

THE EAST COAST TASMANIAN  
**ROCK  
LOBSTER  
FISHERY**

Vulnerability to climate change impacts and adaptation response options



A report to the Australian Government Department of Climate Change



# Vulnerability to climate change impacts and adaptation response options



**Australian Government**  
Department of Climate Change



**A report to the Australian Government Department of Climate Change**

## **The east coast Tasmanian rock lobster fishery – vulnerability to climate change impacts and adaptation response options**

Gretta Pecl<sup>1</sup>, Stewart Frusher<sup>1</sup>, Caleb Gardner<sup>1</sup>, Marcus Haward<sup>2</sup>, Alistair Hobday<sup>3</sup>, Sarah Jennings<sup>4</sup>, Melissa Nursey-Bray<sup>5</sup>, André Punt<sup>6</sup>, Hilary Revill<sup>7</sup>, and Ingrid van Putten<sup>4</sup>

Largely as a function of the interdisciplinary nature of the research, this report represents a major contribution from all authors; the order of co-authors given here is alphabetical.

### **Addresses**

1. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania
2. School of Government and Antarctic Climate and Ecosystems CRC, University of Tasmania
3. Climate Adaptation Flagship, CSIRO, Hobart, Tasmania
4. School of Economics and Finance, University of Tasmania
5. National Centre for Marine Conservation and Resource Sustainability, Australian Maritime College – a specialist Institute of the University of Tasmania
6. Pop Model Ltd
7. Wild Fisheries Management Branch, Department of Primary Industries and Water

### **Please cite this report as:**

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.

© Commonwealth of Australia 2009

This work is copyright. Apart from any use as permitted under the *Copyright Act 1968* (Cth), no part may be reproduced by any process without prior written permission from the Commonwealth. Requests and inquiries concerning reproduction and rights should be addressed to the Commonwealth Copyright Administration, Attorney General's Department, Robert Garran Offices, National Circuit, Barton ACT 2600 or posted at <http://www.ag.gov.au/cca>

ISBN: 978-1-921298-68-4

Cover image: Rock Lobster (Bruce Miller)

### **Disclaimer**

The authors do not warrant that the information in this book is free from errors or omissions. The authors do not accept any form of liability, be it contractual, tortious or otherwise, for the contents of this book or for any consequences arising from its use or any reliance placed upon it. The material includes the views or recommendations of third parties and does not necessarily reflect the views of the Australian Government, or indicate a commitment to a particular course of action. The material in this document is provided for general information only, and on the understanding that the Australian Government is not providing professional advice on a particular matter. Before any action or decision is taken on the basis of this material the reader should obtain appropriate independent professional advice.

### **Acknowledgments**

Funded by the Australian Government through the Department of Climate Change. We thank the Tasmanian rock lobster fishers for contributing valuable information to the various surveys that are incorporated into this report, and the interviews that were conducted as part of Chapter 3 of the report. Many fishers and industry representatives attended the workshop where the range of potential adaptation strategies were generated. Jason Bedelph, Fiona Brodribb and Zoe Doubleday helped prepare some of the figures and provided substantial assistance with the formatting and proof reading of this document. Sven Frijlink kindly allowed access to the unpublished data from recreational fishers cited in Chapters 2 and 3. Dr Adrian Linnane (South Australian Research and Development Institute) kindly provided constructive feedback on the draft report.

# Contents

---

<b>Glossary of Terms</b> .....	<b>vi</b>
<b>Executive summary</b> .....	<b>viii</b>
<b>1 Introduction</b> .....	<b>1</b>
1.1 Project background and aims .....	1
1.2 Project framework .....	2
1.3 Report structure .....	3
<b>2 Current status of the Tasmanian rock lobster fishery</b> .....	<b>4</b>
2.1 Biological component of the rock lobster system .....	4
2.1.1 Rock lobster life-history and distribution overview .....	4
2.2 Human component of the rock lobster system .....	7
2.2.1 Recreational fishery .....	8
2.2.2 The commercial sector.....	8
2.2.3 Rock lobster processors.....	11
2.2.4 Commercial rock lobster fishing business characteristics .....	11
2.3 Current and emerging issues for the fishery.....	12
2.4 Governance framework of the rock lobster fishery .....	13
2.4.1 Background to current arrangements .....	13
2.4.2 Governance: key elements .....	13
2.4.3 Existing governance arrangements and adaptive capacity.....	14
<b>3 Rock lobster fishers' perceptions of climate change</b> .....	<b>15</b>
3.1 Risk perception exercise.....	15
3.1.1 Method.....	15
3.1.2 Results.....	15
3.1.3 Discussion.....	17
<b>4 Potential bio-physical impacts of climate change on rock lobster stocks on the east coast of Tasmania</b> .....	<b>19</b>
4.1 Recent climate change in the east coast rock lobster fishery region .....	19
4.2 Climate change and models.....	20
4.2.1 Predicted climate change scenarios .....	21
4.3 Response of rock lobster stocks to predicted climate change.....	25

4.3.1 Regional assessments (M1).....	27
4.3.2 Puerulus settlement (M2).....	30
4.3.3 Model estimated recruitment and relationship to temperature (M3).....	31
4.3.4 Rock lobster stock projections.....	33
4.3.5 Are recent trends in the stock consistent with model predictions?.....	36
4.3.6 Other potential impacts.....	38
4.3.7 Broader ecosystem issues.....	38
4.4 Summary of potential impacts of climate change on rock lobster.....	41
<b>5 Existing adaptive capacity and potential adaptation actions for the rock lobster fishery.....</b>	<b>43</b>
5.1 Improving adaptive capacity through communication strategies.....	43
5.2 Adaptation planning.....	44
5.3 Adaptation strategies.....	49
<b>6 Adaptation policy assessment and strategy formation – an overview.....</b>	<b>51</b>
6.1 Introduction.....	51
6.2 Adaptation policy assessment methods.....	51
6.3 Issues for adaptation policy assessment and strategy formation in the rock lobster fishery.....	52
6.4 Key lessons for adaptation policy assessment and strategy formation in the rock lobster fishery.....	56
<b>7 Key gaps in knowledge.....</b>	<b>58</b>
<b>8 Issues for further investigation.....</b>	<b>64</b>
High priority: core issues.....	64
Medium priority: essential requirements but not as urgent as high priorities above.....	65
Low priority: potential for useful outcomes.....	66
Summary.....	66
<b>9 Conclusions.....</b>	<b>67</b>

<b>Appendix 1: Staff</b> .....	<b>70</b>
<b>Appendix 2: Summary of rock lobster fishery regulations</b> .....	<b>71</b>
<b>Appendix 3: Rock lobster industry structure and regional differences</b> .....	<b>72</b>
<b>Appendix 4: Provisions of the <i>Living Marine Resources Management Act 1995 (Tas)</i></b> .....	<b>74</b>
<b>Appendix 5: Objectives of the resource management and planning system of Tasmania</b> .....	<b>75</b>
<b>Appendix 6a: Risk perception: East coast rock lobster, Tasmania</b> .....	<b>76</b>
<b>Appendix 6b: Risk perception interview schedule</b> .....	<b>81</b>
<b>Appendix 7: Climate model selection</b> .....	<b>84</b>
<b>Appendix 8: SST and model hind-cast recruitment estimates</b> .....	<b>86</b>
<b>Appendix 9: Overview of the model</b> .....	<b>87</b>
<b>Appendix 10: Model outputs – Case C</b> .....	<b>88</b>
<b>References</b> .....	<b>93</b>

## Glossary of terms

---

**Adaptation:** a deliberate process of change in anticipation of, or in reaction to, external stimuli or stress.

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

**Autonomous adaptation:** changes that are expected to occur spontaneously in reactive response to the effects of climate change, without any intervention occurring.

**Catchability:** the fraction of a fish stock which is caught by a defined unit of the fishing effort.

**East Australian Current (EAC):** this ocean current moves warm water down the east coast of Australia. The EAC originates in the Coral Sea and flows southwards before separating from the continental margin to flow eastwards into the Tasman Sea. This is the dominant current system affecting the east coast of Tasmania.

**Exploitable biomass:** the mass of lobsters above legal size limit.

**Maximum Sustainable Yield (MSY):** the largest average catch or yield that can continuously be taken from a stock under existing environmental conditions.

**Phyllosoma:** the pelagic (living in the upper layers of the ocean) larval stage of rock lobster before they moult into the final puerulus larval stage.

**Planned adaptation:** adaptation actions taken as part of a strategic response to climate change, including those intended to reduce the impact of climate change on the system and those intended to enhance a system's adaptive capacity, and hence resilience.

**Puerulus:** the last larval stage of rock lobster. This is the life stage that settles on the reef and begins the benthic phase of the life cycle.

**Recruitment:** the amount of fish added to the exploitable stock each year. It is a function of settlement and subsequent growth, natural mortality and/or migration.

**Resilience:** the amount of change a system can undergo without losing its basic function and structure while maintaining options to develop.

**Settlement:** the number of puerulus settling on viable habitat. In this report it is measured by the number of puerulus settling on artificial substrates for a given time period.

**Total Allowable Catch (TAC):** the total catch allowed from the stock in a given time period (per quota year), for the commercial and recreational rock lobster fisheries combined.

**Total Allowable Commercial Catch (TACC):** the component of the TAC allocated to the commercial sector

**Total Allowable Recreational Catch (TARC):** the component of the TAC allocated to the recreational sector.

**Vulnerability:** the potential for a system to be harmed as a consequence of exposure to external stimuli or stress, considering both its impacts on the system and the system's adaptive capacity.

**Vulnerability assessment:** the process of identifying, quantifying, and prioritizing (or ranking) the vulnerabilities in a system.

Based in part on *Climate Change 101*, OECD (2009); Nelson et al. (2007); Füssel and Klein (2002)

## Executive summary

---

This case study examines the potential impacts of climate change on the Tasmanian rock lobster fishery, and identifies several options and opportunities for adaptation.

Climate change is expected to have a significant impact on the Tasmanian rock lobster industry with declines in rock lobster biomass occurring initially in northern and north-eastern regions before eventually also potentially declining in the south. As water temperatures increase it is also expected that the range of a damaging sea urchin will be extended. The study found that the rock lobster fishery is reasonably well placed to adapt to the challenges of climate change but identified several possible measures that will assist with this adaptation including improved catch modelling, long-term monitoring, better risk assessment, and effective education and communication with the industry. Understanding the impacts of climate change on the Tasmanian rock lobster industry is important because this fishery is ideally placed to be an ‘early warning signal’ for Australian fisheries generally.

### THE FISHERY

The Tasmanian rock lobster fishery is based on the harvest of the southern rock lobster around the state. It is a valuable industry to Tasmania, being the state’s second most important wild harvest fishery with an estimated value of \$72 million (at the first point of landing). The fishery provides employment for around 760 people in production, processing and distribution. Catching lobsters is also a cherished activity of many Tasmanians, and the fishery supports a thriving recreational sector.

However, climate change is expected to have a significant impact on the ocean environment around Tasmania, particularly on the east coast. Sea temperatures are rising, currents are changing and impacts are already being seen in species composition and ecosystems. These changes are expected to continue in the future, and will produce a range of flow-on impacts on ocean-based industries such as the rock lobster fishery.

At present, management policies for the fishery do not explicitly account for climate change. By understanding how climate change may affect the lobster fishery, managers and local communities are empowered to make better choices between available options. Recognition of the risks associated with climate change is a valuable first step towards better planning and more effective management.

#### LOBSTER GROWTH AND TEMPERATURE

Rock lobsters can live for 20 years or more. In Tasmania, lobsters grow slower in the cooler southern regions and faster in the warmer northern regions. Associated with these spatial patterns in growth is a difference in the size at maturity: larger sizes at maturity are associated with faster growth. Because of the uniform minimum legal size limit for harvest, the densities of lobsters are highest in regions of slower growth, with a considerable portion of the stock below the size limit for capture in southern regions. In south western regions, most females do not reach the legal size limit due to exceptionally slow growth.

## THIS CASE STUDY

To explore the impacts of climate change, this case study examined existing information on the lobster fishery in four regions along the Tasmanian east coast. It investigated the connections between variables expected to alter with climate change (such as temperature and currents), with the biology of lobsters and the manner in which they are harvested (eg, catch composition and catch rates).

Using this information, the existing stock assessment model was modified to project forward and evaluate the likely exploitable biomass and egg production levels for two climate change scenarios – a mid-range scenario (IPCC emission scenario A1B) in the year 2030 and the same mid-range scenario plus a high range scenario (A1FI) in 2070.

This investigation brings together expertise from the biophysical, economic, social and governance disciplines. The report describes the potential impacts of climate change and explores different strategies for adaptation.

Combining information from surveys, expert knowledge and a workshop attended by industry representatives, resource managers, individual fishers, processors and quota holders, the investigation identified a range of potential actions that could be undertaken to minimise the threat of climate change to rock lobster stocks and the long-term viability of the industry.

## WHY IS THIS CASE STUDY IMPORTANT?

The Tasmanian rock lobster fishery is ideally placed to be an ‘early warning signal’ for Australian fisheries generally. Being at the interface of the East Australian Current and southern ocean waters, it is experiencing climate warming faster than any other region in the southern hemisphere. Warming waters in this region have already resulted in altered species distributions and ecosystem impacts. Both industry and government are already considering management responses that take account of these changes making the fishery more responsive to climate related impacts. By building on this solid framework, including the new information provided in this report, this fishery will continue to be an example of adaptive planning and implementation that can provide valuable lessons for fisheries both nationally and internationally.

## PROJECTED IMPACTS ON THE LOBSTER INDUSTRY

Specific impacts of climate change and their consequences for the Tasmanian rock lobster industry are likely to include:

- **Warmer waters by 2030:** Coastal waters off eastern Tasmania will warm to the equivalent of temperatures currently experienced further north in Tasmania or lower Victoria by 2030.
- **Even warmer by 2070:** The warming will be equivalent to the Victorian coast (mid-range scenario) or New South Wales coast (high scenario) by 2070. The associated low productivity and ecosystem function associated with these warmer water temperatures are also expected to move south. This may result in these areas being unable to support rock lobster populations of the same size as found today (section 4.3.1).

- **Long term declines in recruitment of lobsters:** Monitoring of catch rates of lobster larvae off eastern Tasmania show a long-term trend of decline. Under both the mid-range and high climate change scenarios, north-eastern and eastern regions of Tasmania are expected to experience continued declines in larval settlement (section 4.3.2).
- **Declines in lobster biomass:** Declines in rock lobster biomass are predicted to occur initially in northern and north-eastern regions, before eventually also declining in the south (section 4.3.3). Model projections indicated initial gains in biomass, through increased growth, although this would be followed by a reduction in biomass due to declines in recruitment. This pattern was consistent in all regions and for both climate change scenarios.
- **The spread of a second species of lobster:** Climate change may extend the range of a second lobster species into Tasmania (the eastern rock lobster). This was not considered in projections shown here as the species appears less productive than southern rock lobster and only trivial recruitment into Tasmania has been observed to date. Nevertheless, opportunities to target alternative species such as the eastern rock lobster may present themselves and should be carefully monitored.
- **The spread of a damaging sea urchin:** As the water temperature increases it is expected that the range of the sea urchin *Centrostephanus* will be extended. *Centrostephanus* is a rock-scraping grazer and large numbers of the sea urchin can significantly degrade ecosystems (producing so called urchin barrens) and reduce the quality of lobster habitat (section 4.3.7).
- **Using lobsters to control sea urchins:** The interaction between lobsters and *Centrostephanus* is a complex one because large lobsters eat sea urchins. Research is currently underway to determine the density of large lobster biomass that would be required to control sea urchin populations. Active management of the population of large lobsters will be necessary to enhance retention of increased numbers of large lobsters in coastal regions most at risk.
- **Impacts will vary between regions:** Impacts of climate change on the industry will be regional (as opposed to state-wide). The south-western regions are predicted to increase and/or maintain catches longer than other regions.

#### WHAT'S A LOBSTER WORTH?

The commercial rock lobster fishery has been an important component of the Tasmanian fishing industry for over 150 years, dating back to the 1800s.

The main determinant of total returns for a rock lobster fishing operation is the beach price which is largely determined by carapace size or weight and colouring. Processors prefer weights of 0.8 – 2 kilograms. The average weighted beach price in 2008 was around \$42 per kilogram but reached in excess of \$65 per kilogram during periods of high demand/low supply and favourable exchange rates.

## UNCERTAINTIES

There are uncertainties in attempting to forecast future impacts of a complex system such as the lobster fishery. In particular, there is uncertainty surrounding the interplay of catchability and other fishery variables, and the possibility of ecosystem surprises:

- **Catch rates and stock size:** Lobsters become more active as the temperature increases, and as they become more active their catchability increases (therefore catch rates are expected to increase). However, this increase in catch rate is independent of changes in stock size predicted here (section 4.3.7). In stock assessments, catchability is normally assumed to be constant, or stationary through time, so any change would bias conclusions about the condition of the southern rock lobster stock. Other processes that may also bias conclusions by changing through time are growth rates, average recruitment and fishing efficiency.
- **Surprises:** There is the possibility of ‘ecosystem surprises’ and ‘ecological thresholds’ that may result in abrupt changes in ecosystem function, structure or quality, which may impact on rock lobster stocks (either positively or negatively). Sudden, unexpected shifts in ecosystem dynamics are a significant source of uncertainty for managers. Additionally, the impacts of ocean acidification are also unknown and these may be significant (section 4.3.7).

## CAPACITY TO ADAPT

The Tasmanian rock lobster fishery is reasonably well placed to adapt to the challenges of climate change. Although fisheries management policies do not currently explicitly consider climate change, management is beginning to actively integrate the longer-term issues associated with climate change with the relatively shorter-term responses to current stock trends. In addition to this, active management of the stock in the shorter-term suggests the industry has the capacity to evolve and respond to longer-term trends even if the response to climate change is not explicitly managed.

This report identifies several possible measures and actions that may provide a constructive way forward for the rock lobster fishery:

- **Incorporate changes in lobster recruitment into catch modelling:** There is a need to include the impact of climate change on lobster recruitment into projection modelling used in setting the annual total allowable catch.
- **Establish a long-term lobster monitoring program:** Ongoing, long-term monitoring of lobster populations at specific sites (including unfished sites) will allow changes in lobster biology to be incorporated into fisheries management.
- **Develop regional management tools:** There will be a need to use spatial management tools rather than state-wide management tools to address issues arising from climate change. One issue where this is specifically

### PERCEPTIONS OF CLIMATE CHANGE

As part of the vulnerability assessment, a risk perception study was conducted to gain some understanding of commercial fishers’ perceptions of the potential impact of climate change on the industry. All respondents were male, with an average of 10–15 years experience in the industry. Of those interviewed, about 40 per cent did not perceive that climate change was a problem at all. Another 30–40 per cent felt that there was currently no consensus about the reality of climate change. These fishers noted that changes in climate did seem to be occurring, but were not convinced that it was human-induced, and that even if it was, considered it would not have a great impact on the industry.

Younger fishers were less sceptical and more positive about adaptation than fishers closer to retirement. For example, in this survey, 100 per cent of fishers 40 years or under believed climate change was a reality.

required is in managing the potential impact of the sea urchin *Centrostephanus*. Different regional management regimes may, however, be perceived by recreational and commercial fishers as more complex or restrictive. Getting regional management accepted may be a significant challenge.

- **Redefine standard risk management:** Responses to climate change should become part of standard risk management within the industry.
- **Develop longer-term priorities:** Management regimes may need to develop, and constantly re-evaluate, longer-term priorities. Flexibility in fishing across multiple species could be enhanced by reviewing management arrangements for allied fisheries simultaneously (e.g. fisheries with similar logistic requirements such as scallops, rock lobster, and giant crab), rather than a single species in isolation.
- **Make no-regrets adaptation a priority:** Identification of cost effective, ‘no-regrets’ adaptation measures should be a priority (i.e. those measures that would be beneficial under any future scenario). For example:
  - Measures that reduce the potential impact of the sea urchin *Centrostephanus*
  - Communication tools that improve relationships between commercial and recreational fishers over resource allocation issues
  - Utilising a multi-criteria analysis approach in the current fishery management to facilitate incorporation of climate change issues and challenges into ‘core business’.

### COMMUNICATING WITH FISHERS

Communication about climate change needs to be culturally appropriate and palatable to fishers, so that the issue of climate change will penetrate and be accepted within existing cultural norms. In this context it is important to engage with not only how communities identify vulnerability (in this case the quota, debt and succession), but how they engage with, and are able to act to respond to those threats.

Adaptation involves the interaction of a range of social, economic, cultural, ecological and policy factors. Building effective adaptation will require the development of frameworks and models that effectively integrate the various disciplinary approaches. Communication and education awareness for the fishing industry is essential in order to facilitate the implementation of the best strategies. A well-informed industry will be more proactive and will therefore more effectively manage the impacts of climate change, compared with an industry that ignores the threat or an industry that does not have access to sound information and tools for management of the fishery.

## GAPS AND FUTURE ASSESSMENTS

One of the key reasons the east coast Tasmanian rock lobster fishery was selected as a case study for the NCVA was that, relative to most other fisheries, it is a comparatively well researched and data-rich system. Even so, this assessment was still limited by major gaps in knowledge. The study recommends that thorough vulnerability and adaptation assessments should be a high priority for all of Australia’s major fisheries and critical marine ecosystems.

Key gaps that are readily apparent for the current case study include:

- **Impacts on lobster biology:** Full understanding of the impact of increased temperatures, ocean acidification and other climate change variables on rock lobster growth and recruitment
- **Responses by recreational and commercial fishers:** Clear understanding of the likely behavioural responses of users of the rock lobster resource to future climate-induced changes
- **Capacity to explore long-term adaptation:** There is a need to explore innovative institutional mechanisms for promoting long-term adaptation that accounts for intergenerational equity in resource utilisation. Decisions undertaken in the short term have the potential to impact on future generations of fishers.

The report provides a baseline for future assessments. Further assessment should be able to evaluate a range of adaptation measures to provide government and industry with a blueprint to develop policy that is aimed at maximising the opportunities and minimising the harm associated with climate change.

What is needed is an integrated, multi-criteria decision framework for use in assessing different options aimed at adapting Tasmania’s marine fisheries. This will require the development of appropriate objectives, criteria and weights based on input from a broad range of stakeholders. It should reflect the sector-specific characteristics identified in Chapter 6. While this would provide the capacity to develop medium- to long-term adaptation strategies, there is also an urgent need to identify, evaluate and implement no-regrets measures in the rock lobster fishery.

### THE LOOMING PERIL OF THE URCHIN

By 2025, average temperatures along the entire east Tasmanian coast will likely reach a critical threshold that allows the sea urchin *Centrostephanus* to complete its larval life cycle in most years, therefore substantially increasing the risk of barrens forming. Once established, *Centrostephanus* denudes coastal reefs by overgrazing seaweeds and invertebrate fauna and forming persistent barrens. In the islands between NSW and Tasmania, *Centrostephanus* has already denuded approximately 50 per cent of shallow reefs and barren regions are increasing in north-eastern and eastern Tasmania. Experiments in Tasmania show that when sea urchins are removed, the seaweed cover and community structure recovers to that of ungrazed regions within 18 months. There is evidence to suggest that high densities of very large lobsters may be critical in preventing barrens formation.

# 1 Introduction

---

## 1.1 PROJECT BACKGROUND AND AIMS

This case study provides an initial assessment of the vulnerability and adaptive capacity of the Tasmanian east coast rock lobster fishery system to climate change. The rock lobster fishery system is broadly defined to include both biophysical and associated human, or socio-economic, systems.

It is one of a number of case studies initiated as part of the National Coastal Vulnerability Assessment. The case studies are intended to explore and illustrate different aspects of the coastal adaptation challenge in the context of a diverse range of climate change impacts and situations.

The Tasmanian rock lobster fishery was selected as a case study as it is a comparatively well researched and data-rich fishery system. Also, it is ideally placed to be an ‘early warning signal’ for Australian fisheries generally as the east coast of Tasmania is experiencing warming faster than any other region in the southern hemisphere. Greater insight into the implications of changing ocean temperature and currents can provide insights for climate change adaptation options for other coastal fisheries. The case study presented in this report:

- describes the biophysical and human systems that comprise the Tasmanian east coast rock lobster fishery;
- predicts future climate change impacts on Tasmanian east coast rock lobster productivity, yield and distribution under two climate change scenarios;
- assesses the capacity of rock lobster fishers to adapt to predicted climate impacts;
- identifies the range of adaptation responses available to resource users and managers;
- reviews methods that could be used to assess and prioritise possible adaptation responses within the rock lobster fishery and highlights key features of the rock lobster fishery system that adaptation policy makers need to consider.

In doing so, the project has:

- developed procedures for downscaling global climate model data to predict sea surface temperatures for the Tasmanian east coast rock lobster assessment areas (or fishing zones);
- developed models for predicting the effect of sea surface temperature on Tasmanian east coast rock lobster recruitment, growth and biomass;
- expanded stakeholders’ knowledge of the likely impacts of climate change on the Tasmanian east coast rock lobster system and their understanding of sources of vulnerability;
- identified opportunities and constraints related to the uptake of adaptation responses;
- identified key knowledge gaps and policy questions which can guide the direction for future research and adaptation policy development.

The case study has been conducted in a way that reflects two key principles that are essential for developing an effective understanding of adaptation and vulnerability. These are the need for (i) an integrated, interdisciplinary approach and (ii) an inclusive and participatory process. Our commitment to these principles is evidenced in the composition of the project team which brings together expertise in climate interpretation, marine and fisheries ecology, economics, sociology, and fisheries management and governance. The involvement of key stakeholders, including commercial and recreational fishers and fish processors, in the development of adaptation scenarios and strategies reflects our commitment to an inclusive and participatory adaptation policy development process.

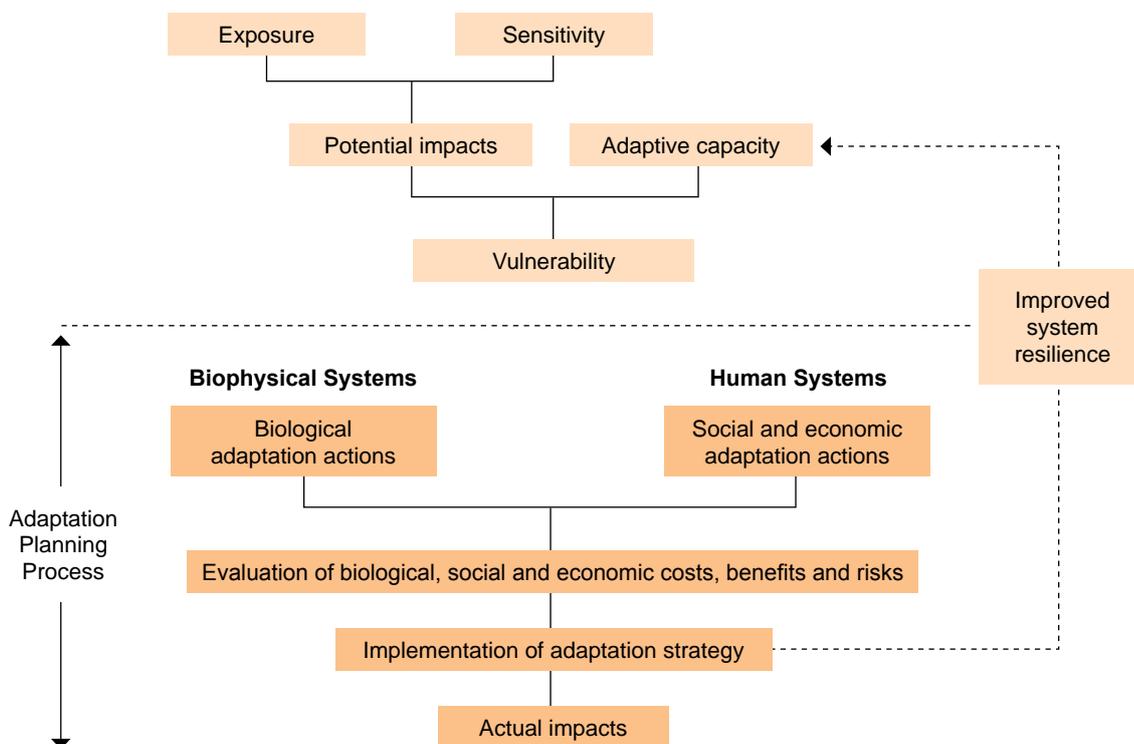
## 1.2 PROJECT FRAMEWORK

This case study has been organised around a conceptual framework that recognises the importance of adaptation as one key element of the overall response to climate change (Figure 1). Figure 1 also illustrates the role a dynamic adaptation planning process can have in increasing the resilience and adaptive capacity of a system.

Broadly defined, adaptation refers to a deliberate process of change in anticipation of or in reaction to external stimuli or stress (Nelson et al. 2007). Adaptation includes changes that might occur in order to avoid or limit damaging impacts as well as changes made to take advantage of beneficial opportunities that might arise.

The term adaptive capacity is used to describe how well-equipped a system is to adjust to climate change to reduce potential damage, to take advantage of opportunities, or to cope with the consequences (Füssel and Klein 2002). Adaptive capacity of a social system reflects such factors as: access to information about threats and possible adaptive measures; availability of the resources and institutions to implement measures; cultural acceptability; incentives; and political will (Füssel 2008). Adaptive capacity, together with the severity of exposure and the system’s sensitivity, determines a system’s vulnerability to climate change.

In this case study, as is common in the climate change literature, we distinguish between autonomous and planned adaptation. Autonomous adaptation refers to changes that are expected to occur spontaneously in reactive response to the effects of climate change, without any government intervention occurring. For example, autonomous adaptation occurs when fishers shift fishing effort between fishing areas in response to observed changes in resource abundance. Adaptation may also involve deliberate, planned actions taken as part of a strategic response to climate change. Planned adaptation includes measures intended to reduce the impact of climate change on the system. In the fisheries context this might involve managers changing the level of catch allowed in the fishery or the type of gear allowed (Hobday and Poloczanska 2007). Füssel and Klein (2002) refer to planned adaptation of this type as implementation measures. Planned adaptation also includes facilitation measures that enhance a system’s adaptive capacity, and hence resilience. Measures that increase fishers’ awareness of the threat of climate change and result in flexible and responsive management systems are examples of planned adaptation.



**Figure 1: Illustrating the role of vulnerability assessment and adaptation planning for a fishery.**

### 1.3 REPORT STRUCTURE

The structure of this report is as follows: Chapter 2 provides an overview of the Tasmanian east coast rock lobster fishery system, highlighting its biological, economic and social characteristics and existing management and governance arrangements. The risk perceptions of Tasmanian rock lobster fishers, particularly as they relate to climate change, are discussed in Chapter 3. Chapter 4 provides predictions under two scenarios of the effects of climate change on key drivers of system exposure and of their impact on rock lobster recruitment, growth and biomass and other ecosystem indicators. Impact and adaptation scenarios are described and existing vulnerabilities identified in Chapter 5. Possible adaptation actions (autonomous and planned) for the Tasmanian rock lobster fishery are also identified. Chapter 6 provides a brief overview of selected adaptation assessment decision tools and develops key lessons for adaptation policy makers in the fishery. Gaps in knowledge are described in Chapter 7 and priority issues for further assessment are highlighted in Chapter 8. The conclusion to this report (Chapter 9) summarises key issues identified in this case study.

## 2 Current status of the Tasmanian rock lobster fishery

### 2.1 BIOLOGICAL COMPONENT OF THE ROCK LOBSTER SYSTEM

#### 2.1.1 ROCK LOBSTER LIFE-HISTORY AND DISTRIBUTION OVERVIEW

Several species of rock lobster are commercially harvested in different regions of Australia, including the western (*Panulirus cygnus*), southern (*Jasus edwardsii*), and eastern (*Jasus verreauxi*) rock lobster, as well as a number of tropical species in northern Australia. This report focuses on the southern rock lobster in Tasmania and this summary of rock lobster life history identifies issues that are considered pertinent to climate change, in particular the projected change in sea temperature and currents due to the increased influence of the East Australian Current (EAC). The characteristics that relate to climate change include:

- abundance of early stage lobster larvae (phyllosoma) is related to the distribution of different water masses (this section);
- growth is related to sea temperature, with slow growth in southern regions resulting in a large portion of the stock in the south being below the size limit for capture (this section);
- settlement of lobsters (puerulus stage) from the plankton is correlated to water temperature (section 4.3.2);
- recruitment of lobsters into the fishery is related to water temperature (section 4.3.3).

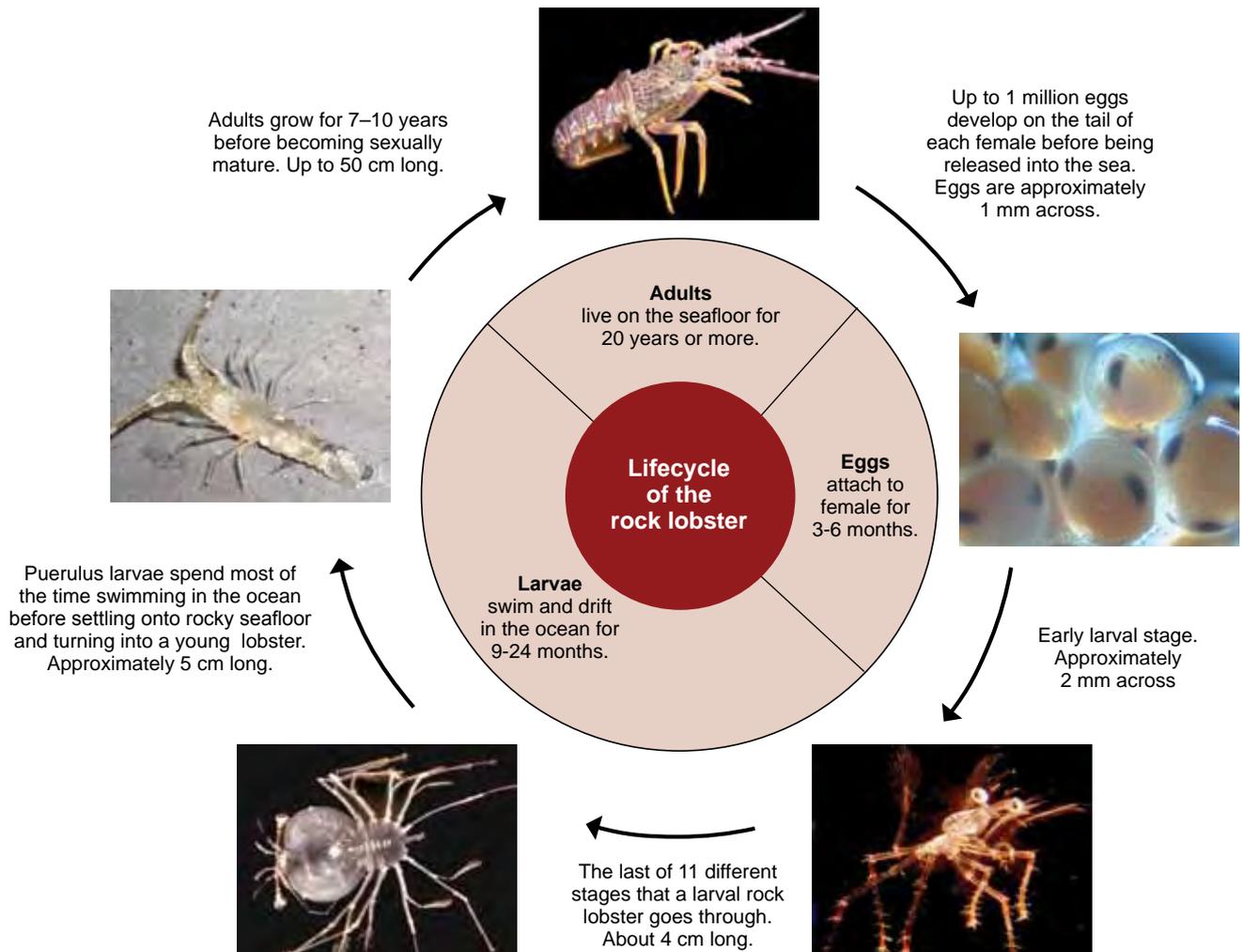
The relevant biology of southern rock lobster in Tasmania is summarised below. More detail is available in Frusher (1997) and Frusher et al. (1999).

#### *Life cycle*

Southern rock lobster eggs hatch into larvae (phyllosoma) with an oceanic phase estimated to last from 9 to 24 months (Figure 2). 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-millimetre lobster and begin the benthic (bottom-dwelling) phase of their life cycle.

Little is known about the oceanic larval phase, although samples of phyllosoma larvae collected during oceanic plankton research surveys show higher abundance in cooler waters just south of the sub-tropical convergence (Tasman front) – the region where the nutrient-poor warm EAC meets the nutrient-rich cooler Southern Ocean waters (Bruce et al. 2000). It has been hypothesised that the main winter peak observed at the puerulus settlement monitoring sites along eastern Tasmania is associated with the alignment of this water mass off the coast. Modelling of potential dispersal pathways suggests that recruits in north-eastern Tasmania are primarily sourced from eggs derived from the eastern Tasmanian management zones, whereas recruitment further south on the east coast is considered to be sourced from the south-western and western regions of Tasmania and as far afield as south-eastern South Australia (Bruce et al. 2007). While the south-eastern regions of South Australia were identified by Bruce et al. (2007) as a potential source of recruits, there was no correlation between projected settlement from the larval transport model and observed puerulus settlement on collectors throughout South Australian, Victorian and Tasmanian regions, suggesting that there are factors in addition to currents that affect puerulus recruitment. Additionally, the contribution of larvae to eastern Tasmania from eggs hatched in regions from south-eastern South Australia to south-western Tasmania would be expected to decline in importance as a stronger EAC would shift the sub-tropical convergence further south so that its influence in distributing larvae would diminish.

Vulnerability to climate change impacts and adaptation response options



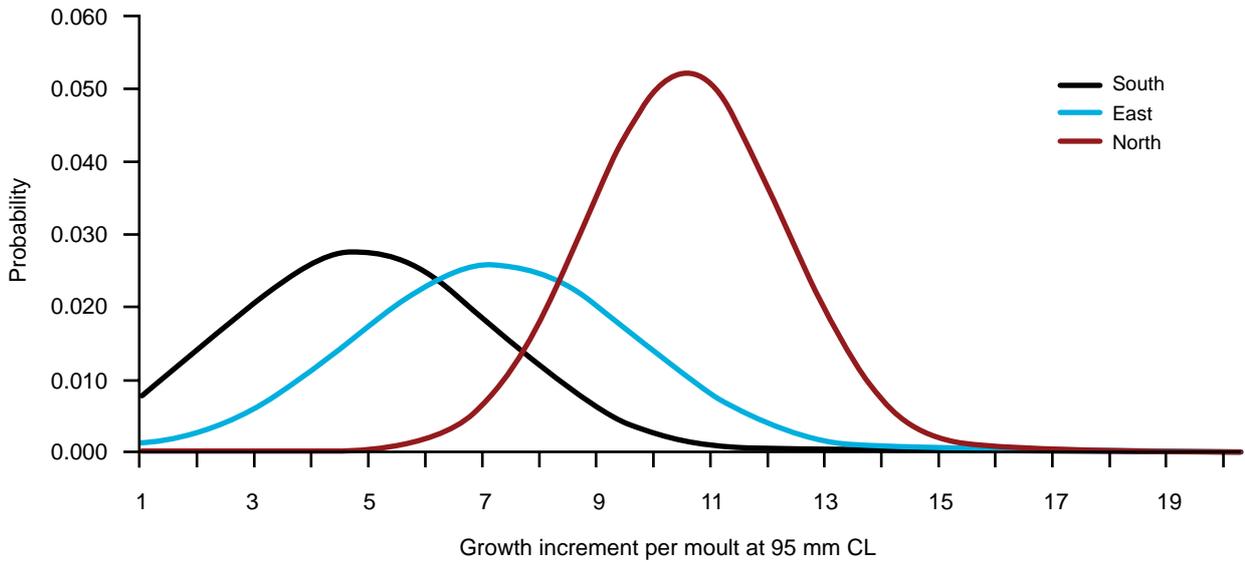
**Figure 2: Overview of the life cycle of southern rock lobster.**

**Growth**

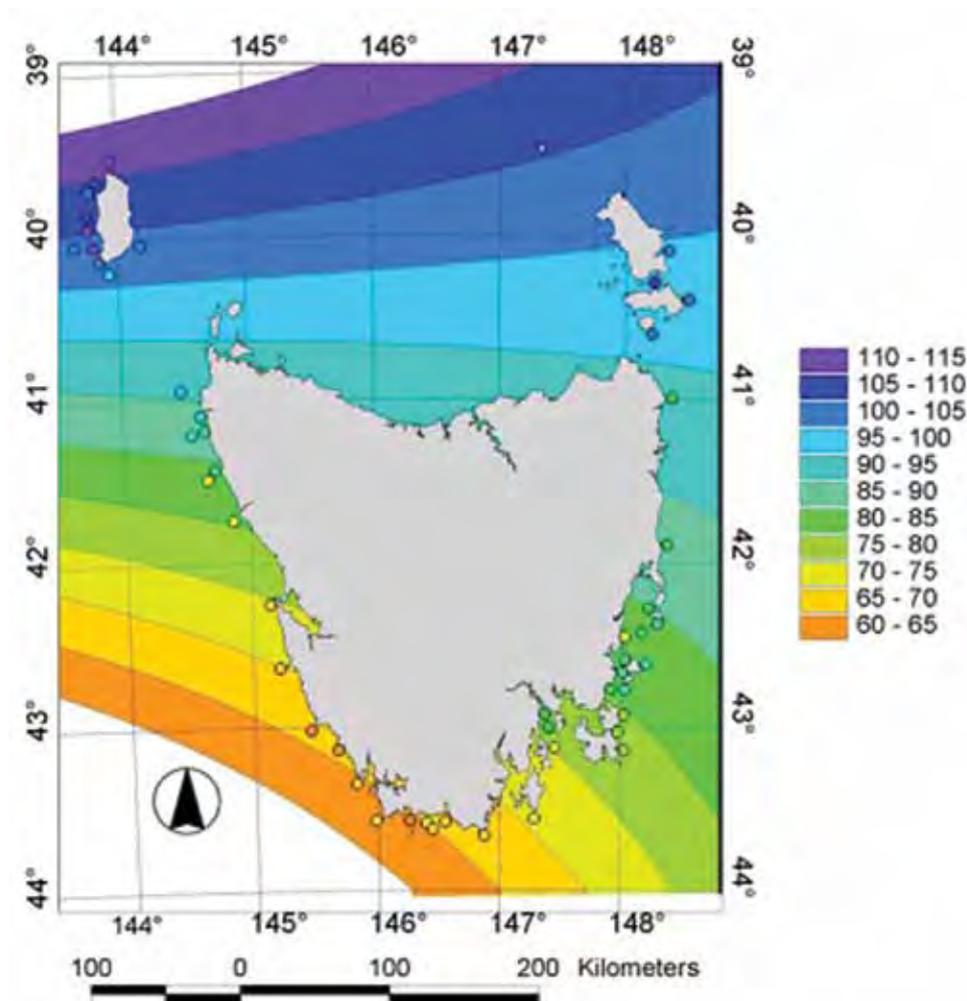
Southern rock lobsters, like all crustaceans, grow by periodically shedding their complete exoskeleton in a process called moulting. The number of moults that a lobster undertakes annually is dependent on its size and maturity. In general, juvenile lobsters moult several times each year and the number of moults per year decreases as they reach maturity. After reaching sexual maturity, lobster normally undertake one moult each year and growth of female lobsters is often reduced because of the high demand on energy reserves for egg production.

