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Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia

Part 1: Fisheries and Aquaculture Risk Assessment

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

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Disclaimer

Statement of contributions

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Institute of Marine and Antarctic Studies (IMAS)
Dr Gretta Pecl co-led the project together with Associate Professor Tim Ward (SARDI). She contributed to the development of the risk assessment methods and analytical framework, and led the synthesis and writing of the main report. Dr Zoë Doubleday coordinated the production of all the individual species assessment profiles, contributed to the development of the risk assessment methods and analytical framework, and led the writing of the aquaculture component of the risk assessment. Associate Professor Stewart Frusher contributed to the development of the risk assessment methods and analytical framework, and wrote some discrete sections of the report.

South Australian Research and Development Institute (SARDI) – Aquatic Sciences and Department of Primary Industries and Resources of South Australia (PIRSA)
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CSIRO Marine and Atmospheric Research (CMAR)
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Department of Primary Industry (DPI) Victoria
Dr Daniel Spooner manages the climate change fisheries initiative work being undertaken at the DPI Fisheries Research Branch, Queenscliff and contributed to all aspects of the SEAP risk assessment project. Dr Neil Hutchinson was the lead scientific author on several individual species assessment profiles and contributed to the development of the risk assessment process.

Industry and Investment New South Wales
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E-Systems Pty Limited
Richard Stoklosa assisted with the development of the risk assessment methodology and chaired the risk assessment workshops. He also contributed to written elements of the report.

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

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Non technical summary

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

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

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

The major goal of this project was to undertake a screening-level risk assessment of the potential impacts of climate change on key fishery species in the south east Australian region. Thorough literature reviews and species assessment profiles were completed for key species to underpin the ecological risk analyses. Physical drivers of climate change stressors on each fishery species were identified. Wild capture fishery and aquaculture species were ranked according to their need for further assessment of their vulnerability to climate change.

- Temperature was the most commonly cited driver of current or potential climate change impacts for both fisheries and aquaculture species. Among other changes, increases in temperature impact growth rates and larval development, timing of annual migrations, onset of spawning, susceptibility to disease and geographical distribution.

- Impacts of ocean acidification were associated with high uncertainty for all species. The consequences of lowered pH may include reductions in calcification rates, increased physiological stress and disruption to settlement cues.
- Potential changes in currents, freshwater flows and salinity were important for fisheries species whilst increases in the severity, duration or frequency of extreme events were the major concern for aquaculture species.
- Each jurisdiction in the south-eastern region had at least one of its two most important species classified as high risk. Fisheries species considered at highest risk also supported the region’s highest value fisheries – blacklip and greenlip abalone and southern rock lobster. These species demonstrate little capacity to move at adult stages, lower physiological tolerances, and have life history stages that are strongly affected by environmental associations (e.g. spawning and settlement). Habitat loss via the barrens causing urchin *Centrostephanus* is also a major concern for both species.
- For aquaculture species, the level of connectivity of growout to the natural environment and vulnerability to disease were the attributes most sensitive to climate change. Sydney rock oysters, pacific oysters and blue mussels were the aquaculture species at highest risk.
- Major knowledge gaps identified for fisheries species included: environmental tolerances of key life stages, sources of recruitment, population linkages, critical ecological relationships (i.e. predator-prey), influence of environmental variables on the timing of life cycle events and responses to lowered pH.
- Key knowledge gaps for aquaculture species included: impacts on physiology and immunology, ability of selective breeding to counteract impacts, interactions between aquaculture species and organisms that affect performance and survival (such as parasites, viruses, and microalgae), and limited availability of fine-scale climate change monitoring and modelling relevant to aquaculture sites.

Changes in the distribution, abundance and species composition of our commercial fisheries resources as a function of changing climate is going to be unavoidable and our industries will need to adapt to minimise exposure to risks which, given constructive adaptive actions, could be avoided. It is imperative that industries and managers are proactive in positioning themselves to undertake a strategic and structured approach to adaptation planning and engage in subsequent actions to minimise losses and maximise opportunities arising from climate change. Successful adaptation planning is not just about implementing strategies to minimise vulnerabilities and potential losses, it is also concerned with ensuring adequate preparedness to maximise advantages offered by new opportunities. However, not all threats identified will be responsive to anticipatory actions and we need to focus on the threats posing the greatest future cost and that will be most responsive to anticipatory action.

OUTCOMES ACHIEVED TO DATE

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

KEYWORDS: Climate change impacts, aquaculture adaptation, fisheries adaptation, risk assessment, research priorities, marine ecosystems

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Wild capture fishery species	Contributor	
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Black bream	Greg Ferguson Greg Jenkins	SARDI Fisheries Victoria
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Eastern king prawn	Steve Montgomery	I&I NSW
Flatheads (5 species)	Matt Koopman Susan Osborne Patrick Coutin Greg Jenkins	Independent consultant AFMA Fisheries Victoria Fisheries Victoria
Gummy shark	Susan Osborn	AFMA
King George whiting	Anthony Fowler Greg Jenkins	SARDI Fisheries Victoria
School prawn	Steve Montgomery	I&I NSW
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Southern calamari	Natalie Moltschaniwskyj Mike Steer	UTAS SARDI
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Aquaculture species	Contributor	
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Yellowtail kingfish	David Stone Bennan Chen	SARDI SARDI

Background

Increasing concentrations of greenhouse gases in the atmosphere due to human activities are driving changes in global climate. Climate change is leading to ocean warming, changes in ocean currents and alterations to ocean chemistry associated with increased CO_2 uptake. The magnitude of the recent physical changes is greater than at any other time during human civilisation and the rate of change is faster. Climate change related alterations in the physical and chemical features of the marine environment are likely to affect marine biodiversity and resources, which may have substantial implications for communities and industries that depend upon goods and services provided by marine ecosystems. Effective adaptation through minimisation of impacts and realisation of opportunities will require social, economic and environmental consequences to be anticipated and addressed.

While the trajectories of some of the major global oceanographic changes are generally known, significant uncertainties remain regarding the magnitude, and in some cases direction, of changes in biological parameters such as the productivity of fish stocks. This uncertainty is caused by poor understanding of how major drivers will individually, collectively and interactively affect ecosystem composition, structure and function. It is critical that scientists improve projections of the future status of ecosystems or individual stocks and communicate these effectively to support the development of policies that minimise impacts and maximise opportunities for adaptation (i.e. stocks that increase in productivity). The resilience and adaptive capacity of marine species to climate change impacts are poorly understood. A risk-based approach to identifying issues that are likely to affect policy decisions and management arrangements, and that may require additional scientific information, is a sensible first step in preparing fisheries for adaptation to climate change.

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

The marine waters of eastern and south-eastern Australia have been identified as being the most vulnerable in Australia to both climate change impacts and overall exposure (Hobday et al. 2008). On the east coast, this vulnerability and exposure relates to changes in the East Australian Current (EAC), which has strengthened by 20% in the last 50 years (Hill et al. 2008). As a result, water temperatures off the east coast have risen and continue to rise more rapidly than elsewhere in Australia and, according to some model projections, more rapidly than the rest of the world. This EAC region is also predicted to experience the greatest increases in sea levels (Hobday and Lough, in press), which may have implications for critical inshore habitats that are important recruitment sites for many species. In some areas of the south-east coast it has been hypothesised that upwelling of nutrient rich waters may increase in future (Hobday and Lough in press). In coastal habitats along the eastern and south-eastern coasts, further increases in salinity levels may occur, particularly within embayments and inlets due to reduced rainfall and freshwater inflows as well as increased evaporation driven by predicted increases in air temperatures. These changes are expected to have significant implications for the productivity and sustainability of fisheries and aquaculture resources in the region, and social and economic flow-on effects for associated businesses and communities.

