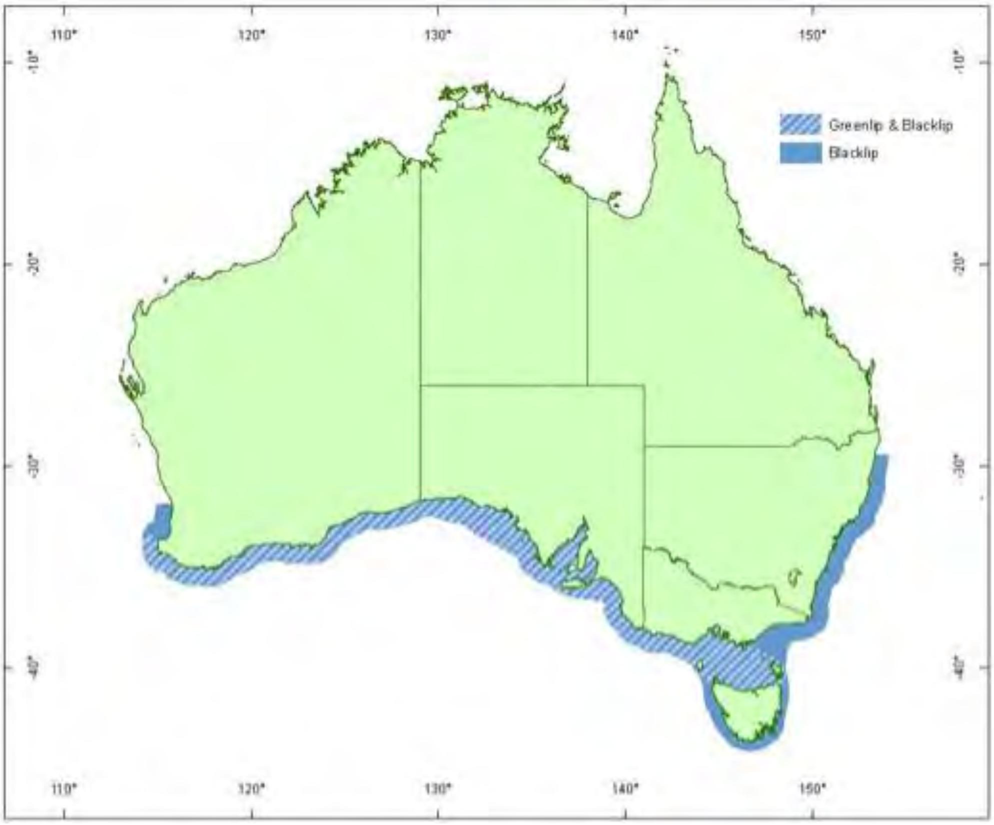

Figure 2. Distribution of blacklip and greenlip abalone.

1.4 ECOSYSTEM CONTEXT: PREY, PREDATORS, COMPETITORS AND DISEASE

Abalone predominantly trap drift algae, but also actively graze on a range of red and brown algae, detritus, bacteria and diatoms (Guest, Nichols et al 2008). Note that southern Tasmania, the most productive region for BA fishery, is characterised by high primary productivity due to the influence of nutrient rich southern ocean waters mixing with warmer nutrient poor EAC waters. This mixing zone, the sub-tropical front, is predicted to move further south as the influence of the EAC progresses southwards. Understanding the linkages between these nutrient rich waters, primary production (benthic algae), abalone diet and population productivity will assist in the longer-term prediction of future harvests.

Abalone are preyed upon by a variety of predators including whelks, crabs, octopus and wrasse at juvenile, cryptic stages, and larger fish, octopus, rock lobster, stingrays, Port Jackson sharks, and starfish at emergent, adult stages. Predator interactions may be strengthened with increasing range expansions of warm affinity species (Rogers-Bennett, Allen et al 2011). It is also possible that competition with other species moving polewards may limit abalone in the future. For instance, the southward incursion of the urchin *C. rodgersii* from NSW and Victoria and its successful establishment in Tasmanian waters is considered the result of larval transport with the extending southern incursions of the East Australian Current (EAC) (Ling, Johnson et al 2009). Once established, *C. rodgersii* denudes coastal reefs by overgrazing important habitat-forming seaweeds and invertebrate fauna and forming persistent barrens (Ling 2008). These barrens are likely to impact reef species through habitat reduction, including BA, and have the potential to increase as a function of a southern range expansion of the urchin. Before barren form, negative relationships between densities of *C. rodgersii* and *H. rubra* in Tasmania. Experiments indicate that increased densities of the urchin caused an increase in abalone mortality rates indicating that it is a superior grazing competitor (generalised verses specialised herbivore) (Strain and Johnson 2009).

Increasing temperature stress is likely to increase the prevalence of diseases in wild abalone populations, in particular perkinsosis (caused by the parasite *Perkinsus olseni*), which can cause mortality and population diebacks in SA and NSW (Goggin and Lester 1995) and the lethal abalone ganglioneuritis virus (AVG) in Victoria and around Bass Strait.

KEY POINTS:

- Lack of predictability of current-driven changes in primary productivity and their subsequent effects on abalone diet and productivity;
- Southward range expansion to eastern Tasmania of the barren-forming sea urchin *C. rodgersii* will impact BA habitat and the urchin outcompetes BA for food resources;
- Temperature may increase abalone vulnerability to diseases (e.g. perkinsosis and AVG).

1.5 VULNERABILITY AND RESILIENCE OF BA AND GA TO KNOWN CLIMATE CHANGE DRIVERS

SOURCES OF VULNERABILITY:

- Polewards contraction of BA distribution;
- Increased exposure to other southwards migrating species in Tasmania (e.g. loss of seaweed bed habitat due to destructive grazing by the invasive long-spined sea urchin and increased competition with the sea urchin);
- Population genetics suggest highly significant sub-division in BA population structure at scales of tens of kilometres. Low population connectivity (low dispersal potential) implies slow recovery from local depletions;
- Abalone have poor tolerance to temperature change and sub-populations may locally suffer high temperature stress and disease outbreaks

- Increase in temperature may reduce growth rate and maximum size;
- Intensification of the southwards incursions of the EAC to eastern Tasmania will affect local environmental conditions (e.g. temperature, nutrient content) and is likely to locally reduce the productivity of BA population in highly productive reefs (e.g. Actaeons) in southern Tasmania.

SOURCES OF RESILIENCE:

- Southwards expansion of GA distribution;
- Abalone, BA in particular, are distributed across a broad latitudinal and longitudinal range from northern NSW to southern Tasmania, and from the east coast to southern WA;
- Abalone population is structured across its range as a complex of meta-populations, i.e. a network of heterogeneous sub-populations (at scales of tens of kilometers) with high genetic and physiological diversity and a range of traits, which can facilitate population adaptation to environmental changes.
- Temperatures within their distribution range from 9–11°C in Tasmania (minimum winter values) to 23–25°C in NSW (maximum summer values). This suggests that across all sub-populations, abalone, both GA and BA, are adapted to a relatively wide thermal range.

ADDITIONAL STRESSORS

Both GA and BA are moderately to fully exploited across south east Australia and due to small-scale spatial heterogeneity in abalone density, productivity and fishing effort, and abalone harvesting has a range of impacts on reefs. The Tasmanian abalone populations are intensively fished and problems can arise when fishing pressure is sufficient to locally prevent the development of aggregations and rebuilding of the stock (Tarbath and Gardner 2009). Managing this spatial heterogeneity in abalone population is a current challenge facing the fishery. Resilience to fishing pressure also varies between BA populations, with some populations failing to recover after a short period of fishing compared to others, which have sustained fishing for over 20 years (Nash, Sanderson et al 1995). Depletion of abalone by fishing can locally lead to a change in benthic algal assemblage from coralline-dominated algae to a brown benthos of filamentous algae, which is detrimental to abalone population (Strain and Johnson In press). Moreover, in eastern Tasmania, harvesting of Southern Rock Lobster (SRL) can indirectly lead to loss of habitat for BA as critical biomass density of large SRL is necessary to prevent the risk of further formation of sea urchin barrens by the invasive *Centrostephanus* (Ling, Johnson et al 2009; Johnson, Banks et al 2011).
Table 1. Summary table of the expected effects of environmental changes in south east Australia on BA and GA biology: recruitment, physiology, habitat / distribution range and trophic context.

	Recruitment	Physiology	Habitat Species distribution	Ecosystem context
Trends & Expected Changes	Localised recruitment failures in depleted population;	Potential for reduced growth and maximum size with increasing temperature (optimal temperature ~ 17-18°C); Low tolerance to high temperature stress;	Loss of seaweed bed habitat in Tasmania due to temperature increase and sea urchin destructive grazing;	Increased exposure to pathogens with raising temperature; Southward range expansion of the barren-forming *C. rodgersii* to eastern Tas. induce habitat loss for BA and increased competition; Invasive species (algae & mussels) are threatening abalone habitat in NSW
Gaps of knowledge Uncertainty	Effects of environmental conditions on recruitment success; Effects of change in pH on larvae;	• Lack of fine-scale monitoring and predictability of physiological changes; • Unknown effects of change in pH and UV exposure;	• Little information available about actual changes in distribution range;	• Lack of monitoring and low predictability of these ecosystem changes; • Effects of large-scale oceanographic features on primary productivity, abalone diet and productivity;
Vulnerability	Low population connectivity; Highly variable recruitment at small spatial scales; • Local depletion in GA and BA sub-population can be hard to reverse; • Temperature as an	• Patchiness / spatial discrepancies in changes to BA and GA physiology hard to account for by management; • Reduced growth and maximum size with temperature;	• Contraction of BA distribution range; • High dependency on pink coralline algae as a source of food and habitat; • In Tas., depletion of BA by fishing facilitate the overgrowth of coralline algae by	• Changes in ecosystem structure with range extension (Habitat loss; increased predation pressure; competition for resources);

	important cue for spawning and larval development;		filamentous algae;	
Resilience (adaptability)	Highly diverse sub-populations with different features at small spatial scale;	• Genetic diversity across all sub-populations of abalone across south east Australia;	• Resilience to change of habitat (successful translocation of adult to enhance recruitment); • Expansion of GA distribution; • Large distribution range around southern Australia;	

2. DESCRIPTION OF THE FISHERY

2.1 THE COMMERCIAL FISHERY

Abalone is commercially harvested in New South Wales (NSW), South Australia (SA), Tasmania (TAS), Victoria (VIC) and Western Australia (WA), and it is the second most valuable wild fisheries product in Australia after rock lobster. Two most commercially important species are blacklip abalone (*Haliotis rubra*) and greenlip abalone (*H. laevigata*), which dominate the catches, accounting for 82%, and 15% of wild abalone production in Australia, respectively. Blacklip abalone are harvested commercially across the all four south-eastern states (NSW, VIC, TAS, and SA), while greenlip abalone are harvested in VIC, TAS, SA and WA.

TOTAL ALLOWABLE COMMERCIAL CATCH (TACC) AND ANNUAL CAPTURE PRODUCTION

Total abalone capture production in Australia in 2009/2010 was 4,981 tonnes, of which 94.6 % was produced in south east Australian fisheries. The largest fishery is in Tasmania (52% of total catches in 2009/10), followed by South Australia, Victoria and NSW.

Commercial abalone fisheries in all four south east states are subject to restrictions on total allowable commercial catch (TACC). In Tasmania, total of 2,659.5 tonnes of abalone were landed in 2010, which was almost the entire TACC (2,660t) and comprised 2526.8 tonnes of blacklip and 132.7 tonnes of greenlip abalone (Gardner et al 2011). While the total annual catch of abalone in South Australia, and Tasmania has remained relatively stable since the early 1990s, the NSW abalone fishery saw a large decline in both TACC and catches over the same period. The annual landings of blacklip abalone in NSW peaked 1,200 tonnes in early 1970s, but the TACC has reduced to just over 300 tonnes in 2000, and the minimum landing size has been increased in several instruments. However, the following 5 years (2000-2005) the catch rates declined markedly across the fishery to historical lows due to a combination of fishing pressure and mortalities from a protistan parasite (*Perkinsus* sp.). This resulted in a series of significant reduction of TACC in NSW, and the most recent catch (2009/10) was just over 73 tonnes. An outbreak of Abalone Virus Ganglioneuritis (AVG) in Victoria in 2006 has caused up to 50% mortality rate in both land and sea based farming and substantial impacts on the health of the wild stock.

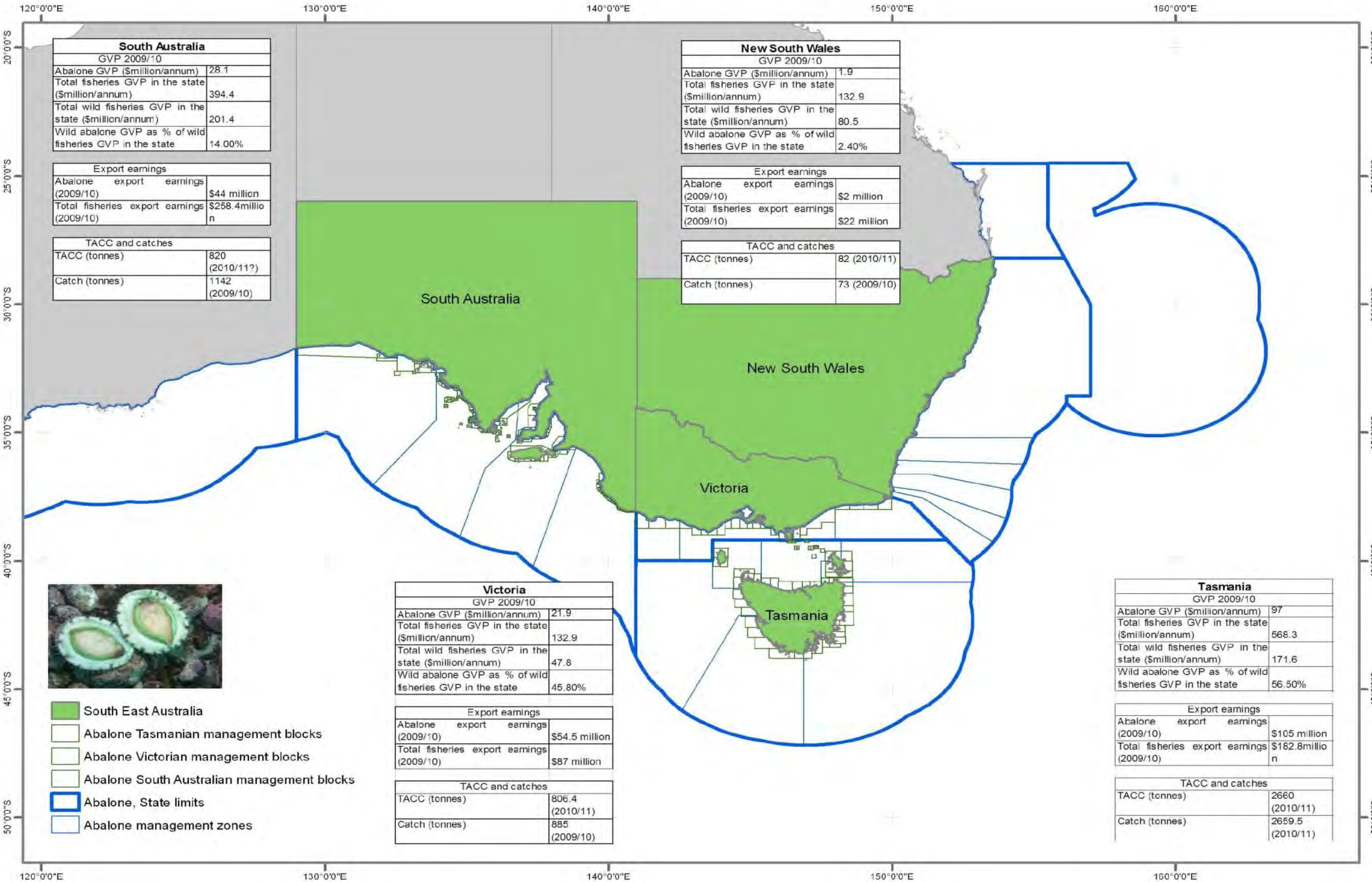

Figure 3. Locations of the abalone fisheries

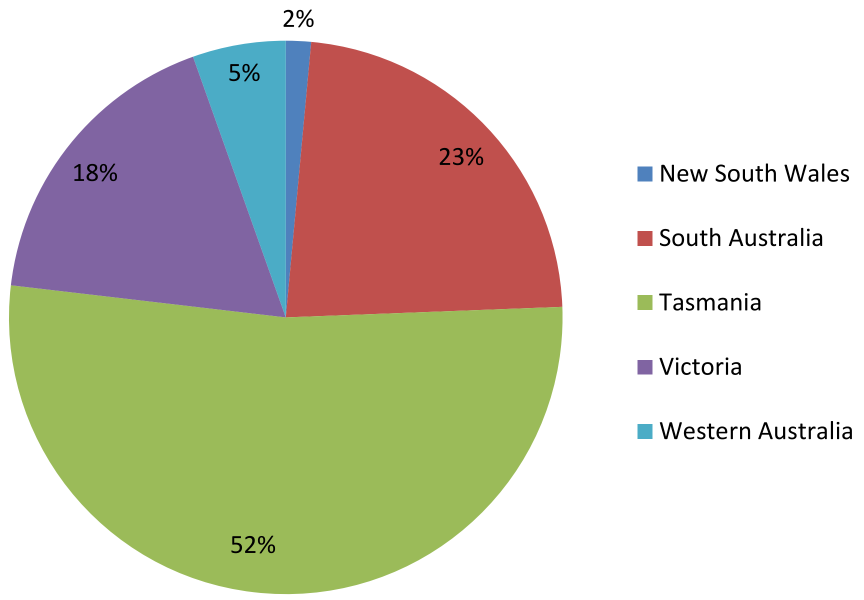

Figure 4. South east states share of the abalone production (2009/10)

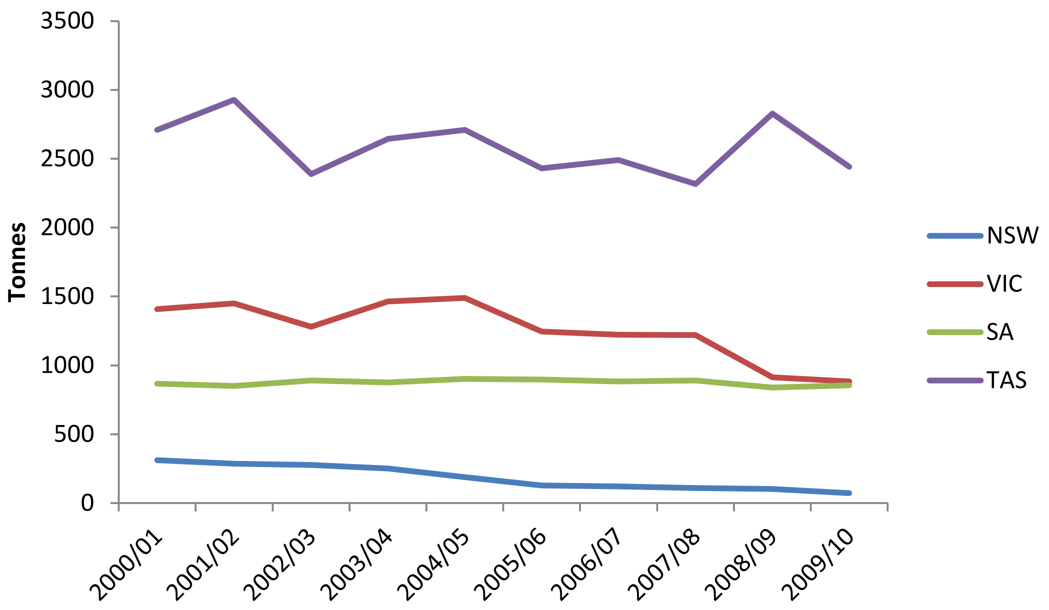

Figure 5. Abalone capture production by state (tonnes/year).

AQUACULTURE PRODUCTION

While the majority of abalone comes from wild catch, there has been a growing trend in the aquaculture production. The abalone aquaculture sector has grown by 20 per cent over the past five years (ABARES 2011b). Abalone accounted for a large proportion of Victorian aquaculture production in value terms over the last five years (ABARES 2011b), reaching to 179 tonnes or 16% of total abalone production in VIC in 2008/9 season, although the latest figure is not publicly available due to policy requirement to protect commercial confidentiality of data. The culture of greenlip abalone has been developing in South Australia since the early 1990's and is now recognised as a significant contributor to the State's aquaculture industry and aquaculture now represents approximately 25% of total abalone production within the state.

ILLEGAL CATCH

The valuable nature of the product has encouraged resource theft and currently the apparent high level of illegal (both greater than the bag limit and abalone smaller than the minimum legal size) and unreported harvest, and difficulties in combating this, are regarded as a major problem within this industry. The most recent estimate indicates that about 1,000 tonnes of abalone was harvested illegally in Australia in 2007 (Fishtech, CA).

MANAGEMENT

Zones are the established method of managing the abalone fisheries in the most of south-eastern states. The use of zones was first introduced into the Tasmanian fishery in 2000 to manage the spatial distribution of catch. Since 2003, the Tasmanian blacklip fishery has been divided into four zones: Eastern, Western, Northern and Bass Strait. A fifth zone (Central West) was introduced in 2009. The greenlip fishery is restricted to the north of the state, and the spatial distribution of its catch is managed by regions. In South Australia, the abalone fishery is divided into three geographical zones (Western, Central and Southern zones). Similarly, Victorian abalone fishery is managed by three zones (Eastern, Central and Western).

TACC and the minimum legal size limit are generally set by zone to account for differences in growth rates and the maximum size among populations. In Tasmania, minimum legal size limit was introduced in the early 1960s, but rapid expansion of the fishery in 1960s has lead an introduction of commercial abalone license in 1969, and subsequent introduction of an individual transferable quota (ITC) and TACC in 1985. Initially, each licensed divers were allocated 20-28 quota units, but in 1994 quota owners were given the choice of continuing with their annual abalone licenses or entering into a Deed of Agreement that applied for 10 years with the right of renewal for perpetuity. 90% of quota owners in Tasmania chose the Deed of Agreement.

There are 71 fishery access licenses (AFAL) in the Victorian abalone fishery, which is subdivided into three management zones. TACC is distributed among those license holders in each zone. AFAL operates as a conduit between quota holders and nominated divers. Units must be attached to an AFAL and divers must be nominated on an AFAL, at only one at any given time. Some divers harvest abalone on behalf of more than one license holder and some holders own more than one license. License ownership may be by individuals or businesses and units of quota may be temporarily transferred among license holders for the duration of a quota year.

The commercial abalone fisheries in South Australia was initially managed by a limited entry in the form of license, but concerns that the abalone resource may be over-exploited has lead an introduction of quotas in the western zone in 1985, and quotas were subsequently introduced into the southern and central zones and this quota management systems remain in place today. License is zone specific, and quota is transferable among licence holders each year but within a zone.

Table 2. Summary of rules for the commercial abalone fisheries

	TAS	NSW	SA	VIC
Management zone	5 zones for BL, 1 zone for GL	Managed as a single zone (Check)	3 zones	3 zones
Limited entry	125 licenses for divers	37 shareholders	36 licenses	71 access licenses
Limited seasons	Closed seasons vary depending on the zones		?	
Quota	TACC of 2,660 t (2010/11) GL: Eastern 896 t Western 924 t Central 304.5 t Northern 332.5 t Bass Strait 70 GL: 133 t	TACC of 82t (2010/11)	TACC of 820t (2009/10) Southern: 144t BL, 6t GL Central: Northern:	Eastern 432t BL Central 328.3t BL, 3.4 t GL Western 27.3 BL, 15.4t GL
Minimum size limits	Eastern 138 mm, Western 140mm, Central 132-140mm Northern 127mm Bass Strait 114mm Greenlip 132-150mm	117mm	Southern: 125mm for BL, 130mm for GL Central: 130mm Western: 130mm for BL, 145mm for GL	Western 145mm Rest 130mm

MARKET AND PROCESSING

A large proportion of abalone is exported, mostly to Hong Kong (China), Japan, Singapore and Taiwan. High quality abalone are typically being shipped live, while lower quality abalone (e.g. damaged shell) are processed (frozen, canned, dried etc.) locally and exported. The demand in the Chinese live abalone market has seen an increasing portion of the catch going to China as the end destination point.