In Tasmania, rock lobster growth rates vary spatially, with slow growth in cooler southern regions and faster growth in warmer northern regions (Figure 3). Associated with these spatial patterns in growth is a difference in the size at maturity: larger sizes at maturity are associated with faster growth (Figure 4). Because of the uniform minimum legal size limit for harvest implemented throughout Tasmania, the densities of lobsters are highest in regions of slower growth, with a considerable portion of the stock below the size limit for capture in southern regions. In southern regions, most females do not reach the size limit due to exceptionally slow growth.

In addition to the effect of temperature, growth is also likely to be affected by food availability and population density; although very little information is available on the impact of these parameters on growth. There is very little information on diet of adult, juvenile or larval lobsters in general, although adults are known to be omnivorous; their diet includes ascidians, urchins and molluscs (Guest et al., unpublished data).



**Figure 3: Comparison of growth increments for 95 mm CL (carapace length) male lobsters caught in southern, eastern and northern regions of Tasmania. In the northern region, male lobsters moult twice per year, thus further increasing the differences in annual growth rates.**



**Figure 4: Regional size at maturity estimates for female southern rock lobsters (from Gardner et al. 2006). Note that the SAM (size-at-maturity) band widths are smaller on the west coast suggesting closer temperature isobars for this region. For the same latitude, SAM values are generally higher on the east coast. Dots represent locations of samples used for generating this pattern.**

## 2.2 HUMAN COMPONENT OF THE ROCK LOBSTER SYSTEM

The rock lobster industry in Tasmania is important for commercial and recreational users. It is Tasmania’s second highest value fishing industry, and therefore of importance socially and economically. Understanding the profile of the industry will be important in assessing how the human components of the fishery may be affected by any climate-induced changes, and also facilitates insights into what adaptation strategies might be appropriate.

Rock lobsters in Tasmania were an important source of food for coastal indigenous tribes (Frusher 2001). Reports from the earliest explorers state that lobsters (known as crayfish) were part of the diet observed at indigenous campsites (Horner 1995). Despite requests for allocation of lobsters to indigenous people, the same rules and regulations for the taking of lobsters, either commercially or recreationally, apply.

### 2.2.1 RECREATIONAL FISHERY

Rock lobster fishing is a popular recreational activity in Tasmania and the number of licences has rapidly increased since the introduction of the current recreational licensing system in 1995 (Lyle and Morton 2004). Rock lobsters are primarily taken by recreational fishers using rock lobster pots (traps) and by SCUBA diving, but in some areas rock lobster rings are also used. During the 2006–07 season approximately 16,583 pot, 8717 dive, and 5210 ring licenses were issued to recreational fishers (Lyle 2008). Recreational rock lobster fishers are restricted in the gear that can be used and in their daily bag limits (currently five lobsters; see Appendix 2 for a list of recreational regulations).

A legislative resource-sharing arrangement allocates part of the total allowable catch (TAC) to the recreational sector (total allowable recreational catch, TARC) creating a ‘notional’, or whole-of-sector, maximum catch level. A recent survey of the recreational fishery estimated that recreational fishers took approximately 135 tonnes of rock lobster compared with the commercial catch of 1523 tonnes (Lyle 2008; Department of Primary Industry and Water 2008).

The recreational catch is primarily taken from inshore waters adjacent to major towns, with the east and south-east of Tasmania (areas 1, 2 and 3 in Figure 5) accounting for over two-thirds of the annual recreational lobster catch (Lyle 2008). Diving restrictions and the greater reliance on manual hauling of pots limits the recreational fishery to relatively shallow waters, although winches and echo-sounders are becoming popular on recreational boats (J Lyle, pers com). Recreational fishers normally access fishing sites via boat launching ramps and densities of lobsters decline with increased proximity to boat ramps (Stuart-Smith et al. 2008). On the east coast, the recreational catch is a significant proportion of the combined commercial and recreational catch in inshore waters. For example, in Area 1 the recreational catch was approximately half of the total rock lobster catch in waters less than 20 metres in depth in 2006–07 (Lyle 2008). Recreational fishing effort is not uniformly distributed across the year, with effort and catch concentrated during the summer and Easter holiday periods.

An initial interpretation of the results of the 2007 Tasmanian Recreational Lobster Fishing Survey indicates that recreational lobster fishers are predominantly male, with about 67 per cent having completed some form of tertiary education. A total of 967 questionnaires were distributed for this survey, with an overall response rate of 37%. The average age of survey respondents was about 46 years and they indicated an average of nearly 20 years of recreational fishing experience. Lobsters caught were generally for personal household consumptive use. The ability to adapt to changes in the recreational rock lobster fishery will in large part be conditioned by the extent to which fishers view alternative fishing and non-fishing leisure activities as substitutes for rock lobster fishing. Recreational rock lobster fishers already participate in a number of other recreational fishing activities.

In the fishing survey, recreational fishers were also asked about the importance of various factors in governing their choice of fishing destination. In terms of the percentage of fishers who indicated that particular factors were either very important or extremely important, the most important of the 11 factors mentioned were weather conditions, safety of location for fishing, familiarity with location, lobster abundance, and distance from home. Time and weather were cited as the two most important factors in keeping fishers from fishing more often. Tasmanians spend over \$50 million on recreational fishing annually. Each fisher is estimated to spend \$416 per year on fishing-related equipment and activities (Lyle 2008).

## 2.2.2 THE COMMERCIAL SECTOR

The commercial rock lobster fishery has been an important component of the Tasmanian fishing industry for over 150 years, dating back to the 1800s. In 1882, during a Royal Commission inquiry into the State of Tasmania's fisheries, Seals et al. (1883) wrote *'The crayfish (P. edwardsii) [J. edwardsii was known as Panulirus edwardsii in 1882] is, perhaps, one of the most important of our marine products, being not only esteemed for its quality, but for its great commercial value from its wonderful abundance, especially around our eastern coasts'*. The Royal Commission reported that the stock was in decline, which resulted in the first set of management regulations being introduced via the 1889 Fisheries Act. Restrictions included size limits, bans on taking berried females, and no possession or sale of soft-shelled lobsters. Since then, the fishery has been regulated by a series of input controls and since the 1960s by limited entry (Phillips et al. 2002). By the 1990s, concerns about stock decline again emerged, resulting in the establishment of an individual transferable quota management system in 1998 (Bradshaw 2004). Since the introduction of the quota, stocks of rock lobster have increased markedly.

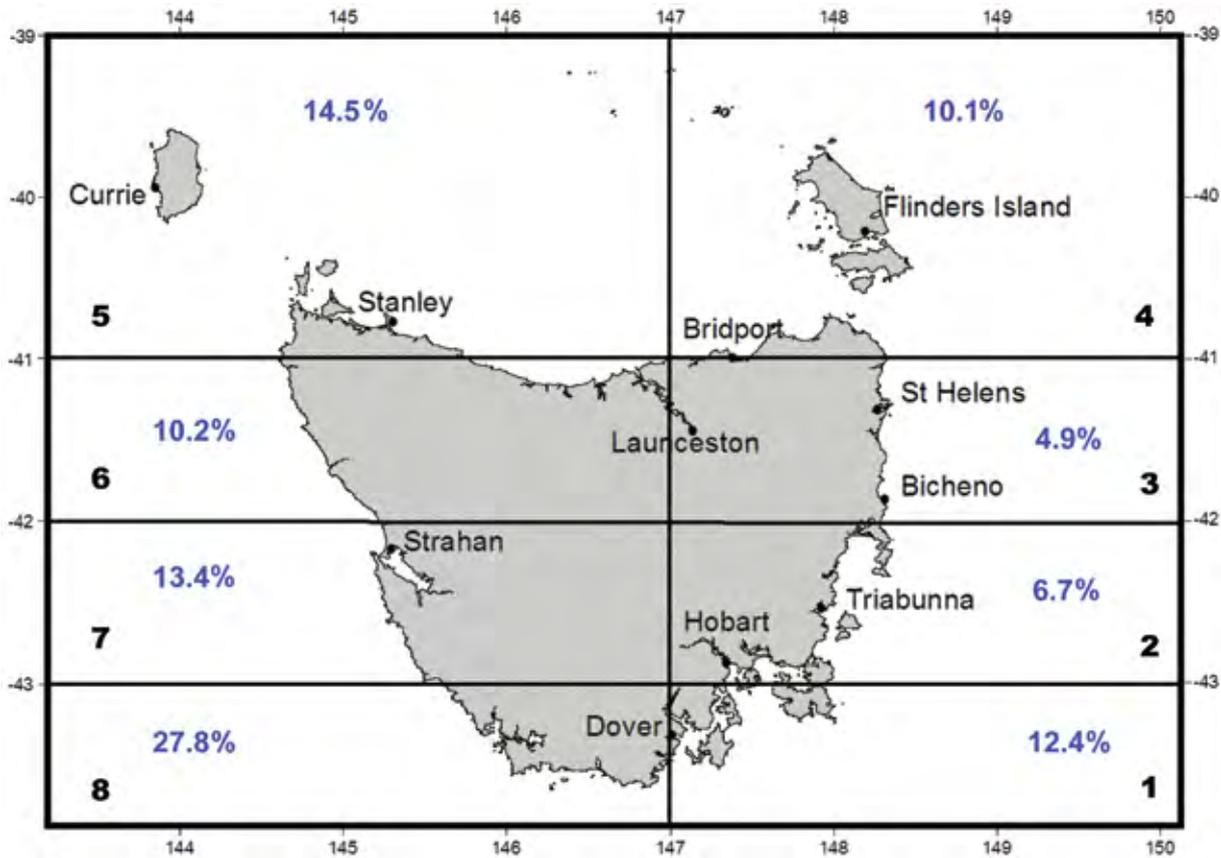
### **Industry today**

In 2006–07, the Australian rock lobster industry (comprising a number of species) had the greatest revenue of wild fishing industries with revenue at point of first sale of \$441 million from a production of 13,698 tonnes. Tasmania contributes nine per cent of the total Australian rock lobster catch by weight and 12 per cent by revenue. It is the second most important Tasmanian wild harvest fishery in terms of revenue, with an estimated value of \$72 million at the first point of landing (2008/09 quota year, DPIW database April 2009); the value of rock lobster quota units was estimated to be approximately \$440 million. In 2007, there were 315 fishing licenses and 10,507 quota units, with 221 active licensed vessels distributed around regional ports, plus a processing sector of over 50 licensed processors. An estimated 700 people were directly employed in the Tasmanian rock lobster fishing, processing and handling sectors in 2006–07 (Department of Primary Industry and Water 2008). There is now a range of management measures or restrictions in place (see Appendix 2 for a list of commercial regulations) to achieve sustainability, environmental, economic and social objectives. Two of the main management tools include limiting the total commercial catch using an individual transferable quota system and setting minimum size limits.

At least 80 per cent of the licenses issued are held by Tasmanians; over 50 per cent of these licences are owner-operated (Bradshaw 2004). The fishing fleet operates around the state and the commercial fishery is managed as a single zone, although the state is divided into eight stock assessment areas for more detailed regional biological assessment of the stock (Figure 5). Currently, most vessels are 6–20 metres long, and work with between 15 and the maximum 50 pots each. Most of these boats work from small coastal towns of Tasmania (Bradshaw 2004). There are a number of major ports/loci for the industry around Tasmania including Strahan, Currie (on King Island), St Helens, Bicheno, Hobart, Triabunna, Dover, Stanley, Flinders Island, Launceston and Bridport (Figure 5).

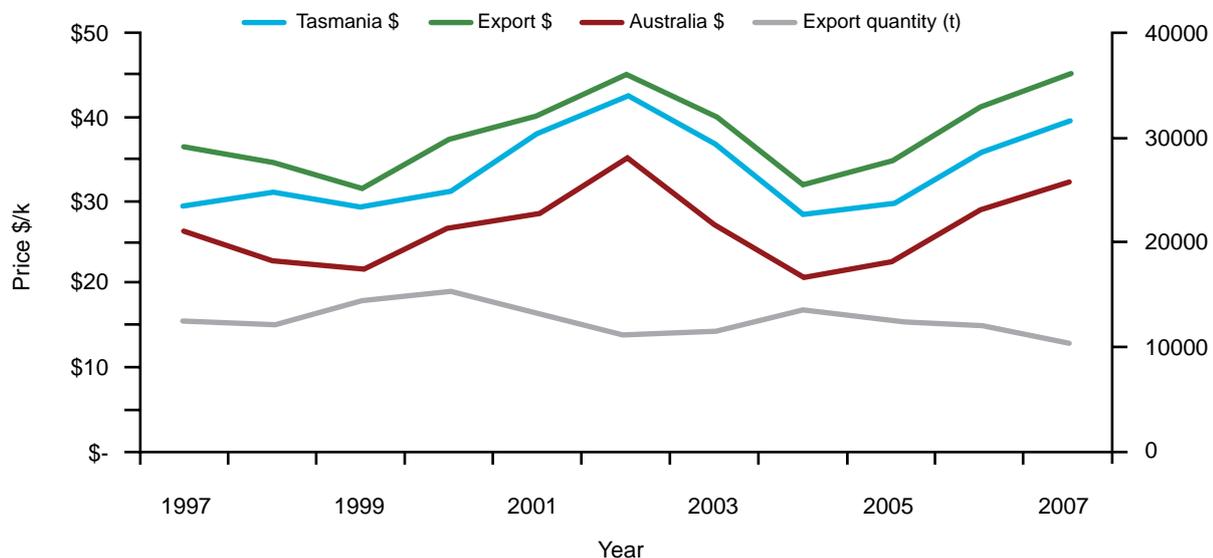
Up to 80 per cent of the catch is exported from Tasmania, largely to Asian markets (particularly China) where southern rock lobster is highly valued and receives premium prices. While the proportion of catch from each fishing area varies due to recruitment variability and the distribution of fishing effort, the southern and western regions of the fishery tend to contribute more to the annual catch than northern and eastern regions. In the 2006–07 fishing season, the four eastern regions contributed 524 tonnes to the overall catch of 1523 tonnes (Figure 5).

The peak period for southern rock lobster catch is between November and January each year, although this seasonal trend has become less pronounced in more recent years (Hurn and McDonald 1997; Haddon and Gardner 2008). Some of the reduced focus on fishing in the traditional peak period is due to the ongoing consolidation of the fleet, with fewer vessels operating for more days of the year. Fishers' profitability is not driven solely by catch rates as periods of low catch rate are characterised by high prices and vice versa. While fishers have little incentive to target fishing in certain seasons, they are expending less effort in deep water where lobsters are pale and generally receive a lower price (Bradshaw et al. 2001). One of the consequences of this shift in effort is that inshore catch rates (numbers of lobsters caught per pot) can be less than half of offshore rates (Haddon and Gardner 2008).



**Figure 5: Spatial scale of the eight Tasmanian rock lobster fishery assessment areas. These assessment areas are used as the basis for predicting climate change impacts at 2030 and 2070 in later sections. The figures in blue indicate the percentage of total allowable commercial catch (TACC) taken from each area in the 2006–07 season. Major ports for the commercial rock lobster fishery in Tasmania are also indicated.**

Beach prices are driven by international levels of supply and market demand (Figure 6), which tends to peak around Chinese holidays or festivals (Harrison 2004). Most rock lobsters imported to China are sourced from the southern hemisphere and biological cycles follow similar patterns resulting in periods of greatest catchability and supply from several fisheries coinciding around the November to January period. Over 90 per cent of the total catch is purchased by processors, while the remainder is sold directly by the fisher in Tasmania or is landed at ports outside of Tasmania (Harrison 2004; Department of Primary Industry and Water 2008). The average beach price in 2008 was \$42 per kilogram (Department of Primary Industry and Water 2008). Although the Tasmanian beach price varies in line with supply, this does not imply a causal relationship between supply and price. The beach price and export price are influenced by external factors such as freight costs, world income and exchange rates (Holland et al. 2005). Much of the variation in exports can be explained by the effect of world events on rock lobster demand, domestic costs and competitiveness.



**Figure 6: Average yearly Tasmanian, Australian, and export price, and export quantity, for rock lobster from 1997 to 2007.**

The fishery has exhibited a trend of increasing biomass and catch rates over the last decade, although this stock rebuilding has not been evenly distributed around the coast (Haddon and Gardner 2008). These spatial patterns are the result of the combined effect of regional patterns in fishing effort and recruitment of lobsters, and also socio-economic changes that have occurred since the introduction of quota management illustrated, for instance, by the move inshore to catch higher-priced red rock lobster. A number of other social issues arose from the introduction of quota. For example, there is now increased ownership of quota units by non-Tasmanians; the fleet has contracted, the distribution of home ports shifted dramatically; the average number of stakeholders has increased; and the proportion of fishers leasing quota has risen.

### 2.2.3 ROCK LOBSTER PROCESSORS

There are over 50 licensed rock lobster processors in Tasmania, although about 12 processors handle 80 per cent of the fish. The small number of wholesale buyers that control the import market in China and the restricted flow of reliable information past these wholesalers are the main price risks in China (Pontecorvo 2003; Lamming et al. 2001). The high reliance on one export market and the uncertainty within that dominant market is of some concern (Richards 2005).

### 2.2.4 COMMERCIAL ROCK LOBSTER FISHING BUSINESS CHARACTERISTICS

Vessels are restricted in the number of physical traps they can use, based on the vessel size, with a maximum of 50 pots per vessel. Quota units are restricted to a maximum of 120 per rock lobster entitlement or licence. The minimum number of quota units a fisher must have on the vessel is 15. Quota allocation per vessel is a function of the total allowable commercial catch (TACC is currently 1470.98 tonnes), the total number of quota units in the industry (currently 10,507) and the number of quota units attached to a licence. In 2009 the allocation was 140 kilograms per unit.

The business characteristics of rock lobster fishers surveyed in 2008 varied widely. For instance, the number of quota units owned varied from 15 to 90, with an average of 60. Some rock lobster fishers did not own any quota but leased all of it. Almost all rock lobster fishers, regardless of whether they owned quota, also leased some quota. The average cost of leasing quota in 2008 was \$19.55 per kilogram (ranging from \$17 to \$21.45).

For a situation where the average pay for the skipper is \$60,000 per annum and the deckhand earns 15 per cent of the value of the catch (van Putten and Gardner unpublished data), labour cost makes up almost 50 per cent of total trip cost. Approximately half of the labour cost is attributable to the deckhand's pay (van Putten and Gardner unpublished data). Other than labour cost, the largest component of the trip cost for rock lobster fishers is the cost of fuel, contributing approximately 33 per cent to the total cost.

A significant contributor to the variable trip costs is the number of days fished and the total length of the fishing trips. These variables are closely related to the vessel size. The larger vessels in the rock lobster fleet travel longer distances to more remote offshore areas and often stay at sea for 10–14 days at a time. Up to approximately five tonnes of live catch can be stored in the wells or tanks of the larger vessels. Smaller vessels (with fewer pots on board) are generally not suited for fishing in the more exposed offshore areas. They tend to make shorter trips, remain closer to port, and work east coast rather than west coast waters. An exception to this is on King Island where the majority of vessels make day trips despite the vessels being relatively large. The 2008 survey of rock lobster fishers found that state-wide, on average, a typical fishing trip was eight days and that on a yearly basis approximately 120 days were spent fishing per vessel. Trips of shorter duration had a higher travelling time to catching time ratio and resulted in a greater total yearly distance travelled and higher variable cost. As the variable cost structure is related to vessel size, and vessel size is related to fishing grounds, patterns in the variable cost structure for different fishing regions in Tasmania can be identified. Fixed costs are highly vessel-size dependent but on a state-wide average basis, the fixed costs for a rock lobster vessel make up around 25 per cent (around \$80,000) of total annual cost. Depreciation, repairs and maintenance make up over 70 per cent of total fixed costs. The next largest fixed cost components are personal, vessel and car insurances adding up to over \$10,000 per annum.

The main determinant of total returns for a rock lobster fishing operation is the beach price which is mainly determined by carapace size or weight and colouring. Processors prefer weights of 0.8 – 2 kilograms. White (pale coloured) lobsters (caught in deeper waters) are discounted by around \$5 per kilogram, regardless of size, and lobsters over two kilograms often receive further discounting of more than \$2 per kilogram. The average weighted beach price in 2008 was around \$42 per kilogram but reached in excess of \$65 per kilogram during periods of high demand/low supply and favourable exchange rates (Department of Primary Industry and Water 2008). The average beach price reported by 2008 survey respondents was \$38 per kilogram (van Putten and Gardner unpublished data). More detail on industry structure, including regional differences, is provided in Appendix 3.

### 2.3 CURRENT AND EMERGING ISSUES FOR THE FISHERY

When the commercial fishery quota management system was introduced in 1998, the aim was to cap the total commercial catch in an attempt to allow the exploitable biomass to rebuild. A secondary aim was to provide a mechanism for the industry to restructure and increase profitability. To date, significant progress towards these aims has been achieved (e.g. legal-size biomass has doubled and asset value of quota units has trebled (Haddon and Gardner 2008)). However, there is still considerable potential to improve the productivity and profitability of the fishery and there are a number of emerging issues that cannot be effectively or optimally addressed under the current management regime and harvest strategies. These issues include:

- significant regional differences in stock abundance, recruitment patterns, growth rates and egg production;
- increased pressure on inshore stocks and a greater spatial overlap within and between the recreational and commercial lobster fishing sectors;
- expansions of sea urchin (*Centrostephanus rodgersii*) barrens on the east coast (see section 4.3.7);
- defining and balancing social outcomes and economic objectives.

Managers, researchers and industry are working closely to develop a range of spatial management tools and changes to existing management controls to address these challenging issues. Some of the options under consideration include regional size limits (minimum and maximum), inshore/offshore management regimes, regional TACCs, translocation, and altered seasonal closures. Translocation is the deliberate and mediated movement of wild individuals or populations from one part of their range to another in an attempt to establish, re-establish or augment populations.

## 2.4 GOVERNANCE FRAMEWORK OF THE ROCK LOBSTER FISHERY

The governance framework within which the rock lobster fishery operates plays a determining role in defining and achieving economic, social and environmental outcomes. In assessing how governance arrangements influence the activities and outcomes of the rock lobster fishery, we have adopted an analysis that focuses on the processes of policy development and implementation, incorporating policy capacity and coordination as important variables. This approach will capture the underlining policy development processes and implementation characteristics (see Pierre and Peters 2005) such as the tools and mechanisms used to manage activities, including economic, market-based and regulatory instruments and collaborative management.

### 2.4.1 BACKGROUND TO CURRENT ARRANGEMENTS

The Tasmanian rock lobster fishery has been the backbone of the Tasmanian fishing fleet since its inception in the 1800s. Historically, rock lobster fishers had access to virtually all fishing operations, being the owners of most of the sea going vessels. Fishers would rotate their activity depending on seasonal catch rates and market prices of a range of species. In addition to pots, lobster vessels would also carry longlines, droplines, gillnets and dredges. As each of these fisheries came under government regulation, entitlements were issued and diversification of activities declined as dropline, longline, gillnet specific fisheries developed. However, currently, all giant crab licences and a large portion of scallop licences are held by rock lobster licence holders. The Tasmanian Scalefish Management Plan also gives rock lobster licence holders limited access to a wide range of scalefish species and many also have some level of access to Commonwealth fisheries.

The Tasmanian rock lobster fishery has been managed under input controls, licenses and limited entry controlling the number of vessels and subsequently the number of pots. A major and far-reaching management reform saw introduction of output controls with the introduction of a quota management system (QMS) in 1998. The QMS was introduced after several years of development, including negotiations with industry. The fishery is managed under state legislation; under the arrangements established by the Australian Offshore Constitutional Settlement (Haward 2003) the Tasmanian government manages the fishery as a single zone in Tasmanian waters out to the edge of the Australian Exclusive Economic Zone, 200 nautical miles offshore.

The *Living Marine Resources Management Act 1995 (Tas)* (the Act), as amended, provides the basis for management (Appendix 4). This Act focuses on a sustainable fishery within the 'Objectives of the Resource Management and Planning System of Tasmania' provided as Schedule 1, balancing economic efficiency with maintaining a sound ecological and social basis to the fisher. These objectives 'promote the sharing of responsibility for resource management and planning between the different spheres of Government, the community and industry in the State' (see Appendix 5). The Act contains a number of key provisions that directly relate to governance of the fishery, and help promote capacity, coordination and adaptive management.

Day-to-day management of the fishery is undertaken by the Department of Primary Industry and Water's Wild Fishery Management Branch. The rock lobster fishery is managed by 'rules' based on a statutory five-year management plan. The rules and management plan can be changed or revised within that period following ministerial approval and a process of consultation and public comment on proposed changes. This consultation includes mandated meetings with industry bodies and advisory committees.

### 2.4.2 GOVERNANCE: KEY ELEMENTS

The Act also provides the basis for economic tools (via the QMS) and stakeholder engagement (the basis of collaborative management). The Act elaborates the Minister’s responsibilities (delegated in a day-to-day manner to the department) and formalises requirements for consultation over the management of the fishery. This formal responsibility is supported by the Department of Primary Industry and Water having clear and ongoing engagement with industry, and the role of the Crustacean Fisheries Advisory Committee (CFAC) in providing advice to the department and the Minister. In addition, the interaction between the department, the CFAC and the Tasmanian Rock Lobster Fisherman’s Association (TRLFA) enhance governance of the fishery. These arrangements appear robust and build on a decade of interaction following the introduction of the QMS.

The CFAC is a recognised fisheries advisory committee under the Act, and is the body that the Minister is required to consult over the management of the fishery. The aim of the CFAC is ‘to provide the Minister with full and frank advice on all significant issues related to commercial fisheries’ (Department of Primary Industry and Water 2008). The broad base of the CFAC provides an important stakeholder forum and is a key governance arrangement. The involvement of industry and other stakeholders in the CFAC provides a useful and important adjunct to advice from the scientists to managers.

The recreational sector is managed under licenses for fishing by trap, rings or diving, with specific limits for each gear and a daily limit of five rock lobster per license holder (see Appendix 2). The recreational sector is represented by the Tasmanian Association for Recreational Fishing (TARFish) and provides formal advice to the Minister through the Recreational Fishery Advisory Committee (RecFAC), a body recognised under the Act. RecFAC has interacted with the CFAC through arrangements such as joint working groups and is involved in formal consultation process over management plans and development of rules for the fishery. This provides mechanisms for input of advice from recreational and commercial sectors. The Rock Lobster Rules, developed through formal consultation with all stakeholders, set the arrangements for formal resource sharing arrangements between commercial and recreational fishers. This arrangement notes that if the fishery TAC is less than 1700 tonnes, recreational catch is limited to 170 tonnes with the commercial catch then set at the TAC less 170 tonnes. If the rock lobster TAC is set at 1700 tonnes or more, the recreational fishery catch is set at 10 per cent of the TAC, with the commercial fishery catch then limited to 90 per cent of the TAC.

### 2.4.3 EXISTING GOVERNANCE ARRANGEMENTS AND ADAPTIVE CAPACITY

The current governance arrangements for the east coast rock lobster fishery as framed by the Living Marine Resources Management Act establish key governance elements: the role of the Minister, the role of scientific and administrative advice to the Minister, the key ‘rules’ that regulate the fishery, the development and review of management plans (including ‘rules’) for the fishery, and provision for the formal recognition of industry and the role of advisory bodies. These elements, together with the opportunities provided by the QMS, ensure maximum opportunities for informed decision making by all stakeholders, enhancing adaptive capacity. This in turn establishes a basis from which to develop climate change adaptation strategies.

The current management arrangements for the Tasmanian rock lobster fishery establish the principles and practices of ‘resource sharing’ between commercial and recreational fisheries. Current arrangements establish a catch of 170 tonnes for the recreational fishery, far in excess of current catches. If recreational catches increased significantly, and for example threatened to exceed agreed limits measures to cap recreational catches may be required. In addition, the development of more formal reporting measures for recreational catch may be required such as logbooks or catch returns.

## 3 Rock lobster fishers' perceptions of climate change

---

### 3.1 RISK PERCEPTION EXERCISE

As part of the vulnerability assessment, a risk perception study was conducted to gain some understanding of commercial fishers' perceptions of the potential impact of climate change on the industry. This is differentiated from what is scientifically or formally known, since what is identified as an actual risk and how industry stakeholders perceive it can differ (see Section 4). A risk perception exercise is aimed at understanding how those in the industry feel and think about an issue. Determining the risk perception regarding climate change within the rock lobster fishery is important in determining the overall vulnerability of the fishery to climate change. This is often overlooked in vulnerability assessments, though it is considered important in terms of identifying and increasing adaptive capacity and adaptive planning (Lorenzoni et al. 2000).

#### 3.1.1 METHOD

This study was undertaken over a three-month period between August and October 2008<sup>1</sup>. Twenty-two qualitative semi-structured interviews were undertaken<sup>2</sup>. Additional information from a range of commercial industry participants was gathered via a workshop and some focus group work. All respondents were male, with an average of 10–15 years experience in the industry. Many of those interviewed fished all around Tasmania, so their feedback includes experience from areas other than the east coast<sup>3</sup>. Subjects of focus for the interviews included: (i) the fisher's experiences of fishing; (ii) the fisher's perception on management regimes; (iii) the fisher's perception of climate change and its impact on the industry; and (iv) the fisher's perception of and ideas for adaptation. Face-to-face validity and Guba's criteria of (i) credibility, (ii) transferability, (iii) dependability and (iv) confirmability (Guba 1981) were used to evaluate the information obtained.

#### 3.1.2 RESULTS

The following is a snapshot of the risks and issues fishers relayed within interviews. This section focuses particularly on the issue of climate change; however, much fisher discourse pointed to a focus on other issues such as succession planning and impacts of management measures such as quota. These factors also have importance when contextualising whether the fishers have the capacity to build on, or accept, the suite of suggested adaptation strategies.

#### *Fishing experience and management issues*

All fishers indicated extensive experience of the sea and fishing. Seventy per cent of fishers were not fishing solely for rock lobster but also fished for shark, scallop, crab and other species. All indicated there had been substantial change in technology over the last 20 years, and all had upgraded their boats over that time. Sixty-five per cent of the fishers were either currently or had been in partnership with their friends or family members, and some were involved in various industry management committees. All fishers talked about the introduction of quota, with discourse clearly differentiating between 'before' and 'after' quota. The consensus for all fishers was that the quota was not satisfactory overall for the fishers, but had 'probably done all right for the species'. Other issues raised included the debate about spatial zoning, burden of debt, the effect of seismic testing, risk of disease through aquaculture, the ageing profile of fishers and associated concerns about superannuation, rising fuel costs, succession planning and how to make entry into the industry more attractive.

---

1 A report can be found at Appendix 6a. The study was approved by the UTAS Human Research Ethics Committee with a Minimal Risk Ethics Application submitted and approved in September 2008. For the interview questions see Appendix 6b.

2 This number represents approximately 10 per cent of fishers currently in the industry.

3 Respondents were chosen using representative sampling, and snowball and purposive methods used to determine the point of information saturation and contact referral.

### ***Climate change***

Of those interviewed, about 40 per cent did not perceive that climate change was a problem at all, reflecting the perceptions of the broader community (Sterman 2008). Another 30–40 per cent felt that there was currently no consensus about the reality of climate change. These fishers noted that changes in climate did seem to be occurring, but were not convinced that it was human-induced, and that even if it was, considered it would not have a great impact on the industry. Some of these fishers felt that they had observed changes in the industry (and other fisheries), and areas they fished, but were not convinced that the cause was climate change. For example, fishers had noted changes in fishing patterns, illustrated by the fact that many fishers were no longer going to northern Tasmania to fish. Another fisher added that his main concern was the very low egg production, especially on the east coast, and wondered whether or not that was due to climate change. In this context, a key discourse about climate change was the view that environmental change was cyclical, and that it was therefore uncertain whether or not changes were simply natural climatic variation. In any case, all fishers added, in this part of the discussion, that while they may not believe in climate change, they did believe in sustainability and making the industry as sustainable as possible. In this context, fishers consistently talked about instances where they had already implemented change such as changing from sonar to GPS systems, upgrading boats, or fishing for different species. Twenty per cent of fishers did express concern about climate change. Of those that indicated they were concerned about climate change, sea level rise and rise in sea water temperature were identified as major concerns in terms of potential impact on the industry. Fifteen per cent of fishers, moreover, observed (whether or not they believed in climate change) that the advent of climate change would provide economic opportunities. About 60 per cent of fishers interviewed also construed climate change as a means by which scientists obtained funds.

### ***Changes observed in species and habitat***

Notwithstanding the general scepticism that characterised fishers' responses to climate change (reflecting general societal patterns), a number of fishers in general discussion relayed their observations of a number of changes to species and habitat (many of which were climate related) over the years. These included:<sup>4</sup>

- i. increase in size of lobster in offshore areas,
- ii. increased pressure on inshore fisheries<sup>5</sup>,
- iii. sightings of species not expected at that time of year or in that region (i.e. sightings of snapper, schools of tuna),
- iv. increased incidence of sea urchins,
- v. little tommies (*Arripis georgianus*, or Australian herring) in the Fortescue Bay area,
- vi. changes in kelp beds,
- vii. low egg production, especially on the east coast,
- viii. whales observed more frequently,
- ix. southern bluefin tuna caught on the south coast,
- x. fewer schools of mackerel and whitebait than previously,
- xi. greater numbers of octopus caught recently,
- xii. greater numbers of dead penguins,
- xiii. better shark catches,
- xiv. more prevalent weed, pulling up string kelp (*Macrocystis*) at Cape Natural and Eucalyptus reef,

4 At the time fishers did not prioritise or order these observed impacts. Rather, each fisher relayed a number of observed effects. This list represents changes that at least 60 per cent of fishers had observed personally or relayed second hand.

5 When discussing increasing pressure, fishers were referring to the increasing trend to fish for inshore fish as their size was more marketable than the larger fish found in deeper waters.

## Vulnerability to climate change impacts and adaptation response options

- xv. changes in recruitment (many fishers noted and expressed concern that warmer temperatures or indeed current changes might affect any or all of the stages of development of rock lobster), and
- xvi. spawning occurring later and/or earlier for rock lobster.

### 3.1.3 DISCUSSION

Overall, as seen above, fishers had a range of views on the industry and in relation to climate change. Generally speaking, younger fishers were less sceptical and more positive about adaptation than fishers closer to retirement. For example, in this survey, 100 per cent of fishers 40 years or under believed climate change was a reality, compared with just 10 per cent of those over 40 years. Fishers active in formal capacities in the industry (i.e. members of industry and government boards) also reported a greater acceptance of climate change and associated risks. Overall, fisher-perceived risks to the industry included:

- i. quota system and future management
- ii. recruitment and reproductive cycles of rock lobster
- iii. market price and pressures
- iv. climate change
- v. lack of successional planning
- vi. economic [in]stability.

These issues are consistent with earlier work undertaken in 2008 by the CFAC that sought, through a discussion paper and questionnaire, the views of commercial rock lobster fishers on a number of issues. Responses to the questionnaire provided an indication that many fishers felt the development of spatial management tools could improve the management of the fishery and fishers also provided suggestions for other management measures that should be investigated by the CFAC. Of interest is the fact that the industry (through the Tasmanian Rock Lobster Fishermen's Association) has subsequently endorsed detailed investigation of a broad range of new management options to address current and future challenges facing the fishery. Many of the options currently under investigation are also those which have been identified in this report as being potential climate change adaptation measures and include: (i) regional minimum and maximum size limits; (ii) regional allowable catches; (iii) inshore/offshore management regimes; (iv) regional seasonal closures; and (v) review of trap restrictions.

Recreational users also form an important part of the rock lobster industry in Tasmania. In the context of climate change, the ability to adapt to changes in the recreational rock lobster fishery will in large part be conditioned by the extent to which fishers view alternative fishing and non-fishing leisure activities as substitutes for rock lobster fishing. Socio-economic surveys conducted by Department of Primary Industry and Water in 2006-07 demonstrate the high value the fishery has as part of overall recreational fishing activity. While fishing was the most important outdoor activity undertaken by nearly 40 per cent of those interviewed, less than two per cent of respondents indicated that rock lobster fishing was the only type of fishing that they engaged in.

Recreational rock lobster fishers, moreover, already participate in a number of other fisheries. For example, 76 per cent of respondents indicated that they also spent time over the study period line fishing in inshore saltwater bays and estuaries. Recreational fishers also held strong views on management, with survey respondents being asked how they felt about various management options for the Tasmanian recreational rock lobster fishery (by indicating their level of agreement or disagreement). Results showed that the strongest view held was against a 'decrease in bag limit to four lobsters per day' with 63 per cent of respondents disagreeing or strongly disagreeing. Fifty-eight per cent disagreed and 51 per cent strongly disagreed with 'lowering the size limit in southern waters' and 'allowing pot-fishers to use one extra pot' as management responses. Strongest support expressed was for 'limits on the number of recreationally caught lobsters that may be taken out of Tasmania' and 'different fishing areas for recreational and commercial fishers at certain times of the year' with 58 per cent and 51 per cent agreeing or strongly agreeing respectively. When asked about what they perceived were the greatest risks facing recreational fishing, fishers ranked management and compliance, and sustainability as the two most important issues. Climate

change per se, however, was only mentioned twice as a specific risk. Nonetheless, these results indicate a consciousness about and flexibility to changing current management arrangements, which is important regarding future climate adaptation programs.

Climate change clearly is an issue of ongoing industry concern (both commercial and recreational), but is not at present a predominant focus on a day-to-day basis. Nonetheless, international experience shows that fishers' local knowledge can play a vital role in developing better knowledge systems overall, and help in acceptance of climate change. There is an opportunity to provide a framework for interpreting local knowledge for further evidence of climate change and hence move ahead, better equipped (Haggan et al. 2007).

## 4 Potential bio-physical impacts of climate change on rock lobster stocks on the east coast of Tasmania

---

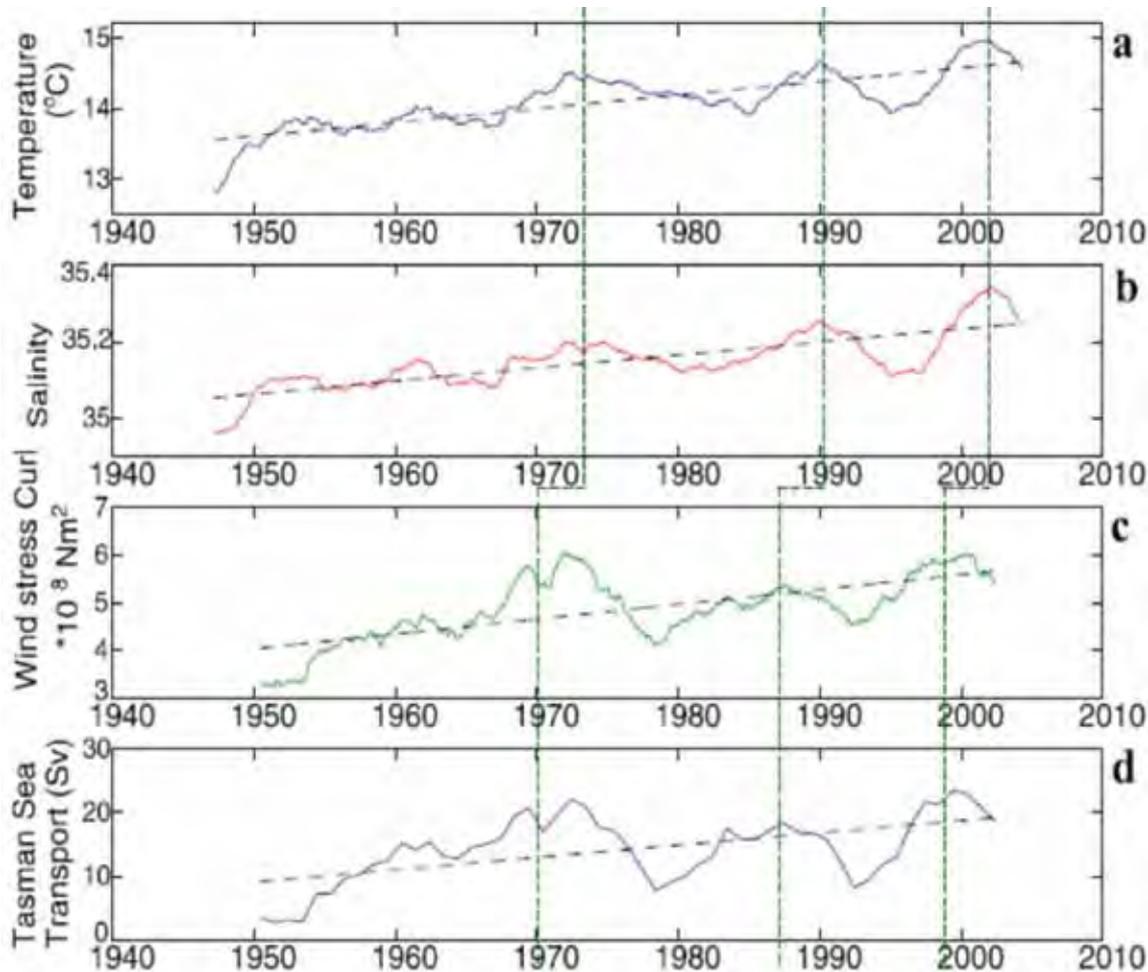
### 4.1 RECENT CLIMATE CHANGE IN THE EAST COAST ROCK LOBSTER FISHERY REGION

The Intergovernmental Panel on Climate Change (IPCC) 4<sup>th</sup> assessment report concludes that climate change is occurring, and is highly likely to be caused by human contributions to greenhouse gas emissions (IPCC 2007). Global average air temperature and consequently sea surface temperature has increased by 0.4–0.8°C since 1900 (Harley et al. 2006). By 2100, global temperature is predicted to rise by 1.4 – 5.8°C, which is more than any change in the past several thousand years, while the increases in CO<sub>2</sub> are leading to concentrations not experienced for the past 800,000 years, as determined from ice cores. Also, the rate of current climate change is very rapid compared to past global climate change in and out of ice ages (IPCC 2007).