The next few decades will present new challenges, and opportunities for government agencies responsible for ensuring that marine natural resources are managed sustainably. This project supports these endeavours by providing a thorough assessment of the sensitivity and tolerances of critical life history stages, habitats and aquaculture systems of key species to climate change drivers. For example, many marine species survive and reproduce only within specific ranges of water temperature and become physiologically stressed or die when water temperatures extend outside that tolerable range. The project builds on the preliminary risk assessments recently conducted in most of the involved jurisdictions and forms a key component of SEAP Program Work Area 1.1 ‘Understanding the biophysical implications of climate change’.

Need

Climate change is expected to alter physical and chemical oceanographic conditions and processes around Australia. The influence that these changes could have on the distribution and abundance of various marine species is poorly understood. Over the next century, the marine ecosystems of south-eastern Australia are expected to exhibit some of the largest climate-driven changes in the Southern Hemisphere. The effects of these changes on the communities and businesses of the region will depend, in part, on how well the fishing and aquaculture industries and their managers respond to the challenges that climate change presents.

A risk-based approach to identifying the key issues that will affect policy decisions and management arrangements, and which may need to be underpinned by additional scientific information, will be critical for ensuring the effective deployment of limited public resources. These risk assessments and the targeted scientific studies that may follow from this prioritisation will be necessary for ensuring that the potential impacts of climate change on key marine resources are identified and communicated effectively to stakeholders. This approach will help to ensure the development of policies that allow industry to minimise adverse effects by optimising adaptation responses (e.g. by providing flexible management arrangements) and seizing opportunities as they arise (e.g. for species where productivity increases).

The need for this project has been identified in the SEAP Program Plan. The results will also establish a baseline from which several key priority areas of the Marine National Adaptation Research Plan (NARP) can be addressed. Priorities identified in the NARP include, for aquaculture 1) which farmed species in which locations are most likely to be impacted as a result of climate change?, and for fisheries 2) which fishery stocks, in which locations, are most likely to alter as a result of climate change? Related questions are: what will those changes be (e.g., in distribution, productivity) and when are they likely to appear under alternative climate change scenarios? This project is based on the premise that synthesising information on the sensitivities and tolerances of key species to support an objective risk assessment is the first step to addressing these priority questions.

Objectives

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

This project will identify a prioritised framework for future research that is based on relative sensitivities of species to climate change drivers, recognises likely resource limitations and highlights the range of values and issues that could be considered when prioritising further work.

Organisation of report

The aim of this report was to develop and conduct a screening-level risk assessment for the key marine species in the south-eastern Australia region. This risk assessment was underpinned by a comprehensive synthesis of information for key species or species groups commercially fished or produced within the south-eastern region. This report is necessarily large and organised in the following manner, with the two parts created as separated documents:

PART 1: Risk Assessment

Section A: Wild Fisheries

Section B: Aquaculture

PART 2: Individual Species Assessment Profiles

Section A: Wild Fisheries

Section B: Aquaculture

SECTION A: WILD FISHERIES RISK ASSESSMENT

Introduction

The oceans are the earth's main buffer to climate change, absorbing up to 80% of the heat and 50% of the atmospheric carbon emitted (Sabine et al. 2004; Domingues et al. 2008). Changes in temperature, environmental flows, ocean pH, sea level, and wind regimes are all contributing to modifications in productivity, distribution and phenology of marine species, affecting ecosystem processes and altering food webs (Brierley and Kingsford 2009, Brown et al. 2010). Alterations to species' rates of growth, survival, and reproduction, or responses to changes at other trophic levels, may have impacts on the catch and distribution of commercial fisheries (Perry et al. 2010). Additionally, the pace of change in marine ecosystems may be rapid compared to terrestrial ecosystems because ranges shift faster in marine than terrestrial environments (Sorte et al. 2010). Global projections of shifts in species' distributions and changes in total primary production, suggest large-scale redistribution of global fisheries catches are likely over future decades (Cheung et al. 2009). Fisheries provide significant social and economic benefits globally, and early warning of changes in resource quality and/or availability is required to minimise social implications (e.g. increased poverty and changes in resource allocation) and societal costs (e.g. income redistribution and government restructuring) (Hobday and Pecl, in review).

Rapid ecological changes throughout the world's oceans present major challenges for regional resource managers and policy makers (Hoegh-Guldberg and Bruno 2010). Species only respond physiologically and behaviorally to the characteristics of their local environment, yet the science needed for regional-scale ecological understanding is immature and thus the likely magnitude and extent of effects remains largely unknown (MacNeil et al. 2010). Nevertheless, irrespective of the absence of complete mechanistic understanding and predictive capacity, ongoing rapid climate change requires strategic planning and informed adaptation actions that ensure that choices made are appropriate for future, rather than past, conditions.

Financial allocations to natural resource management are limited, and investment in adaptation research, planning and implementation is no exception. Approaches to selective resource allocation for adaptation in commercial fisheries could consider highest economic value fisheries, species that are most critical to ecosystem function or those that have the greatest potential to respond favourably to adaptation interventions and/or have the highest probability of persisting through significant environmental change (Hobbs and Kristjanson 2003). There may be species where expending financial resources may be of limited benefit in mitigating negative impacts and funding may be better directed towards other priorities. In order for scientists, policy makers, marine resource managers and stakeholders to optimise the use of financial and human resources, there is a need to identify the key issues, establish a structured and transparent framework to assess their relative importance and assess the feasibility of constructively addressing them (Cabrera et al. 2008).

Waters in south-eastern Australia are responsible for ~50% of Australia's fisheries production (ABARE 2009) and host a high level of endemic species. There is no contiguous land mass further south than Tasmania for species that find the water has become too hot. Range extensions, linked to warming temperatures, have been documented in 45 species, representing approximately 30% of the inshore fish families occurring in the region (Last et al. 2011). Major distributional shifts have also been recorded in barrens-forming sea urchins (Ling et al. 2009), bivalves and gastropods (Pitt et al. 2010), and major declines in rock lobster recruitment have also been related to ocean warming (Pecl et al. 2009).

The south-eastern Australia region is suitable as a case study to develop methods for identifying key climate change issues and establishing a prioritised framework for research to inform adaption as it involves a suite of the complex factors that are likely to be encountered in other global regions. Ocean warming over recent decades has been considerable (Holbrook and Bindoff 1997; Ridgway 2007a), and the oceanography of the region is complex, with changes in the physical environment likely to be heterogeneous within the region (e.g. different between the eastern and southern coasts). Fisheries in south-eastern Australia are based on a wide range of species and involve a diversity of fishing methods; fisheries resources are utilised by commercial, recreational and indigenous sectors leading to complex social considerations associated with resource access and equity. There are five marine jurisdictions within the region (four states and the Commonwealth) with different environmental and fisheries management legislation and systems; consequently, political issues may complicate adaption.