Traditionally, abalone were detached from the shell then canned or individually quick-frozen. Over the last decade, however, the export market for live abalone has expanded rapidly and now predominates. In Victoria, 65 per cent of the catch was sold live (1581t); 4.5 per cent (109t) was frozen; 30 per cent canned (729t); and 0.5 per cent (12t) dried in 2007. In Tasmania, roughly 70-75% of abalone are shipped live, and rest are processed. In South Australia on the contrary, limited quantity of abalone is exported live, and almost all greenlip is frozen, while almost all blacklip is canned.

2.2 THE RECREATIONAL FISHERY

Abalone fishing is a popular recreational activity in all south east states. In Tasmania, the number of recreational abalone dive licenses has tripled since the introduction of the recreational licensing system in 1995 to almost 13,000 persons licensed to fish abalone in 2007, but since then has slowly declined (Lyle et al 2010). The most recent survey of recreational divers estimated the recreational catch at 39 tonnes (2008/9), over half which was taken in the east and south east coast. This figure did not include abalone taken as part of cultural fishing activities by indigenous people, or under permit for special events and research purposes, or through illegal fishing. There was no estimate for the illegal catch.

In South Australia, the recreational catch in 2007/08 was reduced by 78% from 26,000 abalone in 2002 to over 6,500 abalone (Jones 2009). Greenlip abalone were solely harvested by diving, whereas blacklip abalone were harvested by hand gathering from sub-tidal reefs and by diving. Divers either operated from boats or the shore to harvest both species. In NSW, a recreational fishing license is needed for all recreational fishing activities. The annual recreational harvest of abalone in NSW is likely to be less than 20 tonnes. Recreational harvest is believed to have declined following the reduction in the bag limit from 10 to 2. There is no reliable information on the recreational catch in Victoria.

The recreational fisheries in south east states are subject to the same size limitation applied to commercial fisheries, in addition to recreational license requirement, closed season/area and daily bag limit.

Table 3. Summary of rules for the recreational abalone fishery

	TAS	NSW	SA	VIC
License requirements	Yes	Yes		Yes
Daily limit	10 bag limit, 20 possession limit.	2 bag limit	Daily boat limit of 10 abalone.	2 bag limit
Limited seasons	Area restrictions.	Abalone can only be taken between Port Stephens and Wreck Bay Beach on weekends and public holidays	Area closure.	Permanent closed season for central Victorian waters, except for 60 nominated open days of the year
Minimum size limits	127-145mm depending on the location and species.	117mm	145mm for GL in the Western Zone, 130mm for the rest.	100-130mm depending on the location and species.

3. SOCIO-ECONOMIC VALUES

3.1 GROSS VALUE OF PRODUCTION (GVP)

The combined GVP of abalone capture production in Australia was $ 158.1 million in 2009/10, of which 95% ($148.9 million) was originated from south east fisheries. Abalone is the most valuable wild fisheries in Tasmania and Victoria, accounting for, respectively approximately 57% and 46% of wild fisheries GVP. Figure 6 shows real GVP of wild abalone by south east states during the period of 2000/01-2009/10. Real GVP has declined in all south east states since 2000/01 season due to falling unit prices and declined capture production in some states.

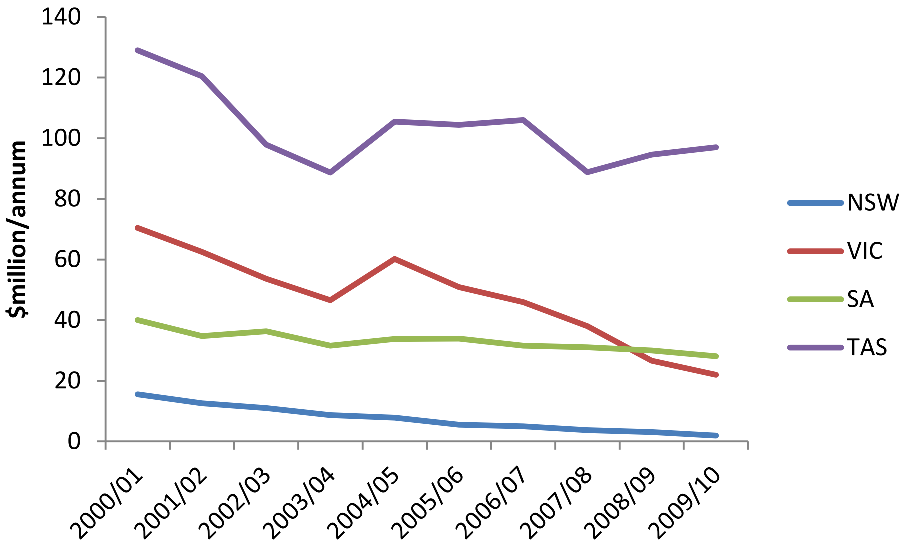

Figure 6. Real gross value of production of wild abalone by states

3.2 BEACH PRICES

Because the majority of Australian abalone enters into the international market, the beach prices of Australian abalone are highly influenced by the international demand and exchange rate movements. The rapid increase in the global production of farmed abalone is an issue of concern for the Australian abalone industry, as it may pose negative pressures on beach prices. In addition, the recent global financial crisis (GFC) has depressed demand for high-valued fisheries products, and the world abalone market has been particularly hard hit by it, with depressed abalone prices (Cook and Gordon 2010). The average beach price of Australian abalone fell by 44% in real term during 2000/01-2009/10 (ABARE 2011a). In South Australia, the average beach prices in 2009/10 has fallen 46 % in real term (or 29% in nominal) to $32/kg since the price peak in 2000/10. Similarly in Tasmania, the monthly average beach price was down from $53/kg in 2000 to less than $40/kg for greenlip, and less than $33/kg for blacklip in early 2011.

There is also a substantial variability in beach prices of abalone across the states, locations within the state, and species. For example in Tasmania, beach prices of blacklip abalone in the Bass Strait and Northern Zone are substantially lower than those in other zones due to difference in quality of abalone.

3.3 EXPORT EARNINGS

Abalone is the 3rd most valuable export seafood products in Australia, with a total value in 2009/10 of $216 million dollars (ABARES 2011a). About $205 million or 95% of this total value is originating from the south east Australian fisheries. Compared with the previous year (2008/09), the total value of rock lobster exported from the region declined by about 5% or $10 million, despite the 8% increase in quantity of abalone export from the region. This is driven by the lower beach prices and strong Australian dollar.

3.4 DOWNSTREAM AND FLOW-ON VALUES

The economic importance of the SRL fisheries may be understated when considering only the direct values obtained through the general methods of national statistics, such as GVP. South Australia is currently the only state in south east who regularly quantifies the economic values of downstream activities (e.g. processing, retails, restaurants etc.) supported by the SRL fishery as well as multiplier effects that flow on other sectors (e.g. transport) of the state economy. In 2009/10, output generated downstream activities was estimated to be $16.2 million, and additional $45.1 million output from flow-on effects to other sectors (EconSearch 2011).

3.5 ECONOMIC RETURNS TO CAPITAL INVESTMENT, ECONOMIC PROFIT

There is limited information on economic returns to capital investment for Australian fisheries. South Australia is the only state which has been systematically collecting economic information of abalone operators for a decade, although studies are underway to collect key economic information for the abalone fisheries in Tasmania and Victoria.

In South Australia, the return on investment is calculated as the profit at full equity (business profit per boat plus interest) as a percentage of the total capital employed (including boats, licence/quota, fishing gear, sheds, vehicles and other capital items used as part of the fishing enterprise). While the rate of return to boat capital, i.e. fishing gear and equipment, is high (122.5 % in 2009/10), the rate of return to total capital was estimated be 4.7%, slightly down on the estimates for 2007/08 (5.1%) and 2008/09 (5.2%). The estimated rate of return on investment for the fishery has declined significantly since 2000/01 as a result of a decrease in profitability in the fishery and a significant increase in the estimated value of fishing licences.

The information on economic profit, here defined as the difference between the price of a good produced and the cost of producing that good, is also sparse for Australian fisheries. Available published information in SA suggests that the abalone fishery in SA has been generating positive economic profit ($11.4 million in 2009/10). However, the economic profit in nominal terms in 2009/10 was well below that estimated in the first year of the series ($13.5 million in 1997/98) and less than half the peak year estimate of $23.1 million in 2000/01.

3.6 EMPLOYMENT

The Australian Bureau of Statistics (ABS) Census Survey provides estimates of employment in the commercial fishing, hunting and trapping industry. In 2009–10, a total of 11,431 people were employed in the commercial fishing, hunting and trapping industry in Australia, with 7,646 employed in the fishing, hunting and trapping sector, and 3,785 in aquaculture enterprises. The ABS data does not have detailed employment figure for abalone industry, but available information from various source suggest that at least around 400 people are employed directly in the catching sub-sector alone. If we include employment in related sub-sectors (processing, fish retails etc.) or outside the fisheries sector, this number will be much higher

Table 4. Employment in the abalone fisheries sectors

2009/10	TAS	NSW	SA	VIC
Fishing (divers, deckhands, skipper)	122 registered (2009), 112 active (as of Mar 2011)	117 including 33 divers, 37 deckhands, 47 shareholders (2003)	90	71 divers
Processing		106 (2003)	36	
Service, transport etc.			2	
Others-direct			3	835 full-time equivalent jobs(2000/01)
Others-indirect		111 (2003)	103	

3.7 GOVERNMENT FEES, ROYALTY

Commercial fisheries provide significant government revenues to cover the cost of management or research in the forms of license fees, or loyalty. South Australian commercial fisheries operate under full cost recovery. Accordingly, license fees are set to cover the cost of managing the fishery. In 2009/10 the revenue from the license fees represents about 9% of the fisheries GVP or $2.5 million. Similarly, under the NSW Government's policy on cost recovery, abalone shareholders are required to pay the attributable costs of managing the fishery and to make a community contribution for exploiting the resource (NSW DPI 2007). The community contribution charge is calculated as a percentage of gross revenue per share. The percentage varies on a sliding scale in accordance with a CPI adjusted average annual beach price (AABP), wherein:

- if the AABP is below $43/kg the percentage rate will be 0% (i.e. no charge will be payable);
- for an AABP between $43 and $52/kg the rate will increase by 0.5% per dollar to 5% of the revenue at $52;
- for beach prices from $52 to $62 the rate will increase by 1% per dollar to 15% of revenue at $62; and
- above $62/kg the rate will remain at 15%.

In Tasmania, the Deed of Agreement set a fee structure that included both management costs and return to the community, based upon an increasing (but non-linear) proportion of beach price. At $6/kg, no fees were payable, at $35/kg fees were 10% at and at $200/kg, fees were 33% of beach price. Royalties collected by the

Tasmanian government in 2010 was $7.2 million. The abalone industry in Victoria pays 100 % of the Fisheries Departments attributable costs for managing the fishery, as well as a royalty payment back to the community. The royalty payment is paid as a percentage of GVP on each kilogram harvested by the industry. The royalty payment over the last 10 years is estimated to be over $25 million (Victorian Abalone Diver's Association website).

3.8 OTHER SOCIAL VALUES

Fisheries provide important social values (spiritual, cultural, tradition, subsistence consumption etc.) to the local communities and indigenous people, but such values are often difficult to quantify and information is therefore limited. To date, no formal studies or surveys have been conducted in relation to the social values of abalone fisheries in south east states, but available information suggests that abalone is highly valued source of food for indigenous families in NSW and Victoria. In NSW there is provision for indigenous groups to request from Department of Primary Industry (DPI) a permit to collect abalone for special cultural events, and the size of the harvest being determined on a case by case basis (NSW DPI 2005).

3.9 RECREATIONAL VALUES

Based on the available estimates of recreational catches in the three south east states, the conservative estimate of the value of harvest is over $1.7 million (assuming $33/kg beach price, 51t). This does not include the other economic activities supported by the recreational abalone fishing, such as travel expenditure (fuel, boat hiring, fishing equipment, accommodation etc.), drink & food, or non-monetary values to the recreational fishers (e.g. enjoyment). Most recent recreational fishing survey in NSW found that the recreational fishers in NSW (including fishing for abalone, prawn, squid, rock lobster and crab) spent more than $550 million on fishing related items during the survey year. According to the National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003), Australian recreational fishers spent on average $552 per fisher per annum between May 2000 and April 2001, with the highest average expenditure by residents of Victoria ($721) followed by NSW ($555) within the south east states. Residents in South Australia, and Tasmania spent $452, $416 per fisher per annum, respectively. The combined expenditure in the four south east was $1.1 billion per annum.

Table 5. Recreational harvest, value and the number of abalone license holders.

	TAS	NSW	SA	VIC
Abalone harvest (tonnes)	39 t (2008/09)	Less than 20t	2.3t (2007/09)	n/a
Value of harvest ($) (market price*harvest)	$1.2m	$0.5m	$0.1m<	
Number of recreational license holders	11,914 (2010/11)		Catch cap (<1% of TAC) introduced in 2009	

KEY STRESSORS:

- Susceptible to Abalone Virus Ganglioneuritis (AVG) and other diseases & parasites;
- Export-oriented, thus vulnerable to external economic shocks ;
- Competition with aquaculture;
- Illegal fishing.

REFERENCES

ABARES (2011a). Australian Fisheries Statistics 2010. Australian Bureau of Agricultural & Resource Economics & Science (ABARES)

ABARES (2011b). Outlook. Australian fisheries - outlook & economic indicators. Australian Bureau of Agricultural & Resource Economics & Science (ABARES)

Babcock, R. & Keesing, J. (1999). Fertilization biology of the abalone *Haliotis laevigata*: laboratory & field studies. *Canadian Journal of Fisheries & Aquatic Sciences* 1668–1678.

Cook, P.A. & Gordon, H.R. (2010). World Abalone Supply, Markets, and Pricing. *Journal of Shellfish Research* 29, 569-571.

Dowling, N., Hall, S. & McGarvey, R. (2004). Assessing population sustainability & response to fishing in terms of aggregation structure for greenlip abalone (*Haliotis laevigata*) fishery management. *Canadian Journal of Fisheries & Aquatic Sciences* 247-259.

EconSearch (2011). Economic indicators for the SA Abalone Fishery 2009/10

Fishtech (2007). Online resource available at: [http://www.worldwildlife.org/what/globalmarkets/aquaculture/WWFBinaryitem11677.pdf]

Gardner, C. Hartmann, K. & Hobday ,D. (2011). Fishery Assessment Report: Tasmanian Rock Lobster Fishery 2009/10. Hobart: Tasmanian Aquaculture and Fisheries Institute.

Gilroy, A. & Edwards, S. (1998). Optimum temperature for growth of Australian abalone: preferred temperature & critical thermal maximum for blacklip abalone, *Haliotis rubra* (Leach), & greenlip abalone, *Haliotis laevigata* (Leach). *Aquaculture Research* 481-485.

Goggin, C.L. & Lester, R.J.G. (1995). *Perkinsus*, a prostitan parasite of abalone in Australia - a review. *Marine & Freshwater Research* 46, 639-646.

Grubert, M.A., Mundy, C.N. & Ritar, A.J. (2005). The effects of sperm density & gamete contact time on the fertilization success of blacklip (*Haliotis rubra*; Leach, 1814) & greenlip (*H-laevigata*; Donovan, 1808) abalone. *Journal of Shellfish Research* 24, 407-413.

Guest, M.A., Nichols, P.D., Frusher, S.D. & Hirst, A.J. (2008). Evidence of abalone (*Haliotis rubra*) diet from combined fatty acid & stable isotope analyses. *Marine Biology* 153, 579-588.

Henry, H & Lyle, J.M. (2003). The National Recreational & Indigenous Fishing Survey. Report of FRDC Project No. 99/158, Department of Agriculture, Fisheries & Forestry, Canberra.

Huggett, M., De Nys, R., Williamson, J., Heasman, M. & Steinberg, P. (2005). Settlement of larval blacklip abalone, *Haliotis rubra*, in response to green & red macroalgae. *Marine Biology* 1155-1163.

Hutchinson, N., Gavine, F., Morris, E. & Longmore, A., (2010). Adaptation of Fisheries & Fisheries Management to Climate Change: Marine, estuarine & freshwater biophysical risk assessment, Department of Primary Industries, Queenscliff, Victoria, Australia.

James, E. (1981). Clinal variation in the maximum size of Tasmanian populations of the abalone, *Haliotis ruber*, as a function of water temperature, University of Tasmania, Hobart.

Johnson, C.R., Banks, S.C., Barrett, N.S., Cazassus, F., Dunstan, P.K., Edgar, G.J., Frusher, S.D., Gardner, C., Haddon, M., Helidoniotis, F., Hill, K.L., Holbrook, N.J., Hosie, G.W., Last, P.R., Ling, S.D., Melbourne-Thomas, J., Miller, K., Pecl, G.T., Richardson, A.J., Ridgway, K.R., Rintoul, S.R., Ritz, D.A., Ross, D.J., Sanderson, J.C., Shepherd, S.A., Slotvvinski, A., Swadling, K.M. & Taw, N. (2011). Climate change cascades: Shifts in oceanography, species' ranges & subtidal marine community dynamics in eastern Tasmania. *Journal of Experimental Marine Biology & Ecology* 400, 17-32.

Jones, K.. (2009). South Australian recreational fishing survey. South Australian fisheries management series, paper no.54. Adelaide: PIRSA Fisheries

Kailola, P., Williams, M., Stewart, P., Reichelt, R., McNee, A. & Grieve, C. (1993). Australian Fisheries Resources, Bureau of Resource Sciences & Fisheries Research & Development Corporation, Canberra.

Keesing, J., Grove-Jones, R. & Tagg, P. (1995). Measuring settlement intensity of abalone: results of a pilot study. *Marine & Freshwater Research* 539-543.

Ling, S.D. (2008). Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new & impoverished reef state. *Oecologia* 156, 883-894.

Ling, S.D., Johnson, C.R., Frusher, S.D. & Ridgway, K.R. (2009a). Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proceedings of the National Academy of Sciences of the United States of America 106, 22341-22345.

Ling, S.D., Johnson, C.R., Ridgway, K., Hobday, A.J. & Haddon, M., (2009b). Climate-driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. *Global Change Biology*, 15, 719-731.

Lyle, J.M. & Tracey, S.R. (2010). Tasmanian Recreational Rock Lobster and Abalone Fisheries: 2008-09 Fishing Season. TAFI Report, Tasmanian Aquaculture and Fisheries Institute, Hobart.

McShane, P.E. (1995). Recruitment variation in abalone - its importance to fisheries management. *Marine & Freshwater Research* 46, 555-570.

Miller, K.J., Maynard, B.T. & Mundy, C.N. (2009). Genetic diversity & gene flow in collapsed & healthy abalone fisheries. *Molecular Ecology* 18, 200-211.

Nash, W.J., Sanderson, J.C., Bridley, J., Dickson, S. & Hislop, B. (1995). Postlarval recruitment of blacklip abalone (*Haliotis rubra*) on artificial collectors in Southern Tasmania. *Marine & Freshwater Research* 46, 531-538.

NSW Department of Primary Industries (2005). Environmental Impact Statement prepared by: The Ecology Lab Pty Ltd. On behalf of NSW Department of Primary Industries and Shareholders of the NSW Commercial Abalone Fishery.

NSW Department of Primary Industries & The Ecology Lab Pty Ltd. (2007). Fishery Management Strategy for the NSW Abalone Fishery.

Onitsuka, T., Kawamura, T., Ohashi, S., Horii, T. & Watanabe, Y. (2007). Dietary value of benthic diatoms for post-larval abalone *Haliotis diversicolor* associated with feeding transitions. *Fisheries Science* 73, 295-302.

Prince, J., Peeters, H., Gorfine, H. & Day, R. (2008). The novel use of harvest policies & rapid visual assessment to manage spatially complex abalone resources (*Genus Haliotis*). *Fisheries Research* 94, 330-338.

Rogers-Bennett, L., Allen, B.L. & Rothaus, D.P. (2011). Status & habitat associations of the threatened northern abalone: importance of kelp & coralline algae. *Aquatic Conservation-Marine & Freshwater Ecosystems* 21, 573-581.

Shepherd, S. & Hearn, W. (1983). Studies on southern Australian abalone (genus *Haliotis*). IV. Growth of *H. laevigata* & *H. ruber*. *Australian Journal of Marine & Freshwater Research* 34, 461-475.

Sloan, N. & Breen, P. (1988). Northern abalone, *Haliotis kamtschatkana* in British Columbia: fisheries & synopsis of life history information. *Canadian Special Publication of Fisheries & Aquatic Sciences* 1-46.

Strain, E.M.A. & Johnson, C.R. (2009). Competition between an invasive urchin & commercially fished abalone: effect on body condition, reproduction & survivorship. *Marine Ecology-Progress Series* 377, 169-182.

Strain, E.M.A. & Johnson, C.R. (2010). Scale-dependent relationships between benthic habitat characteristics & abundances of blacklip abalone, *Haliotis rubra* (Leach). *Marine & Freshwater Research* 61, 1227-1236.

Strain, E.M.A. & Johnson, C.R. (2012). Intensive fishing of marine consumers causes a dramatic shift in the benthic habitat on temperate rocky reefs. *Marine Biology* 159, 533-547.

Strain, E.M.A. & Johnson, C.R. (In press). Intensive fishing of abalone causes a shift to benthic habitat types poorly preferred by abalone. *Ecology*.

Talmage, S. & Gobler, C. (2009). The effects of elevated carbon dioxide concentrations on the metamorphosis, size, & survival of larval hard clams (*Mercenaria mercenaria*), bay scallops (*Argopecten irradians*), & Eastern oysters (*Crassostrea virginica*). *Limnology & Oceanography* 2072–2080

Tarbath, D. & Gardner, C. (2009). Fishery Assessment Report: Tasmanian Abalone Fishery 2008, Tasmanian Aquaculture & Fisheries Institute, University of Tasmania.

Tarbath, D. & Officer, R.A. (2003). Size limits & the yield for blacklip abalone in northern Tasmania, Tasmanian Aquaculture & Fisheries Institute, University of Tasmania.

Temby, N., Miller, K. & Mundy, C. (2007). Evidence of genetic subdivision among populations of blacklip abalone (*Haliotis rubra* Leach) in Tasmania. *Marine & Freshwater Research* 58, 733-742.

Victorian Abalone Divers Association (2012). Online link available at: [http://www.vada.com.au/]

Williams, E.A., Craigie, A., Yeates, A. & Degnan, S.M. (2008). Articulated coralline algae of the genus *Amphiroa* are highly effective natural inducers of settlement in the tropical abalone *Haliotis asinina*. *Biological Bulletin* 215, 98-107.

3.2 Blue grenadier, *Macruronus novaezelandiaei*

1. ECOLOGY

1.1 REPRODUCTION, LARVAL DEVELOPMENT, SETTLEMENT AND RECRUITMENT

There is only limited information available about blue grenadier reproduction and larval phase. Adults migrate from throughout south east Australia to the spawning area off western Tasmania off Cape Sorell (Russel and Smith 2007). Female blue grenadier produce about 1 million eggs on average, possibly released in two to three batches during the spawning season, between late May and early September (Russel and Smith 2007). The eggs are pelagic and hatch 55–60 hours after fertilisation, releasing pelagic larvae. The duration of the pelagic phase is unknown but small pelagic juveniles have been caught along the shelf break off eastern Tasmania and in coastal bays (Russel and Smith 2007; Thresher et al 1989), which suggests a medium to high dispersal potential.

Recruitment variability seems to have a regular pattern with strong year classes recruiting every few years. However, the drivers for these strong recruitment years are unknown and there is only limited knowledge to determine how key climate change drivers can impact recruitment patterns and annual spawning migrations (Tuck 2009).

Onset of spawning appears to be driven by temperature, and so changes in coastal current patterns around Tasmania may impact timing of spawning (Thresher et al 1989; Gunn et al 1989).