The increase in sea surface temperature is already having impacts on Australian marine systems (Hobday et al. 2008). Over the last 50 years, the ocean temperature on the east coast of Australia, as measured at a number of locations, including Maria Island in Tasmania, has increased dramatically (Ridgway 2007; Hill et al. 2008). The observed warming is almost four times the global average, at 2.28°C per century (Ridgway 2007). While this rate of warming cannot continue to be greater than the general rate of ocean warming forever, it is likely to be a region of enhanced warming for the coming decades.

Part of the warming on the east coast of Australia is due to a change in the East Australian Current (EAC) (Ridgway 2007). The increase in temperature and salinity since 1944 corresponds to a southward shift of the climatological surface temperature and salinity properties by about three degrees of latitude (~350 kilometres) (Ridgway 2007; Hill et al. 2008). Recent increases in abundance or presence of northern marine species in Tasmania have been attributed to this increased southward penetration (Hobday et al. 2007; Poloczanska et al. 2007; Ling et al. 2009).

There has been a recent slowdown or reversal in the southward penetration of the EAC and this may reflect a quasi-decadal cycle (Figure 7). These decadal cycles, however, are superimposed on a long-term warming trend consistent with global warming. The overall increase in water temperatures is expected to have an impact on a number of fishery and aquaculture operations in Tasmania, including the rock lobster fishery (Hobday et al. 2008).



**Figure 7: Low-pass filtered (a) sea surface temperature at Maria Island, (b) surface salinity at Maria Island, (c) South Pacific regional mean wind stress curl (20–50°S, 180–280°E), (d) net transport through the Tasman Sea (Hill et al. 2008). Black dashed lines show the linear trend. Green dashed lines illustrate the time lag between Maria Island temperature and salinity and South Pacific water transport.**

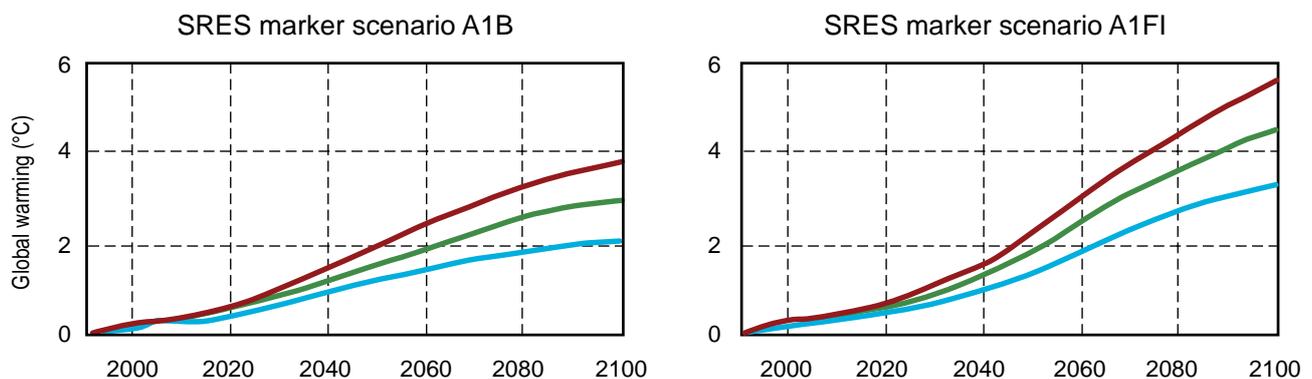
## 4.2 CLIMATE CHANGE AND MODELS

A range of climate models have been used to investigate interactions between the physical ocean–atmosphere system and increased greenhouse gases and aerosols. In general, the climate model simulations of global warming predict oceanic temperature increases, dramatic changes in oceanic stratification and circulation. Here we utilise the most recent climate change projections from the CSIRO Mk3.5 climate model. Although there are differences between this climate model and other international models, many of the general trends are similar (Hobday et al. 2007). These models make global predictions, so there is a high degree of uncertainty when considering regional or local-scale patterns such as we have attempted in this project.

Global climate models predict that the greatest warming in the Southern Hemisphere oceans will be in the Tasman Sea, associated with a strengthening of the EAC. This feature is present in most IPCC climate model simulations. Warming will not only affect surface waters, but will also penetrate deep into the ocean, warming waters down to 500 metres and beyond. Climate change will also substantially modify other physical variables important for regulating marine ecosystems, including incident solar radiation (through cloud formation), winds and mixed layer depth (Hobday et al. 2007).

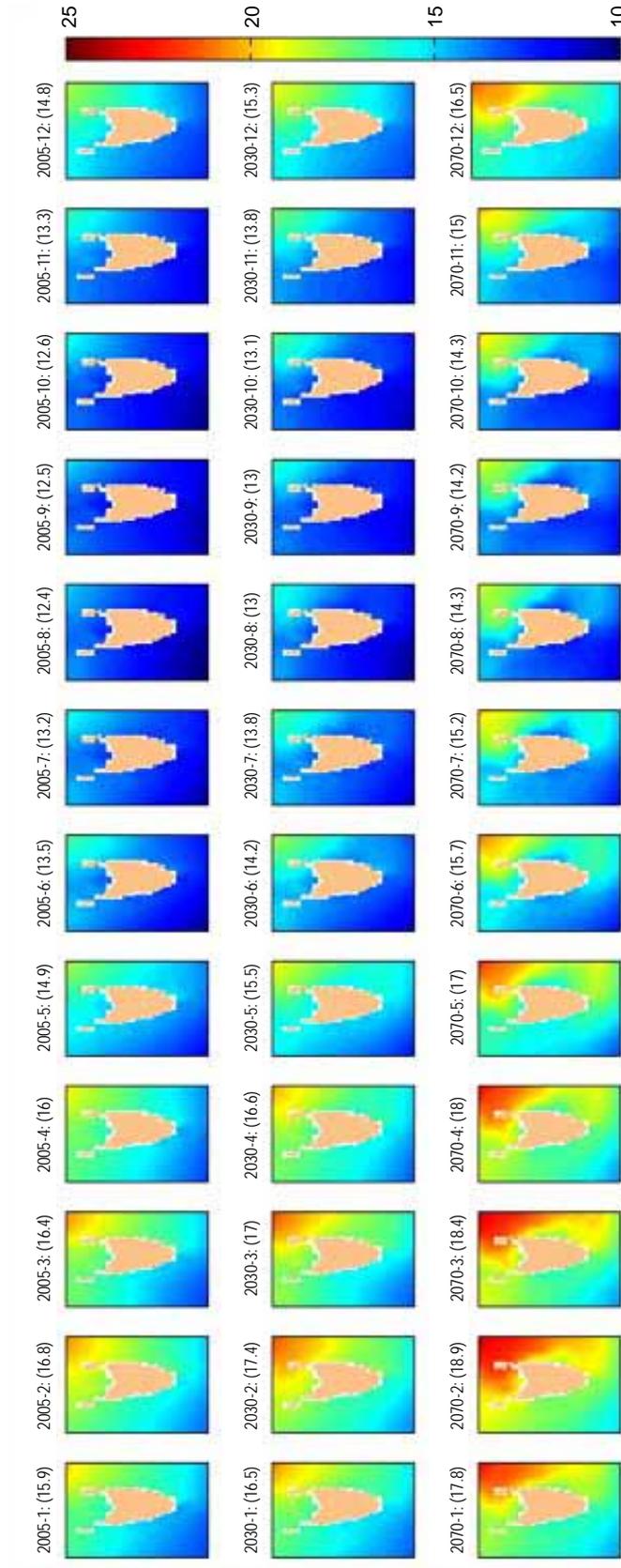
#### 4.2.1 PREDICTED CLIMATE CHANGE SCENARIOS

The climate change impacts analyses for the Tasmanian rock lobster fishery are based upon the IPCC emission scenarios A1B at the year 2030 and A1B and A1FI at the year 2070 (Figure 8). At 2030, there is little difference in the predictions of global warming between scenarios (IPCC 2007), and thus the A1B suffices. By 2070, differences between a mid-range emission (A1B) scenario and a high-emission scenario (A1FI) are marked. Use of the high-emission scenario is justified as analysis shows that the planet is already warming at the upper edge of climate predictions (Rahmstof et al. 2007), and this is likely to continue for the next 50 years (Raupach et al. 2007).



**Figure 8: Global warming scenarios A1B and A1FI SRES (Special Report on Emission Scenarios) showing predicted increases in global warming over the period 1990–2100. The three lines on each panel represent low (blue), medium (green) and high (red) sensitivity of the climate system to the increase in greenhouse gases associated with each scenario.**

Temperature has a large impact on rock lobster population dynamics (see sections 2.1.1 and 4.3) and therefore sea surface temperature (SST) was considered the most appropriate variable to correlate with lobster productivity. To obtain predictions of future SST, several options for data were considered, including (i) a single global climate model (GCM) (CSIRO Mk3.5 model), (ii) CSIRO regional climate predictions derived from a suite of GCMs ([www.climatechangeinaustralia.gov.au](http://www.climatechangeinaustralia.gov.au)), and (iii) downscaled data from a suite of nine GCMs accessed using a CSIRO tool OzClim for Oceans (see Appendix 7 for details). The key need was predictions of SST change at the scale of rock lobster fishery assessment regions (Figure 5). The downscaled predictions using the A1B (Figure 9) and A1FI (Figure 10) scenarios provide sea surface temperatures at the desired scale (see again Figure 5). For example, average SST for the four east coast fishery assessment regions are illustrated in Figures 11 and 12. These SST data for the fishery assessment regions are used to predict the impact of climate change on the rock lobster fishery in subsequent sections of this report.



**Figure 9: Future Sea Surface Temperature for the Tasmanian region based on the A1B scenario and downscaled using the OzClim for Oceans tool, for each month (columns 1–12) and the years 2005 (row 1), 2030 (row 2) and 2070 (row 3).**

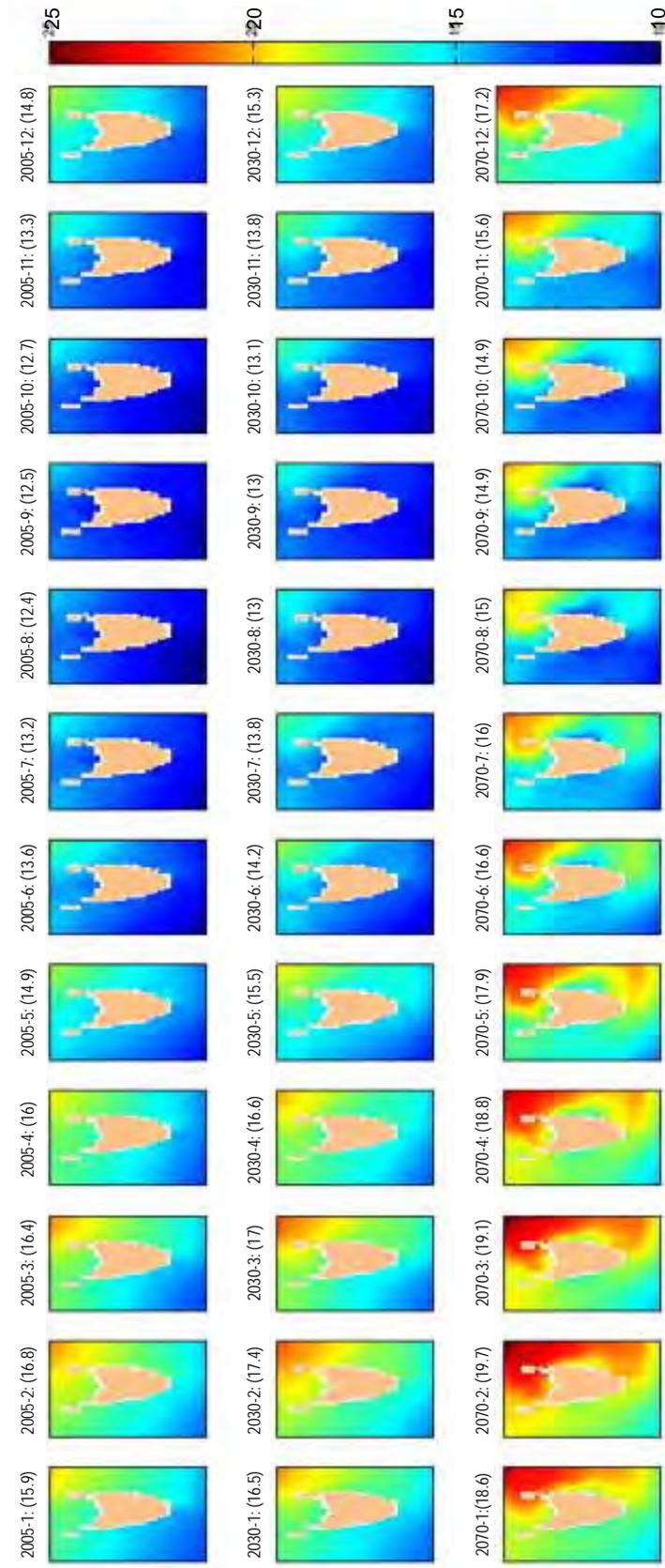
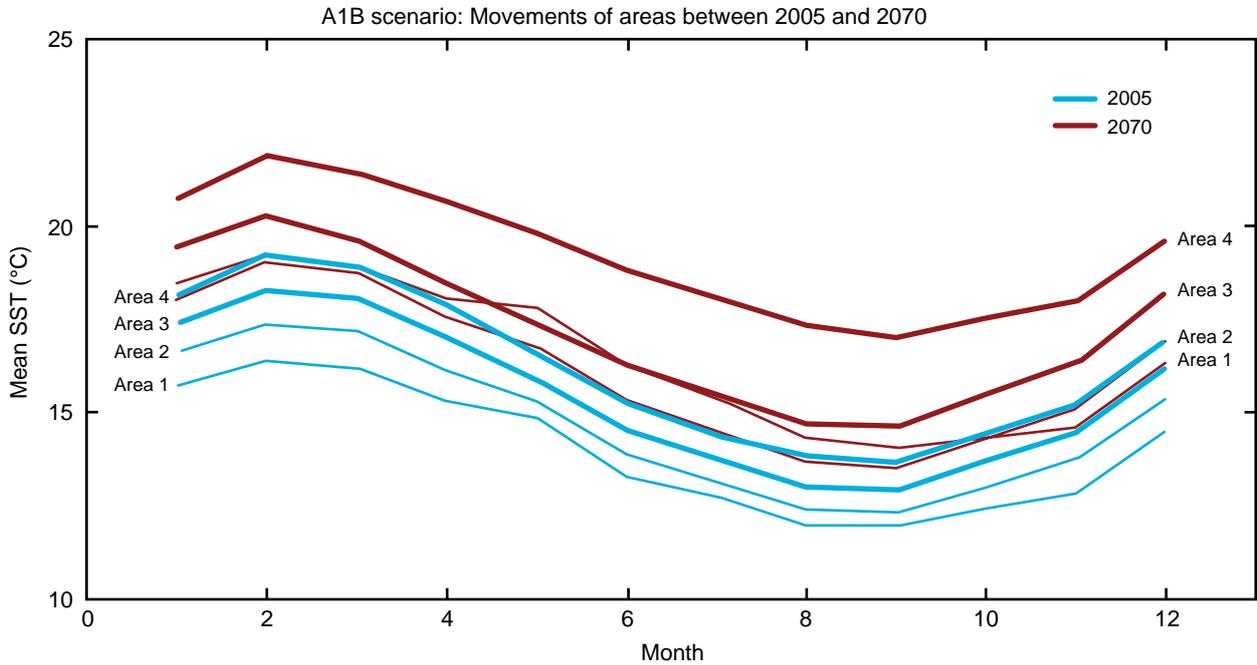
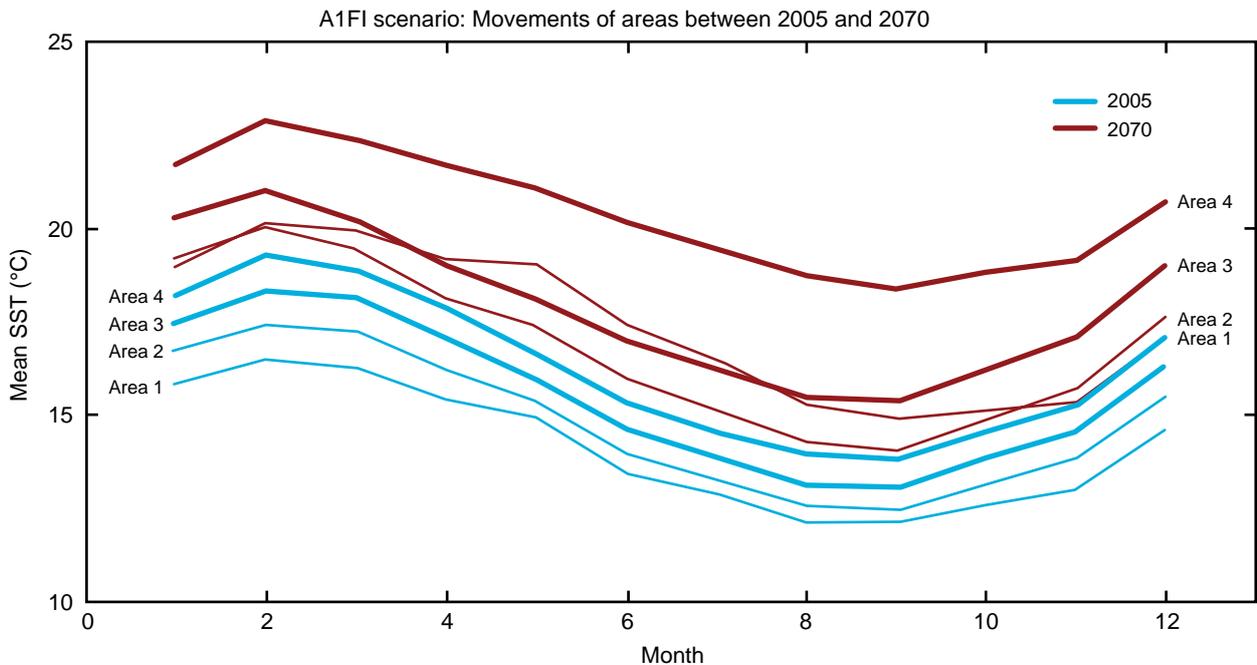


Figure 10: Future SST for the Tasmanian region based on the AIFI scenario and downscaled using the OzClim for Oceans tool, for each month (columns 1–12) and the years 2005 (row 1), 2030 (row 2) and 2070 (row 3).



**Figure 11: The mean SSTs for each of the four east coast lobster areas for each month of the year for 2070, based on the A1B scenario compared with mean SSTs for 2005. The labels on the left-hand side of the panel match the temperature curves for each fishery assessment area in 2005, while those on the right-hand side are the same areas in 2070. By 2070 SSTs in southern Tasmanian fishery assessment areas are expected to be equivalent to those presently experienced in northern Tasmanian fishery assessment areas.**



**Figure 12: The mean SST for each of the four east coast lobster fishery assessment areas for each month of the year for 2070, based on the A1FI scenario compared with mean SSTs for 2005.**

### ***Additional environmental variables***

While SST is the primary variable incorporated in models of the population dynamics of the rock lobster, additional variables may also have impacts on the fishery. These impacts may be on the biology of lobsters, or the way in which the fishery can operate. With regard to biology, for example, current speed and direction may influence settlement patterns of lobster larvae, while temperature at depth (e.g. 50–100metres) may influence growth rates.

### ***Rising sea level***

Rising sea level around Australia will cause flooding and inundation in some coastal environments. This will alter associated marine habitats, and threaten a range of coastal infrastructure. The rock lobster fishery may be affected if port facilities or docks are affected by rising sea level, and this remains an additional uncertainty for the industry. With global warming, the CSIRO climate model projects a doubling in the rate of sea level rise from the observed 1.5 millimetres per year for the twentieth century (Domingues et al. 2008). By the 2080s, sea level is projected to rise by 0.06 – 0.74 metres above the 1990 value (Gregory et al. 2001). Sea-level rise projected by the CSIRO model for just the thermal expansion shows an increase in the entire Australian region but with large spatial variability (Poloczanska et al. 2007). Therefore, over this century the local impact of sea-level rise may substantially deviate from the global averaged value. Sea level is expected to rise at different rates globally (Church et al. 2008). For the Australian region, much greater sea level rise is projected on the east coast than the west coast due to the increased southward penetration of the warm EAC, which causes water on the east coast to expand more than in other regions.

### ***Acidification***

The world's oceans absorb CO<sub>2</sub> naturally from the atmosphere, acting as a buffer for increasing atmospheric CO<sub>2</sub>. As a result of rising atmospheric CO<sub>2</sub> concentrations via fossil fuel emissions, the concentration of CO<sub>2</sub> in the ocean is also increasing, causing the pH to drop and resulting in 'acidification'. It has been estimated that the global oceans have soaked up half of the anthropogenic-induced CO<sub>2</sub> from the atmosphere, which means the current state of global warming has been dampened somewhat by this phenomenon. Current atmospheric levels of CO<sub>2</sub> have already risen to 385 parts per million. Global climate models predict that without major global action to reduce greenhouse gas emissions there will be more than a doubling of global atmospheric CO<sub>2</sub> by the end of this century compared with pre-industrial levels (280 parts per million). A pH drop of 0.4 units is predicted by the year 2100 and a further decline of 0.7 by the year 2300 (Caldeira and Wickett 2003). Within the next several centuries a pH decrease greater than those inferred from the geological record over the past 300 million years, with the possible exception of those resulting from rare, extreme events may occur. Critically, this rapid rate of pH decrease in the future may be faster than the rate at which species can adapt.

Although our understanding is limited, future acidification may adversely affect many organisms that use calcium carbonate for their skeletons and shells, including corals, molluscs and some phytoplankton species (Hobday et al. 2007; Hall-Spencer et al. 2008). Experiments to determine the likely response of marine organisms to pH changes have explored large changes in pH (>1) under laboratory conditions for only a few organisms (see Hobday et al. 2007). Little is known about what gradual long-term effects of lowering pH will have on any marine organism.

## **4.3 RESPONSE OF ROCK LOBSTER STOCKS TO PREDICTED CLIMATE CHANGE**

Assessing how abundance and distribution of commercial species may alter as global climate changes will be fundamental to the successful adaptation of marine fisheries, although it will be a very challenging task. One approach to tackle this issue revolves around the use of bio-climate envelopes via modelling the association between climate variables and a species distribution or relative abundance. Although this approach must be considered within the context of limitations (see Thuiller 2004), it is used widely. In the absence of mechanistic understanding of how a population's abundance and distribution is regulated, bio-climate models provide a solid framework of inquiry. In this report we take available information on the rock lobster stock and fishery characteristics, over a relatively long period of time, and relate these to measured changes in temperature.

Two of our methods of inquiry are qualitative (see regional comparisons and puerulus settlement below), and a third (model estimated recruitment) is quantitative in developing a correlative model to establish a statistical relationship between temperature and recruitment. Additionally, we also address two known issues from the broader ecosystem. There are some limitations which apply to all of these approaches, namely:

- While climate variables will have a direct impact on the productivity and distribution of many species, for others the strongest impact may be indirect resulting from changes in the spatio-temporal availability of natural resources.
- Interactions among species (e.g. predator/prey and competition) will mediate both the direct and indirect effects of climate change (Hulme 2005).
- Changing current systems may impact on the temporal or spatial dispersal of potential recruits, with subsequent impacts on recruitment.

Our three methods of assessment are essentially independent, with differing specific advantages and disadvantages (see Table 1). Briefly they are:

- 1) Regional assessments (Method 1):** This method compares the predicted water temperature estimates in 2030 and 2070 with equivalent geographical regions that experience similar water temperatures today.
- 2) Puerulus settlement (Method 2):** This method uses the observed puerulus settlement trends from three sites around Tasmania. Observations in Western Australia show a strong link between puerulus settlement and future commercial catches. While there is limited work confirming this relationship in Tasmania (see Gardner et al. 2001), it is considered a useful modelling tool for the purpose of this project.
- 3) Model estimated recruitment (Method 3):** The Tasmanian rock lobster fishery assessments are guided by a spatially-explicit size-structured stock assessment model (Punt and Kennedy 1997; Hobday and Punt 2001). Catch and effort data obtained from mandatory logbooks, growth data from mark-recapture programs (Punt et al. 1997) and population size structure obtained from fishery-independent and fishery-dependent sampling are input data for the model. By back-calculating the number of recruits that would have been required to provide the biomass at a point in time, the model can ‘hind-cast’ estimates of recruitment for a given year. We have then examined the relationships between hind-cast recruitment estimates and SST. This relationship has then been used to project the model forward with SST from the climate change scenarios.

**Table 1: Assumptions, advantages and disadvantages of the three methods used to assess the relationship between environmental characteristics (e.g. water temperature) and biological parameters of the rock lobster stock (e.g. recruitment and abundance).**

METHOD	ASSUMPTIONS	ADVANTAGES	DISADVANTAGES
<b>Regional assessments (M1)</b>	<ul style="list-style-type: none"> <li>Water temperature is a good proxy for the physical (salinity, nutrients etc) and pelagic components (e.g. plankton) of the water mass.</li> <li>Water temperature is a proxy for the associated ecosystem.</li> </ul>	Potentially takes into account broader ecosystem processes such as carrying capacity, predation etc	<ul style="list-style-type: none"> <li>Assumes that all components of the ecosystem have the capacity to move with water temperature.</li> <li>Assumes that geology and biogeology relationships are similar.</li> </ul>
<b>Puerulus settlement (M2)</b>	Puerulus catch monitoring sites are representative of the assessment blocks in which they are located.	Based on direct observations of puerulus available for settlement and therefore subsequent recruitment	Assumes that settlement is related to subsequent recruitment of juvenile lobsters. Post-settlement processes, particularly in the first 1–2 years, may have greater impact on subsequent recruitment than actual settlement rates. For example, mortality rates could be highly variable due to changes in predator abundance, food or shelter could be limiting.
<b>Model estimated recruitment (M3)</b>	Changes in catch rates, average weights of landed lobsters, catches and size structure of catches represent changes in recruitment.	<ul style="list-style-type: none"> <li>Catch rate data represents all catch in the assessment region.</li> <li>Combines several different data types and optimises fit to these different sources, improving certainty of inter-annual trends.</li> </ul>	<ul style="list-style-type: none"> <li>Data inputs may vary in response to processes other than abundance (and thus recruitment). For example, water temperature increases catch rates (Ziegler et al. 2004) irrespective of actual lobster abundance.</li> <li>Fishers could move to different fishing locations to maintain higher catch rates</li> <li>There may have been impacts on size structure of catches (an input into the model) due to an increasing abundance of larger lobsters (Frusher et al. 2001, 2003) associated with introduction of the quota management system</li> </ul>

#### 4.3.1 REGIONAL ASSESSMENTS (M1)

Predicted water temperatures for 2030 and 2070 indicate that areas of the Tasmanian coast will possess the sea temperature characteristics currently experienced by geographical areas further north along the eastern coast of Australia (see Figure 13 and Table 2). In 2030, each rock lobster assessment area will have temperatures equivalent to those currently experienced by rock lobster assessment areas immediately to the north. Area 4 (the most northern Tasmanian rock lobster assessment area) will have similar temperatures to those currently occurring around the Victoria – New South Wales border. In 2070, this warming effect will be exaggerated, with all rock lobster assessment areas having annual average water temperatures similar to those currently on the Victorian and New South Wales coasts. The exception is area 1 (southernmost), which in 2070 will be as warm as area 4 currently (under an A1B scenario) or waters around the Victoria – New South Wales border (A1FI scenario). Generally, these regions of Victoria and New South Wales do not support population abundances of either southern or eastern rock lobsters (or both combined) that are the same order of magnitude as currently occurs in

Tasmania. For example, the commercial catch of lobsters off New South Wales was only 109 tonnes in 2006–07 (G. Liggins pers com), and although both lobster species are present in ‘barrens-free’ marine reserves off New South Wales, they are only at very low densities (N. Barrett pers com). In the 2006–07 fishing season the southern region of New South Wales contributed 21.7 tonnes (~20 per cent) to the overall New South Wales lobster catch (Liggins et al. 2008). This is low in comparison to 156 tonnes caught in area 4 during 2006–07 and 524 tonnes for the entire east coast of Tasmania. Montgomery (1999) estimates that the maximum annual catch of rock lobster in NSW by the commercial fishery has never been much greater than 300 tonnes.

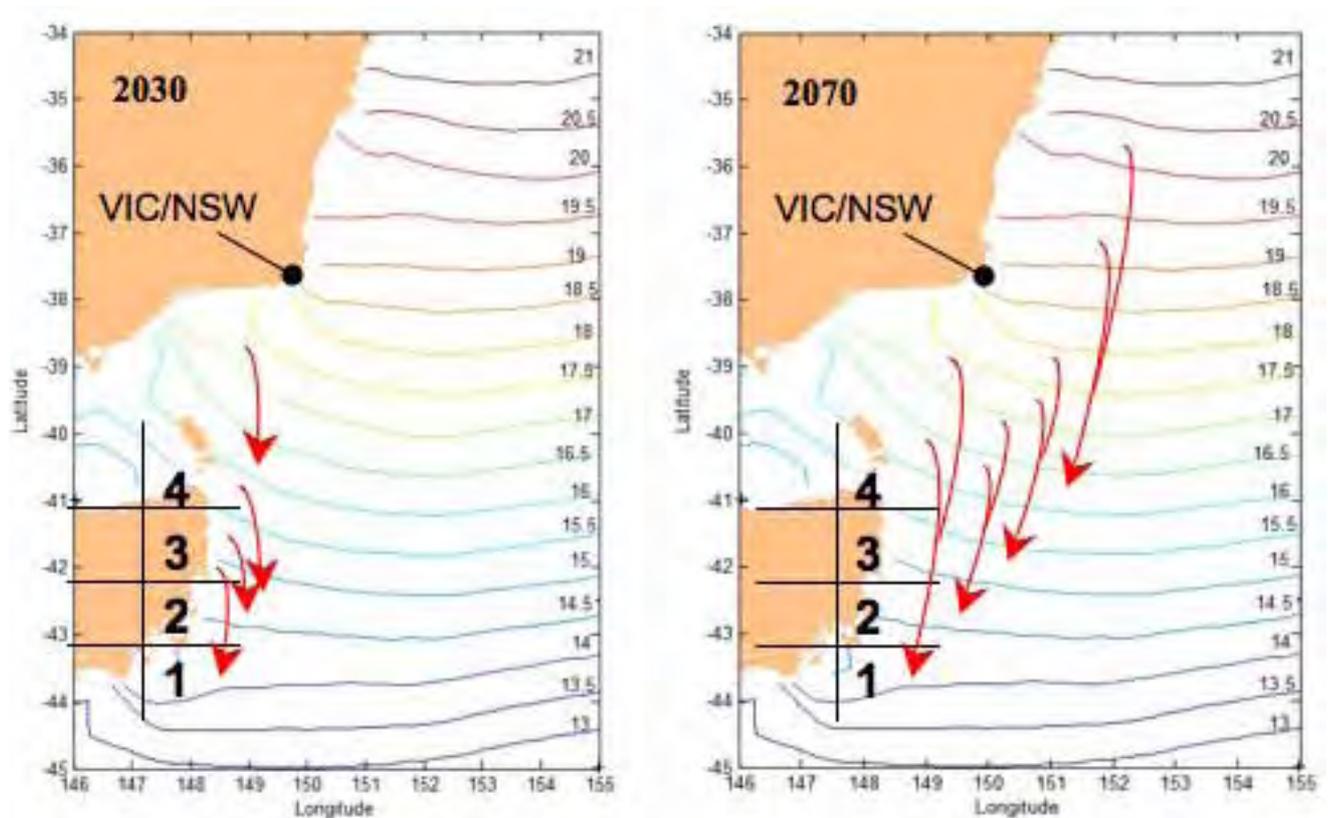
**Table 2: Average annual sea surface temperatures ( $\pm 1$  standard deviation) for each rock lobster assessment area for 2005, and projected annual average temperatures for 2030 (A1B) and 2070 (A1B and A1FI). The approximate current geographical location of water masses of equivalent temperatures are indicated in Figure 13.**

RL AREA	2005 T°C	2030 T°C (A1B)	2070 T°C (A1B)	2070 T°C (A1FI)
1	14.03 $\pm$ 1.66	14.76 $\pm$ 1.72	16.42 $\pm$ 1.90	17.35 $\pm$ 2.10
2	14.72 $\pm$ 1.84	15.16 $\pm$ 1.90	16.19 $\pm$ 2.03	16.76 $\pm$ 2.19
3	15.45 $\pm$ 1.94	15.97 $\pm$ 1.95	17.19 $\pm$ 2.00	17.86 $\pm$ 2.06
4	16.20 $\pm$ 1.99	17.12 $\pm$ 1.89	19.23 $\pm$ 1.67	20.41 $\pm$ 1.63
5	15.03 $\pm$ 1.72	15.48 $\pm$ 1.75	16.53 $\pm$ 1.82	17.11 $\pm$ 1.95
6	14.16 $\pm$ 1.45	14.46 $\pm$ 1.68	15.16 $\pm$ 1.68	15.55 $\pm$ 1.86
7	13.60 $\pm$ 1.45	13.98 $\pm$ 1.52	14.86 $\pm$ 1.68	15.35 $\pm$ 1.86
8	13.09 $\pm$ 1.51	13.65 $\pm$ 1.59	14.95 $\pm$ 1.78	15.66 $\pm$ 1.99

Although lobster productivity is reliant on both biophysical constraints that affect carrying capacity, such as habitat and food availability, and anthropogenic impacts, such as reduced recruitment through overfishing, it is considered unlikely that eastern rock lobster abundances (or a combination of eastern and southern rock lobster) would compensate for the predicted decline in southern rock lobster recruitment on the east coast of Tasmania. In addition to the lower nutrient inputs into the region by a more dominant EAC, anecdotal evidence that also supports this conclusion includes:

- i. there has not been the same magnitude of recovery of lobsters on protected reefs in NSW compared to Tasmania;
- ii. there has not been a commensurate increase in eastern rock lobsters in north eastern Tasmania reefs as southern rock lobster have declined;
- iii. adult eastern rock lobsters prefer deeper waters (between 20 and 100m, Montgomery 1999) and there is limited deeper water habitat in eastern Tasmania;
- iv. it has been suggested that mature eastern rock lobsters migrate northwards to spawn (Montgomery, 1999), and while it is uncertain if they require reef to undertake this migration, Bass Strait may provide a physical barrier (e.g. extent of non-reef habitat) for a similar migration.

Abundance of southern rock lobster is higher at similar latitudes in north-western Tasmania and south-eastern South Australia compared to the eastern Tasmanian coast, as the ocean current systems in these regions are very different and benefit from upwelling systems such as the Bonney upwelling that bring cooler nutrient-rich waters to the surface (Butler et al. 2002).



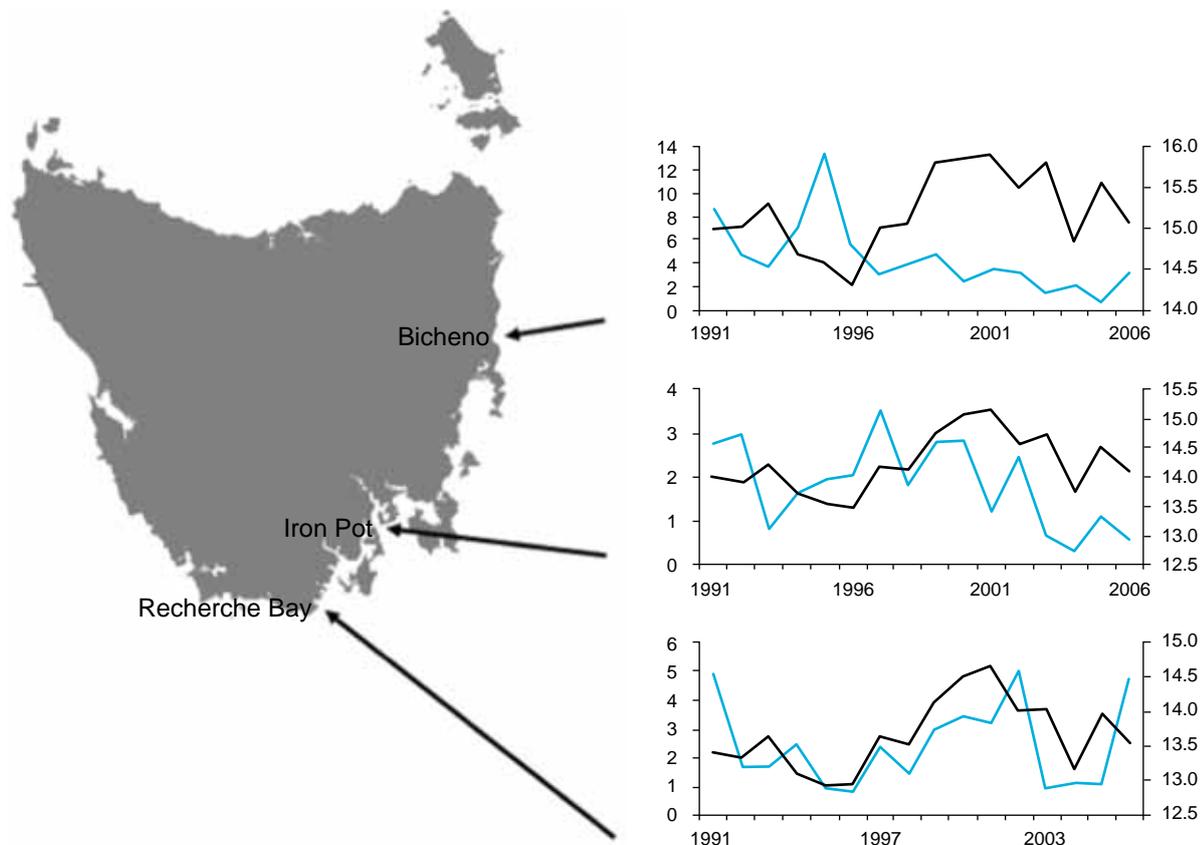
**Figure 13: Map showing the current approximate geographical locations of the projected temperatures for each rock lobster assessment area in 2030 (A1B) (left panel) and 2070 (right panel) (A1B and A1FI, higher origin point of each double line indicates the A1FI scenario). The coloured horizontal lines show the annual mean temperature isobars for 2006.**

The lower abundance of southern lobsters in warmer areas of Australia may be a function of reduced survival of stage III phyllosoma larvae at higher temperatures. Bermudes and Ritar (2008) reported complete mortality of these larvae above 21.5°C. Experiments with newly settled juveniles showed that they are more tolerant of higher temperatures and indeed have greatest growth and food conversion at around 20°C (Thomas et al. 2000). Possible causes of mortality of phyllosoma larvae at high temperature include (i) the burden of an energetic imbalance at the moult to stage II; (ii) oxygen starvation at moulting (Bermudes 2002); (iii) the disruption of cellular membrane structure and function (Willmer et al. 2000); or (iv) a combination of these factors around the time of moult (Bermudes and Ritar 2008). Examination of the monthly average temperatures expected for each rock lobster assessment area in 2030 and 2070 under the two scenarios (see Figures 11 and 12) indicate that temperatures over 20°C, potentially deleterious to larvae, would be reached during several months in northern and eastern Tasmania (areas 3 and 4) by 2030. Hatching of eggs occurs between August and September and stage III larvae would be expected within two to three months after hatching. To impact on stage III larval survival, temperatures greater than 20°C would therefore need to occur towards the end of the year. In general, temperatures greater than 20°C occur in February and March and are unlikely to impact stage III larvae, although the thermal tolerance of later stage larvae (stage IV+) is unknown. Irrespective of the mechanisms or processes responsible, even ‘barrens-free’ regions of Victoria and New South Wales do not support populations of rock lobsters that are the same order of magnitude as currently occurs in Tasmania.

#### 4.3.2 PUERULUS SETTLEMENT (M2)

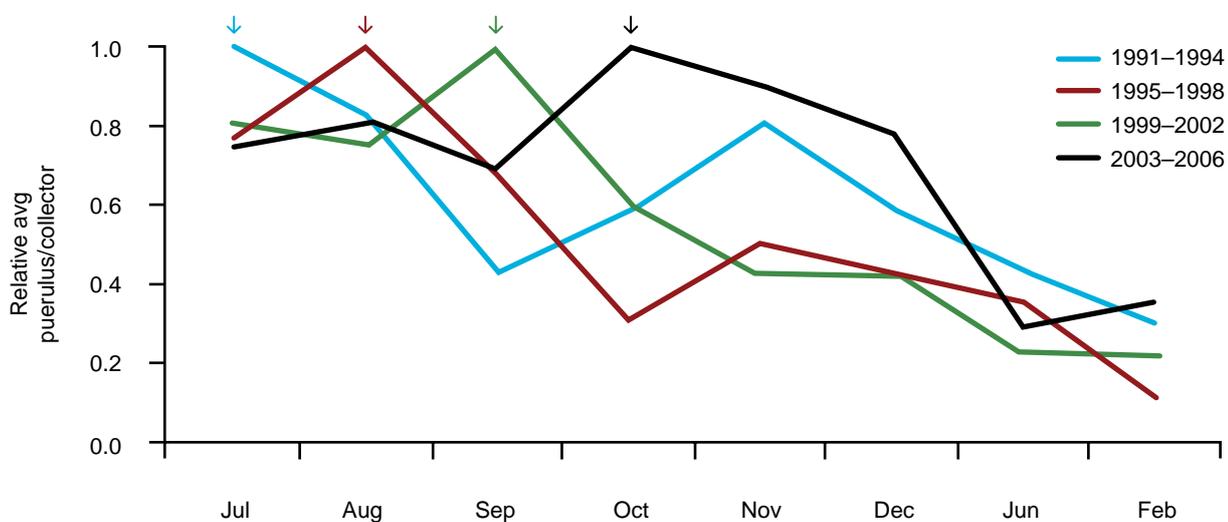
Puerulus settlement has been continuously monitored at three sites along the east coast of Tasmania since 1991 (Figure 14, methodology reported in Gardner et al. 2001). There has been no consistent pattern in settlement observed across all sites within the monitoring period. There was higher settlement observed at the start of the time series at Bicheno, at the middle of the time series at Iron Pot, and towards the end of the time series at Recherche Bay. The correlations between annual SST and annual puerulus settlement are negative for Bicheno (-0.54), close to zero for Iron Pot (0.04) and positive for Recherche Bay (0.37).