This study was initiated to provide scientific advice to fisheries managers and stakeholders regarding the likely impacts of climate change on the fisheries of south-eastern Australia and to identify research required to develop and subsequently refine 'projections' of likely climate change scenarios for key species. The objectives of this report were to 1/ identify the life history stages, habitats and aquaculture systems of key species that may be impacted by climate change; 2/ identify the physical and chemical parameters that may determine the potential impacts of climate change on key species; 3/ conduct a preliminary screening-level risk assessment of each key species to the potential impacts of climate change; 4/ highlight critical knowledge and data gaps, relevant to future assessments of climate change impacts on key species and development of adaptation strategies; and 5/ identify a prioritised framework for future research that is based on species' relative sensitivity to climate change drivers, recognises likely resource limitations and highlights the range of values and issues that could be considered for further work.

Ecological risk assessment (ERA) can be utilised to estimate the relative probability of adverse events from identified environmental stressors. Such approaches have been useful for elucidating and prioritising, risks from effects of fishing, bio-invasion of pest species, and management of data poor species (Fletcher 2005, Astles et al. 2006, Hobday et al. 2007). Here we develop and adopt a two-stage screening-level assessment to examine the relative risk of climate change impacts on the key fisheries species in south-eastern Australia. The first stage involved detailed literature reviews of each priority species to create 'species assessment profiles' that synthesise and describe the life history stages and habitats of each species and identify the key physical drivers that may be associated with climate change impacts. The species assessment profiles were then used by an expert panel to establish the relative risk among the key species for the region.

Methods

Study region

On the east coast of Australia, the East Australian Current (EAC), which is the western margin of the South Pacific gyre, is the key oceanographic feature and transports oligotrophic water from the tropics (Cai 2006; Ridgway 2007a; Ridgway 2007b) and entrained larvae (Johnson et al. 2005; Ling et al. 2009; Banks et al. 2010) southwards. There are also localised upwellings on the east coast, e.g. Smokey Cape in NSW, that are driven by north-easterly winds during summer and enhance local productivity.

Along the southern coast of Australia, two currents significantly influence shelf waters: the Leeuwin Current which, like the EAC, transports water and larvae from the tropics and subtropics into the temperate zone (in this case from north-western Australia into the Great Australian Bight), and the Flinders Current which runs east to west along the shelf slope of the south coast (e.g. Middleton). The south-easterly winds that predominate during summer–autumn off southern Australia facilitate seasonal upwelling of water from the Flinders Current onto the shelf, which enhances productivity along the southern coast between western Tasmania and the eastern Great Australian Bight.

Ranking and selecting priority fisheries species in the south-eastern region

Forty-four species or species groups, from wild fisheries (n = 36) and aquaculture industries (n = 8), were nominated by resource managers and researchers from all relevant jurisdictions for potential inclusion in the study (see Table A3.1, Appendix 3). Regionally specific information on the importance of each species or species group was then circulated to all jurisdictions. Species were subsequently ranked by resource managers based on three criteria: economic (annual gross value of production), ecological (high, medium and low), and recreational importance (high, medium and low). Based on these criteria, each jurisdiction then ranked the 10 most important species with wild fisheries and aquaculture species considered together. Twenty-six wild fisheries species or species groups were assigned a rank, with 22 included in the study (see Table 1.1). Aquaculture species are considered in Section B of this report.

Table 1.1: Commercial fishery species nominated for potential inclusion in this study. Underlined species indicates those which were subsequently selected for assessment. Regional priority represents the sum of priority ranking (larger number equals higher priority) from all states. Note: the top 10 rankings also include aquaculture species and then the highest wild and aquaculture species selected for further assessment (see Appendices 2, 3 and 4).

Common name	Scientific name	Regional priority
Abalone		28
- black lip	*Haliotis rubra*	
- green lip	*H. laevigata*	
Arrow squid	*Nototodarus gouldi*	3
Australian herring	*Arripis georgianus*	
Australian salmon		13
- eastern	*A. trutta*	
- western	*A. truttaceus*	
Banded morwong	*Cheilodactylus spectabilis*	1
Barracouta	*Thyrsites atun*	
Black bream	*Acanthopagrus butcheri*	10
Blue grenadier	*Macruronus novaezelandiae*	4
Blue swimmer crab	*Portunus pelagicus*	4
Blue warehou	*Seriolella brama*	
Broad billed swordfish	*Xiphias gladius*	2
Commercial scallop	*Pecten fumatus*	7
Eastern king prawns	*Melicertus plebejus*	10
Flathead		15
- dusky	*Platycephalus fuscus*	
- southern sand	*P. bassensis*	
- rock	*P. laevigatus*	
- southern bluespot	*P. speculator*	
- tiger	*Neoplatycephalus richardsoni*	
Gemfish	*Rexea solandri*	
Giant crabs	*Pseudocarcinus gigas*	
Gummy shark	*Mustelus antarcticus*	10
King George whiting	*Sillaginodes punctatus*	15
Ling	*Genypterus blacodes*	1
Orange roughy	*Hoplostethus atlanticus*	
School prawn	*Metapenaeus macleayi*	9
Silver trevally	*Pseudocaranx dentex*	
Small pelagics		15
- Australian sardine	*Sardinops neopilchardus*	
- jack mackerel	*Trachurus declivis*	
- blue mackerel	*Scomber australasicus*	
- redbait	*Emmelichthys nitidus*	
- sandy sprat	*Hyperlophus vittatus*	
- blue sprat	*Spratelloides robustus*	
- Australian anchovy	*Engraulis australis*	
- yellowtail scad	*Trachurus novaezealandiae*	
Snapper	*Pagrus auratus*	26
Snook	*Sphyraena novaehollandiae*	
Southern bluefin tuna	*Thunnus maccoyii*	9
Southern calamari	*Sepiotheuthis australis*	4
Southern garfish	*Hyporhamphus melanochir*	3
Southern rock lobster	*Jasus edwardsii*	27
Spanner crabs	*Ranina ranina*	3
Striped marlin	*Tetrapturus audax*	5
Striped trumpeter	*Latris lineate*	
Tailor	*Pomatomus saltatrix*	
Tunas, other		7
- yellowfin	*T. albacares*	
- bigeye	*T. obesus*	
Western king prawns	*Melicertus latisulcatus*	4
Yellowtail kingfish	*Seriola lalandi*	2

Species assessment profiles of climate change risks and drivers for each species

The screening-level risk assessment of the potential impacts of climate change on selected fishery species was underpinned by expertise-based 'species assessment profiles' for each of the 22 species or species groups detailed in Table 1.1 (except 'Tunas, other' for which we referred to existing work completed for the Marine Report Card (Hobday et al. 2009). Each profile used a template to collate existing data, literature and expert opinion on the fishery, species' life history and potential sensitivity and resilience to environmental change, current climate change impacts, and critical knowledge and data gaps. Profiles were produced by a team of authors and expert reviewers from all jurisdictions (see Part 2 of this report to view individual species profiles). The key results from each of the descriptive analyses are tabulated in this section of the report.

Risk assessment approach for wild fisheries species

The development of a fit-for-purpose screening-level methodology by the project team was supported by Mr Richard Stoklosa (E-Systems Pty Limited) who also chaired the workshops to obtain expert input from fisheries biologists. The sources of available information considered are listed in Table 1.2. The species assessment profiles for key species, together with the teams' broader knowledge of marine climate change impacts, were used to develop conceptual models of climate change impacts and select attributes which could be used to assess the sensitivity of wild capture species to climate change.

Table 1.2: Types of information potentially available to inform the risk assessment process.