KEY POINTS:

- One unique spawning ground off western Tasmania;
- Variable recruitment with successful annual recruitment events every few years;
- No information about pelagic larval life and unknown drivers of recruitment variability;
- Changes in temperature may impact timing of annual migration and the onset of spawning.

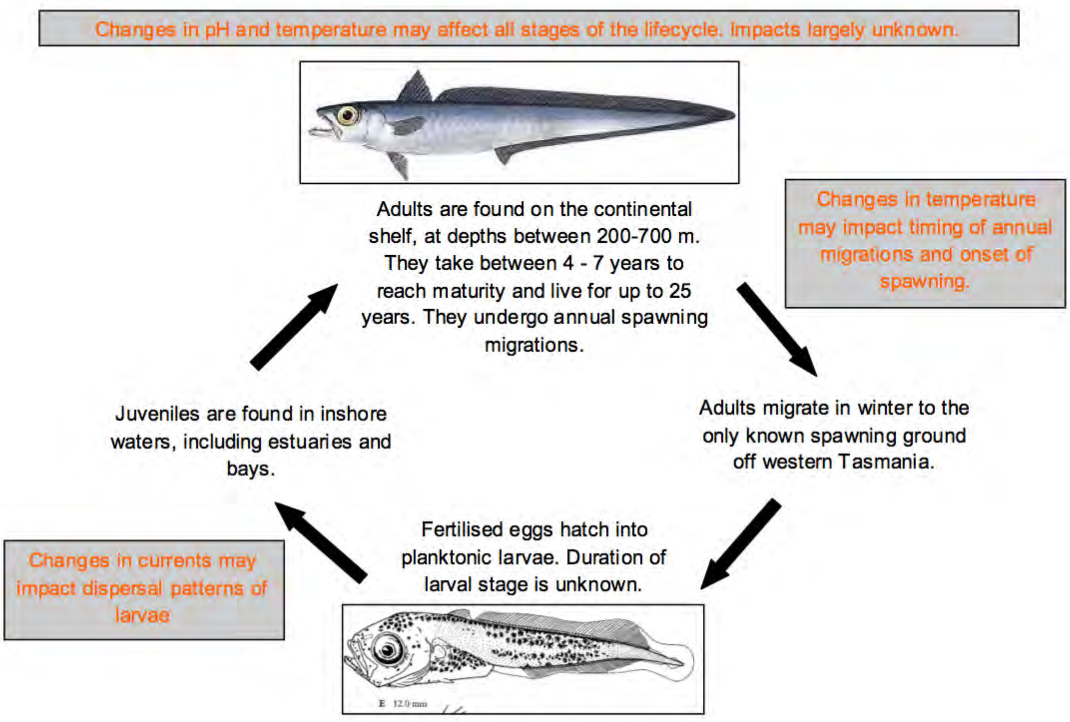

Figure 7. Summary of life cycle of blue grenadier and points of exposure to relevant climate change drivers or known impacts. Pictures from Neira et al 1998.

1.2 ADULT PHYSIOLOGY

Blue grenadier is a moderately long-lived species with a maximum age of about 25 years and an age at maturity of 4–5 years. Females mature at between 4 and 7 years of age and live up to 25 years, with a maximum size of around 110 cm (Kailola et al 1993). No specific information is available about the effects of environmental variables on the physiological traits of blue grenadier.

KEY POINTS:

- Long-lived species with slow population recovery rate;
- Unknown effects of temperature and pH on growth rate and size at maturity.

1.3 HABITAT AND SPECIES DISTRIBUTION

Blue grenadier is a demersal species, which is found on or near the bottom but occasionally move up into mid waters within a depth range of 0–1000 m. Blue grenadier are found in temperate southern waters (33–54°S) from NSW to southern WA, including around Tas. and New Zealand (Figure 4.2). There is a single breeding population in Australia (Kailola et al 1993).

The species inhabits both inshore and offshore waters, with juveniles found in estuaries and coastal bays, while adults live further offshore on the continental shelf mostly at depth of 400-700 m (Tuck 2009). Adult blue grenadier in Australia form dense schools on the seabed during the day, and disperse into the water column at dusk. They annually migrate from their feeding grounds in autumn to the primary spawning area off western Tasmania, and disperse again during spring (Gunn et al 1989).

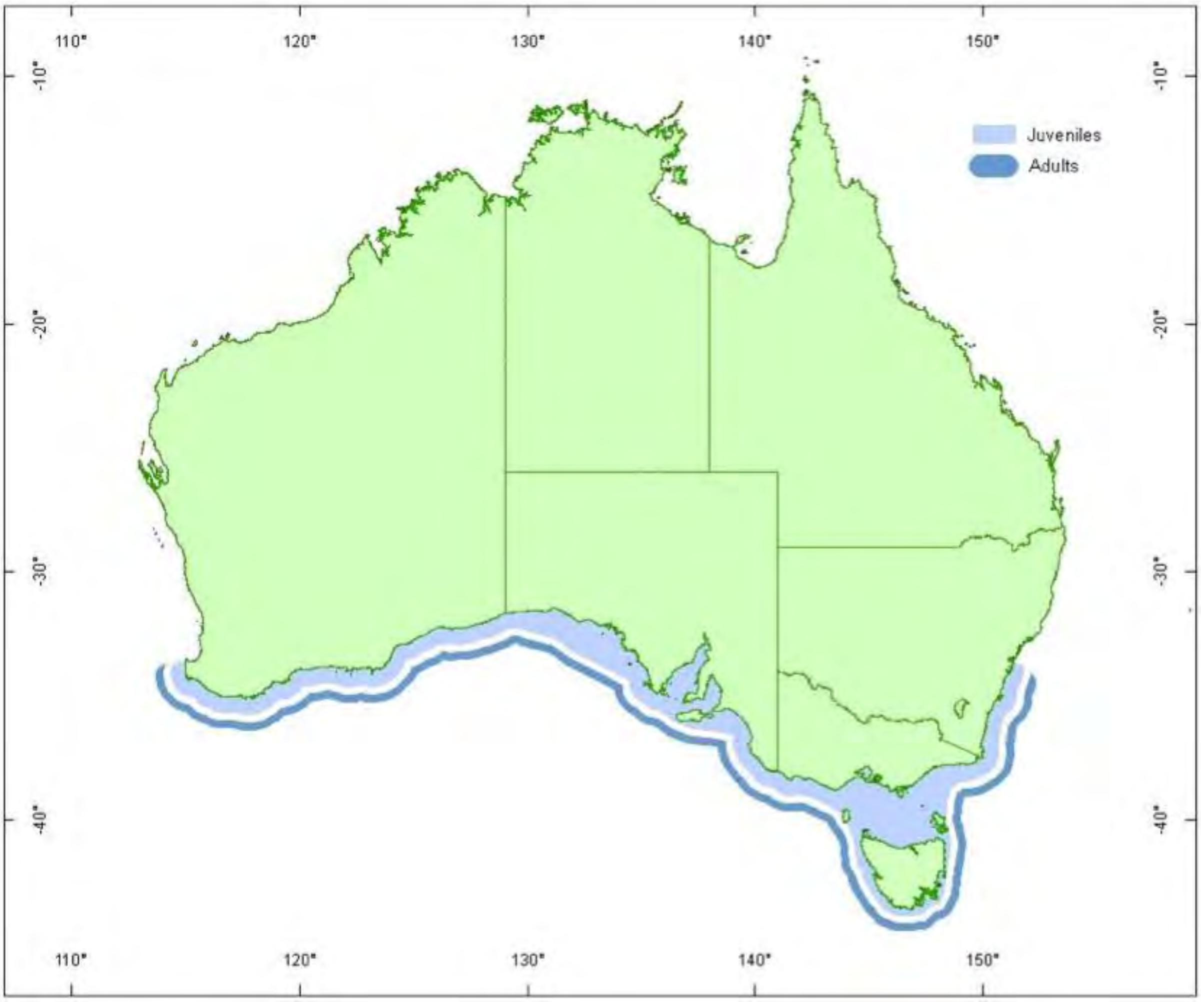

Figure 8. Distribution of blue grenadier around Australia.

KEY POINTS:

- Wide distribution range in southern Australia across different environmental conditions;
- Single breeding population across the distribution.

1.4 ECOSYSTEM CONTEXT: PREY, PREDATORS, COMPETITORS

There is little specific information available about blue grenadier diet, which includes fish, cephalopods and crustaceans (Tuck 2009). Thus, the species appears as a rather generalist predator. Predators of juvenile blue grenadier include adult blue grenadiers and pink ling (Tuck 2009).

KEY POINTS:

- Generalist species;
- Potential change in predation pressure with range shifts of other species.

1.5 VULNERABILITY AND RESILIENCE TO KNOWN CLIMATE CHANGE DRIVERS

SOURCES OF VULNERABILITY:

- Southwards contraction of distribution;
- Elevated temperatures may shift timing of annual migrations and onset of spawning;
- One unique known spawning ground off Cape Sorell, western Tasmania, where individuals are exposed to fishing;
- Long-lived species, which implies slow population recovery rate;
- Heavy fishing.

SOURCES OF RESILIENCE:

- Wide distribution in southern Australia from NSW to WA across a range latitude and temperature;
- Regular good recruitment events despite high inter-annual variability in recruitment;
- Rather generalist diet but more specific information about prey composition required;

ADDITIONAL STRESSORS

- Heavy fishing of a long-lived species (slow population recovery rate);
- Lack of information about pelagic larval stage;
- Potential loss of habitat / pollution / anthropogenic perturbations of inshore areas where juveniles develop.

Table 6. Summary table of the expected effects of environmental changes in south east Australia on blue grenadier biology: recruitment, physiology, habitat / distribution range and trophic context.

	Recruitment	Physiology	Habitat Species distribution	Ecosystem context
Trends & Expected Changes	Strong year to year recruitment variability; Changes in coastal current and temperature can affect timing of spawning;		Southward contraction of distribution range;	
Gaps of knowledge Uncertainty	Poor understanding of drivers of recruitment variability; Little information available about the pelagic larval stage;	• Poor knowledge of effects of environmental changes on growth rate, size at maturity, maximum age;	• Little information available about actual shift in distribution;	• Little information available about diet and trophic status; • Unknown effects of changes in ecosystem structure and composition on population productivity;
Vulnerability	One unique known spawning ground off western Tasmania exposed to fishing; Importance of inshore habitats for larval settlement and juvenile development;	• Heavy fishing of a long-lived species with rather slow population recovery rate;	• Contraction of distribution; • Importance of inshore habitats (exposed to pollution…) as nurseries for juveniles;	• Potential changes in predation pressure with range shifts of other species;
Resilience (adaptability)	Medium to high dispersal population of larvae suggest a good population connectivity;		• Wide distribution around southern Australia across latitudes and temperatures;	

2. DESCRIPTION OF THE FISHERY

2.1 THE COMMERCIAL FISHERY

Blue grenadier are found from New South Wales (NSW) around southern Australia to Western Australia, including the coast of Tasmania, under the Commonwealth jurisdiction. The blue grenadier is targeted in the SEESF (Southern and Eastern Scalefish and Shark Fishery overview); Commonwealth Trawl (CTS) and Scalefish Hook Sectors (ScHS). CTS represents 99% of the blue grenadier landings. There are two defined sub-fisheries: the spawning and the non-spawning fisheries, with the spawning fishery restricted to the western Tasmania fishery in the months of June, July and August. In the 2009 calendar year, 83% of the CTS catch was taken in the spawning fishery. A small quantity (up to 50 tonnes) of blue grenadier is also caught in the Great Australian Bight Trawl Fishery.

TOTAL ALLOWABLE COMMERCIAL CATCH (TACC) AND ANNUAL PRODUCTION

Sector-wide Total Allowable Commercial Catches (TACCs) and individual transferable quotas (ITQs) were implemented in the Commonwealth Trawl Sector for 16 species and species groups including blue grenadier in 1992. The TACC for blue grenadier was steadily reduced from 10,000 tonnes in 2002 to 5,000 tonnes in 2005, and has varied between 3,500 and 5,000 tonnes since then. For the three fishing seasons 2009/10 to 2011/12, the AFMA Commission established a TACC of 4700 tonnes. Once uncaught quota was taken into account, the actual TACC for the 2010/11 fishing season was 5088 tonnes.

Blue grenadier is a key species in the CTS and remains the dominant species in value terms. The total landings from the CTS and ScHS in the 2010-11 fishing season were 4031 tonnes. Blue grenadier catches peaked around June to August, due to spawning season. Blue grenadier has the highest total allowable catch in the SESSF. Due to this and looking at the available access to their fishing grounds, illegal or unreported catches are not considered as a major issue with this species.

Blue Grenadier			
	TAC	Catch (trawl, hook)	Real Value
2009/2010	4700 tonnes	3281 tonnes (3270, 11)	$15.2million
2010/2011	4700 tonnes	4031 tonnes (4025, 6)	$16.3million

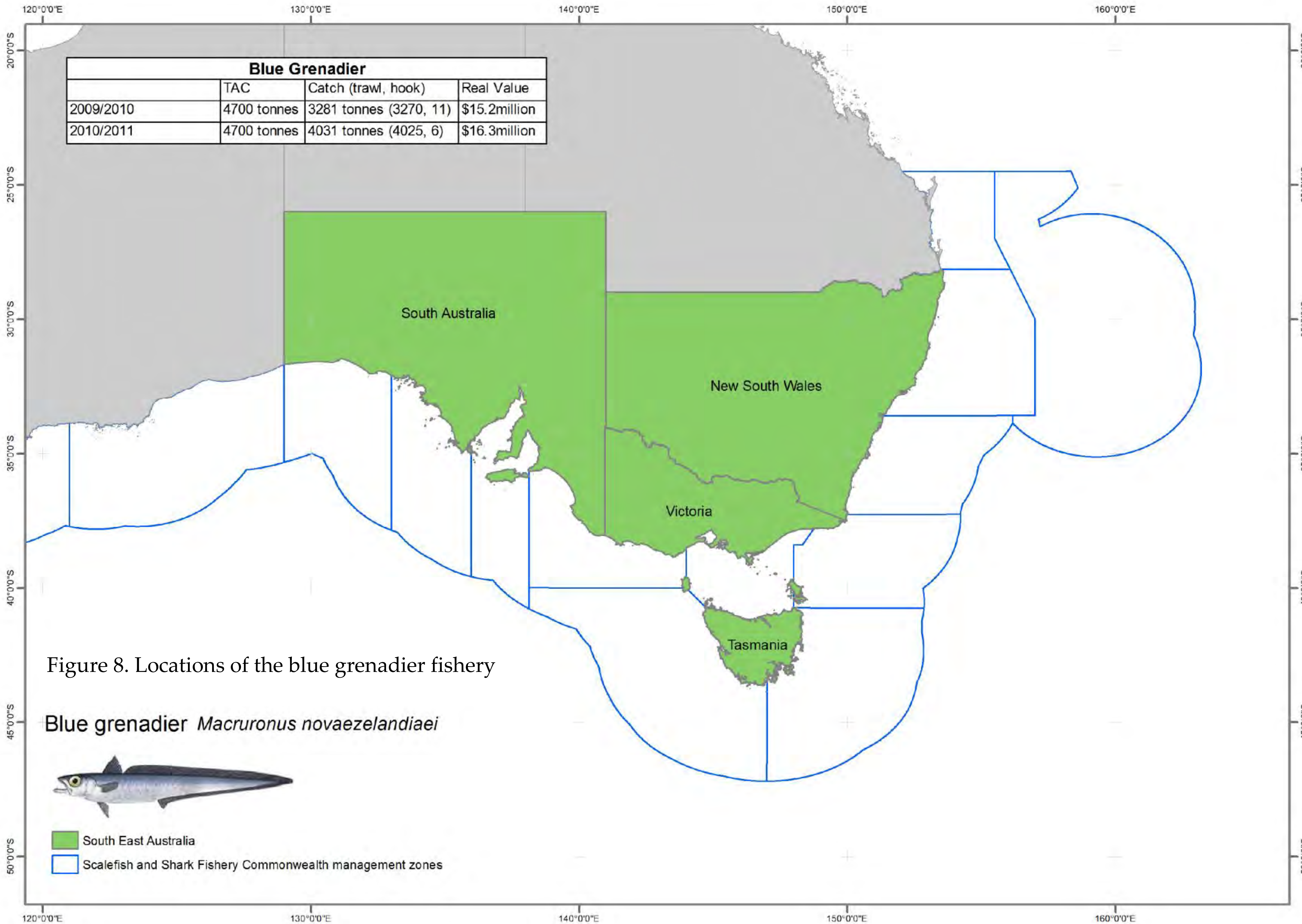

Figure 8. Locations of the blue grenadier fishery

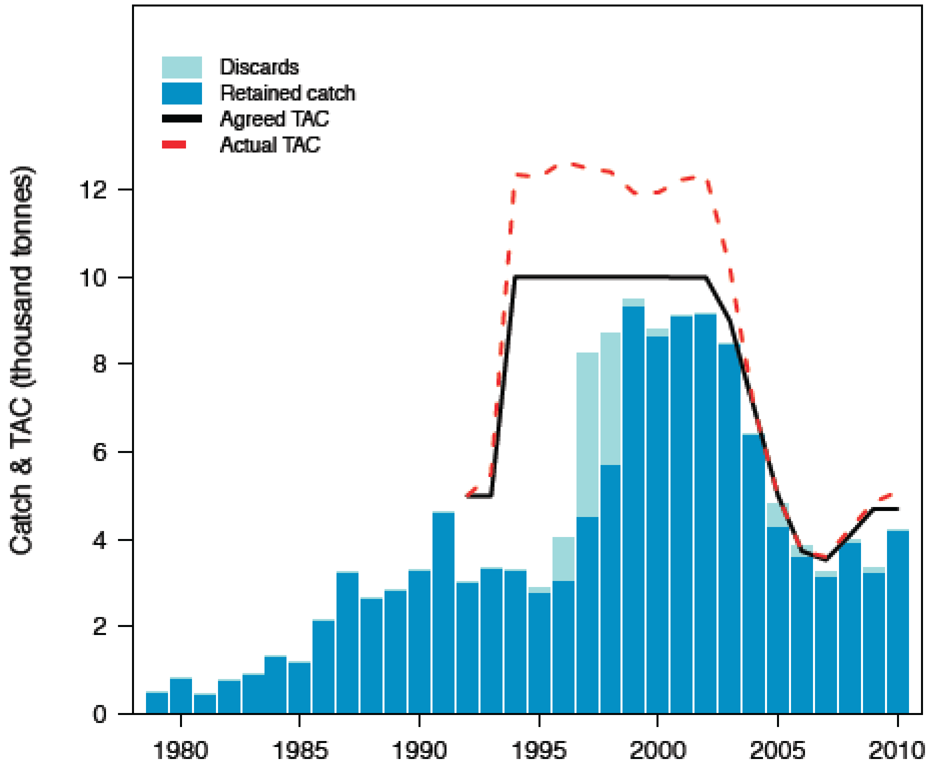

Figure 9. Blue grenadier catch history for the CTS and ScHS, 1979 to 2010. ABARES 2011.

AQUACULTURE PRODUCTION

Production of blue grenadier is entirely from wild capture fisheries.

ILLEGAL CATCH

Both illegal and unreported catches are not considered as a major issue with the blue grenadier.

MANAGEMENT

The primary management tool for blue grenadier is output control. Sector-wide TACCs and ITQs were implemented for 16 species and species groups including blue grenadier in 1992. The system used to manage the south east fishery moved from one based initially on input controls to one based on output controls in the late 1980s. ITQs were introduced into the trawl component of the south east fishery in 1989. Initially one species was managed this way. At the beginning of 1992, ITQs were introduced for a further fifteen species, including blue grenadier. From January 1994, full and permanent transferability of quota has been permitted. Prior to this, operators were only allowed to lease quota on a seasonal basis to other operators within the fishery; the sale of quota was prohibited. Under this system each of the species is subject to a total allowable catch apportioned between the operators who are entitled to fish. The TAC can be adjusted each year by the fishery's managers in response to environmental fluctuations or to satisfy management objectives. The trawl fishery is managed with the objective of maintaining the spawning stock biomass above 40% of its virgin (average 1979-1988) level.

MARKET AND PROCESSING

Catches in the CTS are predominantly sold as fresh product on the Australian domestic market. Given the relative lack of substitutable imports, exchange rate fluctuations tend to have a minimal effect on CTS fish prices.

2.2 THE RECREATIONAL FISHERY

Blue grenadier is a demersal species that occurs within a depth range of 0-1000m. This species is not fished by recreational fishers.

3. SOCIO-ECONOMIC VALUES

3.1 GROSS VALUE OF PRODUCTION (GVP)

The combined GVP of blue grenadier production in Australia in 2010/2011 was $16.3 million. The winter trawl fishery for blue grenadier off west Tasmania is now the most valuable in the South-East Fishery.

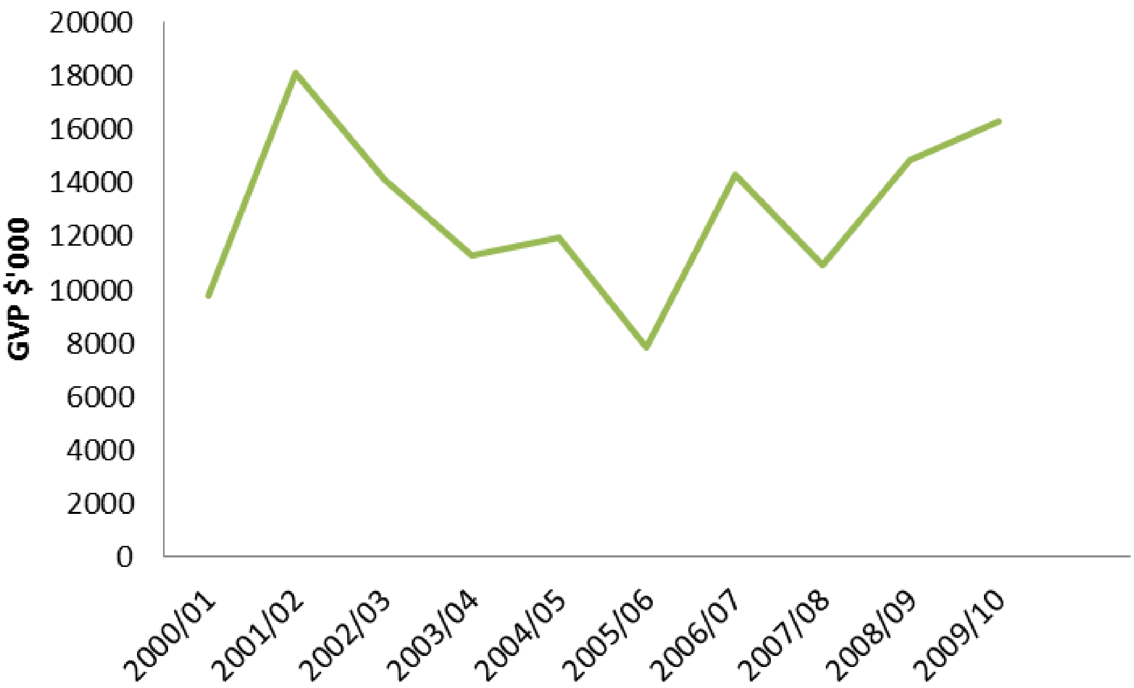

Figure 9. Real GVP of blue grenadier, 2000/01-2010/11.

3.2 BEACH PRICES

Figure 10 shows real beach prices for key species targeted in the Commonwealth trawl sector, between 2001/02 and 2007/08. Beach prices fluctuated over the period 2001/02 – 2007/08 between $1.5 and $4 per kilo. Between 2002/03 and 2007/08, beach prices for blue grenadier increased by 66 per cent. Decreases in the real price of blue grenadier would have had a significant negative impact on sector profitability in 2007/08, as this species is the most caught by weight.

3.3 EXPORT EARNINGS

Since the catches from CTS are predominantly sold as fresh product on the Australian domestic market, export earnings are thought to be negligible.