The patterns in puerulus settlement and the correlations with SST in Tasmania observed in the north at Bicheno, at Iron Pot and in the south at Recherche Bay (Figure 14) support the hypothesis of Bruce et al. (2000) that the position of the sub-tropical convergence (STC), where the EAC meets cooler Southern Ocean water, is important for east coast puerulus recruitment. Furthermore, modelling of lobster larvae transport suggests that regions from south-eastern South Australia to south-western Tasmania are important regions for supply of larvae to eastern Tasmania (Bruce et al. 2007). The supply of later stage phyllosoma larvae and puerulus to eastern Tasmania sourced from these regions may be attributed to strong westerly winds that drive cooler waters from western Tasmania, around southern Tasmania, and up the east coast (Harris et al. 1988). These winds push the STC northward during winter and autumn and provide puerulus to eastern Tasmania. Increases in water temperature along the east coast indicate the increasing strength and southern penetration of the EAC (Ridgeway 2007; see also section 4.1). A stronger EAC results in less northerly penetration of the STC and fewer larvae reaching north easterly and easterly regions of the fishery.



**Figure 14: Trends in annual puerulus settlement (average number per collector per month) (blue line, left axis) and annual seas surface temperatures (black line, right axis) since 1991.**

Relatively high puerulus settlement at Bicheno in the early 1990s suggests that waters there were higher in lobster larvae at this time. The shift in relatively higher puerulus settlement to periods later in the time series with increasing latitude suggest that the water mass with more abundant puerulus is also shifting south. The reversal of the correlations between water temperature and puerulus settlement between northern and southern regions of the east coast can be explained by increasing water temperatures, indicating an increasing southern penetration of the EAC which drives this water mass away from Bicheno (negative correlation) towards southern Tasmania (positive correlation). The recent cooling of the waters at Maria Island (Figure 7) suggests a weakening of the EAC which may result in improved settlement at southern sites as seen at Recherche Bay in 2006. The strengthening and increased penetration of the EAC can be expected to result in a delay in the timing of settlement in the more northerly regions of the east coast as has been observed at Bicheno (Figure 15).



**Figure 15: Comparison of monthly peaks in puerulus settlement at Bicheno from July to February averaged over four-yearly periods since 1991. Arrows indicate peak months of settlement. Puerulus settlement between March and June is low so sampling during these months was discontinued in 1997.**

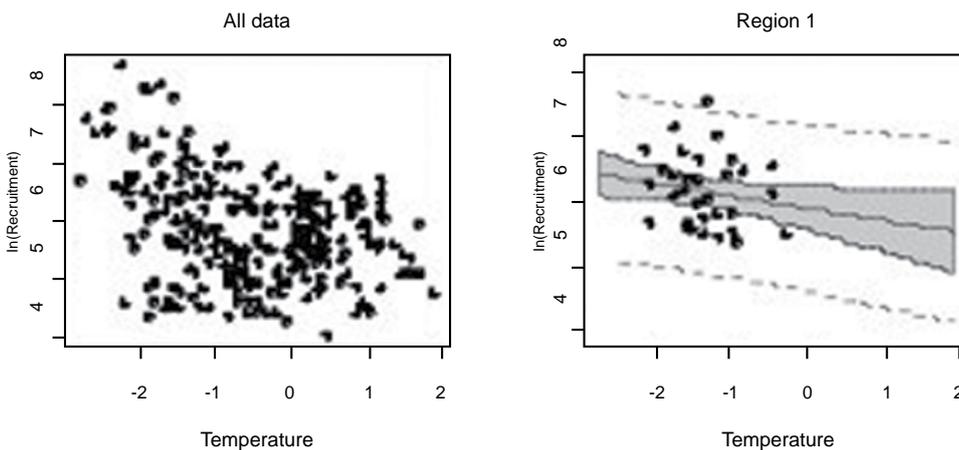
There remains considerable uncertainty regarding the drivers for puerulus settlement for southern rock lobster throughout its distribution. Modelling of larval transport and observed changes in puerulus settlement in eastern and south-eastern Tasmania do support a hypothesis of declining recruitment with the predicted increase in southward penetration of the EAC. This hypothesis would suggest that with the predicted increase in southward penetration of the EAC, north-eastern and eastern regions would experience continued declines in puerulus settlement, whereas south-easterly regions would initially have improved recruitment before experiencing declining puerulus settlement trends similar to northern regions as the EAC extends beyond these regions.

#### 4.3.3 MODEL ESTIMATED RECRUITMENT AND RELATIONSHIP TO TEMPERATURE (M3)

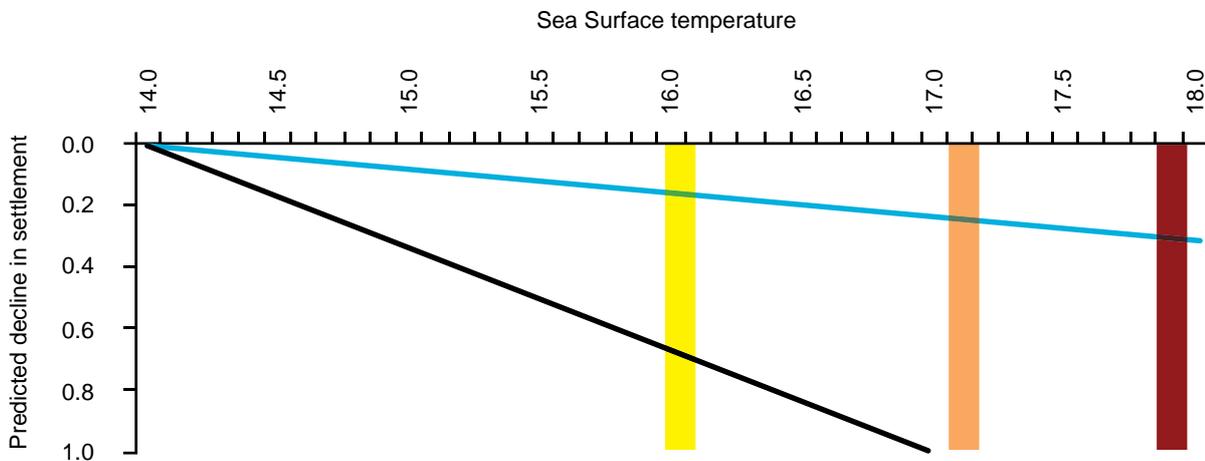
The rock lobster assessment model produces estimates of recruitment for all eight fishery assessment areas (Figure 5) of the fishery as outlined in section 4.3. The estimates are hind-cast estimates of the number of lobsters in the 60–65 mm CL (carapace length) size bin, the lowest size bin used in the model required to produce the legal-sized biomass that generates the observed catch. To correlate water temperature to larval recruitment, estimates of the time required for newly settled puerulus to grow to the 60–65 mm CL size bin are required. This information is currently unknown, although general relative trends are expected. The time taken to grow from puerulus to a 60–65 mm CL lobster is expected to be slower in southern areas and to be slower for the same latitude in western areas (similar to the size-at-maturity differences in Figure 4, Chapter 2). In northern faster-growing regions (areas 3, 4 and 5) the strongest negative correlations between modelled recruitment and sea surface temperature are between one and two years after settlement. The lag period increased to four to five years in south-eastern Tasmania and five to six years in south-western Tasmania (see Appendix 8).

Combining the lagged model recruitments across all regions of the fishery provides a negative relationship between recruitment and SST (Figure 16, all data). Within any region there is considerable variation, especially in southern and western regions. The poorer fit in these areas supports the settlement hypothesis for the puerulus data discussed in the previous section: that current and wind systems influence pre-settlement larval abundances. It is noteworthy that the most north easterly region (area 4) suggests a much stronger negative relationship between lagged model-estimated recruitment and temperature than the overall trend.

Although both puerulus settlement (M2) and model estimated recruitment (M3) trends indicate a decline in recruitment to the fishery with sea surface temperature, there are substantial differences in the rates of decline between estimates (Figure 17). Both estimates of recruitment have biases as outlined in Table 1 and it is likely that the actual rate of decline lies somewhere between these trends. Model projections (the stock assessment model; see section 4.3.4) in this report are based on the relationship between hind-cast model-estimated recruitment and temperature and as such, the impact of temperature on recruitment in these projections is considered to be an underestimate. Adjustment of the model to incorporate the more rapid decline in puerulus settlement with increasing temperature (instead of the more moderate model hind-cast recruitment–temperature relationship) is beyond the scope of the current project and would be a key requirement of any future assessment.



**Figure 16: Model-estimated recruitment was regressed on observed sea surface temperature for each region. Projections of the response of recruitment to continued sea surface temperature increases under climate change used these relationships. The shaded areas show the 95 per cent confidence limits for mean regression and the dotted lines the prediction range for area 1. Temperature on the x-axis has been centred at 15°C (i.e. 0 = 15°C).**



**Figure 17: Comparison in the rate of decline in recruitment indices between puerulus settlement (black line) and model-estimated recruitment (blue line) for area 3. Estimated annual sea surface temperatures for this area from both the A1B and A1FI models are similar for 2030 (yellow region) but differ for 2070 (A1B – orange, and A1FI – red).**

#### 4.3.4 ROCK LOBSTER STOCK PROJECTIONS

The effect of climate change on rock lobster populations was modelled by projecting forwards in time with changes to both growth and recruitment in response to warmer water. The modelled population of lobsters increases through recruitment of new lobsters and growth of lobsters already in the population. Lobsters are removed from the population either by being caught in the fishery or through natural mortality. The model was fitted to real tag recapture and fisheries data for years 1970 to 2007, with annual recruitment of juvenile lobsters estimated by the model based on this data.

The modelled population of lobsters is split by gender, size of lobsters (five mm increments) and location (eight assessment areas). Density-dependent processes were not incorporated into projections; however, these would be expected to interact with growth rates and survival. For a more detailed description of the model see Appendix 9. Models used for projections are listed in Table 3. Outputs from run C only is shown in Appendix 10.

**Table 3: Description of model projections (see Appendix 10 for outputs from run C, other model projections available upon request from TAFI).**

MODEL RUN	DESCRIPTION
A	No climate change or other alterations
B	Recruitment only – A1B
C	Recruitment + growth – A1B
D	Recruitment only – A1FI
E	Recruitment + growth – A1FI
F	Recruitment + 0.67% growth – A1B
H	Case C with TAC increased by 25%
I	Case B with TAC reduced by 32%
J	Case D with TAC reduced by 32%
K	Case E with TAC increased by 25%

Each model projection provided estimates of the exploitable biomass (lobsters above legal size and available to the fishery), commercial catch, egg production and biomass of lobsters above 145 mm CL. The model includes a fleet dynamics sub-model that enables the fleet to move between regions based on the key drivers of fisher behaviour. Thus commercial catch incorporates the dynamics of the fishing fleet. Ling et al. (2008) found that lobsters needed to be above 145 millimetres CL to be able to successfully prey on emergent *Centrostephanus* (i.e. urchins not hiding under rocks) so this minimum size was used in this report. The biomass of lobsters above this size indicates the potential ability of the ecosystem to withstand barrens formation.

Model run A (status quo) indicates that under the existing TACC and with average recruitment and existing growth rates (i.e. no impacts of climate change), the exploitable biomass would likely increase substantially until the year 2070. This prediction effectively continues the observed trend in the fishery since 1993. The increase in biomass is based on the compounding effect of additional growth in biomass of the unharvested legal-sized lobsters. Egg production and the biomass of lobsters larger than 145 mm CL both increase substantially. In all other model runs the 'status quo' or no climate change case is indicated as the black line for comparison with model runs adjusted to incorporate climate change information (red lines)(Figure 18). Information prior to 2006 is observed data in all model runs.

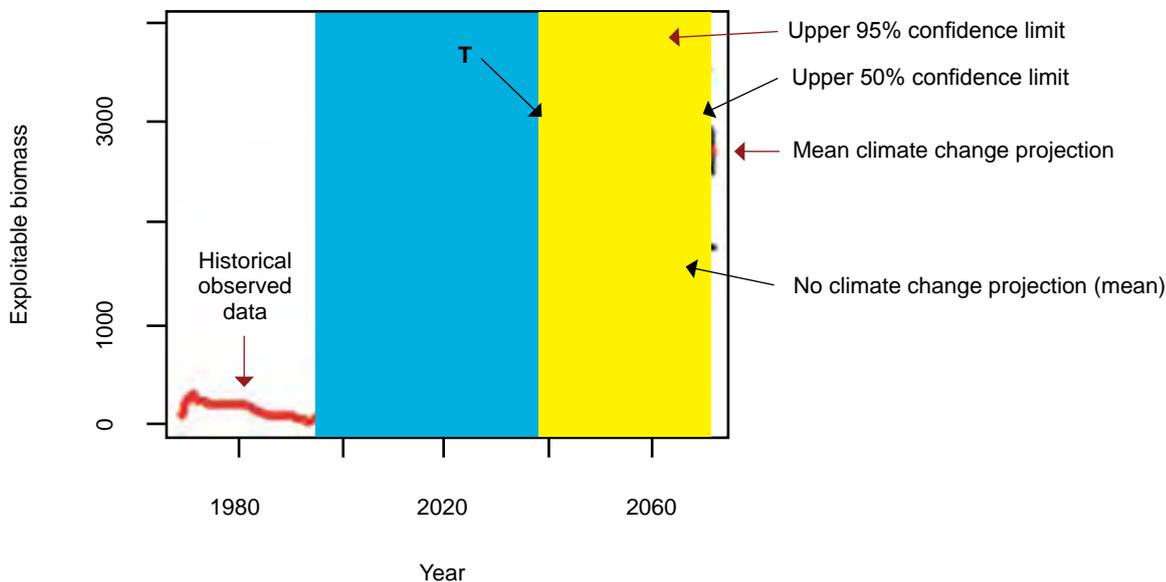
The predicted effect of a decline in recruitment only (i.e. no growth gains) due to temperature increase is shown for model runs B, D, I and J. These led to a rapid decline in stocks so that exploitable biomass was virtually zero by 2030 in all cases. Commercial catch was predicted to become increasingly reliant on the south-western (8) and western regions (6 and 7). By approximately 2030 the TACC could no longer be caught as the fishery was solely based on a dwindling source of recruits. The biomass of lobsters greater than 145 mm CL also declined to zero in virtually all regions by 2030, indicating that under the existing TACC and recreational effort there would be increased barrens formation by *Centrostephanus* (see section 4.3.7). The predicted trends in lobster stocks for both the medium and high climate change scenarios were very similar.

Growth rates are known to increase with temperature (Thomas et al. 2000). This change will be greater in southern regions compared with northern regions where growth rates already appear to be at their maximum. For climate change scenarios where growth responds to the higher temperature (C and E), there are substantial increases in exploitable biomass above the status quo case in all regions of the fishery, although, as expected, these are greater in southern compared to northern regions (Appendix 10 for model run C). Gains from faster growth are finite and are eventually overtaken by declining recruitment (see explanation Figure 18).

Uncertainty in growth and recruitment projections will affect the rate and magnitude of the increase in exploitable biomass as well as the timing of the transition point where recruitment declines begin to outstrip biomass improvements from increased growth rates. The greater potential for faster growth in southern regions is predicted to lead to greater commercial catch from these regions (Figure 19). Region 4 is expected to contribute virtually no catch to the overall harvest by approximately 2040 whereas regions 7 and 8 increase in their proportion of the overall TACC. Egg production shows substantial improvements in southern regions as females grow larger and can thus carry more eggs.

The biomass of large lobsters (>145 mm CL) is expected to increase substantially in all regions before beginning to decline in a pattern similar to that for exploitable biomass. After an initial rebuilding period, all regions should have improved resilience against barrens formation through predation of *Centrostephanus* by large lobsters. Critically, the transition point where biomass of larger lobsters starts to decline occurs earlier in eastern regions, the regions expected to be most prone to *Centrostephanus* impacts (see section 4.3.7).

Vulnerability to climate change impacts and adaptation response options



**Figure 18: Example diagram to demonstrate climate change projections (based on area 1, model C run, Appendix 10). T = the transition point where recruitment declines begin to erode gains in biomass from improved growth. In the blue zone, improvements in growth rates associated with increased temperatures result in improved biomass projections above the no climate change (status quo) projection. The yellow zone indicates the time period where improvements in growth rates can not compensate for the declining recruitment to the exploitable biomass.**

Modelled projections were repeated but with the effect of temperature on growth rate reduced by a third to test the sensitivity of results to growth rates (Table 4). These projections showed a decrease in the rate of exploitable biomass building, and the transition point where declines in recruitment are not compensated by increases in growth was reached earlier. The distribution of the commercial catch remains relatively unchanged with the exception of more catch coming from southern regions in the short term (2030). Gains in egg production are more subdued, with the largest impact in regions 6 and 8. The effect of a change in growth rates on the fishery is complex because of its effect on the large biomass of sub-legal lobsters in southern areas. A small change in growth of these animals leads to a substantial change in their contribution towards the total catch.

For analyses presented here, we assumed that the currently observed regional differences in growth are solely driven by differences in temperature. If other factors such as density dependence, food and shelter availability, predator abundance etc. also impact on growth then the projections we present will provide an excessively optimistic view of change. Irrespective of the uncertainty in growth and recruitment, the general trend of initial gains in biomass before a reduction in biomass is predicted for all regions and for both climate change scenarios.

**Table 4: Percentage reduction in exploitable biomass, egg production and biomass of lobsters > 145 mm CL, with a reduced impact of temperature on growth rates (model run F compared to C) utilised in the model. Red regions experience reductions in excess of the average across the state.**

REGION	EXPLOITABLE BIOMASS		EGG PRODUCTION		BIOMASS >145 MM CL	
	2030	2070	2030	2070	2030	2070
1	18.9	17.4	12.8	16.8	29.4	22.2
2	14.9	16.7	5.8	9.1	29.1	27.9
3	13.4	13.1	6.8	6.8	19.2	17.1
4	16.4	12.7	14.4	13.7	21.7	16.8
5	12.6	16.2	13.1	17.7	15.7	18.1
6	19.7	21.7	19.2	29.7	26.8	29.3
7	27.6	21.7	8.9	13.3	46.7	33.4
8	44.8	23.0	23.6	24.8	64.4	29.5
Average	21.0	17.8	13.1	16.5	31.6	24.3

#### 4.3.5 ARE RECENT TRENDS IN THE STOCK CONSISTENT WITH MODEL PREDICTIONS?

A few simple processes drove trends in model projections. Given that coastal waters around Tasmania have already undergone substantial change in temperature we would expect the projected trends to be consistent with observed patterns in the stock over the last few decades. The main patterns predicted were:

- increase in growth rates in southerly regions
- decline in recruitment in northerly and eastern areas
- shift in fishing activity from north to the south-west.

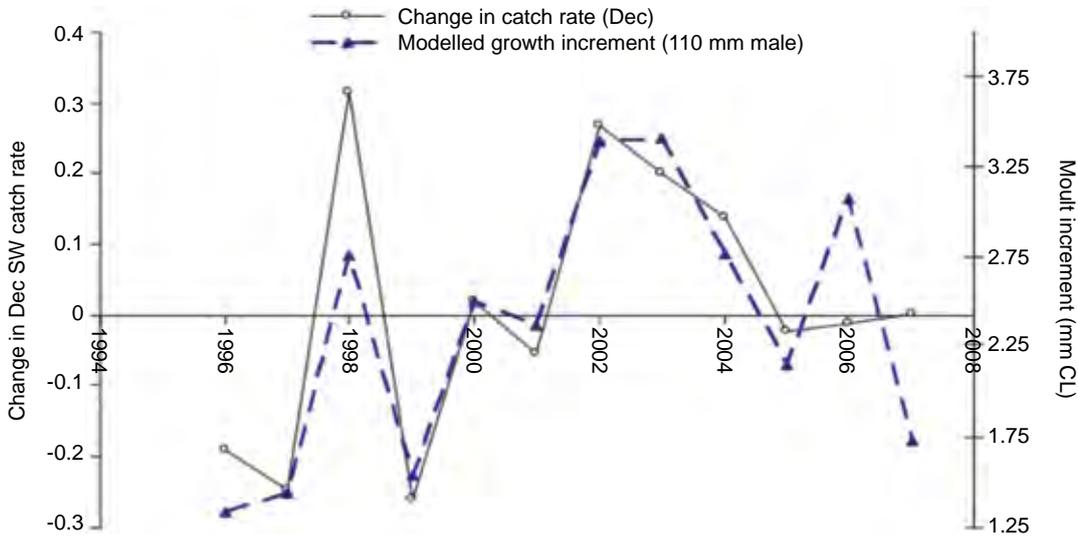
Each of these predictions is consistent with observed trends.

##### *Increase in growth rate in southerly areas*

Growth of lobsters has been monitored at Maatsuyker Island in the south-west by annual tagging operations since 1995. These data show a long-term trend of increase in growth rate of around 0.4 millimetres CL extra each decade for both male and female lobsters at the size limit. This may seem small but is significant with the long-term female growth rate only 0.5 millimetres per year at this size; in other words, the growth rate of females has almost doubled and the trend has the potential to almost double female contribution to catches in this region.

The relationship between growth rate of lobsters and temperature in southern regions is such an important driver of productivity in the region that catch rates in the fishery are highly correlated with water temperature the previous summer when lobsters were accumulating energy reserves (Figure 19).

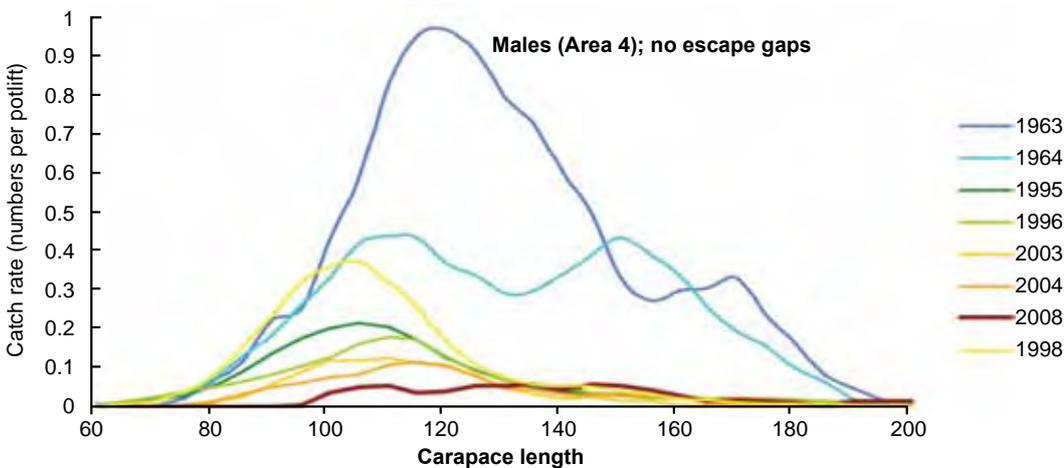
Vulnerability to climate change impacts and adaptation response options



**Figure 19: Growth of lobsters in south-western Tasmania is responding to temperature changes and altering catch rates as predicted by climate change modelling. Male lobsters in the south west of Tasmania grow by moulting once per year, usually in September/October. After moulting they feed to replenish energy reserves. If it is warm in the spring and summer while they are feeding then their growth increment the following moult many months later is larger. Using this relationship it is possible to show that the changes in catch rate from year to year in the south-west appear to be driven by changes in water temperature via different growth rates.**

***Decline in recruitment in northerly and eastern regions***

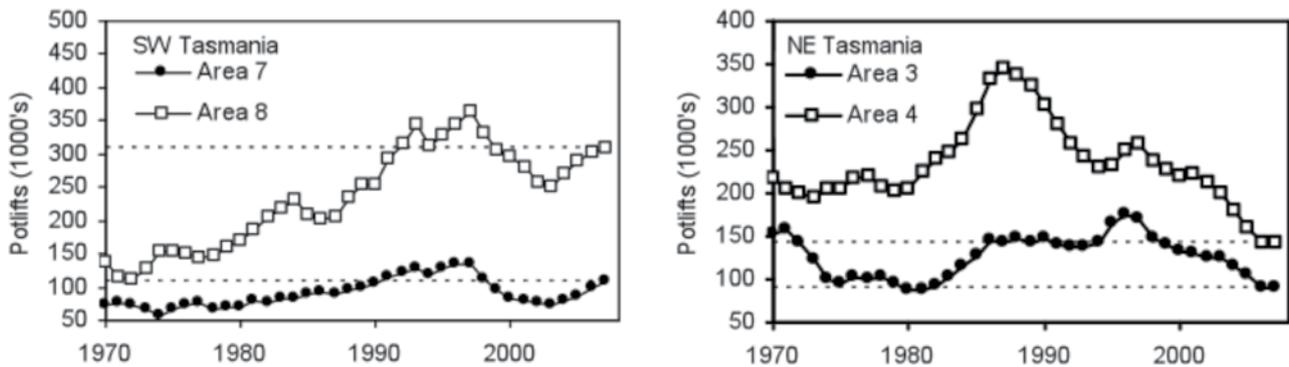
Monitoring of catch rates of puerulus lobsters on collectors off eastern Tasmania appear to show a long-term trend of decline (section 4.3.2). Data are available for catches in commercial pots in the north-east from 1963-2008 (Figure 20). These suggest a long term and severe decline in recruitment over the more than 40-year period.



**Figure 20: The size structure of rock lobster catches in north-east Tasmania indicating a dramatic fall in recruitment over the last 5 decades, which is consistent with the current climate change modelling. The decline in this stock is more remarkable given the large reduction in fishing effort that has also occurred over this period (i.e. reduced fishing effort would normally be associated with stock rebuilding).**

***.Shift in fishing activity from north-east to the south-west***

Fishing activity is measured as pot-lifts and has been recorded on a regional basis since 1970. Fishing effort is now near record lows for this period in the north-east, while near record highs in the south-west (Figure 21).



**Figure 21: Fishing effort is currently shifting away from north-eastern Tasmania and towards the south-west, as predicted by the current climate change modelling. Effort in the south-west is near record highs (and at record highs since quota management was adopted in 1998). Effort in the north has declined over the last 20 years, more than halving in the far north-east. The dashed lines indicate the value of the last year of each series.**

**4.3.6 OTHER POTENTIAL IMPACTS**

- Increased water temperature is also likely to result in increased catchability of lobsters since they become more active as temperatures increase (Ziegler et al. 2003). As changes in catch rates are used as a measure of relative abundance of lobsters, increases in catchability would be misinterpreted as improved recruitment in most assessments.
- Calcium carbonate is a component of lobster exoskeletons which may be affected by decreasing pH due to ocean acidification (see section 4.2.1, and Hall-Spencer et al. 2008). There may also be other physiological stresses, on respiration for example, from decreasing pH.
- Lobsters in the wild are generally free of disease, although many crustaceans have high disease incidence in culture facilities where density and stress are high. The potential risk of disease is expected to increase with increasing temperatures. Shell disease has been reported for the American clawed lobster (*Homarus americanus*) in Long Island Sound and a viral disease has recently been identified in the Florida spiny lobster (*Panulirus argus*) (Shields and Behringer, 2004; Butler et al. pers comm, Old Dominion University, Virginia, US).

**4.3.7 BROADER ECOSYSTEM ISSUES**

***Uncertainty of ecosystem behaviour***

One of the fundamental challenges facing ecologists and resource managers is understanding and ultimately predicting, how natural systems will respond to environmental conditions that have no analogue at present or in the recent past. Future ecological change may therefore surprise us with complex and unexpected responses that are specific to climatic conditions we have not yet experienced (Harley et al. 2006), in addition to the unknown consequences of other pressures (e.g. fishing and climate change, pH and temperature etc.) operating in synergy. The many varied and complex components of ecosystems will respond to climate change influences at different rates and in multiple ways, resulting in a very limited capacity to predict ecosystem behaviour under any climate

change scenarios at the present time. This is an important caveat that overlies all the projections and biological impacts/scenarios presented in this report. For example, very little is known about the main predators of rock lobster, or how predator–prey interactions may modify rock lobster distribution and abundance now, let alone under climate change scenarios. Lobsters are preyed upon by sharks and octopus, and there is a reasonable basis for expecting octopus populations to increase under climate change (Pecl and Jackson 2008).

Although there will undoubtedly be ecosystem ‘surprises’, there are several broader likely impacts that have been identified as resulting from climate change: increased prevalence of ‘green’ eastern rock lobsters, higher abundance of lobster predators (e.g. octopus), and increased potential for barrens formation as a function of southern range expansion of the sea urchin, *Centrostephanus rodgersii*.

### ***Eastern rock lobsters***

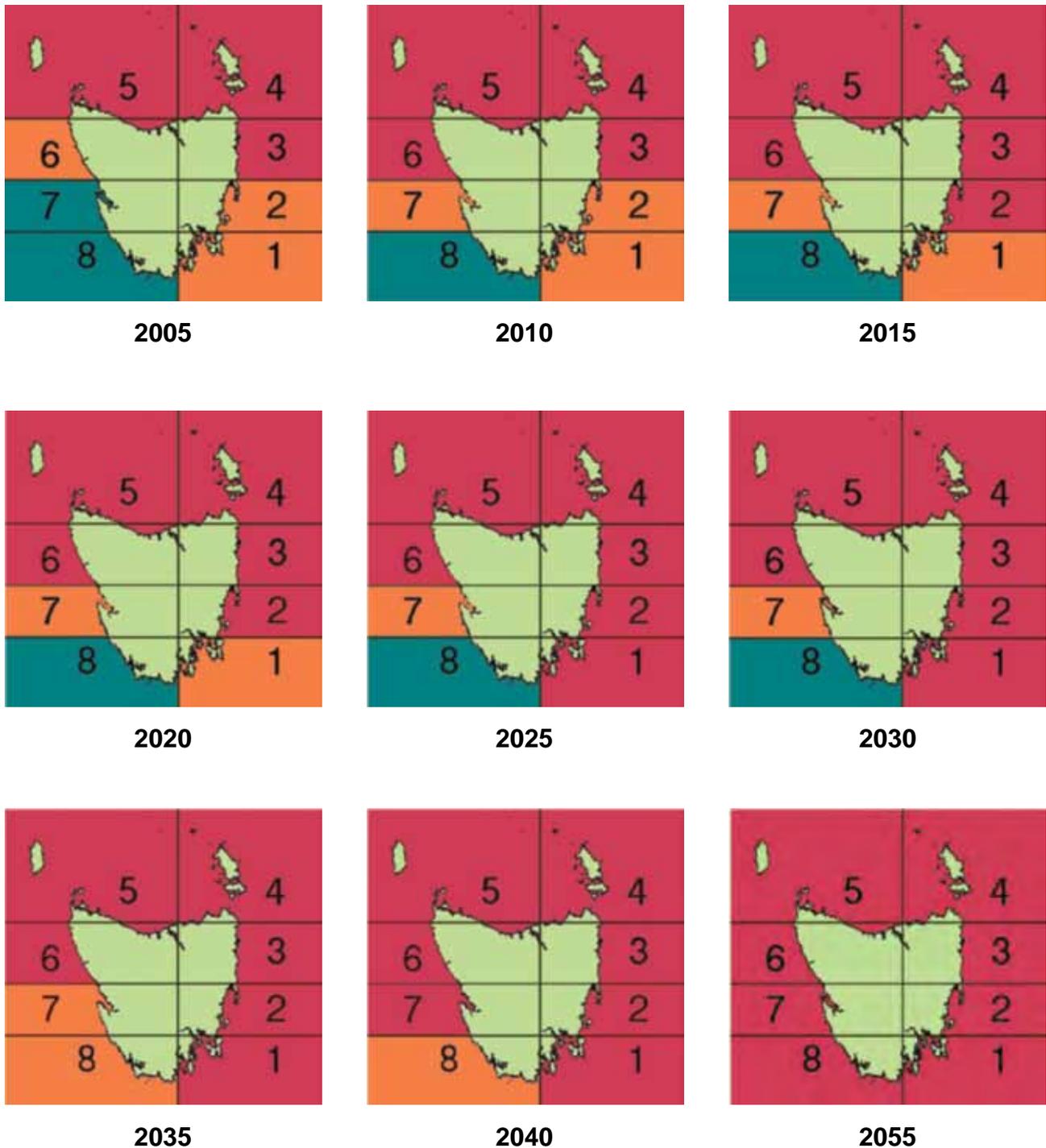
The eastern rock lobster is faster growing than the southern rock lobster and reaches larger sizes, with females maturing at around 165 millimetres CL in New South Wales (compared to 65 millimetres CL for southern rock lobsters in some parts of southern Tasmania). No mature female eastern rock lobsters have been reported from Tasmania and larvae are considered to be brought to Tasmania via the East Australian Current. Eastern rock lobsters are captured regularly in north-eastern regions of Tasmania in small numbers, although fishers report seeing the odd specimen around south-western Tasmania. The catch of eastern rock lobsters may be expected to increase if conditions become more suitable for the species. Settlement of eastern rock lobsters has been monitored in Tasmania for a decade at four collector sites down the east coast. Only a few individuals have been collected at sites at Flinders Island and Bicheno. Catches of eastern rock lobster puerulus comprised 20 per cent of the total catch at Bicheno in 1999 and this translated into a small pulse of eastern rock lobsters captured in the fishery a few years later. The biology and behaviour of this species is quite different to southern rock lobsters with faster growth and different patterns of migration. They are currently managed in Tasmania under the same legislation as southern rock lobsters but this is poorly suited for their biological traits as yield is lost by the permitted small legal minimum length.

### ***Changes in predator/prey interactions***

Lobsters are preyed upon by sharks and octopus, and there is a reasonable basis for expecting octopus populations to increase under climate change (Pecl and Jackson 2008). Commercial catches of octopus (*Octopus pallidus* and *Octopus maorum*) are reported to be increasing in Tasmania (Department of Primary Industry and Water 2008), possibly indicating an increase in abundance. Ecosystem interactions between lobsters and *Octopus maorum* occur through octopus entering lobster pots to prey on the trapped lobsters. These interactions are reported in fisher’s logbooks as lobster mortalities per pot lift due to octopus. Positive correlations ( $r=0.22-0.70$ ) between the number of lobsters killed by octopus and temperature, for each rock lobster assessment area, also suggest an increase in octopus abundance and indicate the need for a broader understanding of ecosystem effects when predicting climate change impacts and developing adaptation scenarios.

### ***Centrostephanus***

The southward incursion of the urchin *Centrostephanus* from New South Wales (NSW) and its successful establishment in Tasmanian waters is considered the result of larval transport, reflecting changes in the behaviour of the East Australian Current (EAC) (Ling et al. 2008). Global warming predictions indicate that the EAC will increase in strength, bringing warmer water further south along eastern Tasmania. This will result in both increased larval supply of *Centrostephanus* to more southern regions and also water temperatures better suited to larval development. Water temperatures need to be above 12°C during late winter (August and September) for *Centrostephanus* to complete its larval phase and self recruit (Ling et al. 2008). Under the A1B scenario, by 2025 it is predicted that the August/September temperatures along the length of the entire eastern coast will be above this threshold temperature and therefore present a very high risk of barrens formation (Figure 22). By 2055, this risk will apply to the entire Tasmanian coastline.



**Figure 22:** Predicted average water temperature of each rock lobster assessment areas during the August/September spawning period for *Centrostephanus* under the A1B scenario. Red = temperatures above 12.5°C, orange = 12–12.5°C, green = below 12°C. *Centrostephanus* larvae do not develop below 12°C.

Once established, *Centrostephanus* denudes coastal reefs by overgrazing seaweeds and invertebrate fauna and forming persistent barrens (Ling 2008). In NSW, this urchin is responsible for barrens covering over 50 per cent of the near shore reef (Andrew and O’Neill 2000). In the islands between NSW and Tasmania, *Centrostephanus* has already denuded approximately 50 per cent of shallow reefs and barren regions are increasing in north-eastern and eastern Tasmania. Experiments in Tasmania show that when sea urchins are removed, the seaweed cover and community structure recovers to that of ungrazed regions within 18 months (Ling and Johnson 2009). It has been suggested that high densities of very large lobsters may be critical in preventing barrens formation. Evidence includes a series of intensive field experiments in ‘no take’ marine reserves and adjacent areas open to fishing using tethered, caged, and tagged (but untethered) adult sea urchins, extensive use of remote underwater video, and other experiments in the laboratory which have all demonstrated that large supra-legal rock lobsters ( $\geq 135$  millimetres CL) are the principal predator of adult *Centrostephanus* in seaweed beds in Tasmanian waters. Densities of lobsters of this size outside of marine reserves are extremely low on shallow reefs due to fishing. Current research is underway to translate the findings of these small-scale experiments to larger field sites in an attempt to determine the density of larger lobsters that is required to prevent barrens formation. If this can be determined then management responses can be used to maintain the appropriate lobster densities and size structures to prevent barrens formation.

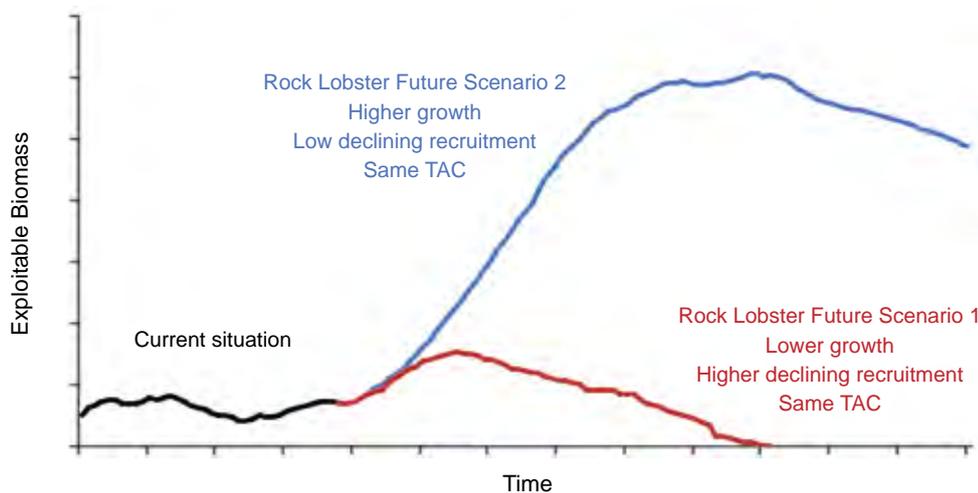
#### 4.4 SUMMARY OF POTENTIAL IMPACTS OF CLIMATE CHANGE ON ROCK LOBSTER

- Warmer waters, such as will occur along the east coast of Tasmania in the future, may mean this area would be unable to support rock lobster populations of the same size as found today (section 4.3.1).
- An increase in water temperature and strength of the EAC, will likely lead to north-eastern and eastern regions experiencing continued declines in puerulus settlement whereas south-eastern regions will initially have improved recruitment on average before subsequently experiencing declining puerulus settlement (section 4.3.2).
- All model projections incorporating temperature influences on growth and recruitment indicated initial gains in biomass, before a reduction in biomass occurred in all regions and for both climate change scenarios. Uncertainty surrounding the effect of temperature on growth makes it difficult to predict the rate and magnitude of the increase in biomass as well as the timing of the transition point where recruitment declines begin to offset growth-related biomass increases. Declines in biomass are predicted to occur in northern and north-eastern regions first, which is consistent with observed patterns over the last 30 years (section 4.3.3).
- Increased catchability of rock lobster, as a function of increased temperature, and increased prevalence of eastern rock lobster (currently not reported by fishery), may reduce the accuracy in fishery statistics used to monitor the fishery and therefore result in misleading conclusions about the condition of the southern rock lobster stock (section 4.3.6 and 4.3.7).
- Recruitment of rock lobster may also become more variable in time, in addition to generally declining, resulting in rock lobster catch rates being less stable and more unpredictable over time.
- There is an increased likelihood of disease, the possibility of ‘ecosystem surprises’ that may impact on rock lobster stocks (either positively or negatively) and unknown impacts of ocean acidification (section 4.3.6 and 4.3.7).
- By 2025, average temperatures along the entire east coast will reach a critical threshold that allows the sea urchin *Centrostephanus* to complete its larval life cycle, therefore substantially increasing the risk of barrens formation (Figure 22, section 4.3.7).
- The biomass of large lobsters ( $>145$  millimetres CL) that are able to consume urchins is predicted to increase in all regions (in response to faster growth) before beginning to decline (as a function of lower recruitment). Although the biomass of large lobsters required to prevent barrens formation is unknown, it is considered to be substantially higher than current levels, requiring an initial rebuilding period before this threshold is reached. Increases in abundance of large lobsters would be expected to increase resilience against barrens formation through predation of *Centrostephanus* – **assuming fishing catch is controlled**. Unfortunately, the point where biomass of larger lobsters starts to decline occurs earlier in the eastern regions, which are currently the regions with expanding *Centrostephanus* barrens.

Aside from the *Centrostephanus* issue, there is a general inability to delineate impacts at 2030 and 2070, or to separate impacts from the two climate scenarios (A1B and A1FI). This is due to uncertainty surrounding the impacts of temperature on growth and recruitment, and other ecosystem unknowns (carrying capacity, density dependence, predator–prey and other competitive interactions). However, it is likely (if barrens formation can be largely prevented), that the impacts of climate change on rock lobster stocks will essentially occur in three phases.