Types of input considered	Information sources to inform ecological risk assessment of fishery species
Expert judgement	Relies on knowledge and beliefs based on personal interpretation of information known to expert, or inferred from familiarity with published scientific work.
Operational data	Not considered at this preliminary, screening-level stage.
Statistical analysis	Not considered at this preliminary, screening-level stage.
Technical databases	FishBase database (publicly available at www.fishbase.org)
	CSIRO compiled database supporting ERAEF data requirements
Spatial data	Not considered at this preliminary, screening-level stage.
Biological data	'Identify the life history stages, habitats and aquaculture systems of key species that may be impacted by climate change' in South Eastern Australia (SEAP project objective 1).
Physical and chemical data	'Identify the physical and chemical parameters that may determine the potential impacts of climate change on key species' (SEAP project objective 2).

An ecological risk assessment (ERA) should be consistent with the Australian/New Zealand Standard for risk management (AS/NZS ISO 31000 2009). The methodology presented here reflects the language and definitions of the Australian/New Zealand Standard.

Guiding principles for the selection and use of the risk assessment methodology in this project were:

- Choosing clear endpoints in the criteria for attributes that were sufficiently relevant to the objectives of the project, but simple enough to minimise uncertainty
- Selecting a fit-for-purpose assessment technique to complete a preliminary assessment, with the goal of performing comparative analysis and ranking of species
- Transparently describing the technical details of the adopted risk analysis method so that it is repeatable
- Making predictions in the risk analysis which rely on available data and can be scientifically tested
- Including a good analysis of uncertainty and demonstrating the robustness of solutions
- Involving an appropriate number of fishery scientists when expert judgement was required
- Making technical information transparent and readily available
- Considering decision-making needs for adaptive management, including opportunities that arise from positive impacts to fishery species.

There was no existing risk assessment methodology suitable for the purpose of this study. ERA generally requires adaptation of a previous method or the formulation of a new approach. The need to conduct a screening-level assessment within the constraints of the SEAP project timetable required the development of a qualitative method involving expert judgement that was based on the adaptation of existing ERA methods for fishery species (e.g. Hobday et al. 2007; Hobday et al. 2011).

Ecological risk assessment methodology

The risk assessment approach taken here follows that developed in the Ecological Risk Assessment for the Effects of Fishing (ERAEF) by Hobday et al. (2011), which is in turn consistent with the AS/NZ ISO 31000 (2009) Standard of expressing risk as the combination of 'likelihood' and 'consequences'— or as it is more commonly expressed in environmental risk assessment as 'exposure' and 'response'. In terms of ecological risk, we were interested in the exposure to stressors (in this case climate change), and the response of receptors (in this case the sensitivity of fishery species). Estimates of the potential impact of climate change on fishery species can be expressed as a simple equation:

$$Exposure \times Sensitivity = Potential\ Impact\ (Relative\ Risk)$$

Consultation with all jurisdictions involved in the SEAP program indicated that it would be desirable for the risk assessment to directly address the National Adaptation Research Plan for Marine Biodiversity and Resources priorities (http://www.nccarf.edu.au/national-adaptation-research-plan-marine-biodiversity-resources) – to estimate the **sensitivity** of fishery stocks to climate change stressors in terms of their *productivity* and *distribution*, and the **exposure** of those stocks to alternative climate change scenarios.

Sensitivity component of risk

Sensitivity of species to climate change cannot be measured or judged *a priori* through scientific data or expert judgement. The risk assessment methodology was developed to *estimate* sensitivity through indicators of a species' likely response to climate change stressors. The sensitivity of species based on measures of their potential for biological productivity, and habitat-dependent distribution requirements for various life stages are a good proxy for their sensitivity to climate change.

Substantial effort has already been made to develop a rigorous methodology for the Ecological Risk Assessment for the Effects of Fishing (ERAEF) (Hobday et al. 2007). In the ERAEF methodology, an approach for estimating the relative productivity of species has been developed. Biological attributes of the species' life cycle are used (combined) to yield a productivity score (or measure of the potential to increase in abundance), which is the approach adopted in this work. However, an extension in this project has been to recognise that climate change impacts can be expressed by a change in a species' abundance, distribution, or phenology. With regard to abundance, higher productivity species are considered to be less sensitive (more resilient, can recover more quickly) to climate change stressors; low productivity species are considered more sensitive (and less resilient, and slower to recover). Similarly, attributes were developed to estimate the sensitivity of species to realise changes in distribution. The third measure of sensitivity incorporated in the risk assessment was to develop attributes for estimating the sensitivity of species to changes in the timing of their life cycle events (phenological changes, such as spawning, moulting and migration).

The scoring of attributes in each category was limited to a scale of 1–3, representing 'low', 'medium', and 'high', with significant consultation occurring across the broader project team before, during and after the risk assessment workshops to develop both the attributes and the criteria for scoring the three categories. The acceptance of the simple three-level scoring technique was subject to the analysis of preliminary results stemming from the first workshop, to confirm that a scale of 1 to 3 was sufficient to show resolution between species for the purpose of ranking. In these semi-quantitative approaches, where data limitations may be an issue, this simple scoring has been shown to be sufficient for use by a wide range of experts and reduces the focus on the 'precise value' of each attribute. Four attributes were eventually agreed for each of the three measures of sensitivity: abundance, distribution and phenology. Following previous methods, the scores for each group of four attributes were combined (averaged) to yield separate scores for abundance, distribution and phenology. These scores were then used to produce a ranking of sensitivity across the selected fishery species.

Exposure component of risk

In a quantitative assessment, the exposure component of risk involves modelling of alternative climate change scenarios to estimate future risk, which, while possible, was beyond the scope of this preliminary assessment. Therefore, the risk assessment method developed here uses the sensitivity of each selected species to climate change as the preliminary risk analysis step, subject to further qualitative consideration of criteria and 'decision rules' for exposure, as well as economic and social values that will later be considered for the most sensitive species in another SEAP project commencing in 2011 (2009/073).

Development of attributes to estimate sensitivity

Conceptual models were developed to inform the selection of attributes that could be used to estimate the sensitivity of fishery species to climate change. Conceptual models of abundance, distribution and phenology were discussed in the technical workshops and further refined to include the key biological features of fishery species that are likely to determine sensitivity.

Abundance

Abundance changes for many species can described by a logistic equation, with abundance increasing if the rate of change is positive, and decreasing if it is negative. Logistic growth is represented as:

$$\frac{dB}{dt} = rB(1 - \frac{B}{K})$$

where the rate of change of biomass of a species, $\frac{dB}{dt}$, is a function of the current amount or extent of the unit (B), its intrinsic rate of increase (r), and its carrying capacity (K). Although information relating to r and K would be preferred, this is rarely available, even for the target species considered in this risk assessment (Hobday et al. 2011). Thus, a set of attributes that are correlated with r and K were selected. For each of the attributes, consultation was undertaken to develop the categorical criteria for expert judgement as low, medium or high (Table 1.3).

A convention was adopted to refer to the attribute criteria as the inability to respond to change (high sensitivity or low resilience to change). A rating of 'high' reflects an attribute that is highly sensitive (i.e. poorly resilient), and received a numerical score of '3'. A rating of 'medium' was assigned a score of '2', and a rating of 'low' received a score of '1'. A rating of 'high' then reflects an attribute that is very sensitive to climate change (i.e. not particularly resilient).