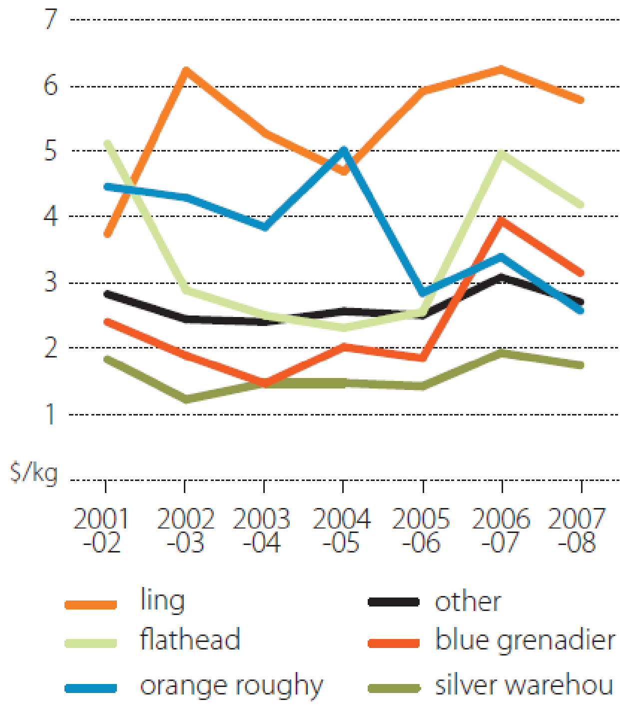

Figure 10. Real beach prices for key species targeted in the Commonwealth trawl sector, 2001/02 to 2007/08 (2008/09 dollars).Source: Vieira and al, 2010

3.4 ECONOMIC RETURN TO CAPITAL INVESTMENT, ECONOMIC PROFIT

The real net economic returns to the south east trawl fishery for the period 1996-97 to 2001-02 show that net returns to the fishery (including management costs) are estimated to have averaged around $2.0 million a year (Galeano et al 2004).

3.5 EMPLOYMENT

The offshore trawl sector of the south east fishery is that part of the fishery targeting primarily orange roughy, and to a lesser extent blue grenadier, with mid to deep water trawls. The offshore fleet consist mainly of the larger boats and operates predominantly out of Tasmanian and Victorian ports.

KEY STRESSORS:

- Susceptible to overfishing due to long-lived, slow population recovery rate;
- Spawning population targeted.

REFERENCES

ABARES (2011). Fisheries status reports 2010: Status of Fish Stocks and Fisheries managed by the Australian Government. Australian Government.

Galeano, D., Langenkamp, D., Shafron,W., & Levantis, C. (2004). Australian Fisheries Surveys Report 2003: Economic Performance of Selected Fisheries in 2000-01 and 2001-02. Canberra: ABARE.

Gunn, J.S., Bruce, B.D., Furlani, D.M., Thresher, R.E., & Blaber, S.J.M. (1989). Timing and location of spawning of blue grenadier, *Macruronus novaezelandiae* (Teloestei: Merlucciidae), in Australian coastal waters. *Australian Journal of Marine and Freshwater Research* 40, 97-112.

Kailola, P.J., Williams, M.J., Stuart, P.C., Reichelt, R.E., McNee, A. & Grieve, C. (1993). Australian Fisheries Resources. Bureau of Resource Sciences, Department of Primary Industry and Energy and the Fisheries Research and Development Corporation, Canberra.

Neira, F. J., Miskiewicz, A. G. & Trnski, T. (1998). Larvae of Temperature Australian Fishes: Laboratory Guide for Larval Fish Identification. University of Western Australian Press, Nedlands.

Punt, Smith, Thomson, Haddon, He, & Lyle. (2001). Stock assessment of the blue grenadier *Macruronus novaezelandiae* resource off south-eastern Australia. *Marine Freshwater Resource* 52 , 701-717.

Russell S. & Smith D.C. (2007). Spawning and reproduction biology of blue grenadier in south-eastern Australia and the winter spawning aggregation off western Tasmania. Final report to Fisheries Research and Development Corporation Project No. 2000/102. Fisheries Research Branch, Fisheries Victoria, Queenscliff.

Thresher, R.E., Bruce, B.D., Furlani, D.M., & Gunn, J.S. (1989). Distribution, advection, and growth of larvae of the southern temperate gadoid, *Macruronus novaezelandiae* (Teleostei: Merlucciidae), in Australian coastal waters. *Fishery Bulletin* 87, 29-48.

Tuck, G.N. (2009). Updated stock assessment of blue grenadier *Macruronus novaezelandiae* based on data up to 2007. pp 13-52 in Tuck, G.N. (ed.) 2009. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2008. Part 1. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 344 p.

Vieira, S., Perks, C., Mazur, K., Curtotti, R., & Li, M. (2010). Impact of the structural adjustment package of the profitability of Conmmonwealth fisheries. Canberra: ABARE research report 10.01.

3.3 Snapper, *Chrysophrys auratus*

1. ECOLOGY

1.1 REPRODUCTION, LARVAL DEVELOPMENT, SETTLEMENT AND RECRUITMENT

Snapper life cycle is depicted in Figure 11. Snapper are serial spawners that reach sexual maturity at 3-5 years of age (Crossland 1977a; b; Fowler 2000; Francis and Pankhurst 1988). Snapper can spawn repetitively during extended periods of up to 3–4 months (Fowler 2000). Snapper form spawning aggregations at depths < 50 m and spawn in coastal waters, semi-enclosed, sheltered bays and gulfs throughout their range (Kailola et al 1993). Spawning occurs near the surface at different times of the year across the distribution. SST is likely to be an important cue for the onset of spawning (Fowler 2000; Aquaculture SA 2003), although water temperature at time of spawning varies considerably across the distribution (Figure 12).

Eggs are buoyant and drift for several days with currents prior to hatching (Kailola et al 1993; Coutin 2000), which occurs 1–2 days after fertilisation depending on water temperature (Cassie 1955; Fowler 2000; Aquaculture SA 2003). The planktonic larvae develop over less than 20–30 days (Fowler and Jennings 2003). Bays and estuaries are essential habitat for the larval settlement phase and also act as nurseries for juveniles during the first two years (Gillanders 2002b; Thrush et al 2002; Sumpton and Jackson 2005). Post-larvae become demersal at about 1 month (Fowler 2000), and then juveniles (<1 year) remain associated with soft sediments while older juveniles are commonly found on a more diverse range of habitat, i.e. soft sediments, reefs, algae or seagrass (Kailola et al 1993; Gillanders 2002a; Fowler and Jennings 2003; Hamer and Jenkins 2007).

While different stocks exist across the distribution of snapper around Australia (Figure 12), there are some overlaps between individual populations. Local spawning grounds and nurseries mostly replenish populations at a regional scale. Movement patterns of older juveniles and adults vary , with some larger individuals moving to other regional waters (Fowler et al 2005).

KEY POINTS:

- Importance of bays, gulfs and estuaries for spawning aggregations;
- Importance of inshore benthic habitat for larval settlement and as nursery for juveniles;
- Recruitment is highly variable from year to year and from region to region;
- Little known about environmental factors (e.g. temperature, nutrient) driving recruitment variability;
- Different breeding stocks with strong connectivity between individual populations across the species distribution.

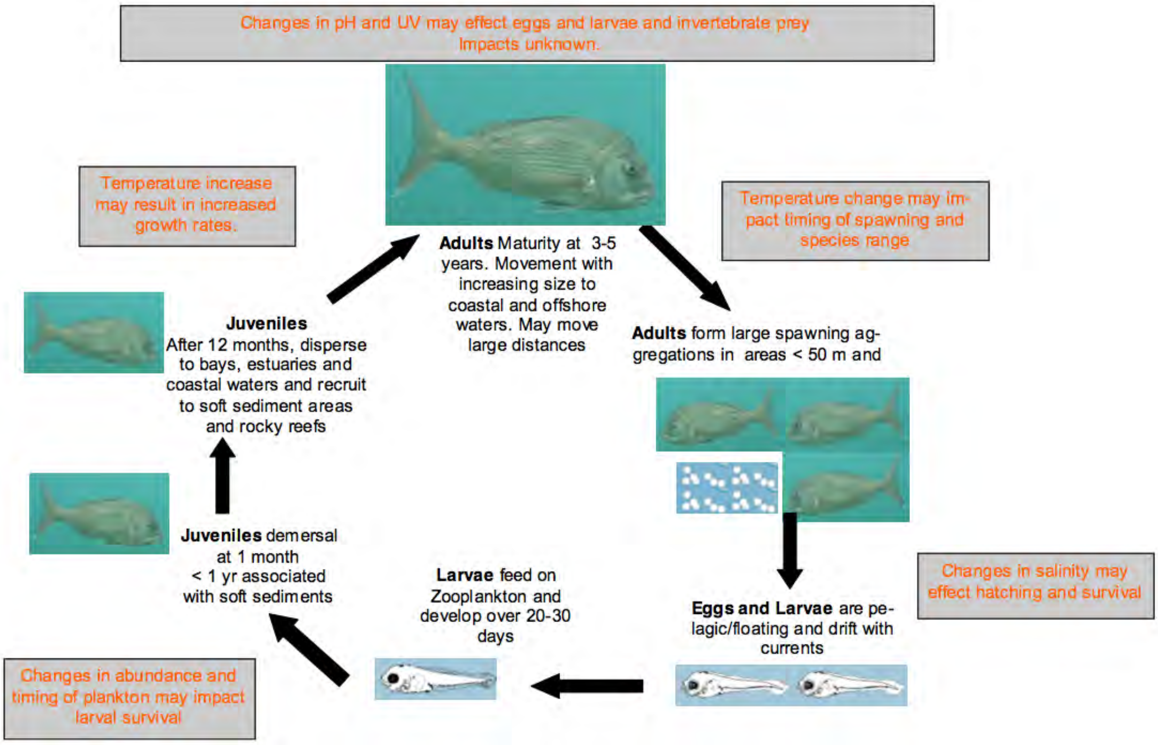

Figure 11. Summary of life cycle of snapper and points of exposure to relevant climate change drivers or known impacts.

1.2 ADULT PHYSIOLOGY

Snapper are a long-lived demersal species, which can live up to at least 40 years in Australia (Hamer and Jenkins 2007) with adults reaching up to 1.3 m (20 kg) (Gomon et al 2008).

Growth rates of the species vary considerably both between regions and at small within-state scales (Sanders and Powell 1979; Jackson 2007), potentially due to differences in habitat type, prey availability and other environmental factors such as temperature (Francis and Winstanley 1989; Aquaculture SA 2003; Jackson 2007). Maximum age, age at maturity and spawning time are also reported to vary at small spatial scales. The environmental drivers of these variations in physiological traits are poorly understood.

KEY POINTS:

- Long-lived species so slow population recovery rate;
- Small scale differences in growth rate, size at maturity, maximum size;
- Poor understanding of the drivers of these small scale differences in physiology (e.g. growth rate);
- Potential increase in growth rate with warming waters.

1.3 HABITAT AND SPECIES DISTRIBUTION

Snapper is a demersal species distributed from shallow bays and inlets to the edge of the continental shelf (Kailola et al 1993). Juveniles are associated with bare soft sediments, reefs, macroalgal and seagrass beds within bays and inshore waters. Adults are demersal and also associated with these habitat types both within bays and in coastal areas (Hutchinson et al 2010) at depths down to 200 m (MacDonald 1982).

The species is broadly distributed around Australia's coast from northern WA to northern Queensland along southern Australia including northern Tasmania (Figure 12). While several stocks of snapper exist in Australian waters, there is some strong overlap between the distributions of individual populations (Kailola et al 1993; Fowler 2000) with little genetic differentiation between these populations. Snapper distribution is expected to expand southwards as abundance is reported to increase and the species distribution to extend southwards in northern Tasmania.

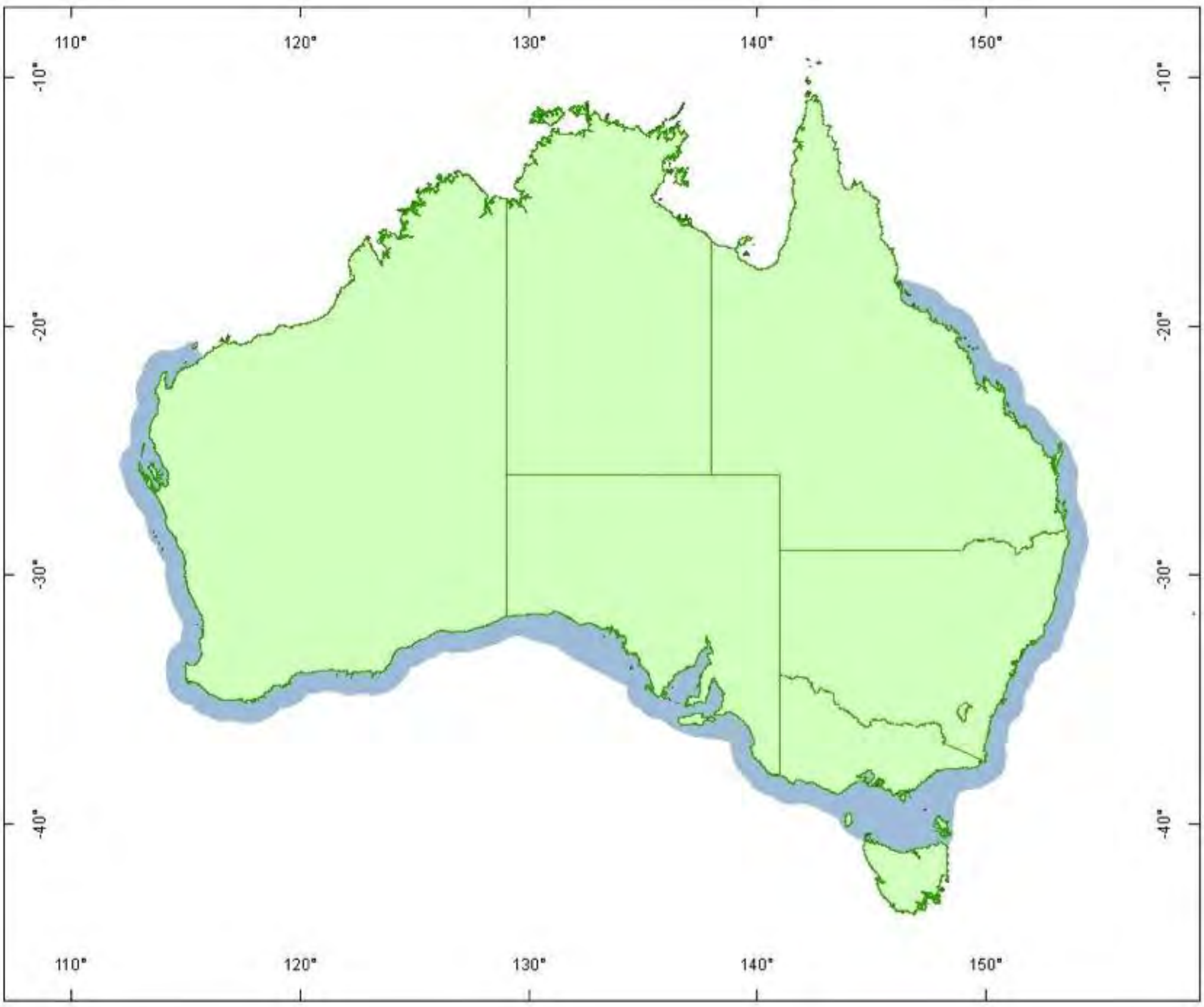

Figure 12. Distribution of snapper around Australia.

KEY POINTS:

- Wide distribution around Australia across a broad range of latitudes and temperatures;
- Range expansion at its southern end: increase in abundance and southwards range extension in northern Tasmania;
- Importance of inshore benthic habitat (soft sediment, reef, seagrass) for larval settlement and as nursery for juveniles.

1.4 ECOSYSTEM CONTEXT: PREYS, PREDATORS, COMPETITORS

While snapper larvae are plankton feeders (both on phyto- and zooplankton), juveniles and adults are generalist predators, with a diverse diet mostly comprising molluscs, crustaceans and small fish (MacDonald 1982). Adult snapper are reported to prey on sea urchins on barren habitat, and hence they can play some important predation control in reef communities (Shears and Russell 2002).

Snapper predators include a range of fish species, sharks and marine mammals (e.g. dolphins, seals) (Kailola et al 1993; Coutin 2000).

KEY POINTS:

- Snapper is a generalist species and is likely to adapt to changes in prey species;
- Potential change in predation pressure with range extension of other species.

1.5 VULNERABILITY AND RESILIENCE OF BA AND GA TO KNOWN CLIMATE CHANGE DRIVERS

SOURCES OF VULNERABILITY:

- Importance of inshore benthic habitats (soft sediment, reef, seagrass beds) for larval development and as nurseries for juveniles;
- Long-lived species, hence slow population recovery rate;

➢ Variable recruitment at the regional scale; lack of understanding of environmental factors driving this variability.

SOURCES OF RESILIENCE:

➢ Wide distribution around Australia across broad ranges of latitude and temperature;

➢ Generalist species, hence plastic diet and ability to adapt to changes in prey composition;

➢ Strong connectivity across the distribution;

➢ Range expansion (distribution extending southwards into Tasmanian waters);

➢ Additional stressors

➢ Snapper form large predictable spawning aggregations which are vulnerable to overfishing (Mackie et al 2009).

Table 7. Summary table of the expected effects of environmental changes in south east Australia on snapper biology: recruitment, physiology, habitat / distribution range and trophic context.

	Recruitment	Physiology	Habitat Species distribution	Ecosystem Context
Trends & Expected Changes	Variable recruitment from year to year and region to region;	Small scale variability in growth, maximum size and age at maturity;	Range expansion, southwards (range extension in northern Tas.);	
Gaps of knowledge Uncertainty	Poor knowledge of the environmental drivers of recruitment variability; Unknown effects of change in pH and UV exposure on larval development;	Poor understanding of the environmental drivers of this variability in physiology;	• Lack of detailed monitoring of shift in distribution and abundance across the whole range;	• Potential changes in predation pressure with range shifts of other species;
Vulnerability	Spawning aggregations in bays and estuaries are vulnerable to fishing; Importance of inshore benthic habitat for larval settlement and juvenile development;		• Reliance on benthic habitat (reef, soft bottom, seaweed or seagrass beds);	
Resilience (adaptability)	Good connectivity between individual breeding stocks across the distribution;	• Exposure to broad range of environmental conditions through its distribution;	• Wide distribution range across latitudes, temperatures and habitat types;	• Generalist feeder with a plastic and diverse diet so ability to adapt to changes in prey composition;

2. DESCRIPTION OF THE FISHERY

2.1 THE COMMERCIAL FISHERY

Snapper support commercial fisheries in each mainland State of south eastern Australia, whilst the commercial catches from Tasmanian waters are negligible. The South Australian snapper catch is now the highest State-based commercial catch, having exceeded that of Western Australia for the first time in 2006/07. Three commercial fisheries have access to snapper stocks. The snapper fishery in SA is geographically extensive and encompasses most of the State's inshore marine waters. For the purposes of stock assessment these waters have normally been divided into six geographic regions; Northern Spencer Gulf, Southern Spencer Gulf, Northern Gulf St. Vincent, Southern Gulf St. Vincent, West Coast, and South East. In Victoria, the main commercial fishing locations are Port Phillip Bay (71%-92% of the Victorian commercial catch) and Victorian coastal waters, Small commercial catches come from Corner Inlet. In New South Wales, snapper are targeted in the multi species Ocean Trap and Line fishery. It represents approximately 12% of the total catch for this fishery.

Total snapper production in Australia in 2008/2009 was 1,795 tonnes, of which 64 % was produced in south east Australian fisheries. South Australia accounted for the largest share of annual commercial production (64.5% or 741 tonnes in 2008/09), followed by New South Wales and Victoria. Although small in commercial production, the recreational sector in Victoria catches 450 tonnes of snapper a year, or 4 times more than its commercial catches.