1. Initially increased growth will compensate for declines in recruitment so that biomass will increase, particularly in the south.
2. At some time increased growth will no longer compensate for the lower recruitment so that biomass will begin to decline – this will occur earlier and to a greater extent in the north.
3. Between these two discrete phases is a transition phase or a tipping point (see Figure 18), the timing of which will vary regionally and as a function of future adaptive management changes.

The interplay between the competing processes of faster growth and lower recruitment is critical to outcomes of modelling (Figure 23). We examined the effect of uncertainty in these processes and have selected two possible rock lobster future scenarios based on high and low stock trajectories.



**Figure 23: Schematic diagram illustrating two possible rock lobster stock trajectories described below.**

**Rock lobster future scenario 1 (red line in Figure 23):** Recruitment decline with increased temperature is greater than estimated from recruitment data derived from fisher logbook data (i.e. we assumed impact would be more in line with the changes in puerulus settlement that have been observed with temperature). Declines in exploitable biomass occur after only minor initial increases in biomass driven by improved growth rates. Reduction in exploitable biomass is predicted to be greater and occur earlier in the north. The abundance of large lobsters would be insufficient to prevent *Centrostephanus* barrens formation along the east coast in the immediate future, and state-wide in the medium term (e.g. 2035).

**Rock lobster future scenario 2 (blue line in Figure 23):** In this scenario growth responds more rapidly to temperature so that the stock is more productive initially. Increases in growth are predicted to lead to increases in exploitable biomass in all regions, driven by gains in productivity in the southern regions of the state, dragging commercial effort southwards. *Centrostephanus* barrens formation remains an immediate risk until the inshore biomass of lobsters over 145 millimetres CL becomes sufficient to limit the spread of barrens. Gains from growth are not negated by falls in recruitment until sometime after 2070, although it is important to acknowledge that this decline would still occur and would also include a decline in larger lobsters, ultimately increasing probability of barrens formation. Increased recreational effort may result as a function of improved catch rates due to increased biomass but only if barrens formation is limited.

## 5 Existing adaptive capacity and potential adaptation actions for the rock lobster fishery

The way the fishery will adapt to climate change to minimise costs and maximise opportunities is partly determined by the ability and willingness of fishers to make autonomous adaptations. The interview process in Chapter 3 identified some important factors in this respect. Additionally, the ability to autonomously adapt is constrained or influenced by the management framework within which the fishery operates. Through adaptation planning, this framework can be structured to provide direct and indirect incentives and regulations to broaden the range of autonomous adaptation responses, encouraging fishers to take actions to limit the vulnerability of the rock lobster fishery system.

### 5.1 IMPROVING ADAPTIVE CAPACITY THROUGH COMMUNICATION STRATEGIES

The risk perception study highlighted a number of factors important to any discussion about vulnerability. It highlighted that there is a communication gap and difference in perception between fishers' views and the actual documented existence of climate change impacts on rock lobster. These issues must be addressed, as they directly affect vulnerability. Communication about climate change needs to be supported so that it is culturally appropriate and palatable to fishers, and the issue of climate change will penetrate and be accepted within existing cultural norms. In this context it is important to engage with not only how communities identify vulnerability (in this case the quota, debt and succession), but how they engage with, and are able to act to respond to those threats. It highlights what Clay and Olson (2008) characterise as the 'frequent mismatch between social and biophysical systems change'.

There are a number of barriers to effectively communicating climate change at local levels, the first being the scale of the problem *per se*. Climate change is a global problem, yet solutions are needed at local levels. Nonetheless, enabling stakeholders to forge the conceptual link between the global and local scale is difficult. Another problem with communicating climate change is that planning decisions are more often than not driven by uncertainty about the predictions. One question fishers often asked was 'how can planning decisions be made when the science itself is unclear?' Thus the issue lacks immediacy for people (Sterman 2008). Climate change is effectively a 'creeping' problem that needs an immediate response due to time lags in the climate system, a notion hard to communicate, let alone implement (Sterman 2008).

This problem is amplified by the disjuncture between people's experience of the 'weather' and the discourse about climate change. If people cannot 'see' climate change and, further, can reconcile it as being simply an 'unusual weather pattern', convincing them that climate change is real and that something really needs to be done about it is that much harder. Many fishers in this study, for example, both in interviews and in the workshop, cited their experience of the weather, as 'proof' that climate predictions were untrue or at the very best, not reliable. Moreover, the complicated nature of scientific and management 'speak' about climate change makes it hard for people to understand the problem in the first place. It is difficult enough for policy makers to respond when faced with having to interpret a multitude of documents across different disciplines on the issue; engaging fishers in this enterprise is harder still. Additionally, access to this information is often constrained. Too often there is a lack of knowledgeable, credible and local people who could champion effective communication about climate change. This study then demonstrates the need for adaptive management to address not just ecological variability but also social variability about issue perception. Education strategies could build on this variability to develop some uniformity of understanding about the issue and in turn assist in the development and uptake of adaptation strategies. An important adaptation strategy in itself will be the construction of a communication strategy about climate change.

How can climate change be effectively communicated so that there is a higher acceptance of the need both to develop and then implement climate change adaptation measures? International experience shows that there are a number of ways in which climate change can be communicated effectively (Moser and Dilling 2007). A first principle is that the fishing industry peak bodies and managers be transparent about communicating the parameters of the issue per se. This includes (i) communicating the existence of climate change, including variability; (ii) using this to explain current climate events and possible future ramifications; (iii) communicating the need to take action as proactively as possible in order to ameliorate negative impacts; and (iv) creating the conditions for discussing positive adaptation strategies and a space to share experiences and lessons.

It is important to make the idea or notion of climate change management culturally palatable. Communication materials and strategies need to work within the culturally accepted discourse about how this issue is run and implemented. A number of strategies can be employed to ensure communication about climate change is appropriate. For example, choosing language that is appropriate to the audience is a good first step. Concentrating on what is achievable and feasible for different groups is also important. Another strategy is to maximise opportunities to utilise other contemporary issues that resonate with local interests and add climate change into local agendas. For example, the risk perception exercise highlighted fishers' concerns about a number of other day-to-day management issues – how could these issues and climate change become interwoven and managed together?

Ultimately, communication strategies must also be based on solid guidelines. While these principles are commonly understood by communication practitioners, they bear repeating: (i) carefully define communication goals; (ii) identify and characterise the intended audiences; (iii) have those working on the front line well informed and committed; (iv) ensure that communication is not just one-way; and (v) don't reinvent the wheel – learn from other fields and from retrospective/evaluative studies of climate change communication efforts.

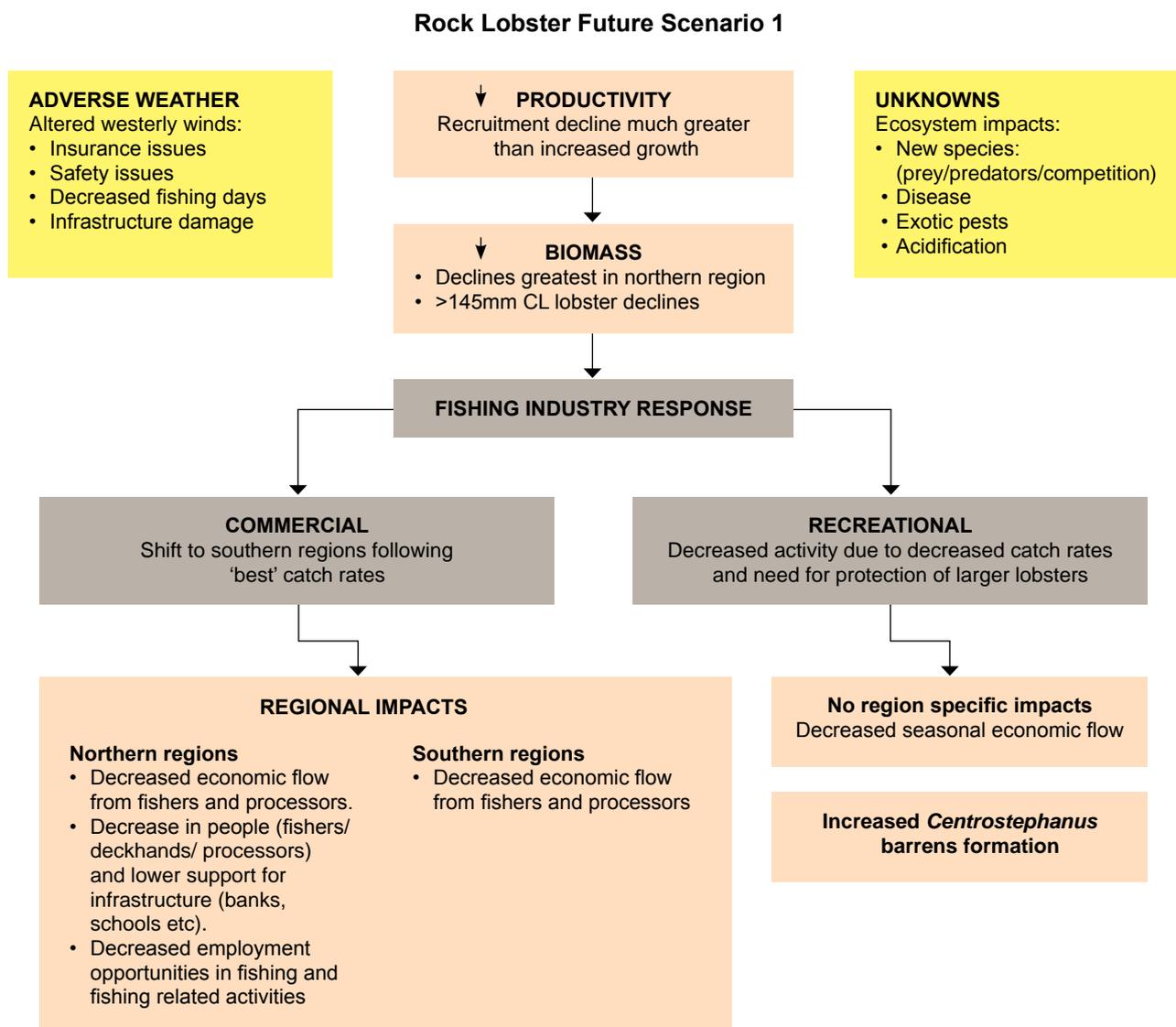
## 5.2 ADAPTATION PLANNING

Adaptation planning involves deliberate measures taken to identify, assess, implement and monitor actions and strategies that will increase the adaptive capacity of a system. In the real world, adaptation is a continuous stream of activities, actions and decisions (Adger et al. 2005) and it is therefore difficult, particularly in an initial assessment such as this, to develop 'an adaptation strategy' and then proceed to evaluate that strategy. In this case study, the uncertainties identified in growth and recruitment would necessitate a program of regular monitoring and evaluation of the actual realised impacts of climate change on biomass through the combined interplay of increases in growth and reductions in recruitment. Assessments would then be made on the adjustments, if any, that would be required to best manage the stock in the longer term, in light of this overall expected pattern. In reality, any adjustments to TACC, for example up or down, would likely be (i) in smaller conservative steps to minimise drastic restructuring of the fishery (usually more acceptable from an industry and political perspective), and (ii) subsequently evaluated for impact and modified accordingly. It is this second part of the management process that cannot be incorporated adequately into a preliminary evaluation of adaptation strategies. Given this, to illustrate and explore potential adaptation options we have selected two possible rock lobster future scenarios based on high and low stock trajectories which span the likely outcomes (see section 4.4).

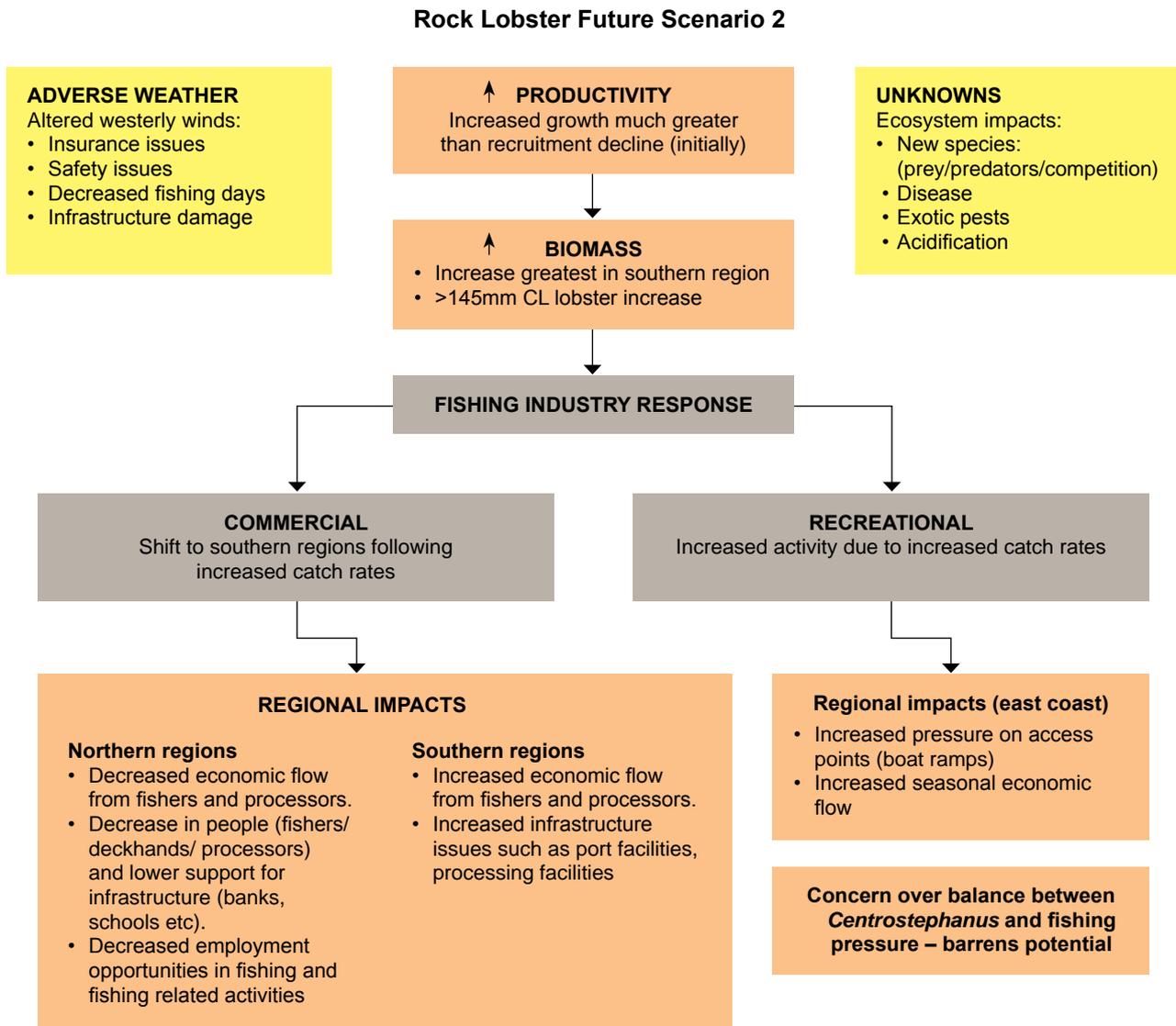
The implementation of successful adaptation strategies requires, among other things, detailed planning involving close collaboration between climate and impact scientists, decision makers and other stakeholders, and policy analysts (Füssel 2007). The range of potential adaptation actions presented in this report were based on surveys, expert knowledge and, importantly, a workshop attended by industry representatives, resource managers, individual fishers, processors and quota holders. Forty-two participants at a half-day workshop were presented with preliminary outcomes from Chapter 4 of this report and then asked to suggest potential adaptation actions that could be implemented to address the specific issues identified (e.g. lower recruitment, increased risk of *Centrostephanus barrens* formation). The range of adaptation actions that were suggested are detailed in Table 5. Participants also noted that they had capacity for adaptation within individual fishing businesses independently of management systems (i.e. autonomous adaptation). Some of the autonomous adaptations that would likely occur (e.g. commercial effort shifting south following higher catch rates) are detailed in Figures 24 and 25.

Vulnerability to climate change impacts and adaptation response options

Successful climate change adaptations are not isolated from other decisions as management needs to be responsive to short-term biological, economic and social changes in the fishery as well as longer term changes. However, there are obvious benefits if common strategies can be used to achieve short-term goals and address long-term issues at the same time. The opportunity to trial the effectiveness of particular measures and address any implementation issues in the short term will also be of benefit. A number of the management measures detailed in Table 5 as adaptation actions are also under current consideration to address issues facing the fishery now (see section 2.3 for details).



**Figure 24: Flow chart indicating likely events, including autonomous fisher responses, for the rock lobster fishery under low rock lobster stocks trajectory (future scenario 1).**



**Figure 25: Flow chart indicating likely events, including autonomous fisher responses, for the rock lobster fishery under high rock lobster stock trajectory (future scenario 2). Note that even under this optimistic scenario, eventual gains from increased growth are unable to compensate for decreased recruitment so biomass ultimately begins to decline.**

**Table 5: Range of adaptation strategies to address specific potential impacts of climate change, as developed at the stakeholder workshop (RL = rock lobster).**

POTENTIAL IMPACT	AUTONOMOUS ADAPTATION	POSSIBLE ADAPTATION ACTIONS	BARRIERS
<b>Biological System</b>			
<i>Centrostephanus</i> (urchin) extend range and increase abundance increasing risk of barrens formation	<ol style="list-style-type: none"> <li>Commercial fishers move to regions of higher catch rates.</li> <li>Recreational trap fishers move further offshore and invest in trap haulers.</li> <li>Recreational dive fishers move to non-impacted areas.</li> </ol>	<ol style="list-style-type: none"> <li>Change RL size limits to increase numbers of large lobsters</li> <li>Reduction of RL catch in affected regions (e.g. by incentives to fish elsewhere, temporal closures, regional gear rules or regional TACCs, reduced bag limits)</li> <li>Translocation of large lobsters into small hotspot areas to remediate specific barrens</li> <li>Investigate development of commercial opportunities for harvesting <i>Centrostephanus</i></li> </ol>	<ol style="list-style-type: none"> <li>Reduced RL recruitment</li> <li>Tension over which sector should pay (commercial or recreational)</li> <li>Localised high levels of depletion allowed by current dive access regulations that allow use of highly efficient dive gear (e.g. hookah) by recreational fishers</li> <li>Support for management with ecological motivation has been undermined by the MPA process in Tasmania and adjacent Commonwealth waters (as fishers considered the lack of adjustment for displaced catch and reduced catch rates weakened their property rights).</li> <li>Translocation likely to be prohibitively expensive.</li> </ol>
Increased prevalence of eastern rock lobster (ERL)	Fishers change species (currently autonomous but issues of access rights may arise)	Different rules for ERL to maximise yield and benefit for the SRL fishery	Access rights, new research required to obtain biological data needed to underpin eastern rock lobster management.
Lower recruitment of rock lobster	<ol style="list-style-type: none"> <li>Commercial fishers move to regions of higher catch rates.</li> <li>Commercial fishers shift to other species or leave fishery.</li> <li>Recreational trap fishers move further offshore and invest in trap haulers.</li> <li>Recreational dive fishers move to non-impacted areas.</li> <li>Recreational fishers shift to alternative recreational fishing activity</li> </ol>	Management strategies to increase yield per recruit, e.g. (a) set quota to maximise sustainable yield (either catch or economic) (b) manage size at harvest to maximise yield (c) reduce/remove input controls that affect economic efficiency, e.g. remove maximum pot limits, remove closed seasons, break legislative link between physical pots and quota units.	<ol style="list-style-type: none"> <li>Resistance to change in management by the commercial and recreational sectors</li> <li>Limited understanding amongst industry/community of the opportunity to increase sustainable yield with different management systems</li> <li>Both recreational and commercial sectors historically measure the value of the fishery in volume of catch rather than profit or utility.</li> <li>Low capacity of government to control recreational catches (specifically a 'floor' to recreational catch that prevents the introduction of management strategies that reduce recreational catch below a minimum tonnage)</li> <li>Fishers who lease quota have greater profit when stocks are more depleted (as demand for quota falls) and thus don't support constraints in catch</li> <li>Tension over which sector should pay (commercial or recreational)</li> </ol>

POTENTIAL IMPACT	AUTONOMOUS ADAPTATION	POSSIBLE ADAPTATION ACTIONS	BARRIERS
Faster growth	<ol style="list-style-type: none"> <li>Commercial fishing effort will shift to the south as productivity increases and legal size biomass rebuilds faster than northern regions.</li> <li>Recreational fishing effort will increase in all regions as catch rates improve.</li> </ol>	<ol style="list-style-type: none"> <li>Manage the interaction between size limits and quota to maximise yield</li> <li>Ensure sufficient port and processing facilities for increased fleet in south</li> <li>Mother ships to provide 'floating' processing facilities in south-west</li> <li>Ensure sufficient access points for recreational fishers</li> </ol>	<ol style="list-style-type: none"> <li>Fishers are resistant to introduction of regional size limits due to fear that fleet movement would be constrained.</li> <li>Compliance to minimise illegal activity associated with zones</li> <li>Regulations about trans-shipping</li> <li>Lack of available foreshore in some areas for ramps and parking</li> </ol>
Transition between increased biomass to reduced biomass as decline in recruitment not compensated by improved growth rates	Fishing effort shifts	<ol style="list-style-type: none"> <li>As above for <i>Centrostephanus</i> and lower recruitment</li> <li>Harvest strategies that shift biomass into the future</li> </ol>	<ol style="list-style-type: none"> <li>As above for <i>Centrostephanus</i> (potential impact 1) and lower recruitment</li> <li>Resistance by fishers to forego today's catch for the future</li> <li>Perception of component of industry that climate change is not an issue</li> </ol>
Reduced spatial variation in growth	Fishery currently managed assuming zero regional differences in growth, so this change in biology makes existing management more appropriate. Catch shifts regionally either by movement of vessels or transfer of quota.	<ol style="list-style-type: none"> <li>Both quota and size limits altered in line with changed productivity</li> <li>Ongoing collection and updating of growth and maturity data in harvest strategy evaluation models (rather than assuming growth is temporally fixed)</li> </ol>	Cost of monitoring
Change in temporal variation in recruitment		As above for <i>Centrostephanus</i> and lower recruitment	As above for <i>Centrostephanus</i> and lower recruitment
Increased spatial variation in recruitment	Catch shifts regionally either by movement of vessels or transfer of quota.	As above for <i>Centrostephanus</i> and lower recruitment	As above for <i>Centrostephanus</i> and lower recruitment
<b>Human system</b>			

Vulnerability to climate change impacts and adaptation response options

POTENTIAL IMPACT	AUTONOMOUS ADAPTATION	POSSIBLE ADAPTATION ACTIONS	BARRIERS
Increased variability of RL yield	Diversification of income earning activities	Increase range of species allowed to be caught on licence	1. As above for barriers to stock building for <i>Centrostephanus</i> and lower recruitment 2. Current licence arrangements
Changes in distribution of RL	Change in fishing areas, i.e. to west and south-west	Create zones or regional TACCs	Resistance to relocation, lack of infrastructure Resistance to zoning of fishing
Decreased RL biomass	Industry attrition, diversification of business activities	1. Retraining programs 2. Incentives to diversify	Age profile of industry Current high debt of some industry participants Current licensing arrangements

### 5.3 ADAPTATION STRATEGIES

The maintenance of a viable rock lobster fishery in Tasmania with declining recruitment that is not fully compensated by increase in growth (i.e. rock lobster future scenario 1) would require changes to management systems because status quo management is predicted to lead to severe stock declines.

Actions that could be used to maintain benefits from the fishery under this scenario include:

- i. Regular adjustment of the TACC to the point where the gap between cost of harvest (i.e. catch rate) and revenue is greatest so that economic benefit is maximised, despite the trend of falling recruitment;
- ii. Introduce regional size limits to better match average size at harvest with regional growth patterns;
- iii. Establish regional and/or inshore/offshore TACs to better match harvests with regional growth patterns;
- iv. Reduce commercial and recreational catch in at-risk coastal regions to prevent proliferation of urchin barrens;
- v. Reduce input controls (e.g. vessel trap limits, seasonal closures) on the commercial sector to reduce costs in the face of declining revenue so that profits are maintained;
- vi. Maintain recreational benefit/enjoyment (utility) despite lower catches by shifting management performance measures away from catch tonnage and towards the success rate of recreational fishers (i.e. fewer lobsters more often);
- vii. Use regional input controls to shift effort away from those areas at most risk of barren expansion (e.g. regional lower or upper size limits, regional seasons, regional gear restrictions);
- viii. Ensure that there is greater ‘fishing to market’ to increase revenue with smaller catch (e.g. season openings targeting festivals in Asian markets);
- ix. Establish total exclusion zones to attempt barren rehabilitation;
- x. Develop different size limits for eastern and southern rock lobster to optimise yield of eastern rock lobster recruits;
- xi. Investigate alternative management arrangements that increase flexibility of fishing operations across different species.

Responses to a situation of gains in growth initially outstripping lower recruitment (rock lobster future scenario 2) are similar to those for scenario 1, although there is a lower potential cost associated with less efficient management; that is, the risk of significant problems occurring through mistakes in management is lower when productivity of the stock is increasing.

Potential actions to maximise gains from increased biomass could include:

- i. Adjust the TACC to the point where the gap between cost of harvest (i.e. catch rate) and revenue is greatest, capturing the trends of increase in growth and falling recruitment;
- ii. Introduce regional size limits to better match average size at harvest with changing regional growth patterns;
- iii. Establish regional and/or inshore/offshore TACCs to better match harvests with changing regional growth patterns;
- iv. Recreational catch is regulated by number of lobsters not weight. Thus the need to constrain recreational catch in coastal regions at risk from climate change impacts remains despite gains in growth;
- v. Maintain recreational fisher enjoyment (utility) with lower catches (by number) through shifting management performance measures away from catch tonnage to success rate of recreational fishers (i.e. fewer lobsters more often);
- vi. Use regional input controls to shift effort away from areas at risk of barren expansion (e.g. regional lower or upper size limits, regional seasons, regional gear restrictions);
- vii. Develop markets for the larger lobsters that are currently discounted;
- viii. Establish total exclusion zones in barrens to attempt rehabilitation;
- ix. Develop different size limits for eastern rock lobster and southern rock lobster to maximise yield per recruit;
- x. Consider alternative management arrangements that can utilise the initial gains in biomass as a tool for compensating future generations as stocks decline.

Both rock lobster scenarios have included a range of possible adaptation actions to address the immediate, in our view serious, risk of further proliferation of urchin barrens (particularly on the east coast). This is classified as ‘anticipatory adaptation’ and is particularly favourable if climate-sensitive risks are already urgent (Füssel 2007). It is noteworthy that the adaptation strategies are similar in both scenarios, although the details may differ. This suggests that changes in the management framework are an important first step (e.g. shift towards a TACC-setting process that maximises economic rent; or a TARC that maximises recreational utility), which would then be followed by specific rules tailored to climate change scenarios.

## 6 Adaptation policy assessment and strategy formation – an overview

---

### 6.1 INTRODUCTION

One of the aims of this case study was to identify a range of possible adaptations that would either occur spontaneously (autonomous adaptations) or could form part of a strategic response by fisheries managers or government to avoid, prepare for, or respond to, the impacts of climate change on the Tasmanian east coast rock lobster fishery. These adaptation measures were described in the previous chapter and ways in which planned adaptations might be used as a policy response to climate change under various bio-physical scenarios were suggested (Section 5.3).

As Smit et al. (1999) note, however, ‘It is not sufficient to specify an adaptation and its likelihood [of success]: some judgement as to its appropriateness, effectiveness or acceptability is also required to make recommendations as part of a response to government.’ A number of methods, or decision tools, are available for evaluating and ranking planned adaptations. However, the lack of baseline social and economic data and of models that would let us predict the effects of climate-induced changes in the biophysical system on the social and economic components of the rock lobster system, has meant that a comprehensive assessment of the adaptation policies described in Chapter 5 has not been included as part of this case study. Instead we present a general discussion of climate change adaptation policy assessment as background to evaluating adaptation measures, and developing an adaptation strategy for the rock lobster fishery as recommended as part of any future work (Chapter 8).

This chapter provides a brief overview of selected adaptation assessment decision tools. Characteristics of the Tasmanian east coast rock lobster fishery system that are relevant to selection of an appropriate assessment method and to the formation of an adaptation strategy, as highlighted by this case study, are then discussed and their implications noted. The chapter concludes with a series of key lessons for adaptation policy makers in the Tasmanian rock lobster fishery.

### 6.2 ADAPTATION POLICY ASSESSMENT METHODS

A number of assessment methods, or decision tools, are available to assist decision-makers in choosing between, or prioritising, alternative adaptation measures. These include benefit-cost analysis, cost effectiveness analysis, multi-criteria analysis, social assessment matrix, environmental impact assessment and expert judgement. Three of the most widely used and recommended of these are briefly outlined below.

#### ***Benefit-cost analysis (BCA)***

BCA provides an empirical test of whether a particular adaptation measure or policy results in a net increase in welfare, in which case its implementation would improve efficiency. It can also be used to construct a ranking of alternative measures and policies and to identify an optimal course of action. BCA relies on converting relevant benefits and costs to a common dollar metric and on discounting benefits and costs that occur in the future to their present day equivalent using a discount rate for the cost of invested capital and/or for society’s preference for current over future utility. In practice, information on benefits and costs that cannot be expressed in dollars or using criteria other than economic efficiency, such as environmental sustainability and employment, is presented either qualitatively or quantitatively to decision-makers as part of the discussion of the results of a BCA. Issues involving equity or distribution are sometimes incorporated explicitly in BCA through the use of distributional weights, but more generally are also addressed as part of this discussion. Data requirements for BCA are generally quite onerous, particularly in cases where the affect of alternatives on human welfare are not reflected in the prices of goods and services traded in markets. For examples of BCA used as a decision support tool in fisheries see a simple application in the US in which two stock rebuilding management scenarios were evaluated (Sumaila and Suatoni 2005).

### ***Cost effectiveness analysis (CEA)***

CEA provides a tool for determining the least-cost way of meeting a predetermined physical, social, economic or environmental goal. So long as each of the alternative measures or policies is expected to result in much the same level of impact or benefit, CEA requires data only on the costs of alternatives. CEA is used as a decision support tool in many areas of natural resource management, such as forestry (Pinjuv et al. 2001) and wetland restoration (Kirk et al. 2004).

### ***Multi-criteria analysis (MCA)***

MCA refers to any structured approach used to determine decision-makers' preferences over alternatives. While BCA and CEA both focus on economic efficiency as the single criterion for evaluating alternatives, MCA accommodates cases where preferences are defined across a number of often conflicting objectives. As well as allowing for more than one objective, MCA permits objective performance criteria to be measured in different units, thereby catering for inclusion of a wider range of quantitative and qualitative information.

In practice, MCA consists of the following six stages:

1. Problem structuring, involving definition of adaptation measures to be ranked or scored, selection of criteria against which the performance of adaptations are to be measured and determination of weights to be assigned to criteria;
2. Collection of performance data or information for each alternative against each of the criteria;
3. Transformation of criteria into units that can be meaningfully aggregated;
4. Ranking or scoring of alternatives by combining transformed performance measures and criteria weights, using a predetermined aggregation method;
5. Testing sensitivity of ranking or score to variation in weights, performance measures and ranking method;
6. Presentation of analysis, complete with caveats and recommendations, to decision-makers.

BCA and CEA both tend to be conducted as 'top down' exercises, relying on managers and policymakers to articulate the structure of the decision and experts to determine the basis for identifying and measuring costs and benefits. In contrast, MCA relies heavily on stakeholder input throughout the assessment process, including the key tasks described at stage 1 above. For examples of MCA used as a decision support tool in fisheries, see Leung (2006) who provides a review of multi-criteria decision-making applications in fishery management.

## **6.3 ISSUES FOR ADAPTATION POLICY ASSESSMENT AND STRATEGY FORMATION IN THE ROCK LOBSTER FISHERY**

This case study has highlighted a number of characteristics of the Tasmanian east coast rock lobster fishery system that need to be considered when selecting appropriate decision tools for evaluating and prioritising planned adaptation measures as a basis for formulating an adaptation strategy. These characteristics are outlined below and their implications synthesised to provide a series of key lessons for adaptation planning in the fishery (Section 6.4).

### ***Multiple objectives***

A key feature of fishery management worldwide is that 'success' is evaluated against a number of sometimes conflicting objectives. Hilborn (2007) identifies the main categories of fisheries objectives as biological, economic, social and political. Hilborn (2007) also notes the wide range of objectives held by different stakeholder groups, including commercial and recreational fishers, indigenous fishers, fisheries managers and scientists, non-government organisations and the general public, and the changing emphasis given these objectives over time. For example, there has been a trend in fisheries management in Australia in recent years away from maximum sustained yield (MSY) and fleet size (or jobs), in favour of economic efficiency and ecosystem

protection, as objectives. Targets such as maximum economic yield (MEY) are preferred as they align with commercial interests and also tend to produce better outcomes ecologically. This is because the stock is less depleted when economic yield is maximised (e.g. Grafton et al. 2007).

Specific objectives, and their associated measurable criteria, are used in ‘top down’ management decision-making in the Tasmanian rock lobster fishery, with current governance arrangements requiring the resource be managed as a sustainable fishery, balancing economic efficiency with ecological and social outcomes (Chapter 2). The current management process for setting the TAC in the rock lobster fishery incorporates mechanisms for evaluating proposed harvest levels against specific economic, sustainability and ecosystem performance criteria. These criteria include egg production relative to the unfished stock, exploitable biomass, and interactions with protected, endangered and threatened species. Other indicators that are recognised in decision-making either informally or implicitly include harvest rate, puerulus settlement, mean weight of lobsters, legal size discards, byproduct and bycatch trends, market capitalisation of quota units and resource rent (= number of kg of quota x lease price). Discounted economic yield, total biomass and the biomass of lobsters greater than 145 mm CL (around 1.6 kilograms) will also be considered in future assessments and decision making. The latter for example, is an indicator of the ecosystem’s resilience to *Centrostephanus* barrens formation. Additionally, the quota management system provides a framework for economic efficiency and fleet rationalisation. Informal consideration is given to the social impact of a management decision in terms of possible impact on the fleet size, differential impacts on different sized vessels, regional ports, and quota owners versus leasing fishers. Resource sharing arrangements and the consultation mechanisms built into governance through the CFAC also formally and informally support the social criteria in operational decision making. However, many of the objectives and defined criteria given above conflict, and although an MCA approach could be beneficial, it is not currently utilised in the management process.

The climate change adaptation literature also suggests a large number of criteria against which adaptive measures might be evaluated including net benefits, ease of implementation, economic viability, environmental sustainability, public acceptability, administrative cost, distributional effects, flexibility, transparency, compliance risk, external or side effects and behavioural flexibility, among others (Smit et al. 1999; Konidari and Mavrakis 2007).

### ***Stakeholder participation***

Successful adaptation requires adaptation planning processes and decision tools that effectively engage various stakeholder communities. This allows the aspirations and objectives of various groups to be integrated within decision and planning frameworks, but also encourages stakeholder ‘buy-in’ to adaptation measures. Existing governance arrangements in the rock lobster fishery provide a strong basis for stakeholder engagement in management and planning (Chapter 2). Together the two key advisory bodies, CFAC and Recreational Fishery Advisory Committee (RecFAC), allow stakeholders direct input to all important resource management and allocation decisions, and underpin the government’s commitment to consultation and collaborative management in the fishery.

The process of climate-related adaptation policy assessment in the fishery must utilise and build upon existing mechanisms for stakeholder participation and input. However, the risk perception study reported in Chapter 3 suggests that few opportunities currently exist within existing institutional and scientific structures to provide entry points or repositories for local fisher knowledge to make contributions. As shown in many case studies world-wide (Santha 2008; McGoodwin et al. 2000), incorporation of local fisher knowledge can have a positive effect on the industry, encourage uptake of new management measures and in many cases value-add to existing knowledge sets. By improving public and industry ‘acceptability’, robust stakeholder involvement processes can reduce the implementation, monitoring and compliance costs of new management instruments and other adaptation measures.

### ***Uncertainty***

Fisheries operate within an environment of great uncertainty (Garnaut 2008). Variability in fish abundance, weather conditions, fish prices, exchange rates and the cost of inputs all contribute to this uncertainty. As indicated in this case study, this uncertainty has meant a history of adaptation for both fishers and managers in the rock lobster fishery. Climate change represents an additional source of long-term uncertainty. While the

magnitude of predicted climate-induced changes on the fishery may be unprecedented, the fishery's past history of adaptation can provide valuable evidence of adaptive capacity and of possible adaptation measures. For example, adaptation strategies conventionally adopted by fishers and fishing communities world-wide include crew share, co-management, information sharing and fishery switching (Clay and Olson 2008). In addition, a review of mechanisms and institutions that have facilitated adaptation in the past, such as adaptive management rules and policy instruments like the QMS, can be helpful in identifying constraints to adaptation and possible planned adaptation measures. Note also that increased uncertainty and heterogeneity in loss aversion and risk preferences (Holland 2007) may itself influence the effectiveness of various management systems. For example, Kompas et al. (2008) suggest that TAC restrictions, as used successfully in the Tasmanian rock lobster fishery, may be less effective where environmental uncertainty is high relative to uncertainty in catch per unit effort. In such cases, an input-controlled fishery may perform better. Adaptation planning in highly uncertain decision contexts and where ecosystem effects are potentially irreversible, as presented in this case study, requires a precautionary approach to management. This also suggests a focus on decision tools and management rules that have viable, rather than optimal, pathways forward.

### ***High level of government involvement***

Fisheries are common resources and are characterised by difficulties in excluding non-payers and rivalry among users. Government intervention, in the form of fisheries management, is widespread and is aimed at avoiding the 'tragic' overuse and overcapitalisation that is typical of open access use of common resources. This suggests that we should look at how existing governance and management systems can be used (adapted) to address climate-induced changes in the fishery system. Many of the adaptation measures identified in Chapter 5, such as spatial management, are already being considered by managers and debated with stakeholders as part of the existing policy formulation process in the fishery.

It is also important to recognise that while management policies and instruments form an important part of an adaptation strategy, existing access arrangements and regulations can also restrict fishers' ability to respond autonomously to change, thereby exposing them to greater risk and increasing the system's vulnerability to climate change. For example, as noted in Chapter 3, many fishers indicated that they believed that existing input controls constrained their ability to respond effectively to observed changes in the distribution of the rock lobster resource.

### ***Valuation of benefits and costs***

Like other natural resource systems, marine systems provide the basis for a wide range of important values. From a traditional economic perspective this encompasses values that arise as a result of people accessing and consuming the resource directly, as is the case with commercial and recreational lobster fishing. It also includes values associated with non-consumptive uses, such as viewing rock lobster on a diving trip. People may also benefit from the resource indirectly, through the role rock lobster populations play in maintaining ecosystem and biodiversity values. Furthermore, as established in section 4.3.7 of this report, climate change will result in an increased risk of establishment of *Centrostephanus* barrens in inshore waters and a consequent loss of associated ecosystem and biodiversity values.

When discussing the value of natural resources, economists also recognise non-use values which arise when people derive pleasure merely from knowing that a resource exists or that it is available as a bequest to future generations. Economists also recognise that individuals might be willing to give up something of value today to make sure that the option to benefit from the resource at some future time is preserved, even if they currently derive no pleasure from the resource either directly or indirectly.

While some values associated with fishery resources, such as commercial harvests, are reflected in the market prices paid for outputs, many fisheries goods and services, such as recreational fishing and ecosystem values, are not traded in markets. In such cases, measuring the economic benefits and costs associated with various planned adaptation measures can be a complex, expensive and uncertain task. AGO (2004) provides a useful overview of commonly used market and non-market valuation methods, including benefit transfer, and their limitations.

This case study has confirmed that climate change will have widespread and substantial effects on a range of important market and non-market values in the Tasmanian rock lobster fishery. Global climate models project that the Tasman Sea will warm faster than other waters in the southern hemisphere. Cold-temperate species found in the waters off south-eastern Australia are considered particularly vulnerable to climate change, given the lack of shelf habitat further south for retreat as waters warm (Hobday et al. 2007). The rapid transformation of local habitat types and the loss of cool-temperate species, such as giant kelp, are already evident (Poloczanska et al. 2007). Nevertheless, almost no empirically-based work has been conducted to establish the economic value of these impacts. Furthermore, there have been no studies that have measured the economic value, in terms of willingness to pay (WTP), of recreational rock lobster fishing in Tasmania. Based on a meta-analysis of 391 estimates of WTP per fish, Johnston et al. (2006) found 'systematic and intuitive relationships between WTP and a wide range of variables characterising anglers, species and geographic regions, and other fishing attributes', indicating that WTP for the various characteristics of recreational fishing may be deeply contextualised and suggesting limited scope for transferring benefits between fisheries.

It is expected that there are a multitude of not easily quantifiable values of rock lobster fishing in Tasmania. The presence of these values complicates the application of the quantification-based BCA approach to evaluating adaptation strategies. A key benefit of MCA is that it accommodates performance measures in different units such as dollars and number of threatened species. MCA is therefore a useful complement to the more straightforward quantitative approaches.

### *Distributional effects*

This case study has indicated that climate-induced biophysical changes in the rock lobster fishery will create 'winners' and 'losers' as costs and benefits are unevenly distributed across individuals and groups, both spatially and temporally (Roessig et al. 2004). Various adaptation measures, such as spatial management of the TAC and changing size limits, will similarly have uneven effects on welfare.

For example, the changing abundance and distribution of rock lobsters will have positive and negative effects on the welfare of recreational fishers. The welfare loss associated with declining recreational rock lobster fishing opportunities in one region may be offset by improved recreational rock lobster catches in other regions, and by the increase in welfare experienced as a result of new recreational fishing opportunities that might arise. The welfare of recreational rock lobster fishers will also be affected by climate change induced impacts on other characteristics of the rock lobster fishing experience that influence willingness to pay, such as weather conditions, lobster size and water clarity. These factors can lead to complex distributional outcomes which may be difficult to predict. For example, in a study of the economic impact of climate change on freshwater sports fisheries across four states in the north-east of the United States, Pendleton and Mendelsohn (1998) found that 'while the economic impact of global (climate) change on any single species group could be large, the combined impacts of global (climate) change' tend to be moderate. However, they also note that the distribution of welfare effects across fishers and locations are unevenly distributed.