Distribution

Dispersal is a key step for a species undergoing distributional change and was therefore used as a proxy for capacity to change distribution in this assessment. An invasion process model was used to underpin the selection of dispersal attributes. A general feature of invasion process models (Crooks 2005, Kolar and Lodge 2001) is the following:

$$arrival \rightarrow colonisation/survival \rightarrow establishment \rightarrow spread/expansion$$

The possible final step in the invasion process model, potential decline, is not shown here because the model does not consider higher-order ecological processes such as trophic interactions in the screening-level assessment. A set of attributes that related to each step in dispersal were selected and refined after extensive consultation to develop appropriate criteria for scoring (Table 1.3).

Phenology

In this assessment, phenology is defined as the interaction between climate variables and biological processes that impact on the timing of species life-cycle events. Species with seasonal life-cycle events that are driven by relationships to temperature will be more sensitive to climate change impacts than those species where the timing of their life-cycle events is more driven by changes in day length for example (a variable not altered by climate change). A life-cycle model was used to support the selection of attributes and scoring criteria were developed for each phenology attribute (Table 1.3). In the case of phenology, the sensitivity of species to climate change can be due to varying environmental variables, or ‘cues’, between species. In practice, the appropriate environmental cue was selected for scoring and noted in the risk analysis. Similarly, sensitivity to temporal mismatches of life-cycle events were assessed with regard to spawning, breeding or moulting season as appropriate.

Table 1.3: Attributes, criteria and risk categories used to assess climate change risk for each species.

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

Qualitative risk assessment to rank sensitivity of species to climate change

There is no formula to obtain the 'perfect' mix of expert input in a qualitative risk assessment. The goal here was to include fisheries scientists with relevant experience and qualifications to provide high quality technical input. It was recognised that in well managed group interactions when there is only a small correlation between expert judgements, there is little value in consulting more than four or five experts (Burgman 2005).

Two workshops were held to refine the risk assessment methodology, trial the assessment process and complete the preliminary risk assessments. The range of expertise represented in the SEAP project team was considered able to provide high quality technical judgements and advice. Those people who contributed to the literature searches and risk assessments and who attended workshops to develop the methodology and debate risk assessments are acknowledged.

The risk assessments were completed at the species level (except for eastern and western Australian salmon, where one assessment was produced for the two species), with 35 risk assessments performed for the 22 species or species groups. A species group was a cluster of similar species, such as small pelagic fishes which contained Australian sardines, Australian anchovy, jack mackerel, blue mackerel, redbait, blue sprat and sandy sprat.

The methodology was trialled on southern rock lobster and King George whiting at a workshop. It was agreed that the trial yielded legitimate results and assisted refinement of the attributes and criteria to be used. Each of the wild capture fishery assessments was reviewed by the author group and in some cases there was discussion of the interpretation of attribute scores and uncertainty in the choices of a discrete score – even with the categorical options of low, medium or high. In many cases, the source of uncertainty was variability in the large geographical ranges of species and habitats where they occur. In fewer cases, the source of uncertainty was due to a lack of scientific evidence or data. In the case of lacking data, the score selected was agreed to be on the higher side of the range (i.e. more sensitive to climate change – a conservative and precautionary approach), following previous risk assessment practice (e.g. Hobday et al. 2007). Participants debated and agreed on selecting consensus scores, rather than the ranges of scores that were used for the preliminary assessment. Results of all of the wild capture fishery assessments are presented in Appendix 5. Based on workshop discussions and consultation following the workshop, there was a high degree of confidence that the methodology was applied consistently across species.

Results

The suite of species considered

The fisheries examined were diverse and involved a range of taxa, habitats and fishing methods (Table 1.4). More than half of the priority fisheries were multi-jurisdictional, with blacklip abalone, Australian salmon, snapper and southern calamari harvested in all south-eastern jurisdictions except the Commonwealth. Some species groups, such as the small pelagic fishes and flatheads were harvested in all five jurisdictions. Catches in approximately half of the fisheries have declined over recent years. Reef-dwelling invertebrates supported the most valuable commercial fisheries, with southern rock lobster (SRL) and abalone worth $177 million and $160 million respectively. Other valuable invertebrates included prawns, scallops and crabs. The most valuable finfish fishery was the highly migratory southern bluefin tuna ($122 million), which is mainly taken in the Great Australian Bight, but is distributed and fished throughout the southern hemisphere. Other wide-ranging oceanic tunas and marlins were also valuable ($70 million). The small pelagic species were the highest volume fisheries in region, with approximately 30,000 tonnes of sardines harvested in 2008–09 in South Australia alone, with a value of approximately $23M. Blue grenadier was the only deep water species and has a value of $33 million. Snapper and King George whiting were the most valuable coastal fish species, worth $12.3 and $7.9 million respectively. More than half of the selected species were recreationally important, with recreational catches exceeding the commercial catch in some species (e.g. black bream and King George whiting).

The ecology and biology of the species was also diverse, with molluscs, crustaceans, teleosts, and elasmobranches represented (Table 1.4). A wide range of habitats were described across the benthic, demersal and pelagic environs, including estuarine, neritic, and oceanic waters and rocky reef, soft sediment and vegetated substrates. Juvenile stages commonly occupied a different habitat to the adult stages, typically inhabiting shallow coastal waters and estuaries. The majority of species were distributed from NSW to southern WA; however, some had large-ranging cosmopolitan distributions (e.g. large pelagic fishes and blue swimmer crab) and others had more restricted distributions (e.g. eastern king prawn, school prawn, and dusky flathead). All species were broadcast spawners with a pelagic larval phase, except for gummy sharks and southern calamari; however, the duration of the larval stage varied extensively between species (e.g. <2 weeks in abalone and 1–2 years in SRL). Species occupied a range of trophic levels, from detritivores and herbivores to apex predators.

Table 1.4: Summary of fisheries statistics for the south-eastern region of Australia as outlined in the individual species assessment profiles.

Species	Gross Value of Production (M, $)[1] per annum	Commercial catch (t) [2] per annum	Recreational catch (t)[3] per annum	Fishery habitat	Commercial fishing method	Commercial catch trend (over the last 10 years)
Abalone – blacklip (BL) & greenlip (GL)	160	**GL:** 468 **BL:** 4221	74	rocky reef	diving	stable
Australian salmon – eastern & western	2.9	2042	976	neritic	purse & beach seine, hauling nets	highly variable
Black bream	1.5	44	992 'bream'	estuarine	line methods	declining
Blue grenadier	33	3773	-	deep sea	otter trawl	declining
Blue swimmer crab	6.5	658	545	soft sediment	crab pots & nets	increasing
Commercial scallops	4.5	2488	40-60 (Tas only)	soft sediment	benthic dredge	highly variable
Eastern king prawn	14.9	559	124 'prawns'	soft sediment	otter trawl, hauling, running, set pocket & seine nets	declining
Flatheads – southern sand, dusky, southern bluespot, tiger, & rock	48.8 (excluding Tas)	3647	1864	soft sediment	otter trawl, Danish seine, handline	stable
Gummy shark	44.5	1549	-	neritic	gillnet	stable
King George whiting	7.9	479	821	neritic	seine & gillnets, powerhauling, handline,	stable
School prawn	5.3	967	124 'prawns'	soft sediment	otter trawl, hauling, running, set pocket & seine nets	increasing
Small pelagic fishes – sardines, jack mackerel (JM), blue mackerel (BM), sandy sprat (SS), blue spat (BS), redbait, anchovy, & yellowtail scad (YTS)	**Sardine:** 21.5 **JM, BM, redbait:** 5.8 (excluding Tas)	**Sardine:** 27850 **BM:** 2072 **Redbait:** 1775 **JM:** 1287 **Anchovy:** 100 **SS:** 60 **YTS:** 600	**BM:** 200 **YTS & JM:** 30	neritic	purse seine, hauling nets, mid-water trawl?	**sardines:** increasing **anchovy:** stable **SS:** declining **BM:** increasing **JM:** declining **Redbait:** declining
Snapper	12.3	1247	821	neritic	Haul seine net, longline, handline	increasing
Southern bluefin tuna	122.9	488	918 'tunas/bonitos'	oceanic	purse seine, longline	stable