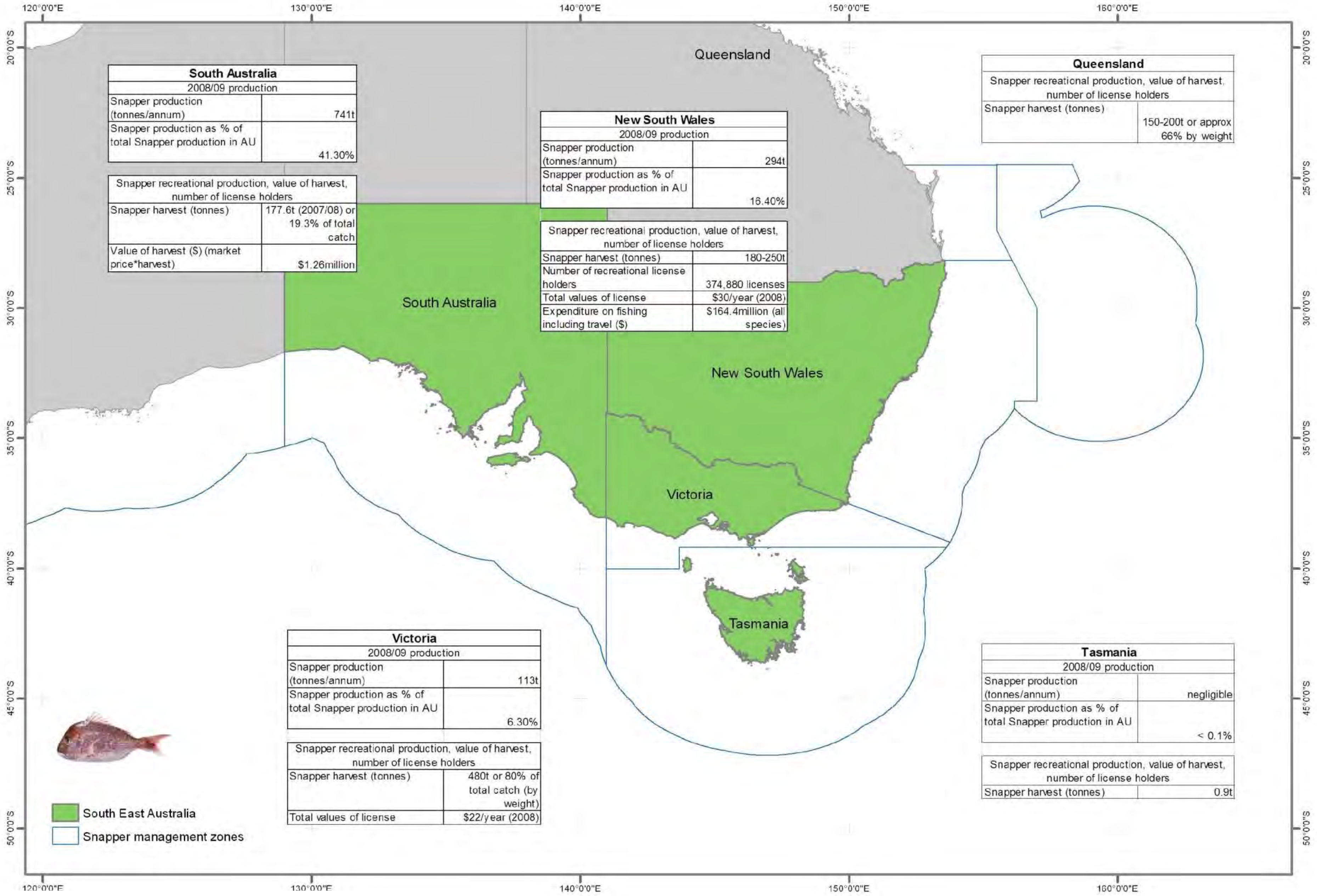

Figure 13. Locations of the snapper fisheries

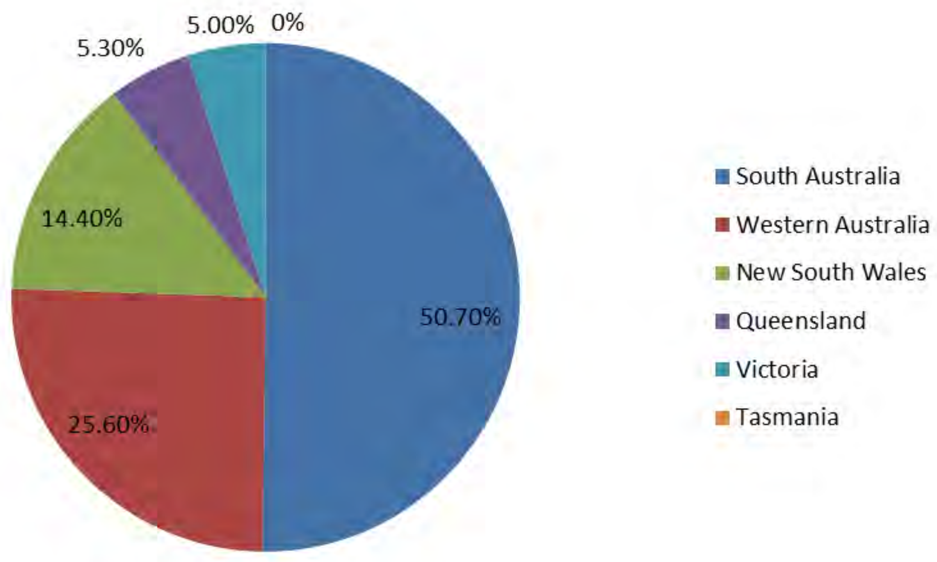

Figure 14. Snapper production by State 2009/10

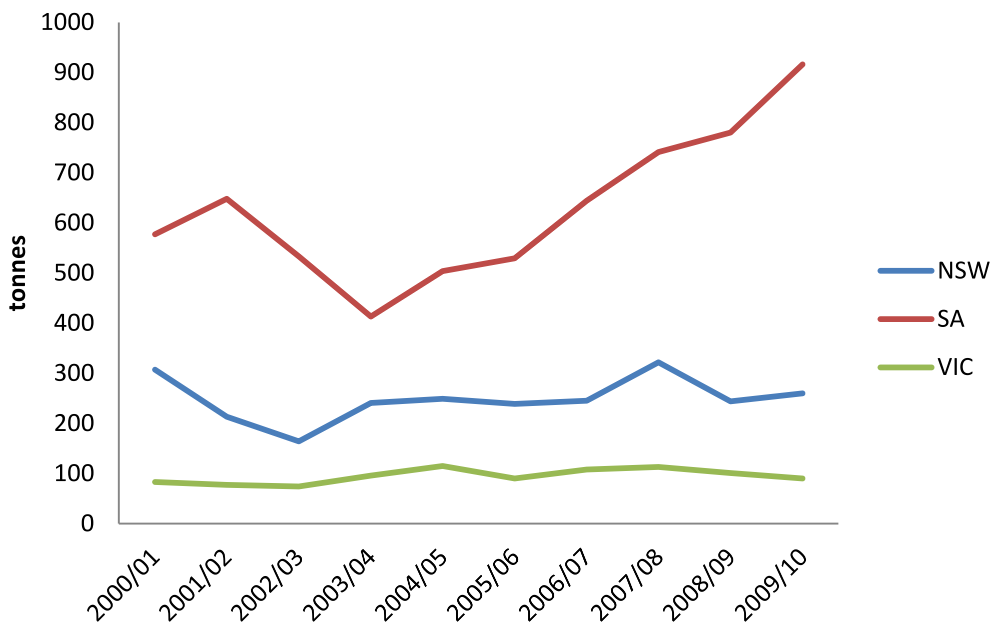

Figure 15. Snapper production (tonnes/year) by state

MANAGEMENT

The snapper fishery is managed under various input measures across the states, including seasonal and spatial closures, legal minimum length, limited entry, and gear restrictions (See Table 8). TACCs and ITQs are not used. As yet there are no structured management arrangements for Victorian finfish fisheries. The main method of management is to limit fishing effort by limiting the number of commercial licenses and restricting commercial fishing equipment, and to apply catch controls such as legal size limit. Since 1 October 2007, all snapper fishing in Victorian waters has been subject to a legal minimum length of 28cm. An Open Fishery Access License permits the take of snapper (and other finfish) with the use of commercial fishing equipment from Victorian waters. There are 246 licenses which are non-transferable. The fishery is managed using input (effort) controls and legal size limits. It is considered not effective to manage the fishery in Victoria with TACC and ITQ units due to the relatively small commercial value.

In New South Wales, the Ocean Trap and Line fishery is currently managed by input controls which limit the fishing capacity of fishers by indirectly controlling the amount of fish caught. These controls include restrictions on the number of endorsements, the amount, design and dimensions of fishing gear, and the waters that may be worked.

In South Australia, three commercial fisheries can take snapper: the Marine Scalefish Fishery (MSF), the Rock Lobster Fishery (RLF) and the Lakes and Coorong Fishery (LCF). Fishers in each fishery have varying degrees of access to MSF species, including snapper. The heterogeneous mixture of participants, fishing devices and license conditions make the task of managing the MSF more complex than some others. The main management methods used are legal size limit, seasonal (six weeks in November) and spatial closures, limited entry, limited effort and gear restriction. Minimum legal length was increased from 28cm to 38cm in 1987. A comprehensive fishery assessment report was completed in July 2013.

At 1st October 2003, there were 720 license holders permitted to take species permitted in the MSF. Of these, 414 had a licence to operate in the MSF, 328 in 2009/10.

Table 8. Snapper management summary

	NSW	SA	VIC
Management zone	Ocean Trap and Line fishery	Marine Scalefish Fishery; Rock Lobster Fishery; Lakes and Coorong Fishery	Victorian finfish fisheries
Limited entry	376 shareholdings	328 license holders in MSF	246 licenses
Limited seasons		November	
Spatial closures	Yes	Yes	
Restrictions on hooks		Upper limit of 400 hooks by commercial long-line operators	
		Prohibition of nets and traps	
Minimum size limits	Yes	38 cm	28 cm

Snapper is sold on the domestic market. The snapper follows a pathway through a few market intermediaries before reaching consumers (see Figure 16). The supply chain can also be long, since imported products add complexity.

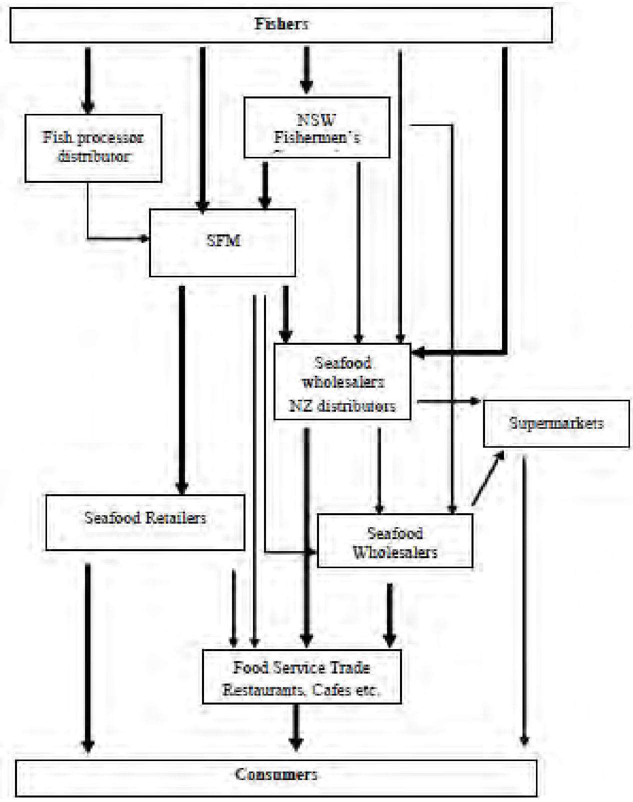

Figure 16. Fresh wild snapper marketing channels in Australia (Allan, Heasman, Bennison, 2008).

2.2 RECREATIONAL FISHERY

Snapper is targeted by recreational fishers in Queensland, New South Wales, Victoria, South Australia and in the north of Tasmania. In each State, it is considered a highly valued recreational species.

RECREATIONAL CATCHES

In South Australia, the estimated recreational catch was 177.7 tonnes in 2007/08 which accounted for 19.3% of the total catch in that year. In Tasmanian waters, relatively low numbers (0.9 tonnes) were caught by fishers in 2008/09. In Victoria, the recreational catch was estimated to represent 80% (480 tonnes) of the total catch in 2008/09. In New South Wales, the recreational catch was between 180 and 250 tonnes in 2008/09.

MANAGEMENT

The recreational fisheries for snapper are managed using various input controls across the states, including seasonal and spatial closures, legal minimum length and gear restrictions. There is no Total Allowable Catch for recreational fishers. They have a limited possession per day. For instance, in Victoria, ten fish, of which no more than three may be equal to or exceed 40cm in length.

In NSW and Victoria, a recreational fishing license is needed for all recreational fishing activities. The South Australian recreational snapper fishery is primarily managed through output controls in the form of daily bag and boats, spatial and temporal (November) closures and a minimum size limit. In all South Australian waters except Gulf St Vincent, the bag limit is 10 snapper between 38 and 60 cm in length, and twosnapper over 60 cm in length.

In response to pressure from angling bodies, the government of Victoria commissioned a co-management approach to review fish resource use in nine of Victoria's bays and inlets and to recommend action. Snapper are targeted by both sectors and there is considerable conflict between commercial and recreational fishers. Indeed, large commercial catches of baitfish species reduce the availability of food for species such as snapper (Kearney, 2002).

3. SOCIO-ECONOMIC VALUES

3.1 GROSS VALUE OF PRODUCTION

The combined gross value of production (GVP) of snapper by commercial sector in Australia in 2009/2010 was $12.9million, of which 76.8% originated from fisheries in the south east region. In this same year, South Australia, New South Wales and Victoria accounted for about 50.2% about 21.1% and about 5.5% of total regional GVP respectively. Figure 17 shows the trends in real GVP.

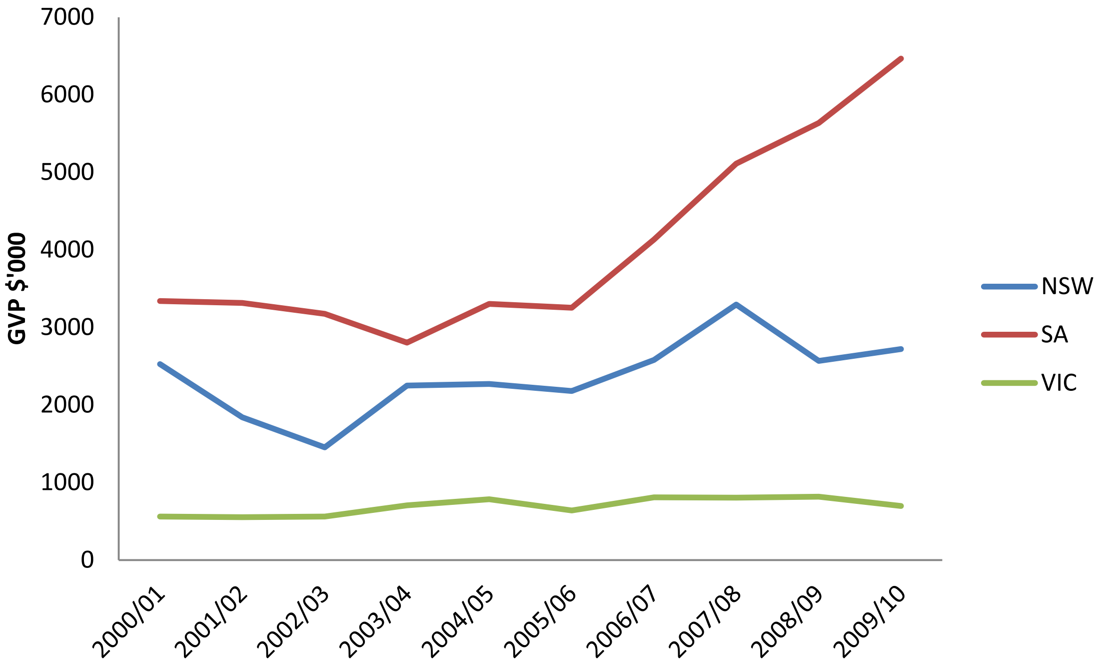

Figure 17. Real GVP of snapper by states

Table 9. Snapper GVP and beach prices

2009/10	TAS	VIC	SA	NSW
GVP ($million/annum)	negligible	$0.69	$6.48	$2.72
Total fisheries GVP in the state ($million/annum)	$568.3	$132.9	$394.4	$58.1
Snapper GVP as % of total fisheries GVP in state	negligible	0.5%	1.6%	4.7%
Fishery ranking in state in terms of total fisheries GVP	NA	8	4	8
Beach price ($/kg) – are they any premiums/discounts?	NA		$7.20	
Beach price trends (in real term)	NA		Stable over two years, increasing over five.	
Beach price fluctuations (year to year or inter-annual)	NA		Inter-annual	

3.2 BEACH PRICES

Snapper was the most important species traded by value and volume in the Sydney Fish Market in 2009/10. 763,560 kilos were traded for a total value of $7,354,663. Thus, the average wholesale price was $ 9.63/kg in 2009/10 and $ 9.83/kg in 2008/09 (Sydney Fish market 2010).

Table 10. Average monthly beach prices in South Australia and wholesale prices in Melbourne fish market, 2009/10

	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Adelaide	$8.95	$8.64	$7.39	$6.90	$6.11	$6.05	$7.47	$8.63	$7.67	$7.71	$6.32	$6.57
Melbourne	$8.97	$7.89	$9.36	$8.31	$6.94	$6.98	$10.0	$8.21	$9.24	$8.44	$8.06	$9.24

3.3 EXPORT EARNINGS

Snapper is mainly sold on the domestic market.

3.4 DOWNSTREAM AND FLOW-ON VALUES

In South Australia, the commercial fishery for snapper contributed ~$6.5 million in 2009/10 to the state's economy, as well as contributing to regional employment and supply of fresh quality local seafood. The industry contributes to state and regional economies through employment and fish processing/markets, the purchase of fishing equipment, vessels, bait supplies and fuel etc.

Table 11. Socio-economic impacts of the MSF in SA

Estimated number of active MSF licence holders living in the region	338
Estimated total number of paid non-licence holder working In MSF in the region	450/ 369.2fte
Estimated total number of unpaid non-licence holder working In MSF in the region	407/ 145.7fte
Estimated proportion of regional population employed full-time or part-time in MSF	0.085%
Average number of dependents per person involved in MSF	1.5
Total MSF household spending in the region	$14,368,400 derived from fishing income: $8,839,700
Total fishing business spending in region	$16,364,900
Estimated GVP of MSF catch landed and commission paid to fish receivers	GVP $20,667,000 Commission $2,289.900

The value of outputs generated directly in SA by marine scalefish fishing enterprises summed to $23.3 million in 2009/10, while output generated by downstream activities (processing, transport, retail/food services and capital expenditure) summed to $13.5 million. Flow-on to other sector of the state economy added another $59.1 million in output. Personal income of $10.6 million was earned in the fishing sector and $4.0 million in downstream externalities in SA. An additional $16.2 million was earned by wage earners in other businesses in the state as a result of fishing and associated downstream activities. The total household income impact was $30.7 million in SA (EconSearch 2012).

3.5 ECONOMIC RETURN TO CAPITAL INVESTMENT, ECONOMIC PROFIT

There is limited information on economic returns to capital investment for Australian fisheries. In South Australia, the return on investment is calculated as the profit at full equity (business profit per boat plus interest) as a percentage of the total capital employed (including boats, licence/quota, fishing gear, sheds, vehicles and other capital items used as part of the fishing enterprise). For the Marine Scalefish Fishery as a whole, the average rate of return to total capital was estimated at 2.1 % in 2009/10, significantly improved from the previous years (-1% in 2008/9, -0.6% in 2007/8) (EconSearch 2012).

The economic profit, here defined as the difference between the price of a good produced and the cost of producing that good, from the Marine Scalefish Fishery in the same year was estimated at -$1.7 million. The fishery has been generating negative profit since the beginning of the economic survey in 1997/08, but 2008/09 was the best in the 13 years for which economic profit has been estimated.

3.6 EMPLOYMENT

In Victoria, there are approximately 350 Fishery Access License holders permitted to conduct commercial snapper fishing in Victorian waters. Activities carried out under these licences provide employment, household income and other economic impact benefits to local communities. These licenses also permit catch and sale of a variety of other finfish species, so the economic values attributable specifically to catch and sale of snapper are difficult to distinguish. In addition, commercial catching, processing and marketing of snapper (and other key finfish species) provides small but significant social benefits through provision of direct and indirect employment in regional coastal communities.

In 2009/10, the SA Marine Scalefish Fishery was responsible for the direct employment of around 566 full-time equivalents (FTE) and downstream activities created employment of around 99 FTE jobs state-wide. Flow-on business activity was estimated to generate a further 280 FTE jobs state-wide. These state-wide jobs were concentrated in the trade (78), manufacturing (49), business services (35) and transport (11) sectors. The total employment impact in SA was estimated to be 945 FTE jobs (EconSearch 2012).

On average, MSF fishing businesses had:

- 1.16 paid part-time or full-time employees, although when a small number of businesses with considerably more employees than usual were removed, the average was 0.67 paid employees per business. 53% full-time and 47% part-time an average of 3.09days a week.
- 0.71 unpaid family employees, who usually worked part-time for an average of 1.78 days per week
- 0.34 non-family unpaid employees, who usually worked part-time for average of 1.79 days a week.
    - On average, 70.3% of household income was derived from fishing activities, and 42% of respondents reported that 100% of their household income came from fishing. 52.7% of respondents reported that a member of their household had work outside commercial fishing, while 47.3% reported having no members of their household who worked outside commercial fishing (Schirmer, & Pickworth 2005).

3.7 GOVERNMENT FEES, ROYALTY

In South Australia, licences fees for the Marine Scalefish Fishery earned $2.04 million in 2010/11.

3.8 OTHER SOCIAL VALUES

Access to or benefit from the use of public snapper resources is known to provide significant social value across a number of Victorian communities. A market research study (Quantum Market Research 2005) found that more than 80% of Victorians had some type of interest in the use of snapper resources. An economic valuation study (Hundloe et al 2006) commissioned by the DEPI in Victoria in 2005 found that the marginal net value of additional catch and use of snapper is $20.30 per recreational fish.

Fishing snapper is an important recreational and sporting activity for the SA community. Snapper is a prized trophy fish in SA, and fishers from other states travel to SA for the opportunity to catch snapper.

3.9 RECREATIONAL VALUES

The average value of the commercial snapper was $7.09/kg in South Australia in 2007/08. Using this price, the approximate value of the 2007/08 recreational catch in South Australia was $1.26million.

In addition, expenditures on fishing including travel are estimated at $164.4million for all species in New South Wales. Snapper is the species with the highest value. In South Australia, a simple cost model using number of passengers various passenger fees was used to estimate the economic value of the Charter Boat Fishery to be between $2,990,770 and $ 4,669,970 for the 2006/07 financial year.

A travel cost demand model was estimated for recreational angling for snapper in Port Phillip Bay based on an on-site expenditure survey conducted during the 1996-1997 season. The model explaining angling trip frequency was initially based on exploratory analysis and Fisher tests on variable including trip-specific expenditure and non-expenditure factors. A final preferred Poisson count model was then estimated and used to calculate the annual angler surplus ($ 7,100 per boat party) and the total benefits to the angling population ($128,000)(Li 1999).

KEY STRESSORS:

- Competition between the commercial and recreational sectors
- Sensitive to fishing on spawning aggregation
- Susceptible to overfishing due to long-lived, slow population recovery rate.
- Depends on inshore benthic habitats

REFERENCES

Allan, G.L., Heasman, H., & Bennison, S. (2008). Development of industrial-scale inland saline aquaculture: Coordination and communication of R&D in Australia. FRDC Project No.2004/241.

Aquaculture SA (2003). Snapper aquaculture in South Australia. Fact sheet FS NO: 55/99. Primary Industries and Resources SA.

Cassie, R.M. (1955). Early development of the snapper *Chrysophrys auratus* Forster in Hauriki Gulf. *Transactions of the royal Society of New Zealand* 83, 705-713.

Coutin, P.E. (2000). Snapper - 1998. Compiled by the bay and inlet fisheries and stock assessment group. Fisheries Victoria assessment report no. 19. Marine and freshwater resources institute: Queenscliff.

Crossland, J. (1977a). Fecundity of snapper *Chrysophrys auratus* (Pisces sparidae) from Hauraki gulf *New Zealand Journal of Marine and Freshwater Research* 11, 767-775.

Crossland, J. (1977b). Seasonal reproductive-cycle of snapper *Chrysophrys auratus* (Forster) in Hauraki Gulf *New Zealand Journal of Marine and Freshwater Research* 11, 37-60.

EconSearch. (2012). Economic Indicators for the SA Marine Scalefish Fishery 2009/10. Marryatville, SA: EconSearch.

Fowler, A.J. (2000). Snapper (*Pagrus auratus*). Fishery assessment report to PIRSA for the MSF fishery management committee. South Australian Fisheries Assessment Series 00/13. SARDI.

Fowler, A.J., Gillanders, B.M., & Hall, K.C. (2005). Relationship between elemental concentration and age from otoliths of adult snapper (*Pagrus auratus*, Sparidae): implications for movement and stock structure. *Marine and Freshwater Research* 56, 661-676. doi:10.1071/mf04157

Fowler, A.J. & Jennings, P.R. (2003). Dynamics in 0+ recruitment and early life history for snapper (*Pagrus auratus*, Sparidae) in South Australia. *Marine and Freshwater Research* 54, 941-956.

Francis, M.P. & Pankhurst, N.W. (1988). Juvenile sex inversion in the New Zealand snapper *Chrysophrys auratus* (Bloch and Schneider, 1801) (Sparidae) *Australian Journal of Marine and Freshwater Research* 39, 625-631.

Francis, R.I.C.C. & Winstanley, R.H. (1989). Differences in growth-rates between habitats of south-east Australian snapper (*Chrysophrys auratus*). *Australian Journal of Marine and Freshwater Research* 40, 703-710.

Gillanders, B.M. (2002a). Connectivity between juvenile and adult fish populations: do adults remain near their recruitment estuaries? *Marine Ecology Progress Series* 240, 215-223.

Gillanders, B.M. (2002b). Temporal and spatial variability in elemental composition of otoliths: implications for determining stock identity and connectivity of populations. *Canadian Journal of Fisheries and Aquatic Sciences* 59, 669-679. doi:10.1139/f02-040

Gomon, M.F., Bray, D.J. & Kuiter, R.H. (2008). 'Fishes of Australia's southern coast.' (Reed New Holland: Sydney.)

Hamer, P.A. & Jenkins, G.P. (2007). Migratory dynamics and recruitment of snapper, *Pagrus auratus*, in Victorian waters. Final report to Fisheries Research and Development Corporation Project No. 199/134. Primary Industries Research Victoria, Marine and Freshwater Systems, Queenscliff.

Hundloe, T., Blamey, R., McPhee, D., Hand, T., & Bartlett, N. (2006). Victorian Bay and Inlet Fisheries Resources Allocation - Valuation Study. Camberwell, Victoria: Mardsen Jacob Associates, Financial & Economic Consultants.

Hutchinson, N., Gavine, F., Morris, E., & Longmore, A. (2010). Adaptation of Fisheries and Fisheries Management to Climate Change: Marine, estuarine and freshwater biophysical risk assessment. Technical Report No. 92, Fisheries Victoria, March 2010. Department of Primary Industries, Queenscliff, Victoria, Australia.

Jackson, G. (2007). Fisheries biology and management of pink snapper , *Pagrus auratus*, in the inner gulfs of Shark Bay, Western Australia. PhD Thesis, Murdoch University.

Kailola, P.J., Williams, M.J., Stuart, P.C., Reichelt, R.E., McNee, A., & Grieve, C. (Eds) (1993). 'Australian Fisheries Resources.' (Bureau of Rural Resources, Department of Primary Industry and Energy, and the Fisheries Research and Development Corporation: Canberra.)

Kearney, R.E. (2002). Co-management: the resolution of conflict between commercial and recreational fishers in Victoria, Australia. *Ocean & Coastal Management* 45 , 201-214.