Similarly, patterns of differential impacts will occur among commercial fishers, as some individuals and groups are subject to greater exposure than others or prove more able to cope with the effects of climate change. Research presented in this case study has shown that commercial lobster fishers have varying levels of adaptive capacity as indicated by different perceptions and knowledge of climate change, different willingness and ability to engage in a discourse about climate change and different levels of access to the financial and other resources required for effective adaptation. Furthermore, communities associated with a decrease in commercial and/or recreational fishing activity will experience a negative impact, while businesses in locations that experience an increase in these activities may benefit. This will also result in changing spatial patterns of demand for support facilities and infrastructure, simultaneously giving rise to new opportunities and highlighting existing vulnerabilities.

There may also be significant issues that arise in the distribution of gains and losses across time. This is common in climate change adaptation, which often involves taking actions and implementing measures today with the prospect of future benefits. In this case study, however, bio-physical modelling indicates that climate change will result in reduced puerulus recruitment and increased lobster growth (Chapter 4). While highly uncertain, the net impact of these conflicting effects on lobster abundance suggest that today's fishers may experience a period of

increasing stocks, while future generations of lobster fishers will encounter substantially depleted stocks and lower returns.

### ***Integrated assessment***

There are a range of tools developed for the evaluation of management strategies in fisheries to aid in decision making. These vary from annual assessments of performance measures such as changes in biomass, egg production and catch rates, to more complex integrated assessments that also include ecosystem, economic and social metrics. In addition to single species and ecosystem-based fisheries management, there is increasing interest in the development of multiple use management strategies that incorporate the different users of the marine systems. An example of this is the multiple use management strategy evaluation undertaken for the north-west shelf of Australia that combines the oil and gas, conservation, fisheries and urban and industrial development sectors (McDonald et al. 2008). Grimm and Railsback (2005) used agent-based models as a platform to iteratively develop, formalise, and test hypotheses and scenarios of tourism policy and local economic management initiatives. The increasing use of agent-based models to link biological, economic and social components of decision support frameworks has considerable promise for use in decision support for climate change. The benefit of these models is that they give us better predictions of impacts because they account for loops, feedbacks and the interconnectedness of parts of the biophysical–human system. Unfortunately, such models are dependent on large volumes of data which are seldom available in the biological component but more readily accessible for social and economic components. Importantly, these models are able to link human behaviour and decision making (e.g. fishing activity) with ecosystem and biological components. For high risk and valuable fisheries, such as the Tasmanian rock lobster fishery, where there are larger datasets, these models warrant further investigation.

### ***Interconnectedness across systems and scales***

The rock lobster fishery operates within an interconnected biophysical-human environment, with individual fisher decision-making and management of the fishery responding to changes over time and space to this environment. These decisions may also have other, broader impacts outside the Tasmanian east coast rock lobster fishery. Adaptation strategies developed for the east coast rock lobster fishery need to be developed to encompass as broad a systemic base as possible and consider likely impacts at local regional and larger spatial scales. There is a need for close coordination of policy development across sectors and jurisdictions.

## **6.4 KEY LESSONS FOR ADAPTATION POLICY ASSESSMENT AND STRATEGY FORMATION IN THE ROCK LOBSTER FISHERY**

Once adaptation measures have been identified, they need to be prioritised and an adaptation strategy formulated. Three main assessment methods are available for this purpose: BCA, CEA, and MCA. The discussion above suggests the following key lessons or guidelines for the assessment of adaptation measures and strategy formation in the Tasmanian rock lobster fishery:

- *Early identification, assessment and implementation of no-regrets, low regrets and precautionary measures.* For example, adaptive management responses that encourage and protect large lobsters in inshore waters will reduce the welfare losses associated with lost ecosystem integrity and biodiversity values associated with urchin barren formation. Importantly, maintaining a productive and healthy barren-free ecosystem also has direct use value to commercial and recreational fishers as well as to tourism operators and independent divers. In addition, the abalone fishery is also negatively impacted by *Centrostephanus* barrens. Research is currently underway to determine management options for minimising barrens formation and remediation of existing barrens is being funded by a coalition of abalone and lobster fishers, recreational fishers and environmental agencies. Other adaptation measures, including improved communication aimed at strengthening the adaptive capacity of fishers and co-management arrangements, may also represent no or low regret actions. For urgent issues such as these, cost effectiveness analysis (CEA) provides a suitable decision tool for informing managers and industry of desirable actions.

## Vulnerability to climate change impacts and adaptation response options

- *Need for integrated, multi-objective adaptation policy assessment.* The assessment of alternative adaptation measures in the fishery must be made against a number of often conflicting objectives that represent the values and aspirations of those communities that have a stake in the rock lobster fishery system. The diverse nature of these objectives, which span the ecological, social and economic domains, necessitates the integration of qualitative and quantitative data not often measured in comparable units. The demonstrated importance of a high level of stakeholder involvement in management and planning in the fishery further suggests that MCA will be an appropriate decision tool in many cases.
- *Dealing with uncertainty.* Climate change will increase uncertainty in the lobster fishery system, suggesting the need for extensive sensitivity analysis around key biological and economic variables to ensure that adaptation measures are desirable under a range of possible future conditions and scenarios. This also favours adaptations that build adaptive capacity, adaptive management approaches and emphasise viability and resilience.
- *Addressing distributional consequences.* There is a need for an adaptation planning process that captures the complex distributional implications of climate change adaptation on different components of the rock lobster fishery system across temporal and spatial scales. It also suggests the importance of considering the need for redistributive and adjustment assistance mechanisms as part of an adaptation strategy for the fishery.
- *The process of packaging desirable adaptation measures into an adaptation strategy for the rock lobster fishery must determine scheduling and time frames for implementation.* A rock lobster adaptation strategy must also be consistent with, and complimentary to, the strategic policies and processes of other fishery and non-fishery sectors and integrated with local, regional, state and national climate change initiatives.
- *Need for flexible and practical planning processes and decision tools.* The overarching aim of adaptation planning in the rock lobster fishery should be to build biophysical and human systems that are resilient under a wide range of possible futures. This means that supporting governance arrangements, management systems and instruments must be adaptive, flexible and responsive. Supporting adaptation policy planning processes and decision-making tools must also embody these attributes. Assessments should rely on careful and well informed consideration of possibilities, consequences and tradeoffs, and involve robust stakeholder processes. While the availability of quality data and information is an important component of adaptive capacity in human systems, adaptation planning decision-tools should not be dependent on high quality data and complex, computer-based models.

## 7 Key gaps in knowledge

---

The east coast Tasmania study is a ‘desk top’ analysis based on existing data and modelling frameworks to provide an initial assessment of the potential adaptation responses to changes in the productivity of the rock lobster resource as a function of climate change. In undertaking this assessment, gaps in our current knowledge were highlighted, indicating areas where additional data would be required to achieve a more thorough assessment. In addition to data gaps, there is also a need to undertake substantial assessment model modifications which were beyond the scope of this initial assessment.

In this chapter we list these knowledge gaps and identify the data and/or analytic tool development that would be required to address these gaps (Table 6).

**Table 6: Identified critical information or data gaps and vulnerabilities for the Tasmanian rock lobster fishery. H=high, M=medium and L= low priority. Indications of the magnitude of the task required to address gaps and vulnerabilities are approximate and should be used as a general guide only.**

GAP OR VULNERABILITY	BENEFIT FOR FUTURE ADAPTIVE PLANNING	METHODOLOGY OR DATA REQUIRED	PRIORITY AND INDICATION OF MAGNITUDE
<p><b>Biophysical</b></p> <p>Model predictions are based on extrapolations (rock lobster growth, recruitment and temperature) beyond the range of available data. Over the small temperature ranges that are available we have used a linear relationship which may not be accurate over broader temperature ranges or beyond the range of the available data. Stepwise or non-linear relationships may occur due to threshold effects, physiological limits or self-regulating mechanisms.</p> <p>Improved knowledge on regional growth of rock lobster and response to temperature. Changes in the number of lobsters entering the legal-sized stock each year can be caused by either changes in abundance of undersize or changes in growth rate. These processes compete in the modelling of climate change impacts so field data would be valuable.</p> <p>Improved understanding of rock lobster growth and recruitment on west coast and links to physical parameters is required to understand the potential for the west coast to absorb regional effort if productivity and therefore catches on the east coast decline.</p>	<p>(a) An improved relationship between temperature and growth for incorporation into the assessment/prediction model</p> <p>(b) Determine the importance of temperature to larval recruitment success and assess whether temperature is a <i>defacto</i> measure of other physical forcing factors.</p>	<p>(a) Test growth and temperature response of rock lobster by experimental manipulation.</p> <p>(b) Undertake detailed analysis on 'other' physical factors that could influence puerulus recruitment trends (e.g. position of sub-tropical front water).</p>	<p>(a) H, &gt;3 years laboratory experiments</p> <p>(b) M, 1-2 years desktop modelling and/or could be approached via multi-year large-scale field research</p>
<p>Changes in productivity caused by larval supply vs changes in growth of existing lobsters have very different longer-term outcomes and will require very different adaptation responses. For example, increased larval supply will result in long-term stability, whereas increased growth of already settled lobsters will result in short-term improvements only.</p> <p>The east and west coasts of Tasmania are influenced by substantially different current systems. The temperature--recruitment relationships established for the north-east and east coast regions may not be representative of the west coast. There is a requirement to understand how much effort could be shifted to the west coast before reductions in the fishing fleet would be required. Future adaptation scenarios will need to understand if the fishery is reducing its capacity or shifting its capacity to another region.</p>	<p>(a) Detailed analysis of regional growth estimates and links to temperature. Existing west coast sites may have sufficient data, otherwise a dedicated tagging program would be required. Bottom temperature data would be required to link SST to bottom temperatures to improve accuracy of relationships developed.</p> <p>Implementation of puerulus collectors for monitoring west coast settlement. These may need to be deeper offshore collectors as shallow water collector trials similar to the east coast have failed due to the west coast weather conditions.</p>	<p>H, 1 year desktop if existing data sufficient, otherwise &gt;3 years field research</p> <p>M, approximately 6 months to establish monitoring system plus ongoing research</p>	

GAP OR VULNERABILITY	BENEFIT FOR FUTURE ADAPTIVE PLANNING	METHODOLOGY OR DATA REQUIRED	PRIORITY AND INDICATION OF MAGNITUDE
<p>Validation of the stock assessment model predictions is necessary through forward projections from [say] 1980 to determine how the predicted trends match the observed data.</p>	<p>Would provide greater confidence for stakeholders in model outputs. This, in turn, would improve stakeholder confidence and willingness to consider adaptation strategies.</p>	<p>Validation runs of the harvest strategy model under climate change</p>	<p>H, 1 year desktop in combination with task below</p>
<p>Incorporation of observed puerulus settlement data in the prediction model as a 'worst case' recruitment scenario.</p>	<p>Would provide a lower boundary and, when compared to observed data, would lessen the uncertainty in which metrics (model recruitment or observed settlement trends) are most realistic</p>	<p>Adjustment of harvest strategy model</p>	<p>H, 1 year desktop in combination with task above</p>
<p>Incorporate other temperature related impacts into the assessment model such as selectivity/catchability</p>	<p>Should improve model predictions</p>	<p>Adjustment of harvest strategy model</p>	<p>L, 6-month desktop study</p>
<p>The source of southern rock lobster recruits is unknown. We only have information on temporal aspects of recruitment/settlement and the relationship to temperature, with very limited information on the source of recruits.</p>	<p>May result in adaptation strategies that provide greater protection of regional sources of larvae</p>	<p>Improved bio-physical modelling of larval transport processes and/or DNA/chemical marker research to directly establish connections between southern Australia populations</p>	<p>M-L, multi-year large-scale modelling or field program</p>
<p>Understanding of potential impacts of lowered ocean pH. A drop in ocean pH of 0.5 units by 2100 is anticipated (IPCC 2007 in Hall-Spencer et al. 2008) and physiological impacts of lowered pH are more pronounced for invertebrates than fish (Portner et al. 2005; Hall-Spencer et al. 2008)</p>	<p>Broader pH impacts are likely to override regional temperature responses. Adaptation responses based on regional temperature changes may be inappropriate.</p>	<p>Empirical studies on larval physiological responses under varying pH ranges</p>	<p>H-M, large 3-year laboratory research program</p>
<p><b>Social</b></p>			
<p>Insufficient knowledge about recreational and commercial values in the fishery, which are necessary to underpin efficient and equitable resource sharing arrangements</p>	<p>Provide information on how to engage sectors, especially with respect to adaptive planning; highlight the autonomous adaptive capacity of stakeholders; enable adaptation strategies to be more informed regarding resource sharing arrangements; identify social and lifestyle factors underpinning fisher behaviour</p>	<p>Stakeholder interviews  Fishery survey/census</p>	<p>H, 1-year research program</p>

Vulnerability to climate change impacts and adaptation response options

GAP OR VULNERABILITY	BENEFIT FOR FUTURE ADAPTIVE PLANNING	METHODOLOGY OR DATA REQUIRED	PRIORITY AND INDICATION OF MAGNITUDE
Information on the kind of incentives that would work to ensure adaptation strategies are politically feasible	Improve management response; improve understanding of scope of autonomous adaptation and increase probability of effective implementation	Include fisher behaviour in bio-economic modelling	M, 1-year desk top study
Assessment of instruments available that could be used to achieve intergenerational equity	Ensure balance between short-term benefits and longer term declines in fishery	Review of political science, governance and intergenerational literature on transfer mechanisms	M, 6-month research program
Structure of ownership in fishery – impact of increasing quota leaseholders and of absentee leaseholders	Enhance bio-economic modelling and management responses	Identification of existing data, survey of leaseholders and incorporation of data into bio-economic models	M, 3-month research program
Awareness of impact of changes in management arrangements in shaping adaptation to climate change	Avoid consequences of constraining autonomous adaptation	Assessment of alternative scenarios and options, including bio-economic modelling	M, 1-year
<b>Economic</b>			
Ability to predict commercial fleet dynamics, including entry/exit decisions Ability to predict recreational fisher behaviour	Understanding how fishers allocate effort spatially and temporally will enable managers to predict how effort will be re-distributed in the fishery in response to changing resource abundance and distribution and to predict the effect of various management policies, such as spatial closures	Econometric modelling and estimation; simulation and prediction of fisher behaviour and fleet dynamics; analysis of recreational survey data	H, 3-4-year research program
Knowledge of commercial and recreational potential of alternative species	The identification of economic and institutional barriers to commercial and recreational use of alternative species and of commercial market potential is required so the sector can take advantage of new opportunities made possible by climate change.	Approaches introduced to monitor development of new species potential; granting of access to developing fisheries under limited period permits; review of management and governance of new species	L-M, ongoing
Knowledge of economic value of fishing rights allocated to recreational and commercial sectors	Needed to support manager's ability to implement efficient resource sharing arrangements in the fishery	Estimation of marginal economic value of TAC allocated to commercial and recreational sectors based on sector models and hypothetical market experiments	M, 1-year

GAP OR VULNERABILITY	BENEFIT FOR FUTURE ADAPTIVE PLANNING	METHODOLOGY OR DATA REQUIRED	PRIORITY AND INDICATION OF MAGNITUDE
Knowledge of the economic implications of current fisheries management policies, including TAC and input controls.	Needed to improve profitability of fleet and to understand trade-off between economic and other objectives of fisheries management	Benefit–cost or cost effectiveness analysis of various fisheries management policies, including input controls	H, 1-year
Ability to predict regional and local economic and social impacts.	Provide information on the potential economic impacts on regional and local communities of changes in the distribution and activity level of commercial and recreational fishing fleets. Needed to predict infrastructure and processing needs and planning of public sector investment; predict impact on marine-dependent tourism	Development of Tasmanian input/output model including fisheries. Primary data collection to determine current direct and indirect contribution	H, 1-2- years
Information on the cost of various adaptation measures, including management, monitoring and enforcement costs	This information is required for assessment of adaptation measures.	Review of costs of existing fisheries management measures and policies, including monitoring and enforcement costs	M-H, 3-months
Economic implications of alternative control strategies for <i>Centrostephanus</i> , including use of size and catch restrictions for inshore rock lobster	Required to ensure effective implementation of control strategy	Benefit–cost or cost effectiveness analysis of alternative <i>Centrostephanus</i> control strategies	H, 3-6- months
Expected economic effectiveness of current marine ecosystem and biodiversity conservation policies, including MPAs, in the face of climate-induced changes	Needed to develop a broader, ecosystem-based adaptive management approach	Analysis of current marine ecosystem and biodiversity conservation policies, including MPAs	M, 1-year
<b>Governance and policy</b>			
Potential limitations of current management arrangements due to species-specific focus.	Provide information on whether current management approaches need to change to increase flexibility in the species harvested. Allied fisheries could be considered simultaneously (e.g. fisheries with similar requirements such as scallops, rock lobster, and giant crab)	Desk top study in consultation with fisheries managers to identify potential limitations and future options	M, 1-year

Vulnerability to climate change impacts and adaptation response options

GAP OR VULNERABILITY	BENEFIT FOR FUTURE ADAPTIVE PLANNING	METHODOLOGY OR DATA REQUIRED	PRIORITY AND INDICATION OF MAGNITUDE
<p>Current management regimes do not consider the balance between gains and losses over generational time scales, as is necessary when considering climate change impacts</p>	<p>Opportunity to develop longer-term management plans that may maintain sustainability of industry for longer periods</p>	<p>Desk top study in consultation with managers and policy makers to define what options are available. Investigate methods used in other primary industries.</p>	<p>M, initial 1-year desktop study (could be combined with above)</p>
<p><b>Integrated adaptation policy assessment</b></p>			
<p>Integrated adaptation policy assessment methodology for east coast Tasmanian fishery system</p>	<p>Needed to allow design of effective and timely adaptation strategy for east coast Tasmanian fishery system</p>	<p>Identification of evaluation criteria, performance measures and weightings using combination of expert and stakeholder input techniques</p>	<p>H, 6-12-months</p>
<p>Further knowledge of adaptive capacity of human systems dependent on current resource and of social, economic and institutional barriers to fishers adapting in an effective and timely way</p>	<p>Improve assessment of likely response and improve future management.</p>	<p>Examination of current fishery management system and identification of factors that facilitated or constrained fisher behaviour</p>	<p>H, 6-months</p>
<p>Understanding of determinants of resilience in the fishery system and of ways in which system resilience can be improved</p>	<p>Improve assessment of likely response and improve future management.</p>	<p>Identify core elements of resilience.</p>	<p>H, 1-year</p>
<p>Identification of cost effective, 'no-regrets' adaptation measures that address a range of possible future threats and/or contribute to building resilience</p>	<p>Improve assessment of likely response and improve future management.</p>	<p>Review of fishery management system; examination of available options within fishery</p>	<p>H, 6-months</p>

## 8 Issues for further investigation

This initial assessment has explored and highlighted potential adaptation responses to climate change for the east coast Tasmanian rock lobster fishery. A degree of uncertainty is inherent in this type of data analysis as projections are necessarily based on existing data that was collected for non-climate related projects. To provide greater certainty there are a number of key issues that require dedicated research that could be undertaken over a five year period. These are broadly associated with data collection, analytical tool development (modelling and integration) and communication, and encompass both physical and social sciences.

In this chapter we outline the priorities required, as identified in the previous chapter, to improve our understanding of the vulnerability of the fishery to climate change and to provide government and industry with the appropriate knowledge to develop adaptive strategies specifically suited to the Tasmanian rock lobster fishery.

### HIGH PRIORITY: CORE ISSUES

- Determining the importance of puerulus settlement in informing future recruitment declines is crucial to understanding the potential magnitude of climate change impacts. Incorporation of puerulus settlement data into the prediction model (a complicated procedure beyond the scope of the current study) followed by adjustment of the model to enable ‘predictions’ from fixed historic starting times (see modelling below) should provide insights into the usefulness of the puerulus data. If the incorporation of puerulus data in the model projections provides a substantial improvement in the match to actual observed data, then increased efforts are required to establish puerulus settlement monitoring sites in regions of the west coast. Previous attempts at monitoring on the west coast have been unsuccessful (due to harsh weather conditions) and new and innovative approaches need to be explored.
- Growth rates were a major variable affecting the predicted rate and magnitude of change in biomass due to a changing climate. In this case study, assessment data from all regions were combined to determine the relationship between growth and temperature. In addition to temperature, other physical and biological parameters are expected to affect growth such as ocean productivity (food availability) and competition for resources (density-dependent factors such as food and habitat). These are expected to vary between east and west coasts and between southern and northern regions of the fishery. For example, there are indications that relatively cooler regions on the north-west coast have faster growth rates than warmer regions on the north-east coast. Impacts of physical and biological parameters on growth need to be assessed on a regional basis; however, a combination of approaches is required that includes experimentation to determine the growth rate of lobsters at predicted future temperatures. Additionally, a detailed analysis of existing mark-recapture datasets can be undertaken to link *in-situ* growth changes with observed regional temperature changes (this is only possible at a few locations, primarily on the south-west coast). Temperatures are based on surface satellite images and relationships between surface water temperatures and bottom water temperatures needs to be obtained. This could be achieved through collaboration with the fishing industry by attaching temperature loggers to their pots and surface floats.
- In addition to individual assessments of single species, we urgently need to move towards understanding the implications of interacting species and ecosystems. Fluctuations in crustacean populations are largely driven by factors affecting larval and juvenile survival; for example, quantity and quality of food, predation, advection by ocean currents, prevailing temperatures (for example through impacts on growth). Understanding the relative importance of these parameters is a challenge that lends itself to a type of qualitative modelling called ‘loop analysis’, where multiple feedbacks and the cumulative effects of climate change could be assessed. Loop analysis is a powerful technique to evaluate the plausibility of alternative hypothesis within a logical framework and provide a means to identify gaps in knowledge. This framework could be used to predict recruitment success under various climate change scenarios incorporating sensitivity of recruitment to different factors, and identifying critical data gaps in ecosystem structure and function. Qualitative models could assess the sensitivity of recruitment to any one particular factor and establish how multiple factors may act synergistically to impact recruitment. This would be particularly valuable in the climate change context

because we could determine risk and uncertainty through extensive simulation of partially specified systems without the need for voluminous and expensive data. Preliminary development of these models will commence late in 2009 as part of a Fulbright Fellowship that aims to explore loop analyses for both the Tasmanian lobster fishery and the west coast Alaskan red king crab fishery.

- The above priorities identify research required to provide increased certainty around the biophysical parameters of the fishery. Of equal importance is the need to integrate this improved information with economic and social outcomes that can assist both industry and government in the development and implementation of adaptation strategies. Unlike biological data and models that have been collected and developed as part of the ongoing routine assessment of fisheries resources, there have been limited data collected on economic and social indicators. Social and economic data and models are required to understand the drivers for decision-making by both commercial and recreational fishers. This data would then inform the biological model on how recreational and commercial fishing activity (people and fleet movements) would alter under differing catch rates due to climate change. The biological model will need to be altered to output changes in catch rates rather than biomass. The integrated biological and economic model should provide the basis for an improved understanding of autonomous adaptation and allow managers to predict the effect on human systems of planned adaptation measures. These models should incorporate economic variables such as fuel and labour costs, exchange rate and lobster price as input variable so that the impacts of uncertainty associated with these variables can be considered in future decision making (e.g. how much would a 20 per cent increase in fuel affect the decision of a fisher to fish further afield, or to relocate closer to the new fishing grounds). A PhD project at the University of Tasmania is currently underway that is developing a bio-economic model incorporating commercial fleet dynamics. Data also needs to be collected on the income and expenditure patterns of commercial, recreational and tourist sectors in order to determine the extent of flow-on economic benefits and to inform development of models capable of predicting regional economic impacts.
- Recreational and commercial sector surveys will be required to improve understanding of fishers' adaptive capacity and to inform the development of capacity and resilience building adaptation measures. In particular, a communication strategy that assists fishers to understand the need for adaptation (based on the above analyses) and engages fishers in the development of adaptation strategies is necessary. Communication tools that minimise tensions between commercial and recreational fishers over resource allocation issues will need to be developed. Research is also needed to further our understanding of the adaptive capacity of fisheries managers and of the role of co-management and adaptive management systems in enhancing the resilience of the rock lobster fishery system.
- An integrated, multi-criteria decision framework for use in assessment of climate change adaptation measures and in the formulation of adaptation strategies for Tasmanian marine fisheries is needed. This will require the development of appropriate objectives, criteria and weights based on input from a broad range of stakeholders and should reflect the sector specific characteristics identified in Chapter 6. While this project will provide the capacity to develop medium to long-term adaptation strategies, there is also an urgent need to identify, evaluate and implement no-regrets measures in the fisheries.
- The increased risk of barrens proliferation on the east coast of Tasmania (section 4.3.7) is an issue that needs addressing immediately. Measures to reduce this risk hopefully will have been implemented prior to further assessment. However, any future assessments will need to thoroughly review any measures undertaken for effectiveness.

### **MEDIUM PRIORITY: ESSENTIAL REQUIREMENTS BUT NOT AS URGENT AS HIGH PRIORITIES ABOVE**

- There have been two previous studies into larval transport and recruitment processes in southern rock lobsters. Improvements in knowledge of ocean circulation systems are ongoing and more refined circulation models are potentially available. The last study (Bruce et al. 2007) indicated that south-eastern South Australia was an important source of potential recruits to many regions of the southern rock lobster fishery. Updating the transport models to include the recent years of settlement data and improved links between circulation and

temperature may improve our understanding of which areas are important for future recruitment to the fishery. While important, this was viewed as being of lower priority in contrast to understanding the links between settlement and recruitment and climate change. Under the current hypotheses of larval transport and the position of the sub-tropical convergence (see section 2.1.1) it is most probable that larvae sourced from regions west and north-west of Tasmania will become of less importance.

- The predicted increase in exploitable biomass (under the most optimistic scenario) is substantially higher than ever previously recorded in the fishery. Adjustments to the model are required to ensure that effort allocation is constrained to ‘achievable’ catch rates. This should be undertaken as part of the model adjustment process (suggested as a high priority above).
- Exploration of innovative institutional mechanisms for promoting long-term adaptation scenarios that account for intergenerational equity in resource utilisation need to be explored. Results from this initial assessment suggest it is likely that potential gains will precede declines. The rate of decline will be minimised if there is willingness for fleet rationalisation and adjustment. Decisions undertaken in the short term have the potential to impact on future generations of fishers.
- Investigation of alternative management strategies that provide increased flexibility for fishers is needed.
- With regard to climate variables that influence the fishery, the ability to operate may be influenced by wind speed and direction. Such additional environmental variables should be considered in more detail in any future assessments

## LOW PRIORITY: POTENTIAL FOR USEFUL OUTCOMES

- Factors such as interannual catchability changes due to changes in water temperature are not currently allowed for in the modelling process. Changes in catch rates are primarily linked to changes in recruitment. For example, increases in catchability due to increases in sea temperature would be interpreted as improved recruitment to the fishery, despite catchability and recruitment being independent processes. Adjustments to the model to link catchability to temperature change should be explored as part of the model adjustment process (suggested above).

## SUMMARY

Further assessments should evaluate a range of strategic adaptation measures to provide government and industry with a blueprint to develop policy that is aimed at maximising the opportunities and minimising the harm associated with climate change. To provide increased certainty and reduce scepticism of projected climate futures there needs to be an improvement in our understanding of the relationships between growth and recruitment in the biological model and a link between biological change and economic and social benefits and losses. The latter will require the development of a regionally-based economic model. Model adjustments also need to incorporate other sources of variability associated with climate change.

Qualitative modelling approaches provide an ideal mechanism to explore ecosystem interactions and have proven insightful as industry–science communication tools since they can be developed in consultation with industry. They also enable some of the more sophisticated quantitative modelling approaches to be articulated in a more simplistic framework, thereby bridging the link between fisher knowledge and a modelling framework.

Development of adaptation options will require clear communication of projected outcomes under climate change, along with industry input into developing adaptation scenarios. Governance and management structures and processes that allow for the effective engagement of science, government and industry will be essential for development, implementation and update of adaptation actions.

## 9 Conclusions

---

Climate change is not only affecting our ecosystems, it is changing scientific priorities, the way we do research, how we make planning decisions and how we design conservation and management approaches. Adaptation is something we need to begin now and the quality of biophysical and social science underpinning this process is crucial. While the trajectory of some of the major global oceanographic changes is now generally known, uncertainty about the magnitude, or even the direction of changes in biological parameters (like productivity of fish stocks) is caused by a lack of understanding about how the major drivers will individually, collectively and interactively affect ecosystem composition, structure and function. This impedes the ability of the scientific community to provide reliable estimates of the future status of ecosystems, let alone individual stocks. It is critical that we improve these estimates and communicate them effectively so that science can better support policy – allowing us the potential to minimise impacts, maximise adaptation and be prepared for opportunities (i.e. stocks that increase in productivity).

### *Southern rock lobster and climate change in Tasmania*

- Warmer waters, such as will occur along the east coast of Tasmania in the future, may mean this area will be unable to support rock lobster populations of the same size as found today (section 4.3.1). The dynamics of populations that inhabit the latitudinal margins of the distribution range are likely to be critically important in determining species' responses to expected climate change (Hampe and Petit 2005). Assessment of the performance of 'rear-edge' populations may provide indications of what to expect with time for current population centres; for example, analysis of populations of rock lobster in New South Wales now, may give insights into what population responses to expect in Tasmania in the future.
- All model projections incorporating temperature influences on growth and recruitment indicate initial gains in biomass, before a reduction in biomass occurs in all regions for both climate change scenarios assessed. There will be a *trade-off* between opposing impacts of increased rock lobster growth and declining recruitment.
- An increase in water temperature and strength of the EAC, will likely lead to faster lobster growth, particularly in southern regions.
- However, north-eastern and eastern regions may experience continued declines in puerulus settlement with consequential reduced recruitment of young lobsters to the population stock. Declines in biomass are predicted to occur in northern and north-eastern regions first, which is consistent with observed patterns over the last 30 years (section 4.3.3). South-eastern regions may initially have improved recruitment on average (as suggested by current trends as well as modelling) before subsequently also experiencing declining puerulus settlement (section 4.3.2). While the decline in recruitment will likely eventually impact adversely on the productivity of the stock, there may potentially be large gains in exploitable lobster biomass, particularly in the south-west, in the shorter term. The picture is not necessarily a 'doom and gloom' story, *assuming that the risk of barrens proliferation can be abated*. Lobsters are relatively long-lived and thus by making informed decisions early there is the potential to optimise the value of the fishery.
- By 2025, average temperatures along the entire east coast will likely reach a critical threshold that allows the sea urchin *Centrostephanus* to complete its larval life cycle, therefore substantially increasing the risk of barrens formation (Figure 22, section 4.3.7). The biomass of large lobsters that are able to consume urchins is predicted to increase in all regions (in response to faster growth) before beginning to decline (as a function of lower recruitment). Although the biomass of large lobsters required to prevent barrens formation is unknown, it is considered to be substantially higher than current levels, requiring an initial rebuilding period before this threshold is reached. Increases in abundance of large lobsters would be expected to increase resilience against barrens formation through predation of *Centrostephanus* – **assuming fishing catch is controlled**. Unfortunately, the point where biomass of larger lobsters starts to decline occurs earlier in the eastern regions, which are currently the regions with expanding *Centrostephanus* barrens.

- Largely because of autonomous adaptations (allowed by the mobility of the fishing fleet), social and economic impacts will be regional. The region most likely to support the fishery for longer is the south-west where necessary infrastructure is currently limited.
- There is an increased likelihood of disease, the possibility of ‘ecosystem surprises’ that may impact on rock lobster stocks (either positively or negatively) and unknown impacts of ocean acidification (section 4.3.6 and 4.3.7).

There are clearly major implications for the fishery in the face of such significant drivers of change and increased uncertainty. Traditional ways of thinking about the fishery and the use of historical patterns or trends as a guide for the future will no longer be as relevant as they have been in the past. It is crucial that uncertainty does not preclude immediate action, as there are many options for adaptation that substantially improve the outlook for the east coast Tasmanian rock lobster fishery, under any future climate change scenario. Identifying, developing and implementing adaptive management responses which can deliver enhanced resilience to the fishery as well as viability to stakeholders will be critical but very challenging given current fisher and community perceptions about climate change.

Successful climate change adaptations are not isolated from other decisions and management needs to be responsive to shorter-term biological, economic and social changes in the fishery as well as longer-term changes. However, there are obvious benefits if common strategies can be used to achieve short-term goals and address long-term issues at the same time. Indeed there are many synergies between the adaptation options presented and those being considered by fishery managers at the present time. The opportunity to trial the effectiveness of particular strategies, and address any implementation issues in the short term, would also be of benefit.

- There is a need to develop integrated assessment models and multi-objective decision tools for use in the Tasmanian rock lobster fishery. While this will provide capacity to assess climate change adaptation options and develop adaptation policy, it will also allow managers and researchers to deal with other challenges currently faced by the industry in a way that formally incorporates and balances social, economic and biological objectives, and allows for increased stakeholder input. Consistency between the approach required to assess climate change adaptation options, and the approach taken for current assessments, would allow a more seamless inclusion and assessment of climate change impacts and possible adaptation options as part of ‘core business’.
- For urgent and specific issues (e.g. the increased risk of *Centrostephanus barrens* formation), cost effectiveness analysis (CEA) provides a suitable tool for evaluating and selecting pathways forward.
- Early identification, assessment and implementation of no-regret or low-regret and precautionary measures are considered vital to ensuring the industry is as resilient to any climate change impacts as possible, and include:
  - Adaptive management responses that promote higher numbers of large lobsters in inshore areas to increase ecosystem resilience to urchin barren formation. In addition to substantial declines in general ecosystem health, proliferation of urchin barrens on the east coast of Tasmania would have major impacts on the rock lobster, abalone and finfish commercial and recreational fisheries and tourism. This is an urgent issue that needs immediate action.
  - Improved communication between industry sectors (recreational, commercial, managerial and research).
  - Movement towards a MCA management approach (as described above) and co-management arrangements.
  - Synergistic effects between climate and anthropogenic variables, particularly fishing pressure, will likely exacerbate climate-induced changes (Harley et al. 2006). The impact of climate change depends on the scale of change, but also on the sensitivity of particular species or ecosystems, and we can control some of the factors that affect sensitivity of species to climate impacts (Brander 2008). Minimising additional threats at a local level (e.g. over-fishing of target species or other ‘key’ ecosystem species, habitat alteration and pollution) is also a ‘no regret’ strategy in relation to climate change, because the benefits apply irrespective of how climate changes (Brander 2008).
  - Adequate and efficient monitoring of our resources will be critical. Climate-induced changes in the abundance or distribution of one or a few leverage species may result in sweeping community-level changes. To be optimally adaptive we will need to know what changes are occurring very quickly.

## Vulnerability to climate change impacts and adaptation response options

- Biophysical climate-induced changes in the rock lobster fishery, and the various impacts of associated adaptation measures (e.g. spatial management of TAC and changing size limits), will result in costs, benefits and effects on welfare that are unevenly distributed. Intergenerational equity is a familiar and complex challenge in environmental negotiations. This is an issue that needs serious consideration in this specific case and in future assessment of climate change impacts and adaptation options generally.
- A solid understanding of potential impacts is obviously a necessary precursor to a thorough assessment of adaptation options. Determining the importance of puerulus settlement in future recruitment, thorough assessment of variables affecting growth regionally and temporally, and data to underpin social and economic issues and models are all required. This fishery, along with many other Australian fisheries, requires a sustained research effort so that a more comprehensive understanding of potential impacts of climate change can be developed. This will give Australian fisheries, with current revenue in excess of \$2.2 billion pa, the best possible prospects for minimising impacts and maximising opportunities (Hobday et al. 2008).
- However, whilst improved quality and duration of critical data sets are required to provide greater certainty for predictions, we caution against managing natural resources under the assumption that accurate predictions will be available at some point. Adaptive capacity should be geared towards managing risks and dealing with uncertainty. Management structures and institutions must therefore be flexible and responsive and must themselves be resilient to shocks.

This project specifically focused on the east coast Tasmanian rock lobster fishery as a species specific case study; however, as with current fisheries management approaches generally, an ‘ecosystem-based’ approach should be considered for the next level of assessment. An assessment of potential climate change impacts and adaptation options at the level of the regional marine system would allow incorporation of fisheries and other marine values more explicitly and would be in synergy with most progressive fisheries management aims (e.g. at the level of the ecosystem). Additionally, there may be much to learn by collectively examining species with similar life-history traits: in this case, species like banded morwong and striped trumpeter that also have extended oceanic larval phases and may also be impacted by changes in oceanic circulation patterns.

Fisheries management is facing unprecedented challenges and the scientific community needs to deliver spatially explicit, scientifically rigorous, priority-based advice about species’ vulnerability and adaptation options. Understanding connections between oceanographic processes and responses to climate change by marine species are challenges facing fisheries scientists and resource managers the world over. By comparing and contrasting different systems facing similar challenges, useful generalities will emerge, assisting us to develop broadly applicable approaches toward sustainable management. We need to ensure that management planning for today is suitable for an uncertain future, and to integrate shorter-term needs within a longer-term view (i.e. building the issue of climate change into core business and not managing them as a discrete threat).

This case study represents the first step towards achieving an integrated, interdisciplinary assessment of climate change as it affects the rock lobster fishery. While expertise from a variety of disciplines has been brought together on this project, we have lacked the methodological framework and models to provide truly integrated assessment and evaluation. Nevertheless, the process has fostered a shared understanding of the importance of such an approach. Building conceptual and analytical capacity at disciplinary boundaries is a priority for future effort. The Tasmanian rock lobster fishery is recognised as well-organised and proactive and is now in a better position than many other Australian fisheries to face and address the challenges that climate change may pose for the industry.

The Tasmanian rock lobster fishery is ideally placed to be an ‘early warning signal’ for Australian fisheries generally. Being at the interface of the East Australian Current and southern ocean waters, it is experiencing climate warming faster than any other region in the southern hemisphere. Warming waters in this region have already resulted in altered species distributions and ecosystem impacts. Both Industry and Government are already considering management strategies that take account of these changes to make the fishery more responsive to climate-related impacts. By building on this solid framework, including the new information developed in this report, this fishery will continue to provide an example of adaptive planning and implementation that can provide valuable lessons for fisheries both nationally and internationally.

## **Appendix 1: Staff**

---

Gretta T. Pecl, Research Fellow, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania

Stewart D. Frusher, Associate Professor, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania

Caleb Gardner, Research Fellow, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania

Marcus Haward, Associate Professor, School of Government and Antarctic Climate and Ecosystems CRC, University of Tasmania

Alistair J. Hobday, Senior Research Scientist, Climate Adaptation Flagship, CSIRO, Hobart, Tasmania

Sarah Jennings, School of Economics and Finance, University of Tasmania

Melissa Nursey-Bray, National Centre for Marine Conservation and Resource Sustainability (NCMCRS), Australian Maritime College, University of Tasmania

André Punt, Research Associate Professor, School of Aquatic and Fishery Sciences, University of Washington, USA

Hilary Revill, Wild Fisheries Management Branch, Tasmanian Department of Primary Industries and Water

Ingrid van Putten, School of Economics and Finance, University of Tasmania

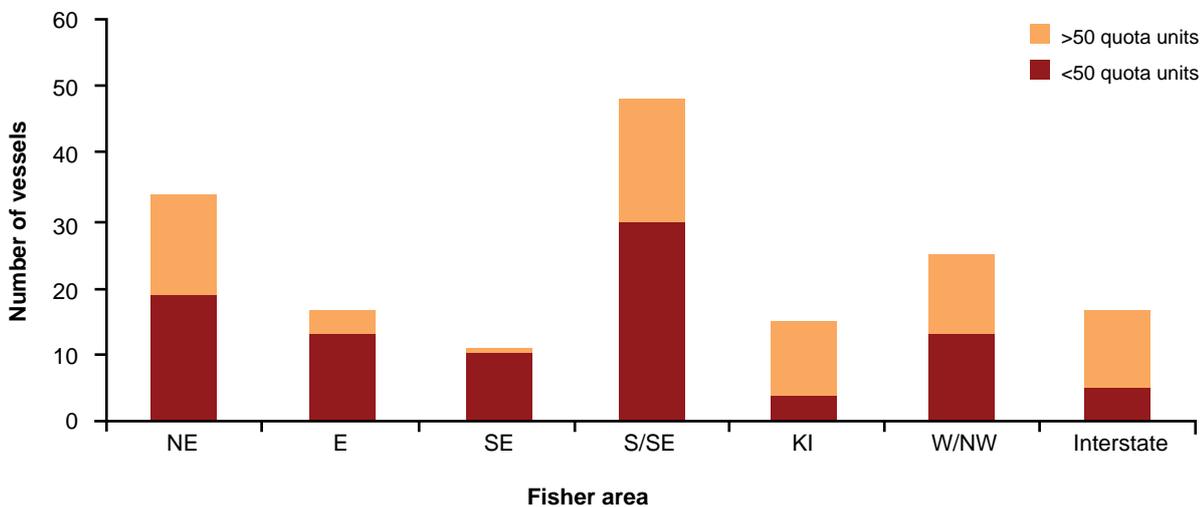
## Appendix 2: Summary of rock lobster fishery regulations

<b>COMMERCIAL</b>	
Management zone	One management zone for the state
Limited entry	314 licenses
Limited seasons	Males: season open from 15 November to 30 September inclusive. Females: season open from 15 November to 30 April inclusive.
Limits of pots on vessels	Minimum of 15 pots, maximum of 50 pots
Individual Transferable Quota Units	Total allowable catch of 1523.5 tonnes 10,533 quota units (145 kg per unit)
Minimum and maximum quota holdings	Minimum of 1 quota unit per licence (but 15 units are needed to activate licence) Maximum of 120 quota units per licence
Restrictions on trap 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
Minimum size limits	105 mm CL for females, 110 mm CL for males
Berried females	Taking of berried females prohibited
<b>RECREATIONAL</b>	
Licence requirements	Rock lobster potting licence – 1 recreational trapper person, rock lobster diving licence, rock lobster ring license – 4 rings per person.
Daily limit	5 per recreational license holder
Limited seasons	Males: first Saturday in November to 31 August inclusive. Females: first Saturday in November to 30 April inclusive.
Restrictions gear dimensions	Traps as per commercial fishers, rings no more than 1 m in diameter, capture by glove only when diving.
Escape gaps	As per commercial fishers
Minimum size limits	As per commercial fishers
Berried females	As per commercial fishers
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.