Southern calamari	3.7 (excluding Tas)	465	605 'squid/cuttlefish	neritic	hand jigs, haul nets	stable
Southern garfish	2.9	421	161	neritic	haul & dab nets	declining
Southern rock lobster	176	3265	230	rocky reef	lobster pots	declining
Spanner crabs	0.9	68	< 1	soft sediment	spanner crab nets	declining
Striped marlin	6.5	109	-	oceanic	longline, handline	declining
Tunas, other – yellowfin, bigeye	63.4	611	918 'tunas/bonitos'	oceanic	longline, trolling, handline	declining
Western king prawns	34.2	2188	124 'prawns'	soft sediment	otter & double-rig trawl	stable
Yellowtail kingfish	1.1	120.4	245 'sampson/kingfish'	neritic	line methods	stable

[1] Tas data: 2007/08, sourced from ABARE.

[2] All for 2008/09, except for abalone and anchovy (2007/08), sandy sprat and yellowtail scad (2006/2007). See individual species profiles (Part 2 of this report) for source information.

[3] All data sourced from Henry and Lyle (2003), except for scallops (Lyle et al. 2009). In some instances data is only available for a species group (i.e. prawns), which is indicated below the catch data.

Summary of key elements emerging from the individual species assessments

Increasing ocean temperatures was overwhelmingly the most commonly cited climate change driver, particularly in relation to physiology and phenology of the species (Tables 1.5, 1.6 and 1.7). Changes in growth rates, susceptibility to disease, timing of spawning events and migrations, rates of larval development and survival, and alterations to levels of reproductive output were all commonly listed impacts of changes in temperature. However, such relationships were largely predicted and generally categorised as having low certainty (southern rock lobster was the exception), due to the paucity of information available.

Another important climate-associated driver that was consistently identified in the individual species assessment profiles was changes in oceanographic conditions relating to a southward extension in the of the East Australian currents. Although intrinsically linked to temperature change, likely impacts discussed in relation to this change were usually based on changes in distribution and abundance (i.e. range shifts). A broad range of taxa were described as currently undergoing range shifts (e.g. southern rock lobster, yellowtail kingfish, abalone, spanner crab and snapper) or predicted as likely to undergo range shifts in the future (e.g. Australian salmon, eastern king prawns, and small and large pelagic species). Such impacts were described with a medium to high certainty. Although temperature was highlighted as the key underlying driver facilitating range shifts, changes in current-mediated larval transport was also identified as influencing range shift patterns.

Range shifts in non-target species, which have ecological ramifications for the target species, were also detailed (Tables 1.5 and 1.6). These ‘secondary’ biological drivers are highlighted as key issues for several species. Abalone and southern rock lobster are currently impacted by increases in sea urchin numbers and a decline in macroalgae in Tasmania. Similarly, jack mackerel abundance has been linked to declines in krill. Range shifts in yellowfin bream and eastern rock lobster may also impact black bream and southern rock lobster populations, respectively. Although no evidence was detailed to suggest that seagrass distributions are currently changing due to climate change, any changes were predicted to impact garfish, southern calamari, some flathead species, and King George whiting with medium to high certainty. Seagrass loss due to other anthropogenic activities, however, was identified as a key additional stressor for seagrass-dependent species (Table 1.5).

The region off western and southern Tasmania, where the Leeuwin Current extension meets the southern extension of the EAC is variable in space and time. The importance of these two currents, and the interaction with Southern Ocean waters, for generating local productivity and the recruitment of fished species in Tasmania is unknown. On the west coast of Tasmania for example, sub-surface productivity at the shelf break may be important, yet is not detectible in satellite-based measurements. The potential change in this region is also highly uncertain, as the currents are low volume and poorly represented in ocean models.

The south-eastern region is a heterogeneous environment, which is particularly evident off the southern coast. The South Australian, western Victorian and western Tasmanian coastline is characterised by two gulfs (hyper-saline inverse estuaries) and a key upwelling region, and unlike the east coast, is not under direct influence of the EAC. Changes in the frequency and intensity of upwelling events was described as a key driver in this region region, potentially impacting food availability for southern bluefin tuna, abundance of sardines, and recruitment in western king prawns (in the West Coast oceanic fishery). Increases in salinity and temperature in the gulfs were also described in relation to southward range shifts (blue swimmer crab, bluespot flathead) and increased periods for growth and reproduction (western king prawn, blue swimmer crab).

Freshwater flow was described as a key climate change driver for estuarine species, particularly school prawns, black bream, and eastern king prawn, with predicted impacts relating to recruitment and timing of migration. However, the level of impact is likely to vary substantially between estuaries, due to differing physical attributes and levels of anthropogenic modification. Additionally, such environments were commonly described as being particularly susceptible to stressors other than fishing and climate change, including habitat degradation, nutrient enrichment, pollution and invasive species (Table 1.5).

Many data gaps were raised throughout the individual species assessment profiles (Table 1.5). Optimal environmental conditions and environmental tolerances of larval stages were regularly emphasised, along with general larval biology, as major data gaps. This was generally described in relation to potential climate change impacts on larval survival, development and dispersal, which were uncertain for many species. The major source areas for recruits to the fisheries were unknown for many species, even for the large and/or valuable fisheries (e.g. rock lobster). Lack of basic knowledge on population linkages and connectivity between sub-populations of many species hinders our capacity to project how these species may be impacted by altered current regimes. Although there was a greater understanding of the biology of adult stages, the impact of environmental changes on reproductive success and disease susceptibility was a commonly uncertain.

Understanding of the key ecological interactions and trophic importance of target species was identified as another broad information gap. This makes it very difficult to predict the likely impacts of range shifts to both target species and other taxa, be they positive (e.g. food, habitat) or negative (e.g. competition, predation) impacts. The impacts of ocean acidification were largely unknown for all species; although it was suggested that ocean acidification may have profound impacts on shellfish species (abalone and scallops), no studies detailed have examined the effects of lowered pH on species investigated in this report.

Table 1.5: Summary of species habitat and distribution, additional stressors and key knowledge and data gaps outlined in the individual species assessment profiles.