Li, E.A.L. (1999). A Travel Cost Demand Model for Recreational Snapper Angling in Port Phillip Bay, Australia. *Transactions of the American Fisheries Society* 128 , 639-647.

MacDonald, C.M. (1982). Life history characteristics of snapper *Chrysophrys auratus* (Bloch and Schneider, 1801) in Australian waters. *Victorian department of conservation, forests and lands, fisheries and wildlife division, fisheries and wildlife paper* 29, 16

Mackie, M.C., McCauley, R.D., Gill, H.S., & Gaughan, D.J. (2009). Management and monitoring of fish spawning aggregations within the west coast bioregion of Western Australia. Final report to Fisheries Research and Development Corporation on Project No. 2004/051. Fisheries Research Report No. 187. Department of Fisheries, Western Australia.

PIRSA Fisheries and Aquaculture (2011). Background paper for management options for snapper in South Australia. Government of South Australia; Primary Industries and Region SA.

Quantum Market Research (2005). Community Preferences for Alternative Uses of Key Victorian Fish Resources.

Sanders, M.J., & Powell, D.G.M. (1979). Comparison of the growth-rates of 2 stocks of snapper (*Chrysophrys auratus*) in southeast Australian waters using capture-recapture data *New Zealand Journal of Marine and Freshwater Research* 13, 279-284.

Schirmer, J., & Pickworth, J. (2005). Social impacts of the South Australian Marine Scalefish Fishery. Australian Government Fisheries Research and Development Corporation.

Shears, N.T., & Russell, C.B. (2002). Marine reserves demonstrate top-down control of community structure on temperate reefs. *Oecologia* 132, 131-142.

Sumpton, W., & Jackson, S. (2005). The effects of incidental trawl capture of juvenile snapper (*Pagrus auratus*) on yield of a sub-tropical line fishery in Australia: an assessment examining habitat preference and early life history characteristics. *Fisheries Research* 71, 335-347. doi:10.1016/j.fisheries.2004.07.003

Sydney Fish Market (2011). *Annual Report 2010.*

Thrush, S.F., Schultz, D., Hewitt, J.E., & Talley, D. (2002). Habitat structure in soft-sediment environments and abundance of juvenile snapper *Pagrus auratus*. *Marine Ecology Progress Series* 245, 273-280.

3.4 Southern rock lobster (SRL), *Jasus edwardsii*

1. ECOLOGY

1.1 REPRODUCTION, LARVAL DEVELOPMENT, SETTLEMENT AND RECRUITMENT

SRL are benthic, but have a very long pelagic larval phase, which is predominantly offshore. The following life cycle information has been derived from (Pecl, Frusher et al 2009) and Hutchinson et al (2010). The fertilisation of SRL eggs occurs externally, from April to July, where they are then carried under the tail of the female for 3–6 months. Up to one million eggs develop under the tail of a female before being released into the sea. Eggs hatch into larvae (phyllosoma), usually between September and October, with an oceanic phase estimated to last 9–24 months. Phyllosoma undergo 11 developmental stages, and at the end of their larval phase and when adjacent to the continental shelf, phyllosomas moult to the last larval stage known as the puerulus and swim towards coastal reefs where they settle as a 25 mm lobster and begin the benthic phase of their life cycle.

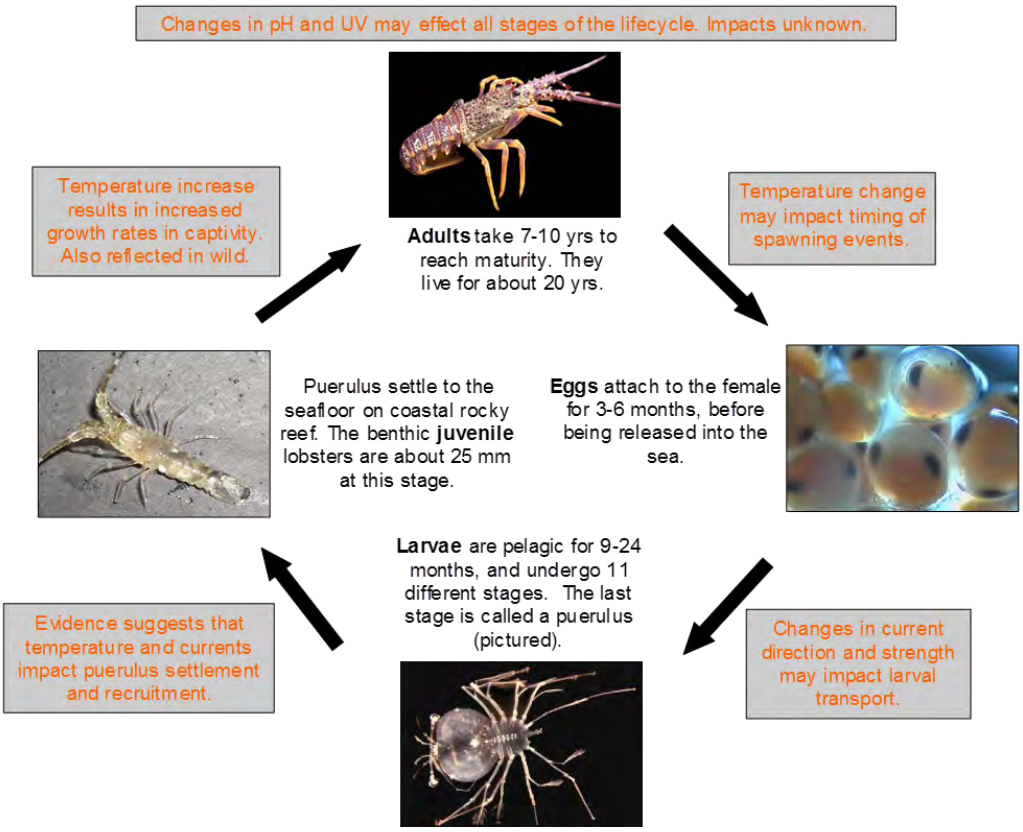

Figure 18. Summary of southern rock lobster life cycle (this section), and points of exposure to relevant climate change drivers or known impacts. Image adapted from Pecl et al (2009).

South-western Tasmania and South Australia are an important source of recruits (Bruce, Griffin et al 2007). Additionally, the position of the sub-tropical convergence (Tasman front), where the nutrient-poor warm East Australian Current (EAC) meets the nutrient-rich cooler Southern Ocean waters, is important for puerulus recruitment in south east Australia: indeed, recent large-scale spatial declines in recruitment patterns across south east Australia, in particular in eastern Tasmania (Pecl, Frusher et al 2009), are associated with an increase in the southward penetration of the EAC.

Little specific information is available about the oceanic larval phase. Although samples of phyllosoma collected during oceanic plankton research surveys show higher abundance in cooler waters just south of the sub-tropical convergence (Tasman front) (Bruce, Griffin et al 2007), there is no robust correlation between projected settlement from the larval transport model and observed puerulus settlement on collectors throughout south east Australian regions. Therefore, in addition to passive dispersion with currents, other factors (e.g. temperature, nutrient richness) are likely to condition the success of larval development and puerulus recruitment (Bermudes and Ritar 2008).

KEY POINTS:

- Large-scale decline in SRL recruitment across south east Australia over the last decade (Linnane et al. 2010);
- Over past 15 years, decline in puerulus settlement in eastern and south-eastern Tasmania, correlated with SST and southern incursions of the warm nutrient-poor EAC (Pecl et al. 2009);
- Uncertainty in dispersal patterns of larvae, source of recruits and drivers of puerulus settlement;
- Poor knowledge of the long pelagic larval stage;
- Unknown impacts of ocean acidification and increasing UV on larvae.

1.2 ADULT PHYSIOLOGY

SRL grow by periodically shedding their complete exoskeleton in a process called moulting. The number of moults that a lobster undertakes annually is dependent on its size and maturity, but frequency declines with age. SRL growth rate varies spatially across south east Australia with slow growth in cooler southern regions and faster growth in warmer northern regions. This ultimately impacts on size of maturity, which can differ greatly depending on the region (Gardner, Frusher et al 2006; Linnane, Penny et al 2008; Linnane, Penny et al 2009). Growth rates are increasing with warming waters in southern Tasmania but appear to be decreasing in South Australia with enhanced upwelling activity and subsequent cooling of coastal waters (Linnane, Gardner et al 2010) (Figure 19).

KEY POINTS:

- Spatial discrepancies in the effects of climate change on lobster growth (and size at maturity): individual growth is expected to increase with warming waters around Tasmania (Thomas et al. 2000), while the expected intensification of upwelling activity in South Australia is likely to have the opposite effect.

1.3 HABITAT AND SPECIES DISTRIBUTION

SRL are found on rocky reef habitats at depth ranging from 0-200 m. The species is distributed throughout southern Australia, from southern NSW (approximately Eden), around Tasmania and across SA into southern WA and also occurs in New Zealand. SRL long-lived (9 to 24 months) pelagic larvae have a high large-scale dispersal capacity so there is no genetic evidence of population subdivision of SLR throughout Australasia, including between Australia and New Zealand (a distance of approximately 2000 km) (Ovenden, Brasher et al 1992)

KEY POINTS:

- Polewards contraction of the species distribution range with increase in temperature;
- Habitat loss (macroalgal cover) along the east coast of Tasmania due to increasing temperature and range expansion of the long spined sea urchin *Centrostephanus rodgersii.*

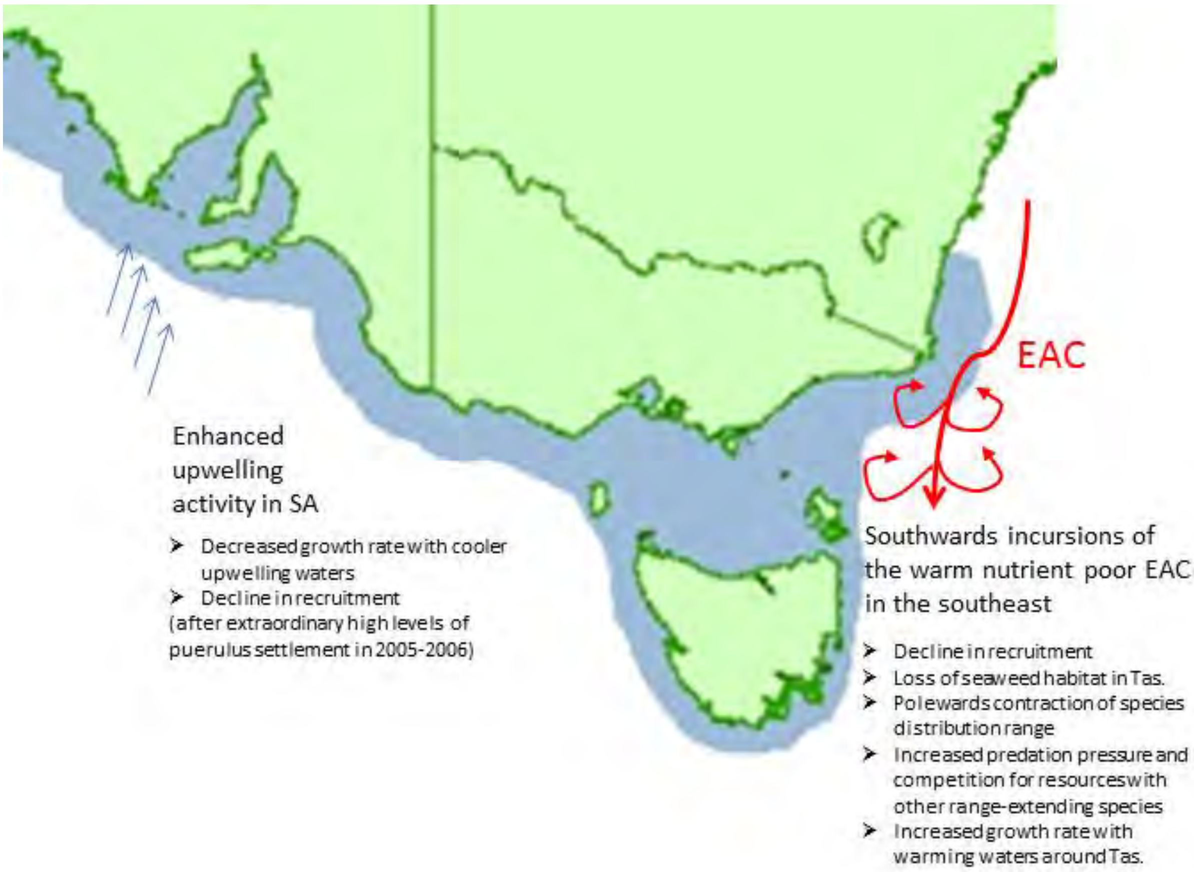

Figure 19. Large-scale drivers of environmental changes in south-east Australia and main effects on SRL biology.

1.4 ECOSYSTEM CONTEXT: PREY, PREDATORS, COMPETITORS

Major predators of both adult and juvenile SRL include octopus, gummy sharks, and a variety of fish. Predation pressure on SRL is likely to increase in Tasmania as octopus populations become more abundant with warming sea temperature, which is likely to both, enhance population productivity, and facilitate the range extension of other octopus species (e.g. *Octopus tetricus*) (Pecl, Frusher et al 2009).

SRL is a generalist species, and consume a wide range of prey, including ascidians, urchins and molluscs (Guest, Frusher et al 2009). Note, that large SRL individuals (of carapace length > 140 mm) deliver key ecosystem services to shallow (depth < 40 m) rocky reef communities in eastern Tasmania through predation on the long-spined sea urchin *Centrostephanus rodgersii*. *Centrostephanus* has progressively extended its distribution from New South Wales to eastern Tasmania over the past three decades as result of larval transport via the southwards incursion of the East Australian Current (Ling, Johnson et al 2009). The species is now viable in eastern Tasmania and has demonstrated the ability to form and maintain extensive sea urchin 'barrens', i.e. bare rocks following the destructive grazing of macroalgal beds. The formation of sea urchin barren constitutes dramatic losses of productivity, habitat complexity and species diversity for reef communities (Ling 2008) and has substantial impact on the productivity of reef species including valuable commercial species such as abalone and SRL (Johnson, Banks et al 2011).

The abundance of eastern rock lobster (*Jasus verreauxi*) is expected to increase in eastern Tasmania as environmental conditions become more suitable for this warmer species. Although eastern rock lobster shows quite different behaviour and biology to SRL, their range extension may increase competition for resources for SRL.

KEY POINTS:

- Increased predation pressure by octopus in Tasmania;
- Increased risk of sea urchin barren formation in eastern Tasmania;
- Chances of increased competition for resources with their northern counterpart, the eastern rock lobster.

1.5 VULNERABILITY AND RESILIENCE OF SRL TO KNOWN CLIMATE CHANGE DRIVERS

SOURCES OF VULNERABILITY:

- Polewards contraction of SRL distribution;
- Increased exposure to other southwards migrating species as document in Tasmania (e.g. increased predation pressure by octopus; increased competition with eastern rock lobster; loss of seaweed bed habitat due to destructive grazing by the invasive long-spined sea urchin);
- Large-scale decline in puerulus recruitment across all south east Australia (Linnane, Gardner et al 2010) correlated with changes in large-scale oceanographic features, in particular the intensification of the southwards incursions of the EAC to eastern Tasmania;
- Changes in oceanographic currents (e.g. intensification of the southwards incursions of the EAC to eastern Tasmania and intensification of upwelling activity in South Australia) will affect local environmental conditions (e.g. temperature, nutrient content), hence will locally have a range of effects on SRL population. Indeed, cooling due to enhanced upwelling activity in South Australia is expected to reduce lobster growth, while warming around Tasmania will increase lobster growth. This spatial heterogeneity of SRL responses to environmental changes is challenging to monitor and incorporate into management.

- Note that the long-term trend in SRL population productivity will result from the combination of changes in local puerulus recruitment (expected to further decline) and changes in individual growth rate (to increase up until an optimal temperature is reached, then decline), while local abundance of SRL will also be affected by broader ecosystem changes (e.g. loss of seaweed habitat; increased predation pressure) (Pecl, Frusher et al 2009).

SOURCES OF RESILIENCE:

- Population genetics suggest that there is no significant sub-division in population structure across SRL Australasian distribution range, hence high population connectivity. SRL larvae have a high dispersal capacity, potentially increasing the species' resilience to changing environmental conditions in particular changes in broad scale oceanographic currents.
- SRL is a generalist species, living in a wide range of reef habitat and consuming a wide range of prey. Successful translocation of SRL individuals in Tasmania, from deep-water to shallow-water inshore reefs, suggests that SRL are resilient to change of habitat with a wide degree of phenotypic plasticity (Chandrapavan, Gardner et al 2010; Green, Gardner et al 2010).

ADDITIONAL STRESSORS

SRL are heavily exploited across south east Australia. Commercial harvesting puts additional stress on the population and decreases the resilience of SRL to environmental perturbations, in particular in the context of the large-scale decline in puerulus recruitment across south east Australia. Moreover, in eastern Tasmania, maintaining a critical biomass density of large SRL is necessary to prevent the risk of further formation of sea urchin barrens by the invasive *Centrostephanus* (Ling, Johnson et al 2009; Johnson, Banks et al 2011).

Table 12. Summary table of the expected effects of environmental changes in south east Australia on SRL biology: recruitment, physiology, habitat / distribution range and trophic context.

	Recruitment	Physiology	Habitat Species distribution	Ecosystem context
Trends & Expected Changes	Recent large-scale decline in SRL recruitment across south east Australia; Further decline expected with changes in large-scale oceanographic features, in particular southern incursions of the warm nutrient-poor EAC;	Increase in growth rate with temperature up to an optimal level; Increase in growth rates around Tas.; Decrease in growth rates in SA due to enhanced upwelling activity; Changes in size at maturity;	Loss of seaweed bed habitat in Tas. due to temperature increase and sea urchin destructive grazing; Polewards contraction of SRL distribution with increasing temperature;	Increased predation pressure by octopus in Tasmania; Increased risk of sea urchin barren formation in eastern Tasmania; Chances of increased competition for resources with their northern counterpart, the eastern rock lobster.
Gaps of knowledge Uncertainty	Uncertainty in dispersal patterns of larvae, source of recruits and drivers of puerulus settlement; Poor knowledge of the long pelagic larval development;	• Lack of fine-scale monitoring and predictability of physiological changes; • Unknown effects of change in pH and UV exposure.	• Little information available bout the contraction of the distribution range;	• Lack of monitoring and low predictability of these ecosystem changes
Vulnerability	Regional decline in recruitment driven by large-scale oceanographic features;	• Spatial discrepancies in changes to SRL physiology hard to account for by management;	• Contraction of the species distribution range	• Commercial exploitation reduces SRL resilience to changes in ecosystem structure (increased predation pressure or competition for resources)
Resilience (adaptability)	High population connectivity across the whole distribution range (large-scale larval dispersal).	• Diversity of physiological responses across south east Australia due to spatial discrepancies in environmental drivers;	• Resilience to change of habitat (successful translocation from deep to shallow reefs); • Ability to occupy a wide range of reef habitats and depths.	• SRL is a generalist species with a plastic diet (wide range of prey).

2. DESCRIPTION OF THE FISHERY

2.1 THE COMMERCIAL FISHERY

Southern rock lobster (SRL) is harvested in South Australia (SA), Tasmania (TAS), Victoria (VIC) and New South Wales (NSW) and it is one of the most valuable wild fisheries in south-east Australia. In NSW, Eastern rock lobster (*Jasus verreauxi*) is the main species harvested and since SRL are caught only occasionally, the following information focuses on the other three SRL states. Total catch in three states consists almost exclusively of SRL but small quantities of eastern rock lobster are taken in eastern Victoria.

TOTAL ALLOWABLE COMMERCIAL CATCH (TACC) AND ANNUAL PRODUCTION

Total rock lobster production in Australia in 2009/2010 was 9,628 tonnes. The catch from three SRL states (TAS, VIC and SA) comprised approximately 42% of the total rock lobster production, or 4,096 tonnes. Among these states, South Australia accounts for the largest share of annual SRL production (54.7% or 2,240 tonnes in 2009/10), followed by Tasmania, and Victoria.

Commercial SRL fisheries in all south-eastern states are subject to restrictions on total allowable catch (TACC). Over the past several years, the TACC has fallen in all south east states, reflecting declines in catch rates and subsequent low recruitment. Tasmania saw increased stock and improved catch rates from 1998 to 2006 attributed to the constraint of total catch as well as extremely high levels of recruitment. However, a prolonged period of very low recruitment since 2006 has contributed to the current decline in the fishery. The TACC for 2009/10 was reduced from 1,524 tonnes in the previous year to 1,471 tonnes, yet was substantially under-caught with a total catch of only 1,356 tonnes. This was the second consecutive year that the TACC was substantially under-caught. South Australia has experienced similar patterns of falling TACC and catches. In the Southern Zone, TACC was reduced from 1,900 tonnes in 2007/08 to 1,770 tonnes in 2008/09, but was substantially under-caught (a 24% fall) with total catch of 1,407 tonnes . This led a further reduction in TACC to 1,400 tonnes for the 2009/10 season, but a subsequent fall in catch to 1,243 tonnes saw the TACC further reduced to 1,250 tonnes for the 2010/11 season. The total catch in 2010/11 was 1,244 tonnes, which was the first time since 2007 that TACC was close to being fully taken. For the Northern Zone, since the introduction of a quota system in 2003/04 season TACC has declined from 625 tonnes to 310 tonnes in 2010/11 season, although catch rates has increased over the past two seasons (Linnane et al 2011a,b). The rock lobster industry in the Western Victoria has faced a numbers of challenges including low stock abundance, reduced profitability, and a 30% reduction in TACC over the last two years prior to declaration of a new management plan in 2009.