## Appendix 3: Rock lobster industry structure and regional differences

The Tasmanian rock lobster industry is characterised by fishing operations of various sizes, both in terms of vessel size and the number of quota units. Size has a significant impact on the cost structure of a rock lobster fishing operation. For example, results from a 2008 survey suggest that smaller vessels with fewer quota units will often be manned by the skipper only, whereas larger vessels, that generally have more quota units, have one deckhand, contributing to higher overall labour costs (van Putten and Gardner unpublished data).

Some regional patterns can be observed in relation to the size of rock lobster fishing operations in fisher areas around the State (Figure 26). The seven different fisher areas represent the ‘homeport’ of fishers, e.g. a vessel in the south-east will have Port Arthur, Nubeena, or Dunalley as their ‘home port’.



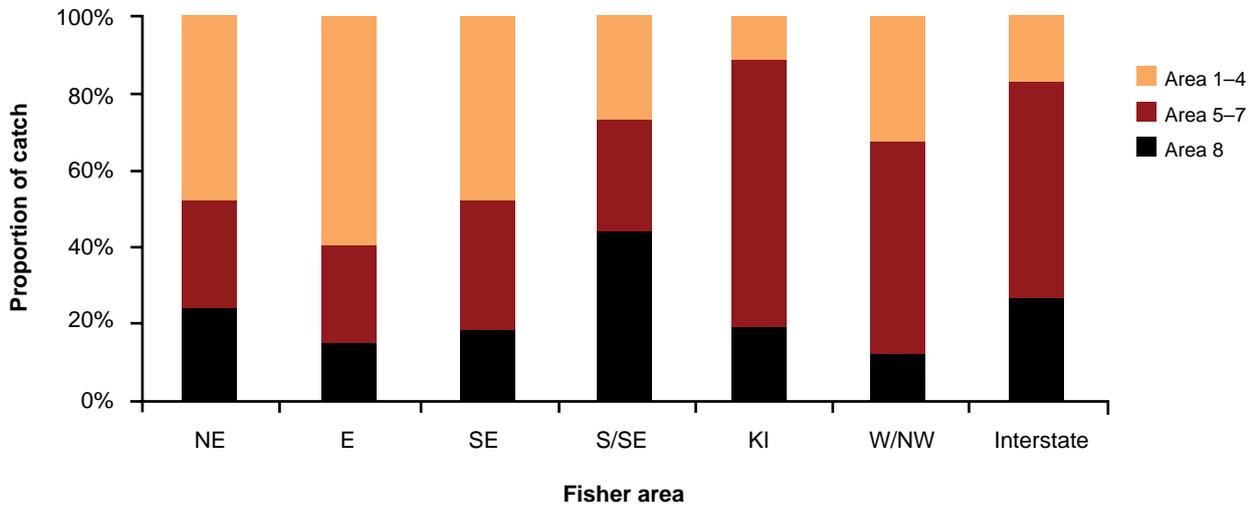
**Figure 26: Number of vessels and quota units by fisher area. Note the quota units may be owned, leased or both. KI= King Island**

State-wide approximately 57 per cent of rock lobster fisher operations have less than 50 quota units. The proportion of rock lobster fisher operations with less than 50 quota units is higher in the east and south-east, and slightly higher in the south and south-east compared to the state average. Because vessel size and number of quota units are related, the east of Tasmania has the largest proportion of small boats and King Island (KI), the north-east, and interstate have a bigger proportion of large vessels.

State-wide, smaller rock lobster fishing operations catch 39 per cent of the total catch. However, in the eastern and south-eastern fisher areas, 64 per cent and 74 per cent of the catch is caught by smaller operations respectively. In contrast, in King Island only 14 per cent of the catch is by the smaller operators.

Overall, Tasmanian fishers from each fisher area will catch rock lobster in all assessment areas around the state, but a large proportion of their catch tends to be from a particular region. For example, fishers from the eastern fisher area catch the highest proportion of their catch (60 per cent) from the east coast assessment areas 1, 2, 3, and 4 (Figure 27).

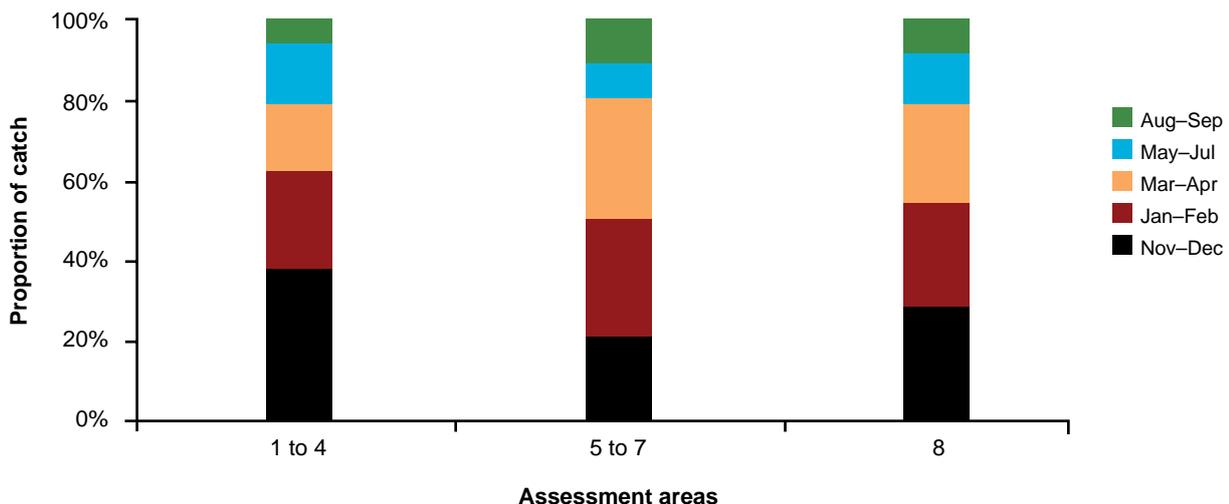
Vulnerability to climate change impacts and adaptation response options



**Figure 27: Proportion of catch in assessment area by fisher area (2007).**

The eastern fisher area was also typified by a higher proportion of small vessels generally not equipped to travel to the more remote and rough fishing grounds of Tasmania. The south and south-east fishers are least dependent on the east coast rock lobster resource as these fishers catch almost 50 per cent of their catch in the south-west (assessment area 8). As expected, fishers in the King Island, western/north-western and interstate fisher areas catch up to 70 per cent of their catch in assessment areas 5, 6, and 7.

Tasmanian rock lobster fishers will go out fishing all months of the year except for the closed month of October. There are some small regional differences in that fishers from the eastern and south-eastern areas catch over 60 per cent of their catch in the first four months of the season (November to February) (Figure 28).



**Figure 28: Seasonal fishing effort by assessment area (2007).**

State-wide, about 20 per cent of the catch is caught between May and September. There is little evidence of a seasonal pattern in relation to the assessment areas, with only a slightly higher proportion of the catch (60 per cent) caught in the first four months of the season in the eastern assessment areas (1 to 4).

## **Appendix 4: Provisions of the *Living Marine Resources Management Act 1995 (Tas)***

---

The *Living Marine Resources Management Act 1995* contains a number of key provisions that directly relate to governance of the fishery, and help promote capacity, coordination and adaptive management.

### **18. Function of Minister**

The Minister must ensure that this Act is administered in a way which promotes the sustainable management of living marine resources.

### **25. Fishing bodies**

- (1) The Minister may issue a certificate certifying that a body corporate is a fishing body if satisfied that it represents the interests of participants in–
  - (a) the fishing industry or part of the fishing industry; or
  - (b) a fishery; or
  - (c) the marine farming industry or part of the marine farming industry; or
  - (d) any combination of these.
- (2) The Minister may issue a certificate certifying that an association is a fishing body if satisfied that it represents the interests of participants in –
  - (a) the fishing industry or part of the fishing industry; or
  - (b) a fishery; or
  - (c) the marine farming industry or part of the marine farming industry; or
  - (d) any combination of these.
- (3) The Minister may revoke a certificate if no longer satisfied as to the matters referred to in this section.

### **27. Advisory committees**

- (1) The Minister may establish advisory committees to provide information and advice to the Minister on matters related to the administration of this Act.
- (2) The Minister may appoint any person as a member of an advisory committee on any terms and conditions the Minister determines.
- (3) The Minister may abolish an advisory committee at any time.

### **32. Management plan**

A management plan consists of rules relating to a specified fishery.

### **33. Rules**

- (1) The Minister may make rules in respect of –
  - (a) a management plan; or
  - (b) a fishery in respect of which there is no management plan; or
  - (c) any other matter under this Act.
- (2) Rules in respect of a management plan take effect on a date specified in the rules that is a date after the provisions of Division 2 of this Part have been complied with.
- (3) The Minister must –
  - (a) consult with the relevant fishing body before making any rules under subsection (1)(b) or (c); and
  - (b) notify any proposed rules by public notice.

## Appendix 5: Objectives of the resource management and planning system of Tasmania

---

1. The objectives of the resource management and planning system of Tasmania are:
  - (a) to promote the sustainable development of natural and physical resources and the maintenance of ecological processes and genetic diversity; and
  - (b) to provide for the fair, orderly and sustainable use and development of air, land and water; and
  - (c) to encourage public involvement in resource management and planning; and
  - (d) to facilitate economic development in accordance with the objectives set out in paragraphs (a), (b) and (c); and
  - (e) to promote the sharing of responsibility for resource management and planning between the different spheres of Government, the community and industry in the State.
2. **‘sustainable development’** means managing the use, development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural well-being and for their health and safety while –
  - (a) sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations; and
  - (b) safeguarding the life-supporting capacity of air, water, soil and ecosystems; and
  - (c) avoiding, remedying or mitigating any adverse effects of activities on the environment.

## Appendix 6a: Risk perception: east coast rock lobster, Tasmania

---

*by Dr Melissa Nursey-Bray*

### 1. INTRODUCTION

This is a report on the findings of a risk perception exercise undertaken with rock lobster fishers within Tasmania in relation to climate change. It comprises part of the social component of the initial vulnerability assessment for the east coast rock lobster fishery, Tasmania.

### 2. METHODOLOGY

This study was undertaken over a three-month period in between August and October 2008. Twenty-two qualitative semi-structured interviews were undertaken, many of which, due to time and travel constraints, were conducted by phone<sup>6</sup>. Additional information was gathered via a workshop with industry and some focus group work. All respondents were male, with an average 10–15 years' experience in the industry. This study was conducted via face-to-face and telephone interviews, focus groups, a workshop and literature review. As many of those interviewed fished all around Tasmania, their feedback must be understood to include other types of rock lobster apart from the east coast. Respondents were chosen using representative sampling, and snowball and purposive methods used to determine the point of information saturation and contact referral. An initial contact list was used as the basis for seeking and conducting interviews with fishers. The study was approved by the UTAS Human Research Ethics Committee<sup>7</sup>. Subjects of focus for the interviews included (i) fishers' experiences of fishing, (ii) fishing perception on management regimes, (iii) fisher perceptions of climate change and its impact on the industry and, (iv) fisher perception of and ideas for adaptation. Face-to-face validity and Guba's criteria of transferability were used to evaluate the information obtained.

### 3. CONSTRAINTS

The main constraint in this study was time, which due to project deadlines meant that not all fishers were available to talk about their perceptions within that time period. Moreover, many fishers were out at sea, and many lived in different parts of the state which made travelling to see them face-to-face more difficult. Due to the time constraints, most interviews were conducted by phone. Approximately 10 per cent (that is, 22 fishers) of all fishers in the industry were interviewed. Most were interviewed prior to the main workshop, a number of them afterwards. Feedback from the latter may be different as fishers were given much information in the workshop which may have influenced their subsequent perception. Many of those interviewed fished all over Tasmania, so their feedback must be understood to include other types of rock lobster apart from the east coast.

### 4. RISK PERCEPTION

A risk perception exercise aims to understand how those in the industry actually feel and think about an issue. This is to be differentiated from what is scientifically or formally known; what is identified as an actual risk and how industry stakeholders perceive it can be two different things. In order to ensure that all parties are 'singing from the same sheet', finding out how climate change risk is understood by different sectors and interests within the community is vital (Dake and Wildavsky 1990; Dake 1992; Slovic and Peters 1998; Loewenstein et al. 2001; Leiserowitz 2006).

---

<sup>6</sup> This number represents approximately 10 per cent of fishers in the industry.

<sup>7</sup> A Minimal Risk Ethics Application was submitted and approved in September 2008.

For example, an American case study highlights the critical influence of risk perception (Gardiner 2001). A risk perception index using nine variables<sup>8</sup> showed that while Americans overall viewed global climate change as a moderate risk, they were more concerned about standards of living, water shortage and disease. More importantly, the use of the index highlighted a trend for Americans to discount local impacts, seeing them as ‘unlikely’, therefore disconnecting them from the possibility of planning for them. This finding had policy implications for municipalities attempting to develop momentum for local climate policy, and highlights the worth of undertaking such studies prior to decision-making and program development.

Moreover, understanding the relationship between risk perceptions and the willingness to address climate change is important (O’Connor et al. 1999; Dake and Wildavsky 1990). Studies of risk assessment show that behavioural intentions can be predicted when risk perception is defined as the ‘perceived likelihood of negative consequences to oneself and society from one specific environmental phenomenon: global warming’ (Dake and Wildavsky 1990). This is an issue often overlooked in studies that focus on the relationship between environmental beliefs and how they predict behavioural intentions as they rarely include specific risk perceptions as independent variables or criteria within vulnerability assessments.

## 5. RESULTS

A number of themes emerged from these interviews. They are as follows:

### 5.1. FISHING EXPERIENCE

Most fishers had extensive experience of the sea and fishing. Most fishers were not sole operators in relation to rock lobster but also fished for shark, scallop, crab and other species. Some also fished abalone. All indicated there had been substantial change in the technology over the last 20 years. This included a progression from echo sounders to GPS and satellite technology. All fishers interviewed felt that rock lobster were safe from the likelihood of disease, but in relation to aquaculture, most expressed the view that ‘if it got off the ground it might cause problems – it’s not natural having fish locked up and it could maybe breed a kind of disease in them, so that’s potentially a worry’.

All fishers had upgraded their boats in the last 20 years. Most fishers were either currently or had been in partnership with their friends or family members. A proportion of the fishers had also become involved in fishing management in a formal capacity, through various committees.

### 5.2. MANAGEMENT

All fishers in discussing their fishing history referred to the introduction of quota, which dominated all discussions about rock lobster management. Discourse around quota was clearly differentiated as ‘before’ and ‘after’ quota. Fishers either owned [quota], leased it or did a bit of both. The consensus for all fishers was that the quota was not satisfactory overall for the fishers, although 70 per cent agreed it had ‘probably done all right for the species’. Of the 20 interviewed only 2–3 agreed or felt the quota was a positive management move. Many fishers from King Island were particularly antipathetic to the introduction of quotas, and went further to express vehement opposition to the idea of zoning, which they indicated is ‘on the table’ at present. All fishers talked about the additional burden that increasing regulation had created in relation to doing paperwork.

### 5.3. CLIMATE CHANGE

Overall, about 40 per cent of fishers interviewed did not agree or perceive climate change was a problem at all. About 30–40 per cent felt the ‘jury is out on that one’. These fishers noted that changes in climate did seem to be occurring, but were not convinced that it was human induced, and that even if it was, it would not have a great impact on the industry. Some of these fishers had observed changes in the industry (and others) and areas

---

<sup>8</sup> These include holistic concern; assessments of the severity of current and future impacts of global climate change on human health (mortality and morbidity); measures of local and global impacts of climate change on standards of living, water shortages and rates of serious disease; the seriousness of the threat to non-human nature; the seriousness of the current impacts of climate change around the world; and the scale of concern.

they fished, but were not convinced that was due to climate change. In this context a key discourse about climate change was the view that it was cyclical, and that it was therefore uncertain whether or not global warming was happening. About two thirds of fishers also construed climate change as a conspiracy by scientists to get more money, in the process expressing a high level of cynicism and distrust towards scientists in general. The remaining 20 per cent of fishers did express concern about climate change with one going so far as to say it was not only ‘the greatest problem facing the industry but the planet’. Sea level rise and sea water temperature rise was identified as a major concern for the industry.

Many fishers added that while they may not believe in climate change, they did believe in sustainability and making the industry as sustainable as possible. About 20 per cent of fishers also saw climate change as a positive opportunity. A key issue with all fishers, whether or not they believed in climate change, was that they did not feel certain about the effects on the industry, and whether or not those effects were going to occur over 10–50–100–1000 years. As such, there was ambivalence to the idea of adapting to change, when the timeframes were unclear. Shorter term issues figured as being worthy of higher and more immediate attention.

#### 5.4. CHANGES OBSERVED

Notwithstanding the general scepticism that characterised fishers’ responses to climate change, a number of fishers relayed their observation of a number of changes over the years. These included: (i) increase in size of lobster in offshore areas; (ii) increased pressure on inshore fisheries; (iii) sightings of species not expected at that time of year or region (i.e. sightings of snapper, schools of tuna); (iv) increased incidence of sea urchins; (v) little tommies in the Fortescue area; (vi) changes in kelp beds; (vii) low egg production, especially in the east coast; (ix) a lot more whale sightings; (x) bluefin caught in south coast; (xi) far fewer schools of mackerel and whitebait than used to be seen; (xii) lots more octopus caught now; (xiii) more dead penguins at certain times of the year; (xiv) catching more shark; (xv) lots more weed, pulling up string kelp at Cape Natural and Eucalyptus reef; (xvi) many fishers noted some change in recruitment and worried that warmer temperatures, or indeed current changes, might affect any or all of the stages of development of rock lobster; (xvii) spawning seemed to be occurring later and/or earlier for rock lobster; (xviii) drop in egg production.

#### 5.5. OTHER ISSUES RAISED

The discussion of whether or not climate change was an issue for fishers, tended to lead to a more in-depth discussion about other issues that were considered more pressing. Of these, one of the most prominent issues was the financial pressure felt by fishers under the quota system. Those who currently lease quota felt that the introduction of quota had led them into a spiralling system of debt and repayments which left little room for confidence. Many fishers discussed the sheer size and emotional weight of their debt, and linked that debt to the existence of quota. A related issue was the rising cost of fuel. Financial pressure or worry about retirement also loomed as a concern for many fishers, who felt they had large assets but not necessarily buyers for them, and this worried them in relation to ensuring good superannuation etc. For some fishers this was simply raised as a note on the overall higher cost of overheads and other running costs, but for others it was discussed as one of the ‘straws that breaks the camel’s back’.

One fisher talked about the seismic testing by SANTOS that is occurring and considered that this must have an effect on reproduction and recruitment and wanted to know why tests had not been conducted on this issue.

Another issue that was consistently raised was the lack of succession planning or capacity for the industry. Many older fishers reflected that their children (usually talking about their sons), were not indicating strong interest in going out fishing. A number pointed out that it was an aging industry, this in itself being considered a vulnerability. Costs for entering the industry are prohibitive, and the work itself is not generating as much income as it did, and hence is not as attractive as a career or livelihood option. This was reiterated often and expressed by fishers overall as a sadness at the passing of an era. In a similar vein, fishers talked about the entry (via the quota) of non-fishers into the industry and the controlling influence they had as a result. Many bemoaned the fact that you could ‘be a lawyer or a real estate agent in Brisbane, whatever, know *nothing* about fishing but still have quota and then get us mugs to fish it for them, and then they reap the benefits... there’s something wrong there...’

## 5.6. ADAPTIVE CAPACITY

About 90 per cent of fishers were confident that the industry was capable of adapting to change. This confidence seemed to be derived from a view that fishers over time and generations had already experienced much change, and as such the industry would be able to also adapt to climate change.

A number of suggestions were made relating to potential adaptive strategies. These included formulation of new regulations or a management change such as giving people a number of days to fish rather than quotas. Another dominant reflection was that fishers would simply adapt by moving on to another species or doing something else. An adaptation strategy that offered incentives to fishers to value-add to their income by being permitted to take other species as well as rock lobster was canvassed. A change from a quota to a system of days allocated was suggested. Fishers also considered the efficacy of managing or monitoring the beach price so that it assisted fishers to have to go out less (hence less carbon; less energy used) yet make the same amount. Similarly, changes/additions to regulations for boat size that would encourage/force fishers to have more efficient boats were mooted.

All fishers expressed the need for good and effective communication between the industry stakeholders and governments and researchers so as to enable adaptive capacity. Establishment of programs such as the 'Clean Green Program' system of independent audit of boats, and commitment to environmental responsibility was raised. Given that the carbon footprint of the industry *per se* was perceived to be large due to the pressure exerted by international markets, another suggested adaptation strategy was the institution of a change to financial incentives so fishers sold to local and national markets rather than international markets, thus necessitating less travel and use of food miles.

## 6. DISCUSSION

Overall, as seen above, fishers had a range of views on the industry and in relation to climate change. It is interesting to note that, generally speaking, younger fishers were less sceptical and more positive about adaptation than fishers closer to retirement. Fishers who were also active in formal capacities in the industry also evinced a greater belief in climate change and associated risks. Risks overall to the industry in summary included (i) the quota system and future management, (ii) recruitment and reproductive cycles of rock lobster, (iii) market price and pressures, (iv) climate change, (v) lack of successional planning, and (vi) economic [in]stability.

Specifically, the risk perception study also highlighted a number of factors important to any discussion about vulnerability. First it highlighted that there is a communication gap and difference in perception between fishers' views and the actual documented existence of climate change impacts on rock lobster. This in itself is a vulnerability that must be addressed. It highlights what Clay and Olson (2008) characterise as the 'frequent mismatch between social and biophysical systems change'.

There are a number of barriers to effectively communicating climate change at local levels, the first being the scale of the problem *per se*. Climate change is a global problem, yet solutions are needed at local levels. Nonetheless, getting stakeholders to forge the conceptual link between the global and local scale is difficult. Another problem with communicating climate change is that planning decisions are more often than not driven by uncertainty about the predictions. The question the fishers often asked is 'how can planning decisions be made when the science itself is unclear?' Thus, the issue lacks immediacy for people. It is effectively a 'creeping' problem that needs an immediate response, a notion hard to communicate let alone implement. This is amplified by the disjuncture between people's experience of the 'weather' and the discourse about climate change. If people cannot 'see' climate change and, further, can reconcile it as being simply an 'unusual weather pattern', convincing them that climate change is real and that something really needs to be done about it is that much harder. Many fishers in this study, for example, both in interviews and the workshop, cited their experience of the weather as 'proof' that climate predictions were untrue or at the very best, not reliable.

Moreover, the complicated nature of scientific and management 'speak' about climate change makes it very hard for people to understand the problem in the first place. It is difficult enough for policy makers to respond when faced with having to interpret a multitude of documents across different disciplines on the issue; engaging fishers in this enterprise is harder still. Moreover, access to this information is often constrained. Too often there is a lack

of knowledgeable, credible *and* local people who could champion effective communication about climate change. There is also a lack of presented alternatives which increases the levels of disenfranchisement that individuals and communities may feel.

This study also demonstrates the need for adaptive management to address not just ecological variability but also social variability about issue perception. Education strategies could build on this variability to develop some uniformity of understanding about the issue which will in turn assist in the development of and uptake of adaptation strategies.

Communication about climate change needs to be supported so that it is culturally appropriate and palatable to fishers, so that the issue of climate change will penetrate and be accepted within existing cultural norms. It also highlights that few opportunities currently exist within existing institutional and scientific structures to provide entry points or repositories for local fisher knowledge to make contributions. As shown in many case studies world-wide (Santha 2008; McGoodwin et al. 2000), incorporation of local fisher knowledge can have an emancipatory effect on the industry, encouraging its uptake of new management measures and in many cases actually value adding to existing knowledge sets.

The study showed that while climate change was part of fisher discourse about their business, it was not the predominant concern – management of the quota and the future viability of the industry in relation to succession and debt management were of most concern. To build the resilience within the industry to enable adaptive change to occur, the impact of these other factors cannot be underestimated. Building resilience to overcome social vulnerability will require acknowledgment of (i) kinship and gender relations, (ii) the importance of the resource base, (iii) vulnerability of interrelated infrastructure and community supports, and (iv) the fact that fishing is seen as a way of or part of life and much more than a job (Clay and Olson, 2008). This is consistent with work by Tuler et al. (2008) that highlights that there are many drivers of vulnerability that go beyond the environmental and include (i) demographic factors, (ii) individual decision making factors, (iii) institutional factors, (iv) economic factors, (v) socio-cultural factors and (vi) technological factors. All these drivers were very apparent in the interviews for this study.

In this context, adaptation strategies that have been conventionally adopted by fishing communities world-wide, such as crew shares, egalitarianism, information sharing and fishery switching (Clay and Olson 2008) could be in themselves adapted to build social resilience to climate change. It is important to engage with not only how communities identify vulnerability (in this case the quota, debt and succession), but how they engage with, and are able to act to respond to, those threats. The scale of events is also important; understanding how a global scale event like climate change can merge at local levels will facilitate uptake of adaptation strategies.

## SUMMARY

Fishing communities will vary as to their levels of vulnerability, sensitivity and exposure to threats. They will also vary within each group according to place, kinship and family relations (and support), infrastructure and other driving factors. Understanding all these dimensions is crucial to assessing what type of adaptation strategy is appropriate, at what scale and within what timeframe. As Tuler et al. (2008) note, ‘risk and vulnerability are intimately related concepts’, risk being the probability of hazards that could cause undesirable outcomes and vulnerability filtering the severity of those outcomes.

A vulnerability assessment helps stakeholders and managers understand and focus on factors that build adaptive capacity; those elements that will ensure the success of mitigation, adaptation, and resilience strategies. This risk perception can go some way to providing some of the insights needed to build effective adaptation strategies, and fisher cooperation in their implementations. As summed up by Clay and Olson (2008) ‘the problem of vulnerability and resilience goes far beyond fishery regulations and must encompass a more holistic approach to fishing communities and...demands that social concerns be integral to the management process in its early stages’ (Clay and Olson 2008).

## Appendix 6b: Risk perception interview schedule

---

### INTERVIEW QUESTIONS

Note: these questions are a guide only; as we will be using semi-structured interviewing processes, we will be building on them as interviews progress. We also (in the initial consultation phase and determination of consent) anticipate that we will obtain some insight into further questions based on respondent/industry/cultural priorities. We will then add these into the mix and send an amended copy to the ethics committee. In this way the project will become partly community-driven and owned, and therefore applicable and relevant.

### PREFACE

Thank you for agreeing to participate in this project. Are you sure you understand what this project is about? Great. First of all I just want to get some idea of your general background, if you don't mind, so we can get some broad idea amongst all the participants who we are dealing with...

#### 1. Introductory questions

What is your name?

Your age (optional – may be age range)

Place of birth

Date arrived in Tasmania (if not Tasmanian)

Basic life history

#### 2. Icebreakers

OK. Thanks for that. Now I am wondering if it would be OK to ask you a few more questions about your country, affiliation, things like that? That will help us get a picture of who comes from where, and there might even be differences in your experience related to where you are from. Is that OK?

Great. Well, I know fishing is important to lots of us, for different reasons! Do you remember when you first went out? What is your first memory of fishing? Fishing for east coast rock lobster? When did you get your first east coast rock lobster?

Do you fish now? For recreation or business?

How did you get into the business?

Thanks for that, that's great. Now I would like to move from thinking about how you first began in the business, to how you do business! So these are some questions related to fishing practice...

#### 3. Fishing practice

How do you undertake the harvest of east coast rock lobster? What tools/implements do you use?

Have the techniques changed over the years? Has technology changed much? What do you find has helped or hindered your practice/harvest?

What changes have you seen, if any, over the years? In the species? Their distribution? Quality, size etc...

What do you think are the causes of these changes?

Do you worry or were you worried about outbreaks of disease? Have you ever experienced anything like that? What did you do?

#### 4. Regulation questions

OK. Thanks for that. I would now like to ask you a bit about what we call the ‘institutional arrangements’; that is, the laws and policies that impact on your business. This will help us understand what is and is not possible in relation to addressing climate change. It will also help us understand the level of adaptive capacity to respond to change within the industry. Are you clear/OK with that?

For example, what policies / management regimes are in place now in relation to east coast rock lobster?

Do they work? Why or why not?

How do you think they can be changed / made better?

What laws have you worked to in the past? Have they changed much over time? How? Are there any informal rules about managing for east coast rock lobster that you can talk to us about?

#### 5. Climate change questions

I would now like to move onto talking to you about climate change in particular. There are no right or wrong answers here; I would just like to understand a bit better some of the challenges (if any) you think you face in relation to this issue. As there is such a lot said about it also it would be good to know how much you know or feel you know about climate change generally and if this affects how you do business in any way. Is that OK?

Great. First, do you know much about climate change? Thanks.

What is your perception about it – i.e. what is it, its causes, does it exist etc? Where do you get most of your information from?

Do you think climate change is an issue generally?

Why or why not?

Do you think climate change is an issue for east coast rock lobster?

Why or why not?

Have you noticed any changes over the years in weather and/or other ecological aspects?

Would you attribute them to climate change or other causes?

Is the industry making any formal response to climate change yet?

What is your perception of the risks you feel face the rock lobster industry?

#### 6. Aquaculture

I would now like to ask you specific questions about the aquaculture industry here. How important is aquaculture to the success of the east coast rock lobster industry here?

What challenges might climate change impacts bring to the aquaculture industry?

What can the industry do to adapt to the threats/issues identified?

#### 7. Adaptation/capacity

Thanks for that – we are almost finished! I just want to ask a few final questions about how you think you have the capacity to adapt if necessary to climate change. What are some of your opportunities, weaknesses, strengths etc? Is that OK? Thanks.

What strengths do you think the east coast rock lobster fishing community has that will help it to adapt to climate change and other identified impacts?

What weaknesses do you think the east coast rock lobster fishing community has that will hinder its capacity to adapt to climate change and other identified impacts?

## Vulnerability to climate change impacts and adaptation response options

What ideas, if any, do you have about how the industry copes with and could adapt to climate change?

What changes would you make to existing policies, laws/ regulations to enable/facilitate east coast rock lobster fishing whether (i) recreational cultural or (ii) commercial to adapt to climate change?

8. Finally, one last question. Very broadly and again there are no right or wrong answers, but from your perspective, how do you see the future of the east coast rock lobster industry in (i) Tasmania, (ii) the world?

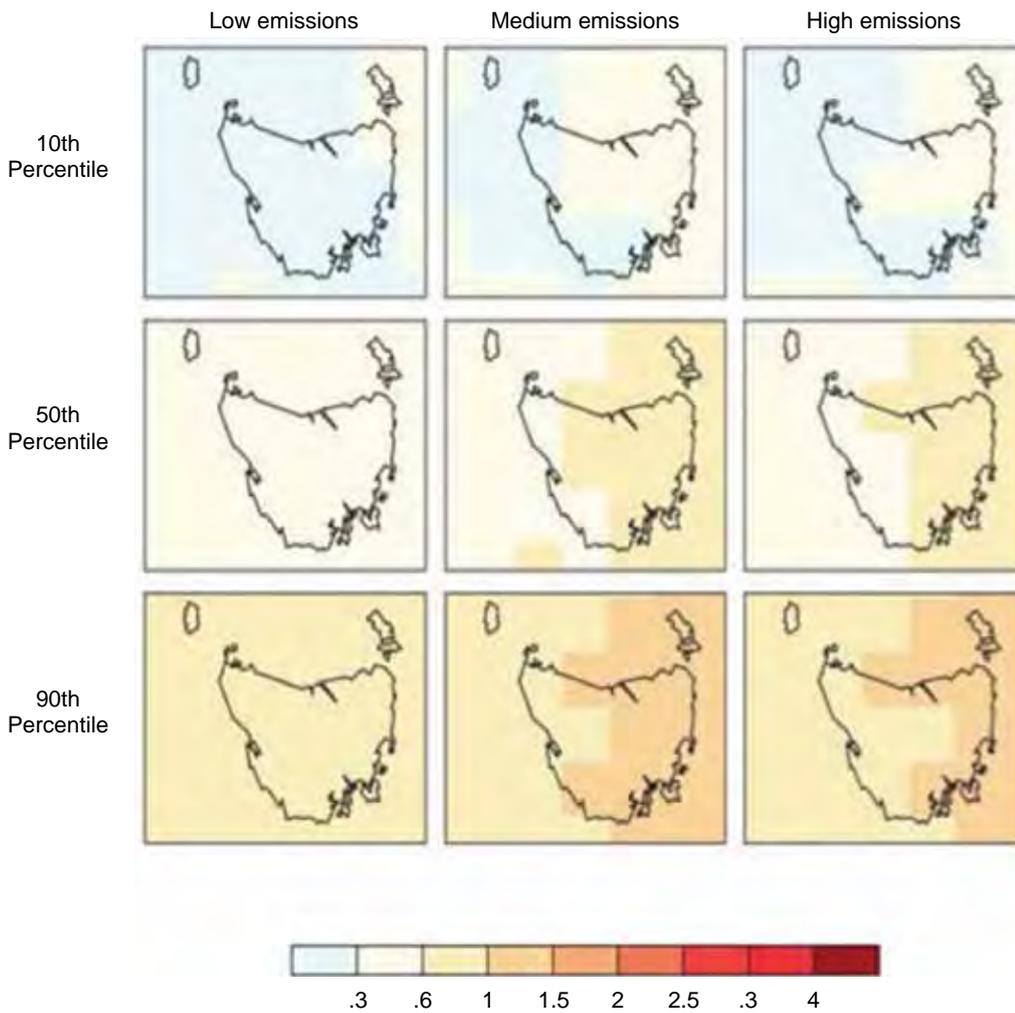
Is there anything else you want to add?

Thank you very much for your time! I will write up your answers and send them back to you – if you don't mind can you look them over and make sure I have heard and interpreted your answers correctly?

Thanks again...

## Appendix 7: Climate model selection

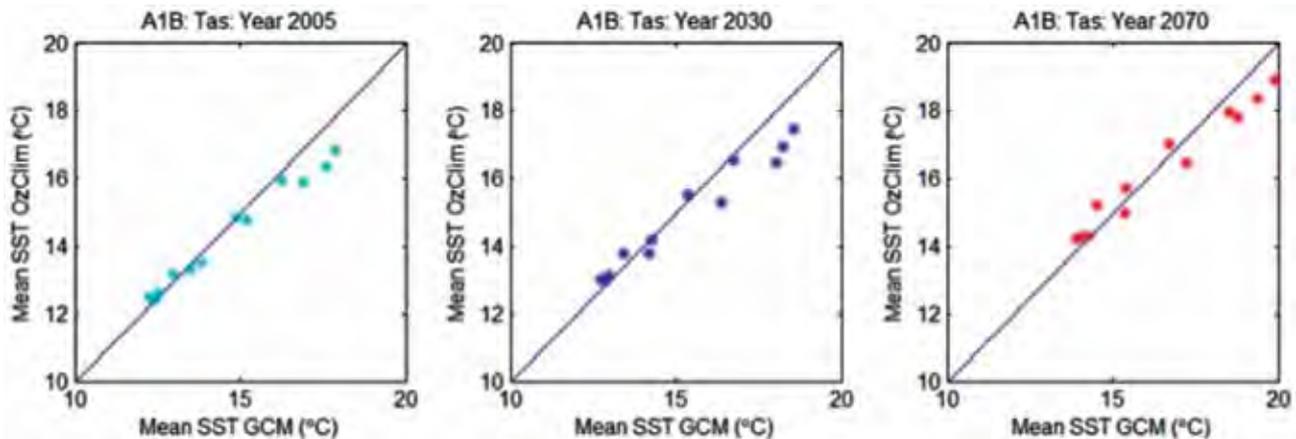
The scale of SST predictions from the single GCM (CSIRO Mk 3.5) was too coarse for the desired spatial scale, with a single pixel covering approximately 1.5 square degrees, such that the area illustrated in Figure 29 below would be covered by only 2–3 pixels. The regional predictions, while at a finer scale, were also relatively coarse and thus considered unsuitable for the required analyses (Figure 29).



**Figure 29:** Example of CSIRO regional climate change predictions, specifically the predicted rise in sea surface temperature (°C) for Tasmania for the year 2030. Note the coarse resolution in the region illustrated (approximately 4.5 pixels high by 6 wide).

Vulnerability to climate change impacts and adaptation response options

In this project, downscaled predictions from the CSIRO tool, OzClim for Oceans, have been applied. To confirm that this downscaling approach did represent the predictions from the GCM, the average temperature each month for the region of Tasmania was compared between the GCM and the downscaled data (Figure 30). This analysis showed that downscaling still preserved the overall mean temperature, and thus the downscaled temperature predictions were used for generating future SST patterns for the regions around Tasmania.



**Figure 30: Mean sea surface temperature for Tasmania (141–151°E, 39–45°S) for each calendar month in five-year periods centred on the years 2005, 2030 and 2070, using the A1B scenario. Mean SST from the CSIRO Mk3.5 model is plotted against the mean SST derived from nine downscaled GCMs accessed using the OzClim for Oceans tool. The diagonal line represents a 1:1 line. A similar relationship holds for the A1FI scenario.**

## Appendix 8: SST and model hind-cast recruitment estimates

Table 7: Correlation between annual temperature and model hind-cast recruitment (60–65mm CL) for each of the rock lobster assessment areas. The red text indicates lags that were considered biologically feasible (see section 4.3.3).

LAG (YEARS)	AREA 1	AREA 2	AREA 3	AREA 4	AREA 5	AREA 6	AREA 7	AREA 8
0	0.0657	-0.1525	-0.2934	-0.3948	-0.1855	0.0272	0.3651	0.1065
1	0.1524	0.0146	-0.3166	-0.4759	-0.2210	0.0785	0.4399	-0.3260
2	0.0346	0.0353	-0.1822	-0.3548	-0.1975	-0.0661	0.1276	-0.2378
3	-0.1863	-0.0558	0.0319	-0.1409	-0.0657	-0.3101	0.0254	0.0969
4	-0.3423	-0.1067	0.0576	0.1438	-0.0174	0.0275	-0.0849	0.0743
5	-0.2658	-0.1235	0.0243	0.1319	0.3678	0.1384	-0.1813	-0.2899
6	-0.1188	0.0429	-0.2158	0.0546	0.3480	0.0976	-0.2627	-0.3061

## Appendix 9: Overview of the model

The rock lobster resource off Tasmania is modelled using a regional, size and sex-structured population dynamics model in which natural mortality occurs throughout each of eight model time-steps per year; catches are assumed to occur instantaneously in the middle of each time-step, and growth occurs at the end of January, March, April, and October. Settlement of new individuals occurs to the first size class in the model. Growth is represented by size-transition matrices which determine the probability of growing from one size-class to another. The population in each region is assumed to be independent of all the others (i.e. there is no movement of animals among regions).

The equation that specifies the number of animals of sex  $s$  in size-class  $l$  in region  $z$  at the start of time-step  $i$  of year  $t$  takes account of natural mortality, fishing mortality, movement, growth, and settlement is:

$$N_{y,i+1,l}^{s,z} = \sum_{l'} X_{y,l',l,i}^{z,s} N_{y,i,l'}^{s,z} e^{-M_{t,i}} \{1 - \tilde{H}_{y,i,l'}^{s,z}\} + R_y^z \quad (\text{A.1})$$

where  $N_{y,i,l}^{s,z}$  is the number of animals of sex  $s$  in size-class  $l$  in region  $z$  at the start of time-step  $i$  of year  $y$ ,  $X_{y,l',l,i}^{z,s}$  is the fraction of the animals of sex  $s$  in size-class  $l'$  in region  $z$  that grow into size-class  $l$  at the end of time-step  $i$  of year  $z$ ,  $M$  is the instantaneous rate of natural mortality (assumed to be independent of sex, size, region, and time),  $\tilde{H}_{y,i,l}^{s,z}$  is the exploitation rate on animals of sex  $s$  in size-class  $l$  in region  $z$  at the start of time-step  $i$  of year  $y$ , and  $R_y^z$  is the settlement of animals to region  $z$  during year  $y$ .

Future settlement is modelled as an exponential function of temperature, i.e.:

$$R_y^z = \tilde{R}^z e^{\lambda(T_y^z - 15^\circ\text{C})} e^{\varepsilon_y^z - (\sigma^z)^2/2} \quad \varepsilon_y^z \sim N(0; (\sigma^z)^2) \quad (\text{A.2})$$

where  $\tilde{R}^z$  is the settlement to region  $z$  at a temperature of  $15^\circ\text{C}$ ,  $\lambda$  is the rate at which settlement changes with temperature,  $T_y^z$  is the temperature in region  $z$  during year  $y$ , and  $\sigma^z$  is the extent of variation in settlement for region  $z$ . The values for the parameters ( $\tilde{R}, \lambda, \sigma^z$ ) are sampled from the multivariate normal distribution for these parameters obtained by fitting equation A.2 to the estimates of settlement for 1970–2006 and the associated region-specific temperatures.