Species	Habitat[1]	Distribution	Additional stressors[2]	Key knowledge and data gaps
Abalone – blacklip (BL) & greenlip (GL)	benthic; neritic; rocky reef	**BL:** NSW, Vic, Tas, SA, S WA **GL:** Vic, N Tas, SA, S WA	**BL:** Invasive species (algae & mussels) are threatening abalone habitat in NSW **BL:** Habitat loss (see Table 1.6 'Current Impacts') Lethal viral outbreak in Vic *Perkinsus* sp. (microsporidian disease common in SA) is more common in high stress environs e.g. higher temp.	Effect of ocean acidification on shell development and physiology Effects of elevated temperature on biology (e.g. growth, reproductive success, larval survival, disease susceptibility)
Australian salmon – eastern & western	pelagic; neritic, inshore	**Eastern:** NSW, Vic Tas **Western:** Vic, Tas, SA, S WA		**Eastern:** Linkage between EAC and recruitment Source of recruits Predator-prey interactions
Black bream	demersal; estuarine to freshwater; often with seagrass (juveniles)	NSW, Vic, Tas, SA, S WA	Increased frequency of harmful algal blooms in Vic Anthropogenic modification of estuaries Degradation of seagrass beds in Vic (Coutin et al. 1997)	Key environmental and habitat conditions essential for spawning, survival and growth The relationships between stratification, flow and recruitment in different estuaries.
Blue grenadier	demersal; neritic; inshore (juveniles); shelf break/slope (adults)	Vic, Tas, SA, S WA		Influence of environmental drivers on recruitment patterns
Blue swimmer crab	benthic; inter-tidal & neritic; sandy & muddy substrates, often vegetated	Qld, NSW, SA, WA (not S coast), NT	Habitat degradation due to pollution and development, especially in inter-tidal zones	Future changes in oceanographic patterns which are critical to larval advection and adult movement. Understanding of growth patterns, in particular effect of temperature. Understanding effect of temperature on reproductive patterns.
Commercial scallops	benthic; neritic; soft sediment substrates	Tas, SA, NSW, S WA	Introduced species (e.g. northern Pacific Sea Star, which predates on scallops) (Hutson et al. 2005)	Effect of ocean acidification on shell development and physiology Effects of temperature, currents, and salinity on growth, reproduction and recruitment Population structure and dispersal
Eastern king prawn	benthic; estuarine (juveniles); neritic (adults)	mid Qld, NSW, Vic		Strength of recruitment from Qld Estimates of stock biomass
Flatheads – southern sand, dusky, southern bluespot,	benthic; soft sediment substrates	**Sand & Rock:** NSW, Vic, Tas, SA, S WA	**Dusky & Rock:** Loss of seagrass habitat Sensitive to pollution	Sensitivity of eggs and larvae to variation in physiochemical factors Impacts of long-term salinity changes on eggs and

tiger, & rock	**Sand:** neritic, in- & offshore **Dusky:** estuarine to freshwater, often vegetated **Bluespot:** estuarine & neritic, often vegetated **Rock:** neritic, inshore with seagrass **Tiger:** neritic, offshore	**Dusky:** Qld, NSW, E Vic **Bluespot:** W Vic, N Tas, SA, mid WA **Tiger:** NSW, Vic, Tas, SA Gulfs		larvae Habitat preferences and ecology interactions Links between recruitment, temperature, and freshwater input Population structure and connectivity
Gummy shark	demersal; neritic; inshore (juveniles); offshore (adults)	mid NSW, Vic, Tas, SA, mid WA		Ecological interactions Distribution of nursery areas
King George whiting	demersal; neritic; inshore with seagrass (juveniles); offshore rocky reef (adults)	NSW, Vic, N Tas, SA, S WA		Ecological interactions Influence of environmental variables on larval development and survival Source of spawning populations Links between older juveniles and seagrass
School prawn	benthic; estuarine to freshwater, mostly vegetated (juveniles); neritic (adults)	S Qld, NSW, Vic		Recruitment and early life history Schooling behaviour
Small pelagics – sardines, jack mackerel (JM), blue mackerel (BM), sandy sprat (SS) , blue spat (BS), redbait, anchovy, & yellowtail scad (YTS)	pelagic; **sardines, anchovy, JM, YTS, BS & SS:** neritic, inshore & offshore **BM:** oceanic **redbait:** shelf break	**YTS, JM:** NSW, Vic, Tas, SA, mid WA **Redbait:** NSW, Vic, Tas, SA, S WA **BM:** Qld, NSW, Vic Tas, SA, mid WA, NT **Anchovy, sardine, BS & SS:** S Qld, NSW, Vic, N Tas, SA, mid WA	**Sardines:** viral outbreaks, leading to large mortality events, however, recovery has been rapid in SA (Ward et al. 2001)	Long-term information on egg and larval abundances (best long-term data is for sardines) Age structure information representative of entire population for each species Temperature tolerance of eggs and larvae and the impact of increasing temperatures on larval survival and growth YTS and JM eggs cannot currently be distinguished from each other
Snapper	demersal; neritic; soft sediment substrates, often vegetated, & rocky reefs; inshore (juveniles); often offshore (adults)	Qld, NSW, Vic, N Tas, SA, WA	Introduced species and pollution in Port Phillip Bay (Vic) affect habitat in juvenile nursery areas Current low winter temperatures in SA upper gulfs are stressors (knowledge from aquaculture)	Environmental influence on recruitment variation Habitat conditions required for spawning and larval survival Movement and migration patterns
Southern bluefin tuna	pelagic; oceanic	NSW, Vic, Tas, SA, WA		Spawning frequency Proportion of juveniles moving to southern Australia

				Population size estimate
Southern calamari	semi-pelagic; neritic; inshore with seagrass (juveniles & spawning adults); offshore (sub-adults)	NSW, Vic, Tas, SA, WA		Unknown use of deep water habitats for spawning Size of pre-spawning adult population Mortality rates of juveniles and sub-adults
Southern garfish	demersal; neritic; inshore with Zosteracean seagrass	Vic, Tas, Sa, S WA	Loss of Zosteracean seagrass habitat	Reproductive biology and early life history Physiological tolerances of different life history stages and between sub-populations
Southern rock lobster	benthic; neritic; rocky reef	Vic, Tas, SA, S WA	Habitat loss (see Table 1.6 'Current Impacts')	Dispersal patterns of larvae, source of recruits and drivers of puerulus settlement
Spanner crabs	benthic; neritic; sandy substrates	S Qld, NSW, mid WA		Biology and distribution in southern range limit
Striped marlin	pelagic; oceanic	Qld, NSW, E Tas, WA		Biology, habitat and distribution of larval and juvenile stages Importance of sub-surface habitats as spawning grounds Stock status is uncertain
Tunas, other – yellowfin (YF), bigeye,	pelagic; oceanic	**YF:** Qld, NSW, E Tas, WA **Bigeye:** Qld, NSW, E Tas, WA, SA		Not available, assessment not conducted as information for the risk assessment was sourced from the CSIRO Marine Report Card
Western king prawns	benthic; sandy substrates; estuarine (juveniles); neritic (adults)	Qld, NT, WA, SA	Habitat degradation due to pollution and development, especially in estuarine regions.	Diet and the importance of seagrass in SA The upper salinity tolerance of adults Future changes in oceanographic patterns which are critical to larval advection and adult movement Possible negative effects if there is a loss of seagrass
Yellowtail kingfish	semi-pelagic; neritic, inshore & offshore	S Qld, NSW, Vic, N Tas, SA, S WA	Current low winter temperatures in SA upper gulfs are stressors (knowledge from aquaculture)	General biology (age, life cycle, spawning grounds) and population dynamics

[1] Different life history stages are noted if they are associated with different habitats. Larval stages are not detailed as all species have a pelagic larval stage except gummy shark and southern calamari.

[2] In addition to fishing and climate change.

Table 1.6: Summary of current and predicted climate change impacts outlined in individual species assessment profiles, with level of certainty of the associated information indicated. Level of certainty is divided into high (H) = strong clear evidence, backed by several studies with solid datasets with little confounding interactions; medium (M) = evidence supported by one or more studies, conclusions may be partially ambiguous or confounded; low (L) = anecdotal evidence, limited data and/or predicted conclusions based on theoretical knowledge.