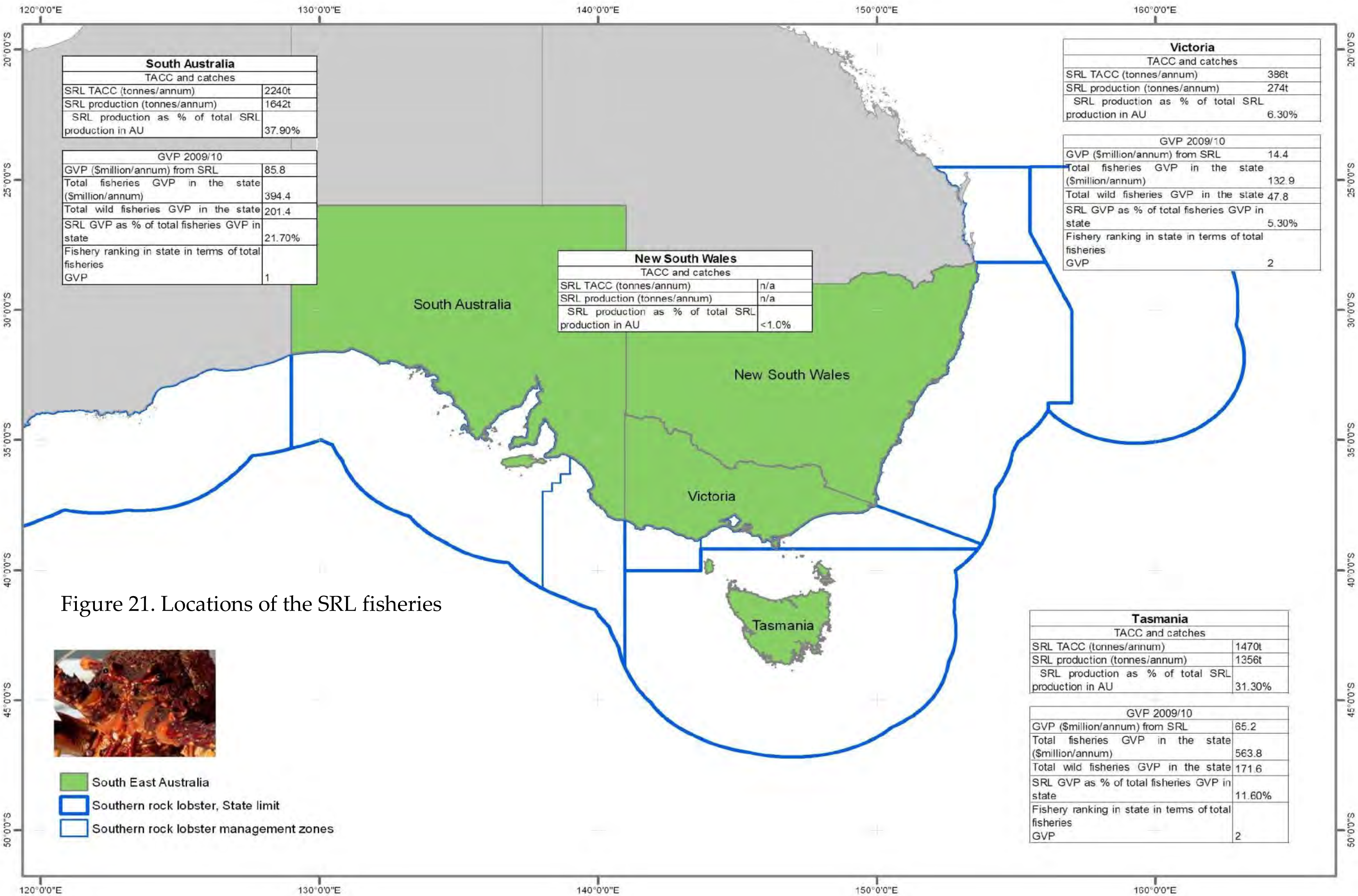

Figure 21. Locations of the SRL fisheries

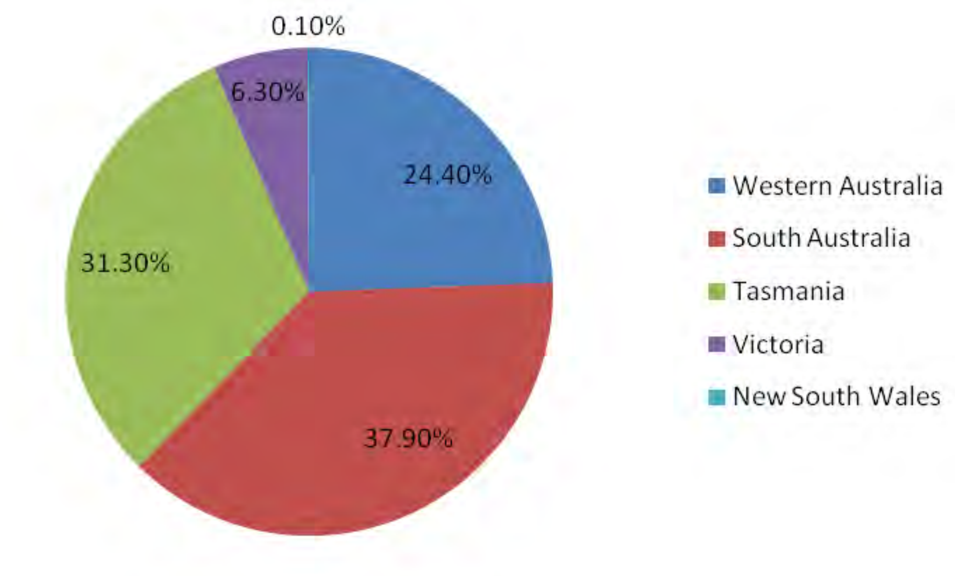

Figure 21: State share of the SRL production (2009/10)

AQUACULTURE PRODUCTION

SRL lobster production is entirely from wild capture fisheries.

ILLEGAL FISHING

Reliable estimates of illegal catches (both greater than the bag limit and lobster smaller than the minimum legal size) are not available, but Illegal catch was included in stock modelling at 2% of the total commercial catch in TAS, based on estimates by Tasmanian Police and DPIPWE quota audit staff. In South Australia, some license holders have raised concerns for illegal fishing by the recreational sector during the annual economic survey.

The SRL fisheries are managed under various control measures across the states, including limited entry, a total allowable commercial catch (TACC), Individual Transferable Quotas (ITQs) system, pot restrictions, gear restrictions, seasonal closures, legal minimum size limits and protection of berried females. In South Australia, the SRL fishery is managed in two separate zones under formal management plans using an ITQ system. The quota management system is monitored through catch disposal records (CDR). CDR forms are formally used to decrement quota, and are submitted by fishers at the time of weighing and consigning the catch. A limited entry regulation applies to the fishery and TACC is set each year for each zone of the fishery. A closed season is used to protect spawning females, and gear restrictions apply. Minimum size limits are also in place for each fishery.

MANAGEMENT

In Tasmania the fishery is managed as a single zone, although the state is divided into eleven stock assessment areas for more detailed regional assessment of the stock. In Victoria the fishery is divided into eastern and western zones. TACC and ITQ systems are the primary output control tools used in all south east states.

In Victoria, ITQ units are attached to Rock Lobster Fishery Access Licenses and it is a requirement that a commercial rock lobster fisher hold a license to which a minimum number of ITQ units are attached. ITQ units are tradable and a license holder may apply to transfer ITQ units to the holder of another Rock Lobster Fishery Access License within the same zone (Department of Primary Industry, 2009). In July 2008, the Minister for Agriculture in Victoria announced a $5 million structural adjustment program to assist the Western Zone rock lobster industry. The one-off program aims to restore investor confidence, improve economic efficiency and provide financial assistance for struggling licence holders to exit the industry. The program was delivered by the Rural Finance Corporation and based on guidelines developed by DEPI in consultation with the rock lobster industry. Upon completion of the program in June 2009, 14 Western Zone Rock Lobster Fishery Access Licences and 366.52 quota units, equivalent to 29.3 tonnes of rock lobster quota, will be permanently removed from the fishery (Department of Primary Industry, 2009).

MARKET AND PROCESSING

The majority of the Australian rock lobster production is exported to Asian markets, especially to the Hong Kong (China) market. Rock lobster processed in TAS is exported to the mainland or directly overseas as live, fresh product. Export of live product has increased dramatically since the late 1980s, while exports of cooked product have declined. TAS, SA and VIC continue to work collaboratively to market their product with the aim of expanding export opportunities beyond South East Asia.

Table 13. Summary of the SRL management measures for the commercial sector

	TAS	SA	VIC
Management zone	One management zone for the State	Southern and Northern zones	Western and Eastern zones
Limited entry	314 licenses	68 (Northern); 181 (Southern)	71 (Western), 47 (Eastern)
Limited seasons	Males: season open from mid November to end September. Fe-males: season open from mid November to end April. (Actual dates change slightly from year to year.)	1 June to 31 October (Northern); 1 May to 30 September (Southern)	Closed season for females from 1 June to 15 November. Closed season for males from 15 September to 15 November.
Limits of pots on vessels	Minimum of 15 pots, maximum of 50 pots	Maximum of 100 pots per license, minimum of 20 pots/license in the Northern zone, 40 in the Southern zone.	Minimum of 20 pots, maximum of 140 per boat in the Western zone, 120 per boat in the Eastern zone.
Quota	TACC of 1523 tonnes (2009/10)	1243 tonnes in the Southern zone, 310 tonnes in the Northern zone (2009/10)	66 tonnes in the Eastern zone, 320 tonnes in the Western zone (2008/09?)
Restrictions on pot size	maximum size of 1250 mm x 1250 mm x 750 mm.		
Escape gaps	one escape gap at least 57 mm high and 400 mm wide and not more than 150 mm from the inside lower edge of the pot, or two escape gaps at least 57 mm high and 200 mm wide and not more than 150 mm from the inside lower edge of the pot	Compulsory in the Northern zone (2 gaps per pot; 57 mm high x 280 mm wide; 180° apart; no obstructions). Optional in the Southern zone.	
Minimum size limits	105 mm CL for females, 110 mm CL for males	105 mm CL for the Northern zone, 98.5mm CL for the Southern zone.	105 mm CL for females, 110 mm CL for males
Berried females	taking of berried females prohibited	No retention of spawning female	

2.2 THE RECREATIONAL FISHERY

SRL fishing is a popular recreational activity in Tasmania and South Australia. In Tasmania the number of licences has more than doubled since the introduction of the recreational licensing system in 1995 to over 21,487 in 2010 (Lyle and Tracy 2010). Estimated recreational catches also increased steadily from 1992 until 2002/2003 after which they appear to have increased in 2006/07 and declined to 107 tonnes in the latest survey in 2008/09. Because the majority of the recreational catch comes from the East coast of Tasmania, where the commercial catch rate has declined, there has been an on-going conflict between commercial fishers and recreational fishers.

SRL fishing is also an important recreational activity in SA. The most recent survey of recreational fishers indicated that during 2007/08 about 48,000 animals were taken representing a combined weight of 60 tonnes (Jones 2009). Higher total, harvested and released numbers and harvested weights were taken in the Southern Zone. The recreational SRL catches in Victoria were estimated at only 20-30 tonnes/year, although the social and economic values associated with diving for rock lobsters is recognised by the recreational communities and contributes to the tourist industry along the Victorian coast (PIRSA SA Fisheries Resources, 2007).

In general, rock lobster pots are the main method of capture, although other gears such as rings (TAS), drop nets (SA), hoop nets (SA, VIC), and various diving methods are also permitted. To date there has been no formal annual TAC set separately for recreational sector in TAS, but the annual catches from the recreational sector are accounted for in setting the commercial TAC. In South Australia, the recreational catch is nominally capped at 4.5% of the total state-wide lobster catch. Under these arrangements, if more that 4.5% is taken, the Minister and Director of Fisheries will use various management measures to ensure the average annual recreational catch remains within the established benchmark (PIRSA Fisheries website). SA also employs closed areas for recreational fishing.

Table 14. Summary of rules for the recreational SRL sector

	TAS	SA	VIC
License requirements	lobster potting licence - 1 recreational pot per person	No license required but lobster pots must be registered.	A Recreational Fishing Licence (RFL) is required when taking, or attempting to take, any species of fish by any method
Daily limit	5 per recreational license holder	4 per day; 8 per boat; possession limit 15	2 (bag limit), 4 (possession limit)
Limited seasons	Males: season open from start November to end September. Females: season open from start November to end April. (Actual dates change slightly from year to year.).	The taking of lobsters from the southern zone is prohibited between 31 May and 1 November every year. In the northern zone is prohibited between 31 May and 1 November every year.	Male - 15 Sep to 15 Nov inclusive. Female - 1 June to 15 Nov inclusive
Restrictions on gear	Pots as per commercial fishers, rings no more than 1 m in diameter, capture by glove only when diving.	Up to 2 rock lobster pots (these must be registered) per person; or 3 drop nets per person; or 3 hoop nets per person. A spear, hook or other pointed instrument are not permitted	Not more than 2 hoop nets.
Escape gaps	as per commercial fishers		
Minimum size limits	as per commercial fishers		Male - 11cm carapace length. Female - 10.5cm carapace length
Berried females	as per commercial fishers	Female rock lobsters carrying eggs are totally protected and must be returned to the water immediately.	Not allowed to possess female rock lobster with eggs, or remove the eggs. Not allowed to take soft-shelled rock lobster
Sale or barter of lobsters	prohibited		
Marking	All recreational lobsters must be tail clipped within 5 minutes of landing. No tail-clipped lobsters to be sold.	All recreational lobsters must have the middle tail fan clipped in half to a recognisable straight line before landing.	All recreational lobsters must to be tail-clipped or tail-punched with a hole not less than 10mm in diameter.

3. SOCIOECONOMIC VALUES

3.1 GROSS VALUE OF PRODUCTION (GVP)

The combined gross value of production (GVP) of SRL in the three south east states in 2009/2010 was $165 million. SRL is the most valuable wild fisheries in SA, accounting for about 43% of wild fisheries GVP (or 22% of the total fisheries GVP including aquaculture). SRL is the second most valuable wild fisheries in Tasmania and Victoria, accounting for 38%, and 30% of total capture fisheries GVP, respectively, in 2009/10. Figure 22 shows the trends in real GVP. The real GVP has increased from 2003 to around 2008 due to the increase in price of SRL despite the strong Australian Dollar, owing to increased demand for rock lobster on international markets and lower supply from key producers (ABARES 2011a).

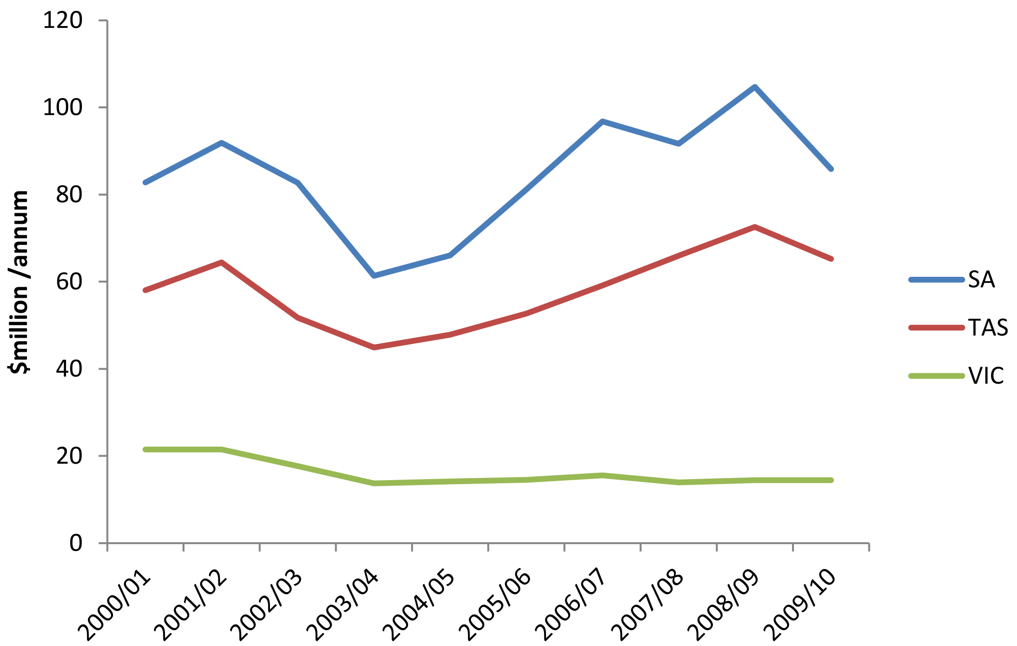

Figure 22. Real GVP of SRL by state

3.2 BEACH PRICES

Overall, the beach prices of SRL has been increasing trend since the late 1990s in both nominal and real teams due to an increased demand in the Asian markets, declining supply from traditional producers, and lack of competition with aquaculture substitutes. In Tasmania, the average nominal beach price was almost doubled from $28/kg in 1999 to $52/kg in 2010, which equates about 33% increase in a real term (inflation adjusted). In South Australia, the beach price has increased by 88% in nominal (or 31% in real price) in the Southern Zone, and by 66% (or 15% in real price) in the Northern Zone from 1997/98 to 2009/10.

The beach prices of SRL are subject to large intra annual fluctuations associated with both phenological characteristics (e.g. moulting season) and market demands. Because the majority of SRL is exported to the Asian market, beach prices are influenced by seasonal demand specific to Asian culture. For example, beach prices tend to be higher around the months of Chinese New Year and Moon Festival, and during these months the beach prices can jump up by 20-30%. Colour of animal also affect the beach prices, with pale colour lobster (called strawberry or brindle) prices being $3-10/kg lower than the red coloured lobster prices. In Tasmania, the new fishing season for SRL usually begins in November and the catch rates in the initial few months tend to be higher, while the beach prices tend to be lower due to the abundance of SRL enter into the markets. Soft shell animals (due to moulding) earlier in the season also get lower prices than the hard shell lobsters. These factors contribute to the fluctuations in beach prices.

Table 15. SRL beach prices in 2009/10 and trend.

2009/10	TAS	VIC	SA
Beach price ($/kg) – are they any premiums/discounts?	Average $38/kg but can reach $65/kg;		
Beach price trends (in real term)	increasing		increasing
Beach price fluctuations (year to year or inter-annual)	Interannual, driven by international supply and demand		

3.3 EXPORT EARNINGS

Rock lobster is Australia's most valuable export fisheries product with a total value in 2009/10 of $400 million dollars (ABARES 2011a). About $150 million or 38% of this total value is originating from the south east Australian fisheries. Compared with the previous year (2008/09), the total value of rock lobster exported from the region declined by about 20% or $39 million. This was driven by a 15% reduction in the volume of rock lobster export.

In late 2010, action by Chinese authorities was taken to ensure all Australian lobster imports into that country are subject to established tariffs. This had an immediate negative impact on export prices. However, the overall effect in annual terms is minimal, given that record high prices prevailed in the first quarter of the 2010/11 financial year (ABARES 2011b). Total RL exports are forecast to remain relatively constant because of the production limitations enforced in the major RL producing states (ABARES 2011b).

3.4 DOWNSTREAM AND FLOW-ON VALUES

The economic importance of the SRL fisheries may be understated when considering only the direct values obtained through the general methods of national statistics, such as GVP. Input-Output (IO) analysis is useful in capturing the multiplicative impacts of capture fisheries. South Australia is currently the only state in south east who quantifies the economic values of downstream activities (e.g. processing, retails, restaurants etc.) supported by the SRL fishery as well as multiplier effects that flow on to other sectors (e.g. transport). In 2009/10, output generated downstream activities was estimated to be $26 million, and additional $128.7 million output from flow-on effects to other sectors of the state economy (EconSearch 2011a,b).

3.5 ECONOMIC RETURNS TO CAPITAL INVESTMENT, ECONOMIC PROFIT

There is limited information on economic returns to capital investment for Australian fisheries. South Australia is the only state who has been systematically collecting economic information of SRL operators for a decade, although studies are underway to collect key economic information for the SRL fisheries in Tasmania and Victoria.

In South Australia, the return on investment is calculated as the profit at full equity (business profit per boat plus interest) as a percentage of the total capital employed (including boats, licence/quota, fishing gear, sheds, vehicles and other capital items used as part of the fishing enterprise). For the Southern Zone, the rate of return to total capital was estimated be 3.3 per cent in 2009/10, significantly down from 2007/08 (5.4%) and 2008/09 (4.9%). The rate of return to capital has followed an increasing trend since 2003/04, despite a large fall in 2009/10, as a result of improved profitability in the fishery and despite increases in average licence value (EconSearch, 2011b). In the Northern Zone, the rate of return to capital in 2009/10 was 1.6%, slightly decreased from 2008/09 (2.2%) but increased from 2007/08 (-0.4%).

The information on economic profit, here defined as the difference between the price of a good produced and the cost of producing that good, is also scares for Australian fisheries due to the lack of information about the fishing costs. Available information in SA suggests that the SRL fishery in the Southern Zone has been generating positive economic profits ($13.4 million in 2009/10), while the Northern Zone SRL fishery has been generating negative economic profit ($ -1.3 million in 2009/10) since 2000/01. The aggregate value of licences was estimated to be $679.9 million (181 licences with an average value of $3.8 million per licence) for the Southern Zone, while it was estimated at $97.8 million (68 licences with an average value of about $1.44 million).

3.6 EMPLOYMENT

The Australian Bureau of Statistics (ABS) Census Survey provides estimates of employment in the commercial fishing, hunting and trapping industry. In 2009–10, total of 11,431 people were employed in the commercial fishing, hunting and trapping industry in Australia, with 7,646 employed in the fishing, hunting and trapping sector, and 3,785 in aquaculture enterprises. According to ABARES (2011a,b) estimates, rock lobster fishing employed 1,154 people, of which roughly half or 546 people were employed in four south east states in 2006.

In 2009/10 the SRL fishery in SA provided 275 full-time job and 447 part-time job, which combine generated 569 full-time equivalent (FTE) jobs in the catching sub-sector (EconSearch, 2011a,b). The downstream activities created an additional employment of around 147.5 FTE jobs and a further 738.8 FTE jobs from flow-on business activities state-wide (EconSearch, 2011a,b). In Tasmanian, an estimated 1,350 jobs are reliant on the commercial SRL fishery (Gardner et al 2011).

3.7 GOVERNMENT FEES, ROYALTY

The commercial fishing industry in South Australia is obliged to meet the agreed costs of all services required to support the commercial sector, including research (biological and economic), management and compliance, as well as a range of additional services in support of the industry. License and registration fees are calculated on a cost-recovery basis. In 2009/10 the average management cost per licence holder was $14,332 for the Southern Zone, $17,339 for the Northern Zone (EconSearch, 2011a). This equates to the annual government revenue of $3.9 million.

In Victoria, licence holders contribute to the cost of management, compliance and research through an annual levy imposed at licence renewal.

3.8 OTHER SOCIAL VALUES

SRL has been an important natural resource for indigenous communities. Although the social values (spiritual, cultural, tradition, subsistence consumption etc.) to the indigenous communities are difficult to quantify, their importance has been widely recognized. For example, providing opportunities for indigenous communities to access the SRL resource for traditional purposes is one of the key objectives in the Rock Lobster Management Plan in Victoria.

3.9 RECREATIONAL VALUES

Based on the available estimated recreational catches in three south east states of around 177-187 tonnes, the value of harvest from recreational sector is roughly $12-13 million/year (assuming a market value of $70/kg). The most recent survey of recreational fishing estimated additional $52 million/year expenditures by the recreational fishers (targeting mainly SRL and abalone) in Tasmania alone over the 12-month period between May 2000 and April 2001 (Henry and Lyle 2003). Another study of recreational fishing in TAS suggests that the recreational lobster fishers have a high willingness to pay between $83 to $112 per trip (Yamazaki et al unpublished), confirming the sizable economic impact from the SRL recreational sector.

Table 16. Recreational SRL catches and their economic values

	TAS	SA	VIC
Southern rock lobster harvest (tonnes/year)	107t (2008/09)	60t (2007/8)	10-20t
Value of harvest ($) (market price*harvest)	$7.5m	$4.2m	$0.7-1.4m
Number of recreational license holders	21,487	N/A	
Expenditure on fishing including travel ($)	$50million/year		
Estimated willingness to pay ($)	$416/year/fisher		

KEY STRESSORS:

- Competition between the commercial and recreational sectors;
- Export-oriented, thus vulnerable to external economic shocks;
- Habitat degradation due to increased sea urchin populations;
- Current low recruitment and high uncertainty about the future recruitment.

REFERENCES

ABARES (2011a). *Australian Fisheries Statistics 2010.* Australian Government .

ABARES (2011b). Outlook. Australian fisheries - outlook & economic indicators. Australian Bureau of Agricultural & Resource Economics & Science (ABARES)

Bermudes, M., & Ritar, A.J. (2008). Tolerance for ammonia in early stage spiny lobster (*Jasus edwardsii*) phyllosoma larvae. *Journal of Crustacean Biology* 28 (4), 695-699 DOI: 10.1651/08-2994.1

Bruce, B., Griffin, D., & Bradford, R. (2007). Larval transport and recruitment processes of southern rock lobster. FRDC report Project No. 2002/007. CSIRO.

Chandrapavan, A., Gardner, C., & Green, B.S. (2010). Growth rate of adult rock lobsters *Jasus dwardsii* increased through translocation. *Fisheries Research* 105, 244-247.

PIRSA SA Fisheries Resources (2007). Current Status & Recent Trends; Available at [http://outernode.pir.sa.gov.au/fisheries/products/sa_fisheries_resources_current_status__and__recent_trends/sa_resources/9]

Department of Primary Industry (2009). Victorian Rock Lobster Fishery Management Plan. Fisheries Victoria Management Report Series No. 70, July 2009

EconSearch (2011a). Economic indicators for the SA Northern Zone Rock Lobster Fishery 2009/10.

EconSearch (2011b). Economic Indicators for the SA Southern Zone Rock Lobster Fishery 2009/10.

Fisheries Victoria (2009). Victorian Rock Lobster Fishery Management Plan 2009. Fisheries Victoria Management Report Series no.70. Department of Primary Industries.

Gardner, C., Frusher, S., Barrett, N., Haddon, M., & Buxton, C. (2006). Spatial variation in size at onset of maturity of female southern rock lobster *Jasus edwardsii* around Tasmania, Australia. *Scientia Marina* 70, 423-430.