Future growth can depend on temperature:

$$\mathbf{X}_y^z = \alpha_y^z \mathbf{X}_{2000}^z + (1 - \alpha_y^z) \mathbf{X}_{2000}^5 \quad (\text{A.3})$$

where  $\alpha_y^z = \max(0, \min(1, 1 - \frac{T_y^z - T_{2000}^z}{T_{2000}^z - T_{2000}^5}))$

The harvest rate by region, time-step and year is calculated from the catch by region, time-step and year, which is, in turn, computed from the TAC by time-step and year using an effort allocation model in which the proportion of the catch from each region ( $P_{y,i}^z$ ) depends on exploitable biomass, and the split of the catch to region in the previous time-step in the current year, and that in the current time-step in the previous year:

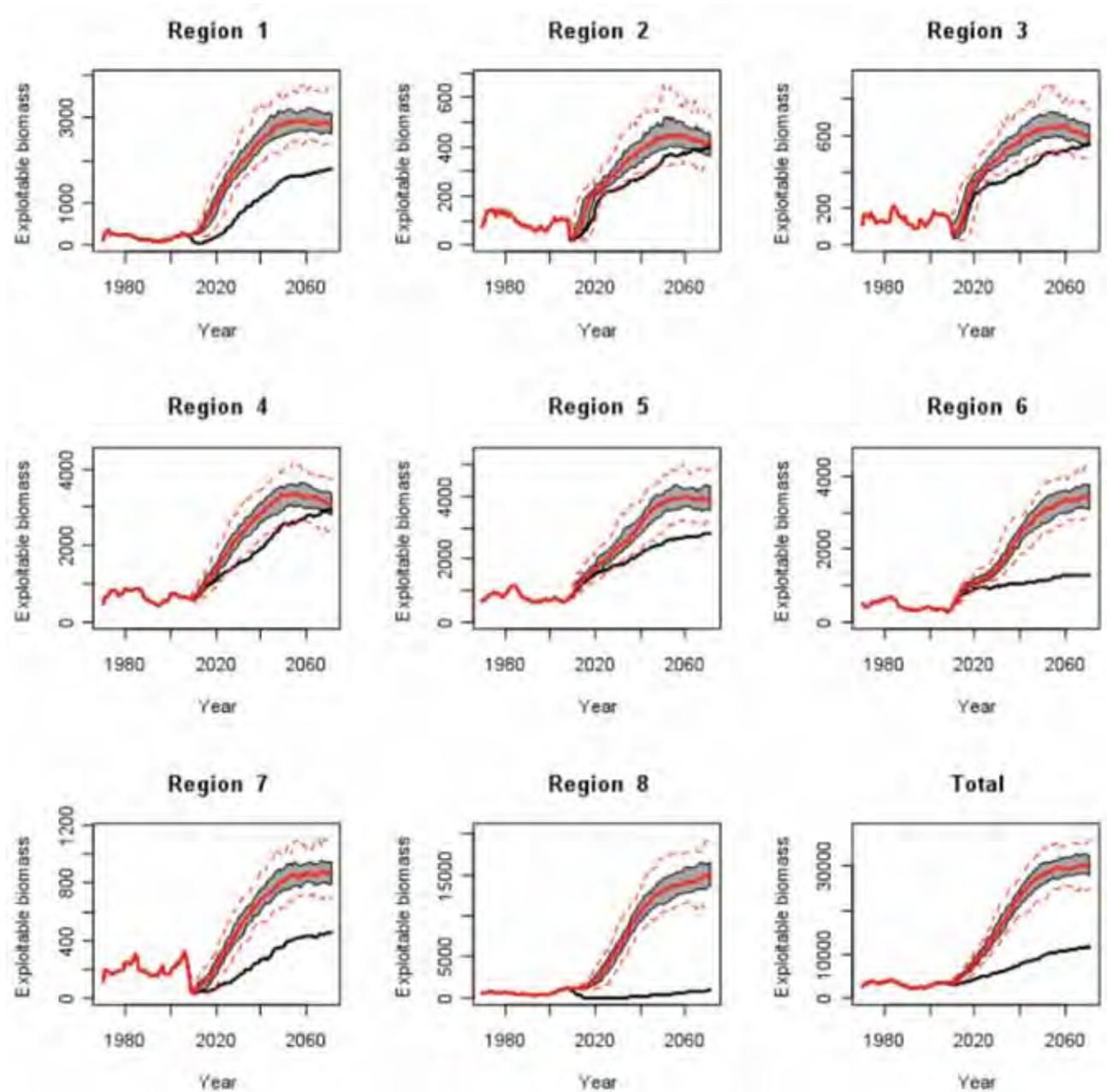
$$P_{y,i}^z = Y_{y,i}^z / \sum_{z'} Y_{y,i}^{z'} \quad (\text{A.4})$$

where  $Y_{y,i}^z$  is given by:

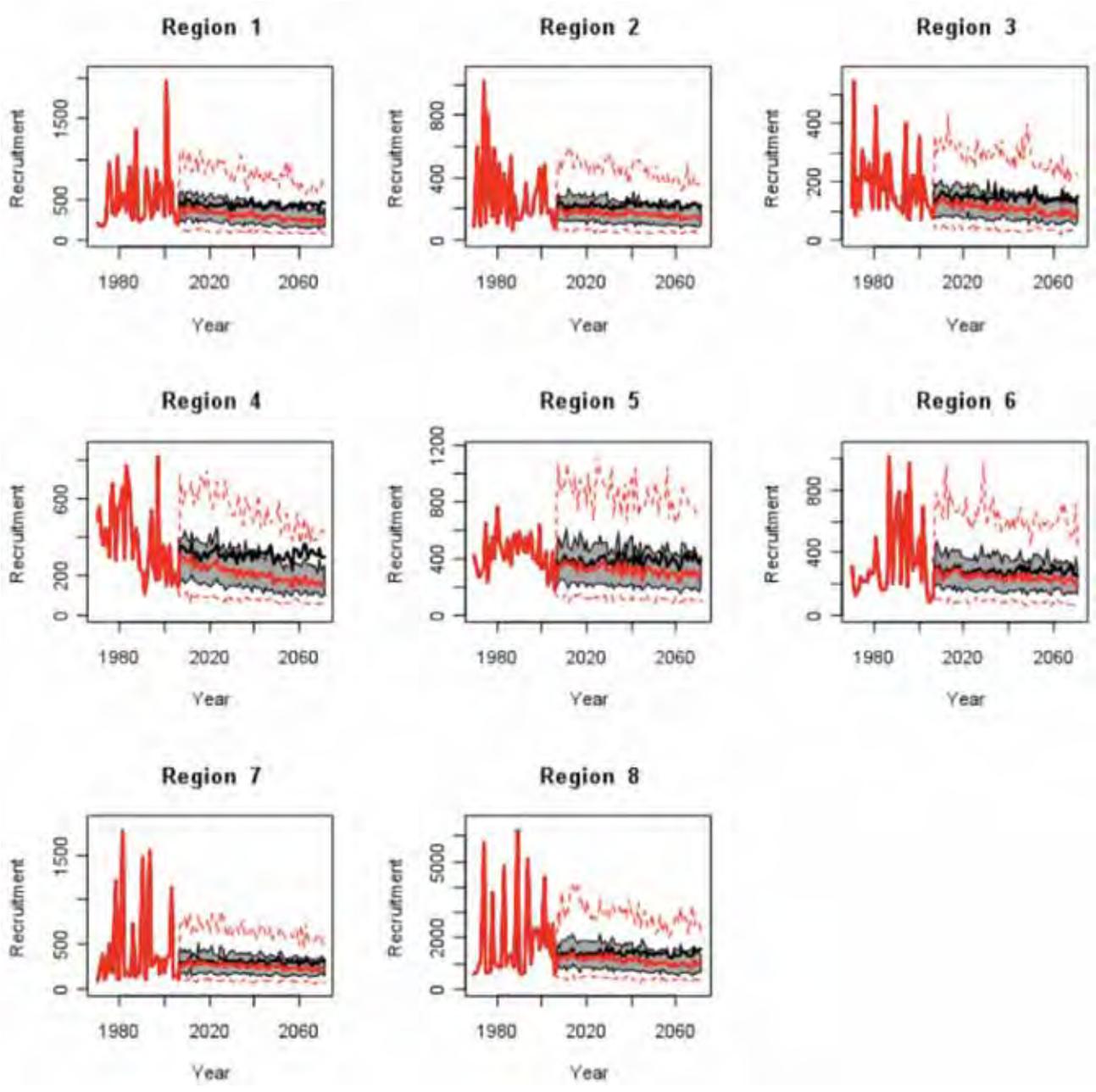
$$\ln Y_{y,i}^z = a_i^z + b_i^z B_{y,i}^z + c_i^z P_{y,i-1}^z + d_i^z P_{y-1,i}^z \quad (\text{A.5})$$

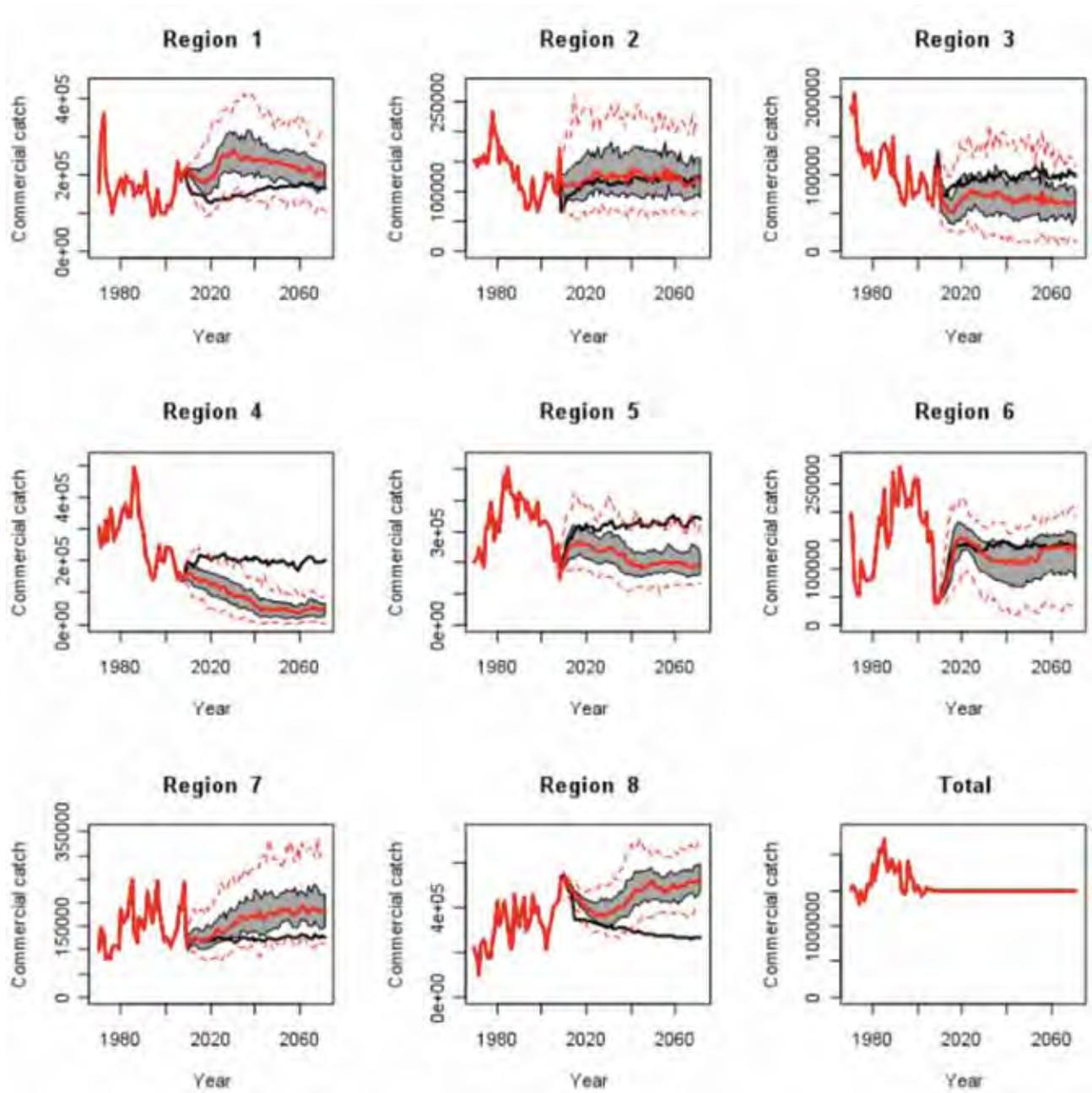
$B_{y,i}^z$  is the exploitable biomass in region  $z$  at the start of time-step  $i$  of year  $y$ , and  $a, b, c, d$  are coefficients. The values for parameters of equation A.4 are estimated by fitting the model to the proportion of the catch by region from 1997–2007 (data for 1994–96 are ignored because there was a month in 1995 in which the catch from all areas was zero).

## Appendix 10: Model outputs – Case C

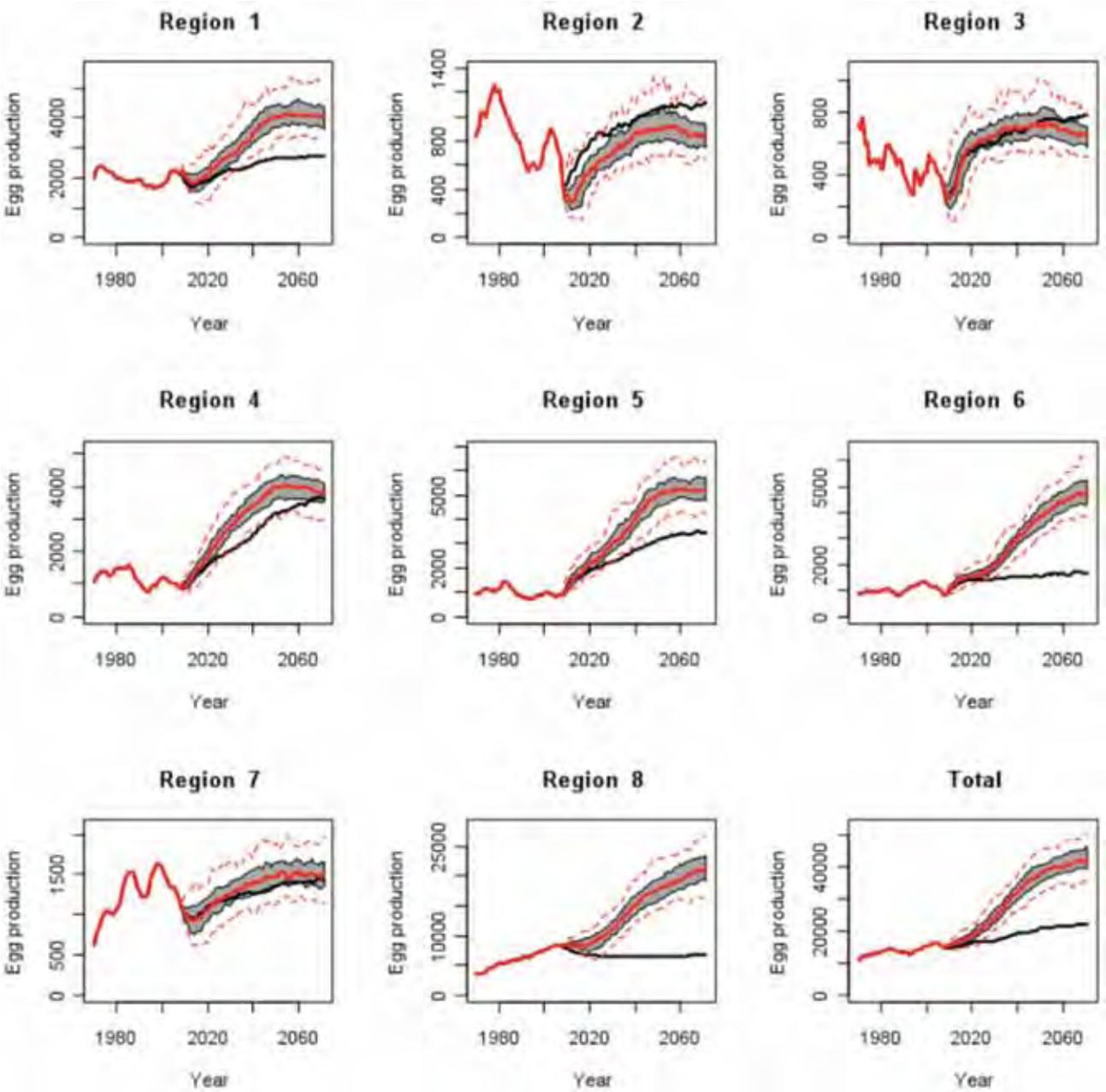


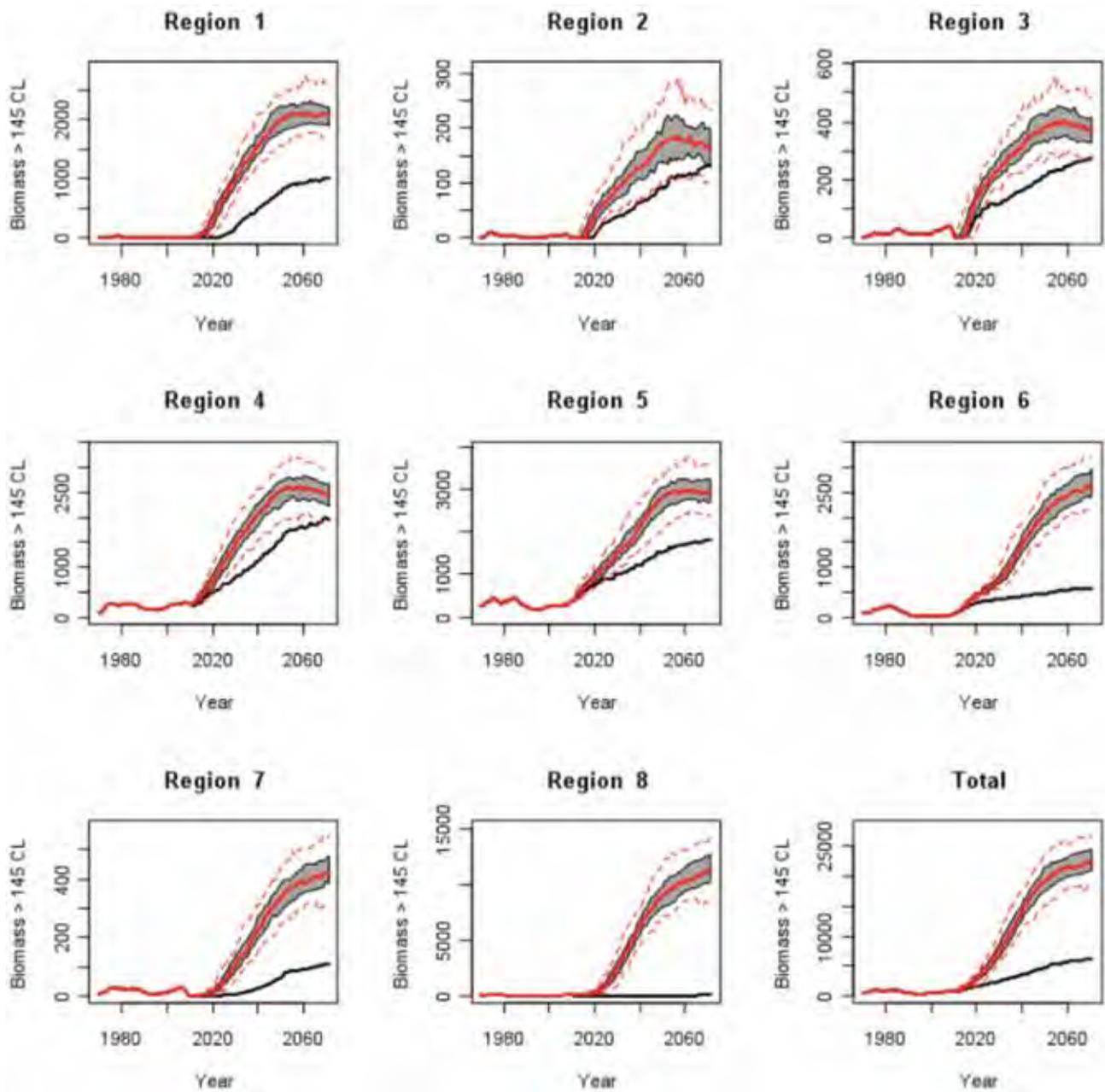
Vulnerability to climate change impacts and adaptation response options





Vulnerability to climate change impacts and adaptation response options





## References

---

- ABARE (2004) Australian Bureau of Agricultural and Resource Economics, 2004, Fisheries Statistics.
- Adger WN, Arnella NW, Tompkins EL (2005) Successful adaptation to climate change across scales, *Global Environmental Change* **15**, 77–86.
- AGO (2004) *Economic issues relevant to costing climate change impacts*, Australian Greenhouse Office.
- Allen Report (2005) Climate change: risk and vulnerability: promoting an efficient adaptation response in Australia. Final Report to the Australian Greenhouse Office, Department of the Environment and Heritage; Allen Consulting Group (March 2005) <http://www.greenhouse.gov.au/impacts/publications/risk-vulnerability.html>
- Andrew NL, O’Neill AL (2000) Large-scale patterns in habitat structure on subtidal rocky reefs in New South Wales. *Marine and Freshwater Research*, **51** (3), 255–263.
- Bermudes M (2002) *Environmental physiology of cultured early-stage southern rock lobster (Jasus edwardsii Hutton, 1875) larvae*. PhD Thesis, University of Tasmania, Australia.
- Bermudes M, Ritar, AJ (2008) Response of early stage spiny lobster *Jasus edwardsii* phyllosoma larvae to changes in temperature and photoperiod. *Aquaculture*, **282**, 63–69.
- Bradshaw M (2004) A combination of state and market through ITQs in the Tasmanian commercial rock lobster fishery: the tail wagging the dog? *Fisheries Research*, **67** (2), 99–109.
- Bradshaw M, Wood L (2003) Zoning and the Tasmanian commercial rock lobster fishery. *Local Environments*, **8** (5), 513–525.
- Bradshaw M, Wood L, Williamson S (2001) Applying qualitative and quantitative research: a social impact assessment of a fishery. *Applied Geography*, **21**, 69–85.
- Brander K (2008) Tackling the old familiar problems of pollution, habitat alteration and overfishing will help with adapting to climate change. *Marine Pollution Bulletin*, **56** (12), 1957–1958
- Brooke C (2008) Conservation and adaptation to climate change. *Conservation Biology*. **22** (6), 1471–1476.
- Bruce B, Bradford R, Griffin D, Gardner C, Young J (2000) *A synthesis of existing data on larval rock lobster distribution in southern Australia*. Fisheries Research and Development Corporation. Hobart, CSIRO Marine Research.
- Bruce B, Griffin D, Bradford R (2007) *Larval transport and recruitment processes of southern rock lobster*. Fisheries Research and Development Corporation. Hobart, CSIRO Marine Research.
- Butler A, Althaus F, Furlani D, Ridgeway K (2002) *Assessment of the conservation values of the Bonney upwelling area: a component of the Commonwealth Marine Conservation Assessment: a report to Environment Australia*. CSIRO Marine Research 73 pp.
- Butler MJ, Behringer DC, Shields JD (In review) Transmission of *Panulirus argus* virus 1 (PaV1) and its effect on the survival of juvenile Caribbean spiny lobster. *Dis. Aquat. Organ.*
- Caldeira K, Wickett, ME (2003) Anthropogenic carbon and ocean pH. *Nature*, **425**, 365.
- Church JA, Gregory JM, Huybrechts P, Kuhn M, Lambeck K, Nhuan MT, Qin D, Woodworth PL (2001) Changes in sea level. In *Climate 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. JT Houghton et al. (eds) Cambridge, UK and New York, USA: Cambridge University Press, 639–694.
- Church JA, White NL, Hunter JR, Lambeck K (2008). Briefing: a post-IPCC AR4 update on sea-level rise. The Antarctic Climate and Ecosystems Cooperative Research Centre. <http://www.acecrc.org.au/drawpage.cgi?pid=publications&aid=797037>

- Clay P, Olson J (2008) Defining fishing communities: vulnerability and the Magnuson-Stevens Fishery Conservation and Management Act. *Human Ecology Review*, **15** (2), 143–160.
- Connolly SR, Menge BA, Roughgarden J (2001) A latitudinal gradient in recruitment of intertidal invertebrates in the northeast Pacific Ocean. *Ecology*, **82**, 1799–1813.
- Dake K (1992) Myths of nature: culture and the social construction of risk. *J Soc Iss*, **48**, 21–27.
- Dake K, Wildavsky A (1990) Theories of risk perception: who fears what and why?, *Daedalus*, **119**, 41–59.
- Department of Agriculture, Fisheries and Forestry, 2001, National Recreational Fishing Survey; available on <http://www.daff.gov.au/brs/fisheries-marine/data/rec-indig/survey-stats/rec-tas>.
- Department of Primary Industry and Water (2008) Taking the mystery out of CFAC. *Fishing Today*, October–November 2006.
- Domingues CM, Church JA, White NJ, Gleckler PJ, Wijffels SE, Barker PM, Dunn JR (2008) Improved estimates of upper-ocean warming and multi-decadal sea-level rise. *Nature*, **453**, 1090–1093.
- Edgar GJ (1997) *Australian marine life*. Reed Books Australia.
- FAO (2008) Climate change for fisheries and aquaculture: Technical document from the Expert Consultation 7–9 April 2008. Rome, FAO.
- Frusher SD (1997) Stock assessment report: Rock lobster, July 1997. DPIF Internal Report No. 35, 79pp.
- Frusher SD (2001) *Evaluation of techniques for estimating fishery assessment parameters in the Tasmanian rock lobster fishery*. PhD Thesis. University of Tasmania.
- Frusher SD, Hoenig JM (2001) Impact of size related dominance hierarchies on selectivity of traps for southern rock lobster (*Jasus edwardsii*). *Canadian Journal of Fisheries and Aquatic Science*, **58**, 2482–2489.
- Frusher SD, Hoenig JM, Gardner C (2003) Have inappropriate selectivity curves masked recruitment declines in a lobster fishery in Tasmania? *Fisheries Research*, **65**, 467–474.
- Frusher SD, Prescott J, Edmunds M (1999) Southern rock lobsters. In: *Under southern seas – the ecology of Australia’s rock reefs*. N. Andrews (ed). UNSW Press. Sydney Australia, 104–113.
- Füssel H-M, Klein RJT (2002) Assessing vulnerability and adaptation to climate change: an evolution of conceptual thinking. Paper presented at the UNDP Expert Group Meeting on ‘Integrating Disaster Reduction and Adaptation to Climate Change’ Havana, Cuba, 17–19 June 2002.
- Füssel H-M (2007) Adaptation planning for climate change: concepts, assessment approaches and key lessons. *Sustainability Science*, **2**, 265–275.
- Füssel H-M (2008) Assessing adaptation to the health risks of climate change: what guidance can existing frameworks provide? *International Journal of Environmental Health Research*, **18** (1), 37–63.
- Gardiner S (2001) The Real Tragedy of the Commons. *Philosophy & Public Affairs* **30**, pp. 387–416.
- 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. *Sci Mar*, **70**, 423–430.
- Gardner C, Frusher S, Eaton I, Haddon M, Mackinnon C (2002) *Tasmanian rock lobster fishery 2000/2001*. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania.
- Gardner C, Frusher SD, Kennedy RB, 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.
- Garnaut R (2008) *The Garnaut climate change review*. Cambridge University Press.
- Grafton RQ, Kompas TR, Hilborn W (2007) Economics of Overexploitation Revisited *Science*, **318** (5856), 1601.

- Gregory JM, Church JA, Boer GJ, Dixon KW, Flato GM, Jaxtett DR, Lowe JA, O'Farrell SP, Roeckner E, Russell, GL, Stouffer RJ, Winton M (2001) Comparison of results from several AOGCMs for global and regional sea-level change 1900–2100. *Climate Dynamics*, **18**, 223–240.
- Grimm V, Railsback SF (2005). *Individual-based modeling and ecology*. Princeton, New Jersey: Princeton University Press.
- Guba E (1981) Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communications of Technology Journal*, **29**, 75–92.
- Guest, MA, Frusher SD, Nichols PA, Johnson CR, Wheatley KE (In review) The trophic effects of fishing southern rock lobster (*Jasus edwardsii*): what can combined fatty acid and stable isotope analyses tell us? *Marine Ecology Progress Series*.
- Haddon M, Gardner C (2008) *Tasmanian rock lobster fishery 2006/07*. Tasmanian Aquaculture and Fisheries Institute Fisheries Assessment Report.
- Haggan N, Neis B, Baird, I (2007) Fishers' knowledge in fisheries science and management, UNESCO.
- Hall-Spencer JM, Rodolfo-Metalpa R, Martin S, Ransome E, Fine M, Turner SM, Rowley SJ, Tedesco D, Buia MC (2008) Volcanic carbon dioxide vents show ecosystem effects of ocean acidification, *Nature*, **454**, 96–99.
- Hampe A, Petit RJ (2005) Conserving biodiversity under climate change: the rear edge matters. *Ecology Letters*, **8**, 461–467.
- Harley, CDG, Hughes AR, Hultgren K, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF, Tomanek L, Williams SL (2006) The impacts of climate change in coastal marine systems. *Ecology Letters*, **9**, 228–241.
- Harris GP, Davies P, Nunez M, Meyers G (1988) Interannual variability in climate and fisheries in Tasmania. *Nature*, **333**, 754–757.
- Harris GP, Griffiths FB, Clementson LA, Lyne V, Van der Doe H (1991) Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters. *Journal of Plankton Research*, **13**, 109–131.
- Harrison AJ (2004) *A report on the abalone and rock lobster post harvesting industry in Tasmania*. Tasmanian Abalone Council, Hobart, Australia, 121 pp.
- Haward M (2003) The ocean and marine realm. In: *Managing Australia's environment*, S Dovers, S and W Wild River (eds), Sydney, Federation Press, 35–52.
- Haward M, Vince J (2008) *Ocean governance in the twenty-first century: Managing the blue planet*. Edward Elgar, Cheltenham UK.
- Hilborn R (2007) Defining success in fisheries and conflicts in objectives. *Marine Policy*, **31**(2), 153–158.
- Hill KL, Rintoul SR, Coleman R, Ridgway KR (2008) Wind forced low frequency variability of the East Australia Current. *Geophysical Research Letters*, **35** L08602, doi:10.1029/2007GL032912
- Hobday AJ, Okey TA, Poloczanska ES, Kunz TJ, Richardson AJ (2007) *Impacts of climate change on Australian marine life*. CSIRO Marine and Atmospheric Research. Report to the Australian Greenhouse Office, Canberra, Australia. September 2006. <http://www.greenhouse.gov.au/impacts/publications/marinelifelife.html>
- Hobday AJ, Poloczanska ES (2007) 12. *Marine Fisheries and Aquaculture*. In C. Stokes, (ed). An overview of climate change adaptation in the Australian agricultural sector - impacts, options and priorities. December 2007. <http://www.csiro.au/resources/AgricultureAdaptationReport2008.html>.

- Hobday AJ, Poloczanska ES, Matear R (2008) *Implications of climate change for Australian fisheries and aquaculture: A preliminary assessment*. Report to the Department of Climate Change, Canberra, Australia. August 2008.
- Hobday D, Punt AE (2001) Length-structured population modelling and risk assessment of the Victorian southern rock lobster, *Jasus edwardsii*, fishery. *Marine and Freshwater Research*, 53 1495–1507.
- Holland DS (2007) Are fishermen rational? A fishing expedition, *Marine Resource Economics*, 23, 325–344.
- Holland DS, Bentley N, Lallemand P (2005) A bioeconomic analysis of management strategies for rebuilding and maintenance of the NSS rock lobster (*Jasus edwardsii*) stock in southern New Zealand. *Canadian Journal of Fisheries and Aquatic Science*, 62, 1553–1569.
- Horner F (1995) *Looking for La Perouse: D'Entrecasteaux in Australia and the South Pacific 1792–93*. Miegunyah Press/ Melbourne University Press.
- Hulme PE (2005) Adapting to climate change: is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology*, 42, 784–794.
- Hurn AS, McDonald AD (1997) A simple measure of price risk for Tasmanian southern rock lobster (*Jasus edwardsii*). *Marine and Freshwater Research*, 48, 1023–1027.
- IPCC (2007) Summary for policymakers. In: *Climate change 2007: The physical science basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S Solomon, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor and HL Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Johnston RJ, Ranson MH, Besedin EY, Helm EC, (2006) What determines willingness to pay per fish? A meta-analysis of recreational fishing values, *Marine Resource Economics*, 21, 1–32.
- Kirk JA, Wise WR, Delfino JJ (2004) Water budget and cost-effectiveness analysis of wetland restoration alternatives: a case study of Levy Prairie, Alachua County, Florida. *Ecological Engineering*, 22(1), 43–60.
- Kompas T, Che TN, Grafton RQ (2008) Instrument choice under uncertainty, *Land Economics*, 84, 652–666.
- Konidari P, Mavarakis D (2007) A multi-criteria evaluation method for climate change mitigation policy instruments. *Energy Policy*, 35(12), 6235–6257.
- Lamming R, Caldwell N, Harrison D (2001) Transparency in supply relationships: Concept and practice. *Journal of Supply Chain Management*, 37, 4.
- Legislative Council Select Committee (1997) *Tasmanian rock lobster fishery report*. Parliament of Tasmania.
- Leiserowitz A (2006) Climate change risk perception and policy preferences: the role of affect, imagery and values, *Climatic Change*, 77, 45–72.
- Leung P (2006) Multiple-criteria decision-making (MCDM) applications in fishery management, *International Journal of Environmental Technology and Management*, 6 (1-2), 96–110.
- Liggins GW, Miller ME, McLeod J (2008) *Resource assessment—lobster*. NSW Department of Primary Industry, 96 pp.
- Ling SD (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 SD, Johnson CR (2009) Population dynamics of an ecologically important range-extender: kelp bed versus barrens sea urchins. *Marine Ecology Progress Series* 374, 113–125.
- Ling SD, Johnson CR, Ridgway K, Hobday AJ, Haddon M (2009) Climate driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. *Global Change Biology* 15(3), 719–731.
- Ling SD, Johnson CR, Frusher SD, King CK (2008) Reproductive potential of a marine ecosystem engineer at the edge of a newly expanded range. *Global Change Biology*, 14, 907–915.

- Loewenstein G, Weber E, Hsee C, Welch E (2001) Risk as feelings, *Psychol Bull*, **127**, 267–286.
- Lorenzoni I, Jordan A, Hulme M, Turner K, O’Riordan T (2000) A co-evolutionary approach to climate change impact assessment. *Global Environmental Change* **10**, 57 – 68.
- Lyle JM (2008) *Tasmanian recreational rock lobster and abalone fisheries – 2006/07 fishing season*. Tasmanian Aquaculture and Fisheries Institute internal report.
- Lyle JM, Morton AJ (2004) *Survey of the 2002/03 Tasmanian recreational rock lobster and abalone fisheries*. Tasmanian Aquaculture and Fisheries Institute Fishery Assessment Report. Hobart, Australia. 33 pp.
- Lyle J, Morton A, Forward J (2005) Characterisation of the recreational fishery for southern rock lobster *Jasus edwardsii* in Tasmania, Australia: implications for management. *New Zealand Journal of Marine and Freshwater Research*, **38**, 703–714.
- McDonald AD, Little LR, Gray R, Fulton E, Sainsbury KJ, Lyne V D (2008) An agent-based modelling approach to evaluation of multiple-use management strategies for coastal marine ecosystems. *Mathematics and Computers in Simulation*, **78**, 401–411.
- McGoodwin JR, Neis B, Felt L (2000) Integrating fishery people and their knowledge into fisheries science and resource management. Issues, prospects, and problems. In: B. Neis, L. Felt (eds.) *Finding our sea legs. Linking fishery people and their knowledge with science and management*. ISER books, Memorial University, St. John’s, Newfoundland. pp. 249-264.
- Miles, EL (1999) The concept of ocean governance: evolution toward the 21st century and the principle of sustainable ocean use. *Coastal Management*, **27**, 1–30.
- Montgomery, S (1999) Chapter 13. Eastern Rock Lobsters. In: N. Andrews (ed.) *Under southern seas: the ecology of Australia’s rocky reefs*. University of New South Wales Press Ltd., 114 – 117.
- Moser S, Dilling L (2007) *Creating a climate for change: communicating climate change*. Cambridge Press.
- Nelson DR, Adger WN, Brown K (2007) Adaptation to environmental change: contributions of a resilience framework. *Annual review of Environment and Resources*, **32**, 395 -419
- O’Connor R, Bord R, Fisher A (1999) Risk perceptions, general environmental beliefs and willingness to address climate change. *Risk Analysis*, **19**, (3), 461–471.
- OECD (2008) *Economic aspects of adaptation to climate change: costs, benefits and policy instruments*. Organisation for Economic Co-operation and Development 2008 (edited by Agrawala S, Fankhauser S).
- OECD (2009) *Climate Change 101: Understanding and responding to Global Climate Change*, Pew Center on Global Climate Change.
- Pecl GT, Jackson GD (2008) The potential impacts of climate change on inshore squid: biology, ecology and fisheries. *Reviews in Fish Biology and Fisheries*, **18**, 373–385.
- Pendleton LH, Mendelsohn R (1998) Estimating the economic impact of climate change on the freshwater sportsfisheries of the northeastern US. *Land Economics*, **74**, 483–496.
- Phillips G, Kriwoken L, Hay P (2002) Private property and public interest in fisheries management: the Tasmanian rock lobster fishery. *Marine Policy*, **26**, 459–469.
- Pierre J, Peters BG (2005) *Governing complex societies: Trajectories and scenarios*. Basingstoke, Palgrave Macmillan.
- Pinjuv G, Daugherty PJ, Fox BE (2001) Cost/effectiveness analysis of ponderosa pine ecosystem restoration in Flagstaff Arizona’s wildland-urban interface. In: RK Vance, CB Edminster, WW Covington, JA Blake (eds) *Ponderosa pine ecosystems restoration and conservation: steps toward stewardship*. 2000 April 25-27, Flagstaff, AZ. Proceedings RMRS-P-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

- Poloczanska ES, Babcock RC, Butler A, Hobday AJ, Hoegh-Guldberg O, Kunz TJ, Matear R, Milton D, Okey TA, Richardson AJ (2007) Climate change and Australian marine life. *Oceanography and Marine Biology Annual Review*, **45**, 409–480.
- Pontecorvo G (2003) Insularity of scientific disciplines and uncertainty about supply: the two keys to the failure of fisheries management. *Marine Policy*, **27**, 69–73.
- Portner HO, Langenbuch M, Michaelidis B (2005) Synergistic effects of temperature extremes, hypoxia, and increases in CO<sub>2</sub> on marine animals: From Earth history to global change – art. no. C09S10. *Journal of Geophysical Research-Oceans*, **110**, S910.
- Punt AE, Kennedy RB (1997) Population modeling of the Tasmanian rock lobster, *Jasus edwardsii*, resources. *Marine and Freshwater Research*, **48**, 967–980.
- Punt AE, Kennedy RB, Frusher SD (1997) Estimating the size transition matrix for Tasmanian rock lobster. *Marine and Freshwater Research*, **48**, 981–992.
- Rahmstorf S, Cazenave A, Church JA, Hansen JE, Keeling RF, Parker DE, Somerville RCJ (2007) Recent climate observations compared to projections. *Science*, **316** 709, doi:10.1126/science.1136843.
- Raupach MR, Marland G, Ciais P, Le Quere C, Canadell JG, Klepper G, Field CB (2007) Global and regional drivers of accelerating CO<sub>2</sub> emissions. *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.0700609104.
- Richards T (2005) *The role of information systems and technology – An integrative approach to managing the Tasmanian rock lobster industry*. PhD Thesis. University of Tasmania.
- Ridgway KR (2007) Long-term trend and decadal variability of the southward penetration of the East Australian Current. *Geophysical Research Letters*, **34**, L13613, doi:10.1029/2007GL030393.
- Roessig JM, Woodley CM, Cech JJ, Hansen LJ (2004) Effects of global climate change on marine and estuarine fishes and fisheries. *Reviews in Fish Biology and Fisheries*, **14**, 251–275.
- Rudd MA (2001) The non-extractive economic value of spiny lobster, *Panulirus argus*, in the Turks and Caicos Islands. *Environmental Conservation*, **28**, 226–234.
- Santha S (2008) Local ecological knowledge and fisheries management: a study among riverine fishing communities in Kerala, India. *Local Environments*, **13** (5) 423–435.
- Seals M, Allport C, Johnston RM, Riddoch A, Swan J, Webster AG, Belstead CT, Swan ED (1883) Royal Commission on the Fisheries of Tasmania, Report of the Commissioner. *Tas. Parl. J. and Pap.*, House ASS. J., XLIII. Government Printer, Hobart.
- Shields JD, Behringer, DC (2004) A new pathogenic virus in the Caribbean spiny lobster *Panulirus argus* from the Florida Keys. *Dis. Aquat. Organ.*, **59**, 109–118.
- Slovic P, Peters E (1998) The importance of worldviews in risk perception, *Risk Decision and Policy*, **3**, 165–170.
- Smit B, Burton I, Klein RJT, Street R (1999) The science of adaptation: a framework for assessment. *Mitigation and Adaptation Strategies for Global Change*, **4**, 199–213.
- Sterman JD (2008) Risk communication on climate: mental models and mass balance. *Science*, **322**, 532–33.
- Stuart-Smith RD, Barrett NS, Crawford CM, Frusher SD, Stevenson DG, Edgar GJ (2008) Spatial patterns in impacts of fishing on temperate rocky reefs: are fish abundance and mean size related to proximity to fisher access points? *Journal of Experimental Marine Biology and Ecology*, **365**, 116–125.
- Sumalia UR (2004) Intergenerational cost-benefit analysis and marine ecosystems restoration. *Fish and Fisheries*, **5**, 329–343.
- Sumaila UR, Suatoni E (2005) *Fish economics: the benefits of rebuilding U.S. ocean fish populations*, Report for the Fisheries Economics Research Unit, Fisheries Centre, University of British Columbia.

- Sutton SG (2006) Understanding recreational fishers' participation in public consultation programs. *Human Dimensions of Wildlife* **11**, 329–341.
- Thomas CW, Crear BJ, Hart PR (2000) The effect of temperature on survival, growth, feeding and metabolic activity of the southern rock lobster, *Jasus edwardsii*. *Aquaculture*, **185**, 73–84.
- Thuiller W (2004) Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology*, **10**, 2020–2027.
- Tuler S, Agyeman J, Pinto-Desilva P, LoRusso K, Kay R (2008) Assessing vulnerabilities: integrating information about driving forces that affect risks and resilience in fishing communities. *Human Ecology Review*, **15** (2), 171–184.
- White T, Wall, R (2008) National, regional and local attitudes towards climate change: Identifying appropriate target audiences for communications. *Local Environments*, **13** (7), 589–607.
- Willmer P, Stone G, Johnston I, (2000) *Environmental Physiology of Animals*. Blackwell Science Publication Ltd, Oxford.
- Ziegler PE, Haddon M, Frusher SD, Johnson CR (2004) Modelling seasonal catchability of the southern rock lobster *Jasus edwardsii* by water temperature, moulting, and mating. *Marine Biology*, **145**, 179–190.
- Ziegler PE, Frusher SD, Johnson CR (2003) Space-time variation in catchability of southern rock lobster *Jasus edwardsii* in Tasmania explained by environmental, physiological and density-dependent processes. *Fisheries Research*, **61**, 107–123.