Gardner, C. Hartmann, K. & Hobday, D. (2011). Fishery Assessment Report: Tasmanian Rock Lobster Fishery 2009/10. Hobart: Tasmanian Aquaculture and Fisheries Institute.

Green, B. S., Gardner, C., Linnane, A., & Hawthorne, P.J. (2010). The Good, the Bad and the Recovery in an Assisted Migration. *Plos One* 5, 8.

Guest, M.A., Frusher, S.D., Nichols, P.D., Johnson, C.R., & Wheatley, K.E. (2009). Trophic effects of fishing southern rock lobster *Jasus edwardsii* shown by combined fatty acid and stable isotope analyses. *Marine Ecology-Progress Series* 388, 169-184.

Henry, H & Lyle, J.M. (2003). The National Recreational and Indigenous Fishing Survey. Report of FRDC Project No. 99/158, Department of Agriculture, Fisheries and Forestry, Canberra.

Hutchinson, N., Gavine, F., Morris, E., & Longmore, A. (2010). Adaptation of Fisheries and Fisheries Management to Climate Change: Marine, estuarine and freshwater biophysical risk assessment. Technical Report No. 92, Fisheries Victoria, March 2010. Department of Primary Industries, Queenscliff, Victoria, Australia.

Johnson, C. R., Banks, S.C., Barrett, N.S, Cazassus, F., Dunstan, P.K.,Edgar, G.J., Frusher, S.D., Gardner, C., Haddon, M., Helidoniotis, F., Hill, K.L., Holbrook, N.J., Hosie, G.W., Last, P.R., Ling, S.D., Melbourne-Thomas, J., Miller, K., Pecl, G.T., Richardson, A.J., Ridgway, K.R., Rintoul, S.R., Ritz, D.A., Ross, D.J., Sanderson, J.C., Shepherd, S.A., Slotvvinski, A., Swadling, K.M., & Taw, N. (2011). Climate change cascades: Shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. *Journal of Experimental Marine Biology and Ecology* 400, 17-32.

Jones, K. (2009). South Australian recreational fishing survey. South Australian fisheries management series, paper no.54. Adelaide: PIRSA Fisheries and Aquaculture

Ling, S.D. (2008). Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. *Oecologia* 156, 883-894.

Ling, S.D., Johnson, C.R., Frusher, S.D., & Ridgway, K.R. (2009a). Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. *Proceedings of the National Academy of Sciences of the United States of America* 106, 22341-22345.

Ling, S.D., Johnson, C.R., Ridgway, K., Hobday, A.J., & Haddon, M. (2009b). Climate-driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. *Global Change Biology* 15, 719-731.

Linnane, A., McGarvey, R., Feenstra, J., & Hawthorne, P. (2011). Southern Zone Rock Lobster Fishery Status Report 2010/11. Fishery Status report to PIRSA fisheries and Aquaculture. South Australian Research and Development Institute, Adelaide.

Linnane, A., McGarvey, R., Feenstra, J., & Hoare, M., (2011). Northern Zone Rock Lobster Fishery 2010/11, Fishery Status report to PIRSA fisheries and Aquaculture. South Australian Research and Development Institute, Adelaide.

Linnane, A., Gardner, C., Hobday, D., Punt, A., McGarvey, R., Feenstra, J., Matthews, J., & Green, B. (2010). Evidence of large-scale spatial declines in recruitment patterns of southern rock lobster *Jasus edwardsii*, across south-eastern Australia. *Fisheries Research* 105, 163-171.

Linnane, A., Penny, S., Hawthorne, P., & Hoare, M. (2009). Spatial differences in size of maturity and reproductive potential between inshore and offshore fisheries for southern rock lobster (*Jasus edwardsii*) in South Australia. *Fisheries Research* 96, 238-243.

Linnane, A.J., Penny, S.S., & Ward, T.M. (2008). Contrasting fecundity, size at maturity and reproductive potential of southern rock lobster *Jasus edwardsii* in two South Australian fishing regions. *Journal of the Marine Biological Association of the United Kingdom* 88, 583-589.

Lyle, J.M., & Tracey, S.R. (2010). Tasmanian Recreational Rock Lobster and Abalone Fisheries: 2008-09 Fishing Season. TAFI Report, Tasmanian Aquaculture and Fisheries Institute, Hobart.

Ovenden, J.R., Brasher, D.J., & White, R.W.G. (1992). Mitochondrial DNA analyses of the red rock lobster *Jasus edwardsii* supports an apparent absence of population subdivision throughout Australasia. *Marine Biology* 112, 319-326.

Pecl, G., Frusher, S., Gardner, C., Haward, M., Hobday, A., Jennings, S., Nursey-Bray, M., Punt, A., Revill, H., & van Putten, I. (2009). The East Coast Tasmanian Rock Lobster Fishery - Vulnerability to climate change impacts and adaptation response options. Report to the Australian Government Department of Climate Change.

TAC Committee (2011). Report and Determination for 2011/12 Rock Lobster Fishery. TAC Committee.

Thomas, C.W., Crear, B.J., & Hart, P.R. (2000). The effect of temperature on survival, growth, feeding and metabolic activity of the southern rock lobster, *Jasus edwardsii*. *Aquaculture* 185, 73-84.

Yamazaki, S., Rust, S., Jennings, S., Lyle, J., & Frijlink, S. (Unpublished). Valuing recreational fishing in Tasmania and assessment of response bias in contingent valuation.

Appendix 4 - Governance benchmarking survey

For each of the attributes below you are asked to indicate whether you believe that attribute is either:

1. Fully in place in the fishery;
2. Partially in place in the fishery;
3. Not in place in the fishery.

For some attributes that you identify as being either fully or partially in place, you are also asked to indicate the extent to which they are operational in the fishery (always/mostly; sometimes; rarely/never). For attributes that you identify as not being in place in the fishery, you are also asked to indicate whether their importance is currently recognized and whether progress is being made towards implementing them.

Accountability

- **Rights and responsibilities of all parties clearly defined**
- **Mechanisms to ensure operational accountability**
- **Independent fishery report cards and/or accreditation**
- **Biological performance indicators**
- **Economic, social and community performance indicators**
- **Ecosystem performance indicators**
- **Inter-agency and inter-jurisdictional roles and responsibilities clearly defined**

Planning

- **Inclusive and collaborative planning process**
- **Planning occurs across the entire fishery value chain**
- **Planning is forward-looking and strategic**
- **Planning includes risk assessment and evaluation**
- **Goals and objectives of fishery management clearly defined**
- **Plan includes process to monitor outcomes, values and pressures**
- **Plan has social legitimacy**
- **Planning review process is responsive and self-reflexive**

Transparency

- **Non-confidential data easily accessible**
- **Open and publically recorded decision-making processes**
- **Clear processes for making trade-offs between conflicting objectives**
- **Open and systematic process for fishery performance monitoring and**

evaluation

- Mechanisms for meaningful stakeholder involvement in decision-making
- Clear and equitable rules for allocation of rights across user groups
- Clear and equitable processes to deal with interactions or conflicts among user groups

Incentives

- Incentives fully aligned with goals and objectives
- Secure and durable individual or community harvesting or area fishing rights
- Competitive and well-developed market for fishing rights
- Monitoring and enforcement of fishing rights
- Monitoring and enforcement of other regulations, including input controls
- Incentives to avoid negative externalities, including habitat damage and by-catch
- Monitoring of negative externalities
- Incentives to minimise compliance costs
- Incentives to minimise management costs
- Mechanisms to ensure re-investment of some economic rent in fishery

Adaptability

- Adaptive and responsive decision-making
- In-season adjustment to management possible
- Limit and target reference points used and regularly reviewed
- Range of operational fisheries management tools available
- Management is at appropriate temporal and spatial scales
- Flexibility to manage range shifting species
- Ability and preparedness to effect change in management

Knowledge

- Systematic use of localized fisher and community knowledge
- Decision systems integrate ecological, social and economic knowledge
- Management based on 'best' science
- Research provides timely, robust and useable science

(Adapted from Grafton et al 2006)

Appendix 5 - Governance benchmarking results per case study

ABALONE GOVERNANCE BENCHMARKING

Accountability	NSW	SA	Tas	Vic
• Rights and responsibilities of all parties clearly defined	X-	√	√	P
• Mechanisms to ensure operational accountability	P-	√	√	P-
• Independent fishery report cards and/or accreditation	P	P0	√	√
• Biological performance indicators	P0	√	P	√
• Economic, social and community performance indicators	P0	P	X0	X
• Ecosystem performance indicators	P0	√	X0	X
• Inter-agency and inter-jurisdictional roles and responsibilities clearly defined	X-	√	√	√

Planning	NSW	SA	Tas	Vic
• Inclusive and collaborative planning process	X	√	√	√
• Planning occurs across the entire fishery value chain	X-	X-	√	P-
• Planning is forward-looking and strategic	P0	P	√	√
• Planning includes risk assessment and evaluation	P-	√	X0	√-
• Goals and objectives of fishery management clearly defined	P	√	P	P
• Plan includes process to monitor outcomes, values and pressures	P-	P-	P-	√-
• Plan has social legitimacy	P	√	P	P
• Planning review process is responsive and self-reflexive	P0	√-	√	√-

Transparency	NSW	SA	Tas	Vic
• Non-confidential data easily accessible	P	X	P	√
• Open and publically recorded decision-making processes	P-	√	√	√

	NSW	SA	Tas	Vic
• Clear processes for making trade-offs between conflicting objectives	X-	P-	P-	X-
• Open and systematic process for fishery performance monitoring and evaluation	P-	√	√	P-
• Mechanisms for meaningful stakeholder involvement in decision-making	X	√	√	√-
• Clear and equitable rules for allocation of rights across user groups	X-	√	√	X
• Clear & equitable processes to deal with interactions or conflicts among user groups	X-	P-	√	X

Incentives	NSW	SA	Tas	Vic
• Incentives fully aligned with goals and objectives	X-	X0	√	X
• Secure and durable individual or community harvesting or area fishing rights	P	√	√	P
• Competitive and well-developed market for fishing rights	P-	√	√	P-
• Monitoring and enforcement of fishing rights	P-	√	√	√
• Monitoring and enforcement of other regulations, including input controls	P-	√	√	√
• Incentives to avoid negative externalities, including habitat damage and by-catch	P-	√	X0	√
• Monitoring of negative externalities	X-	P-	X0	X
• Incentives to minimise compliance costs	X-	P	P	X
• Incentives to minimise management costs	P-	P	P	X
• Mechanisms to ensure re-investment of some economic rent in fishery	X-	X-	P	P

Adaptability	NSW	SA	Tas	Vic
• Adaptive and responsive decision-making	P0	P	√	√
• In-season adjustment to management possible	P0	P	√	√
• Limit and target reference points used and regularly reviewed	P0	P-	X	√
• Range of operational fisheries management tools available	P0	√-	√	√

• Management is at appropriate temporal and spatial scales	P	P	√	X
• Flexibility to manage range shifting species	P0	P0	√	X0
• Ability and preparedness to effect change in management	P0	P-	P	X

Knowledge	NSW	SA	Tasmania	Vic
• Systematic use of localized fisher and community knowledge	P-	P-	√	√
• Decision systems integrate ecological, social and economic knowledge	P0	P-	P	√
• Management based on 'best' science	P0	√-	√	P-
• Research provides timely, robust and useable science	P-	√-	√	P

Notes:

√ = Fully in place and always/mostly operational

√ - = Fully in place and sometimes operational

√ 0 = Fully in place but rarely/never operational

P = Partially in place and always/mostly operational

P- = Partially in place and sometimes operational

P0 = Partially in place and rarely/never operational

X = Not in place but importance recognized and working towards it

X- = Not in place but importance recognized but not working towards it

X0 = Not in place and importance not recognized

Accountability	CMW
• Rights and responsibilities of all parties clearly defined	√
• Mechanisms to ensure operational accountability	√0
• Independent fishery report cards and/or accreditation	
• Biological performance indicators	√
• Economic, social and community performance indicators	
• Ecosystem performance indicators	√
• Inter-agency and inter-jurisdictional roles and responsibilities clearly defined	√

Planning	CMW
• Inclusive and collaborative planning process	√
• Planning occurs across the entire fishery value chain	√
• Planning is forward-looking and strategic	√
• Planning includes risk assessment and evaluation	√
• Goals and objectives of fishery management clearly defined	√
• Plan includes process to monitor outcomes, values and pressures	√-
• Plan has social legitimacy	
• Planning review process is responsive and self-reflexive	√

Transparency	CMW
• Non-confidential data easily accessible	√
• Open and publically recorded decision-making processes	√
• Clear processes for making trade-offs between conflicting objectives	P-
• Open and systematic process for fishery performance monitoring and evaluation	√
• Mechanisms for meaningful stakeholder involvement in decision-making	√
• Clear and equitable rules for allocation of rights across user groups	√
• Clear and equitable processes to deal with interactions or conflicts among user groups	

Incentives	CMW

• Incentives fully aligned with goals and objectives	√
• Secure and durable individual or community harvesting or area fishing rights	√
• Competitive and well-developed market for fishing rights	√
• Monitoring and enforcement of fishing rights	√
• Monitoring and enforcement of other regulations, including input controls	√
• Incentives to avoid negative externalities, including habitat damage and by-catch	P-
• Monitoring of negative externalities	√
• Incentives to minimise compliance costs	√
• Incentives to minimise management costs	√
• Mechanisms to ensure re-investment of some economic rent in fishery	

Adaptability	CMW
• Adaptive and responsive decision-making	√
• In-season adjustment to management possible	
• Limit and target reference points used and regularly reviewed	√
• Range of operational fisheries management tools available	P-
• Management is at appropriate temporal and spatial scales	P
• Flexibility to manage range shifting species	√
• Ability and preparedness to effect change in management	P-

Knowledge	CMW
• Systematic use of localized fisher and community knowledge	√
• Decision systems integrate ecological, social and economic knowledge	√
• Management based on 'best' science	√
• Research provides timely, robust and useable science	√

SNAPPER GOVERNANCE BENCHMARKING

Accountability	NSW	SA	Vic
• Rights and responsibilities of all parties clearly defined		√	X
• Mechanisms to ensure operational accountability		√-	P
• Independent fishery report cards and/or accreditation		P	√
• Biological performance indicators		√	X
• Economic, social and community performance indicators		P-	X
• Ecosystem performance indicators		P	√
• Inter-agency and inter-jurisdictional roles and responsibilities clearly defined		X	X

Planning	NSW	SA	Vic
• Inclusive and collaborative planning process		P	P-
• Planning occurs across the entire fishery value chain		X-	√-
• Planning is forward-looking and strategic		P-	X
• Planning includes risk assessment and evaluation		√	√-
• Goals and objectives of fishery management clearly defined		√	√
• Plan includes process to monitor outcomes, values and pressures		√-	X
• Plan has social legitimacy		P	X
• Planning review process is responsive and self-reflexive		P	X

Transparency	NSW	SA	Vic
• Non-confidential data easily accessible		P	√
• Open and publically recorded decision-making processes		P-	P
• Clear processes for making trade-offs between conflicting objectives		P-	X
• Open and systematic process for fishery performance monitoring and		√	P

evaluation			
• Mechanisms for meaningful stakeholder involvement in decision-making		√	√
• Clear and equitable rules for allocation of rights across user groups		√-	X
• Clear & equitable processes to deal with interactions or conflicts among user groups		X	P-

Incentives	NSW	SA	Vic
• Incentives fully aligned with goals and objectives		X0	√
• Secure and durable individual or community harvesting or area fishing rights		X0	P
• Competitive and well-developed market for fishing rights		X0	P
• Monitoring and enforcement of fishing rights		X0	√
• Monitoring and enforcement of other regulations, including input controls		√	√
• Incentives to avoid negative externalities, including habitat damage and by-catch		X0	√
• Monitoring of negative externalities		X0	P
• Incentives to minimise compliance costs		P-	P
• Incentives to minimise management costs		P-	P
• Mechanisms to ensure re-investment of some economic rent in fishery		X0	X-

Adaptability	NSW	SA	Vic
• Adaptive and responsive decision-making		P	P
• In-season adjustment to management possible		√	√
• Limit and target reference points used and regularly reviewed		P	X
• Range of operational fisheries management tools available		P	√-
• Management is at appropriate temporal		√	P

and spatial scales			
• Flexibility to manage range shifting species		√-	√
• Ability and preparedness to effect change in management		√	√-

Knowledge	NSW	SA	Vic
• Systematic use of localized fisher and community knowledge		P-	√
• Decision systems integrate ecological, social and economic knowledge		P-	√
• Management based on ‘best’ science		√	√
• Research provides timely, robust and useable science		√-	√

Accountability	SA	Tasmania	Victoria
• Rights and responsibilities of all parties clearly defined	√	P	P
• Mechanisms to ensure operational accountability	√	P-	√
• Independent fishery report cards and/or accreditation	√	√	√
• Biological performance indicators	√	√	√
• Economic, social and community performance indicators	P	P	X
• Ecosystem performance indicators	P-	√	X
• Inter-agency and inter-jurisdictional roles and responsibilities clearly defined	√	P	√

Planning	SA	Tasmania	Victoria
• Inclusive and collaborative planning process	P-	√	√
• Planning occurs across the entire fishery value chain	P	√	P
• Planning is forward-looking and strategic	√-	√	P
• Planning includes risk assessment and evaluation	√-	√	P
• Goals and objectives of fishery management clearly defined	√	X0	√
• Plan includes process to monitor outcomes, values and pressures	P-	X0	√-
• Plan has social legitimacy	P	√	√
• Planning review process is responsive and self-reflexive	√-	√	√-

Transparency	SA	Tasmania	Victoria
• Non-confidential data easily accessible	P	P	√
• Open and publically recorded decision-making processes	√-	√	√
• Clear processes for making trade-offs between conflicting objectives	P-	P-	X
• Open and systematic process for	√	P	√-

fishery performance monitoring and evaluation			
• Mechanisms for meaningful stakeholder involvement in decision-making	√	√	√-
• Clear and equitable rules for allocation of rights across user groups	√	√	√-
• Clear and equitable processes to deal with interactions or conflicts among user groups	√-	P	√0

Incentives	SA	Tasmania	Victoria
• Incentives fully aligned with goals and objectives	P-	P	√-
• Secure and durable individual or community harvesting or area fishing rights	√	√	P
• Competitive and well-developed market for fishing rights	√	P	P
• Monitoring and enforcement of fishing rights	√	√	√
• Monitoring and enforcement of other regulations, including input controls	√	√	√
• Incentives to avoid negative externalities, including habitat damage and by-catch	√-	√0	√
• Monitoring of negative externalities	P	√	P
• Incentives to minimise compliance costs	P-	P-	P
• Incentives to minimise management costs	P-	P-	√-
• Mechanisms to ensure re-investment of some economic rent in fishery	P-	P	√-

Adaptability	SA	Tasmania	Victoria
• Adaptive and responsive decision-making	√-	P	√
• In-season adjustment to management possible	√-	X	√
• Limit and target reference points used and regularly reviewed	√	√	√

• Range of operational fisheries management tools available	√	√	√-
• Management is at appropriate temporal and spatial scales	P	P	P
• Flexibility to manage range shifting species	P-	√	√-
• Ability and preparedness to effect change in management	√-	√-	P-

Knowledge	SA	Tasmania	Victoria
• Systematic use of localized fisher and community knowledge	√-	P	P
• Decision systems integrate ecological, social and economic knowledge	√-	P	P
• Management based on 'best' science	√	√	√
• Research provides timely, robust and useable science	√	√	√

Appendix 6 - References

This section contains all the references cited in this report, except for the case study chapters and species profiles where the appropriate references are cited at the end of each chapter

Adger,W.N., Arnell, N.W., & Tompkins, E.L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change* 15, 77-86.

Bates AE, Pecl GT, Frusher S, Hobday AJ, Wernberg T, Smale DA, Dulvy N, Edgar GJ, Feng M, Fulton EA, Hill N, Holbrook NJ, Radford B, Slawinski D, Sunday JM, Thompson PA, Watson R (in press). Evaluating pathways of geographic range extensions and contractions. *Global Environmental Change*

Grafton, Kompas, McLoughlin, & Rayns. (2006). *Benchmarking for Fisheries Governance.* Australian National University.

Haggan, N., Neis, B., & Baird, I. G. (2007). Fishers' knowledge in fisheries science and management. (Nigel Haggan, N. Barbara, & I. G. Baird, Eds.) Coastal Management (Vol. 4, pp. 2008-2008). UNESCO Publishing. Retrieved from http://portal.unesco.org/science/en/files/5199/11744843521Fishers-Knowledge-sections2007.pdf

Hobday A and Pecl GT (2014). Identification of global marine hotspots: sentinels for change and vanguards for adaptation. *Reviews in Fish Biology and Fisheries* 24:409–413

Holbrook NJ, Bindoff NL (1997). Interannual and decadal temperature variability in the southwest pacific ocean between 1955 and 1988. *J. Climate*, 10, 1035–1049.

Kalaugher, E., Bornman, J.F., Clark, A. & Beukes, P. (2012). An integrated biophysical and socio-economic framework for analysis of climate change adaptation strategies: The case of a New Zealand dairy farming system. *Environmental Modelling & Software.*

Last P, White W, Gledhill D, Hobday A, Brown R, Edgar G, Pecl G (2011). Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices Global Ecology and Biogeography 20(1): 58-72.

Madin, EMP, Ban, NC, Doubleday, ZA, Holmes, TH, Pecl, GT, Smith, F (2012). Socio-economic and management implications of range-shifting species in marine systems. *Global Environmental Change*

Moser & Ekstrom (2010). A framework to diagnose barriers to climate change adaptation. *PNAS vol.107* , 22026-22031.

Norman-López A, Pascoe SD, Hobday AJ, (2011), Potential economic impacts of climate change on Australian fisheries and the need for adaptive management, *Climate Change Economics*, 02 (03): 209-235.

Nursey-Bray, M, Pecl G, Frusher, S, Gardner, C, Haward, M, Hobday, A, Jennings, S, Punt, A, Revill, H, van Putten, I (2012). Communicating climate change: climate change risk perceptions and rock lobster fishers, Tasmania, *Marine Policy* 36 (2012) 753 – 759

Oliver, E. C. J., S. J. Wotherspoon, M. A. Chamberlain and N. J. Holbrook (2014), *Projected Tasman Sea extremes in sea surface temperature through the 21st century*, Journal of Climate, 27 (5), pp. 1980-1998, doi: 10.1175/JCLI-D-13-00259.1

Pecl, G., Frusher, S., Gardner, C., Haward, M., Hobday, A., Jennings, S., Nursey-Bray, M., Punt, A., Revill, H., & van Putten, I. (2009). The east coast Tasmanian Rock Lobster fishery: vulnerability to climate change impacts and adaptation response options. Department of Climate Change Australia.

Pecl G.T., 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., & Stoklosa R. (2011). Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia. Fisheries Research and Development Corporation, Project 2009/070

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Pitt NR, Poloczanska ES, Hobday AJ (2010). Climate-driven range changes in Tasmanian intertidal fauna. *Marine and Freshwater Research* 61, 963–970.

Plagányi EE, Weeks SJ, Skewes TD, Gibbs MT, Poloczanska ES, Norman-López A, Blamey LK, Soares M, Robinson WML (2011). Assessing the adequacy of current fisheries management under changing climate: a southern synopsis. ICES J. Mar. Sci. 68(6): 1305-1317

Ridgway KR (2007). Long-term trend and decadal variability of the southward penetration of the East Australian current *Geophysical Research Letters* 34: L13612, doi:10.1029/2007GL030393, 2007.GRL.

Silvertown, J. (2009) A new dawn for citizen science. *Trends in Ecology and Evolution,* 24 (9), 467-471, ISSN 0169-5347, 10.1016/j.tree.2009.03.017.

Stafford Smith M, Horrocks L, Harvey A, Hamilton C (2011). Rethinking adaptation for a 4 °C world. Philosophical Transactions of the Royal Society A, 369:196–216

Stobart, B., Mayfield, S. & McGarvey, R. (2013). Maximum Yield or Minimum Risk: Using Biological Data to Optimize Harvest Strategies in a Southern Australian Molluscan Fishery. *Journal of Shellfish Research* 32(3), 899-909.

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