Species	Current climate change impacts	Predicted climate change impacts	Range shift potential (extension or contraction)
Abalone – blacklip (BL) & greenlip (GL)	**BL:** Habitat loss (macroalgae) along east coast Tas due to increasing temperatures and range expansion of the sea urchin *Centrostephanus rodgersii* (Ling 2008; Strain and Johnson 2009) Johnson et al. in press. (H)	Reduced growth rates and size at maturity (Johnson et al 2011, Vilchis et al. 2005) (M) Increase in disease outbreaks (e.g. perkinsosis) in northern range of distribution (Goggin and Lester 1995; Travers et al. 2009) (M) Changes to timing of spawning events and duration of larval phase (L)	Contraction (BL) Extension (GL)
Australian salmon – eastern & western		**Eastern:** Southward contraction due to increasing southern penetration of EAC (M) **Western:** Westward contraction due to increased frequency of El Niño events (Dimmlich et al. 2000) (M) Elevated temperature may impact seasonal migration and distribution, and may increase growth rates in the southern range of the species (L)	Contraction
Black bream	Increases in harmful algal blooms (HABs) in Gippsland Lakes (Vic) (e.g. *Noctiluca scintillans*), increasing temperature is a contributing factor (M)	Reduced rainfall and environmental flows in Gippsland Lakes (Vic) may negatively impact recruitment (Jenkins 2010) (H) Yellowfin bream may hybridise with black bream if its distribution shifts southwards (Roberts et al. 2010) (L)	Contraction
Blue grenadier		Elevated temperatures may shift timing of annual migrations and onset of spawning. There is only one known spawning ground off western Tas (L)	Contraction
Blue swimmer crab	Southward range expansion in the gulfs of SA due to increasing salinity and temperature (H)	Elevated temperature may increase period for growth and reproduction in SA (M)	Extension
Commercial scallops		Elevated temperatures may shift timing of spawning, and impact larval development, recruitment, and growth rates (Heasman et al. 1996; Shephard et al. 2010) (L) Decreased pH may have a profound impact on development and survival (Talmage and Gobler 2009) (L)	Contraction
Eastern king prawn		Strengthening of the EAC, increases in temperature, and changing freshwater flows may result in a southward shift in distribution and a shift in the timing of migration from the estuaries and spawning (Montgomery 1990)(M)	Extension
Flatheads – southern sand, dusky, southern bluespot, tiger, & rock	**Sand:** Population decline in Vic may be partly related to increasing temperatures and declines in freshwater flow (which may cause declines in nutrients and food for larvae)(Jenkins 2010)(L)	**Dusky & Rock:** Changes in seagrass distribution due to climate change may impact populations (M) **Bluespot:** Southward range shift from the gulfs of SA (L) Temperature may impact distribution and spawning cues and increase disease susceptibility (L)	Contraction (Rock) Contraction (Sand) Extension (Dusky) Contraction (Tiger) Extension (Bluespot)

Gummy shark		Environmental change may impact migration patterns, especially in females (L) Changes in temperature, salinity, and freshwater flows may impact nursery habitat (L)	Contraction
King George whiting	A decline in zonal westerly winds in Vic may be having a negative impact on recruitment (Jenkins 2005)(L)	Loss of seagrass due to climate change may negatively impact populations (Jenkins 2005)(M) Increasing temperatures may lead to increased growth rates and larval development (Ham and Hutchinson 2003; Jenkins and King 2006) (L)	Extension
School prawn		Decreases in rainfall and river discharge may negatively impact productivity. Modelled linkage between higher rates of river discharge and commercial harvest (Ives et al. 2009)(M).	Extension
Small pelagics – sardines, jack mackerel (JM), blue mackerel (BM), sandy sprat (SS) , blue spat (BS), redbait, anchovy, & yellowtail scad (YTS)	**Sardines:** Increase in strength of upwelling off the eastern GAB may have enhanced recovery of population after two major mortality events (Ward et al. 2008)(H). **Sardines:** the northern range edge in WA has appeared to have shifted south in response to the increasing strength of the Leeuwin current (Gaughan et al. 2004)(H) **JM:** Decline in catch in Tas since the mid 1980s may be partly due to climate change. Low abundance has been linked to reduced productivity and krill abundance due to La Niña conditions and the increased extension of the EAC (Harris et al. 1992; Young et al. 1993). (M) **Redbait:** Is an EAC species, and may be increasing in abundance in Tas. The small pelagics fishery in Tas was predominantly JM, but is now dominated by redbait. (L)	**Sardines:** The southward extension of the EAC could advect eggs and larvae further south into Tasmania (Uehara et al. 2005)(M). **SS:** Positive relationship between catches off western WA and strength of the Leeuwin current. Populations in WA may increase in the future (Gaughan et al. 1996)(M). **BM:** Timing of spawning coincides with the southward movement of the EAC off NSW and the Flinders Current along southern Australia; therefore, any changes in these currents could influence the distribution and/or abundance in these two areas (L). **YTS:** May increase in abundance in the southern range of its distribution (L).	Extension (Sardines) Contraction (JM) Extension (BM) Extension (SS) Extension (BS) Contraction (Redbait) Extension (Anchovy) Contraction (YTS)
Snapper	Increases in abundance in N and E Tas, distribution appearing to shift southward (Last et al. 2011) (M)		Extension
Southern bluefin tuna		Southward shift in core distribution. By 2100 it is predicted that suitable habitat would move further south by ~450 km on the east coast and ~ 390 km on the west coast (Hobday 2010) (M). Increases in upwelling in SA may increase food availability (small pelagics) in important foraging grounds (L).	Extension
Southern calamari		Increases in temperature may lead to shorter embryonic development resulting in smaller hatchlings (Steer et al. 2002; Steer et al. 2003), and subsequently smaller adults. May lead to reduced fecundity and increased hatchling mortality. (H) Changes in the distribution of spawning habitat (seagrass) may lead to	Contraction

		changes in the spatial patterns of spawning (H?)	
Southern garfish		Populations are under stress due to exploitation. Highly vulnerable to environmental change that might result in poor recruitment, even over a few consecutive years (H). Any loss in seagrass due to climate change will impact abundance (H).	Contraction
Southern rock lobster	Habitat loss (macroalgae) along east coast Tas due to increasing temperatures and range expansion of the sea urchin *Centrostephanus rodgersii* (Ling 2008) Johnson et al. 2011. (H) Increase in growth rates in SW Tas over past 15 years (Pecl et al. 2009) (H) Decline in puerulus recruitment in E Tas over past 15 years, which is correlated to SST (Pecl et al. 2009) (H) A delay in the timing of settlement in NE Tas (Pecl et al. 2009) (H)	Increase in predator abundance (octopus) (Pecl et al. 2009)(L) Southward range shift of the eastern rock lobster from NSW, may compete with SRL (Pecl et al. 2009)(L). Range extension of another octopus predator (*Octopus tetricus*) may result in additional predation pressure.	Contraction
Spanner crabs	Southward range expansion into NSW associated with the EAC and transport of larvae		Extension
Striped marlin		Southward shift in core distribution. By 2100 it is predicted that suitable habitat would move further south by ~450 km on the east coast and ~390 km on the west coast (Hobday 2010) (M). Spawning grounds and times may change with increasing temperatures (L) Contraction of depth range due to increased stratification (Bromhead et al. 2004; Prince and Goodyear 2006), may increase susceptibility to fishing (L)	Extension
Tunas, other – yellowfin, bigeye		Southward shift in core distribution. By 2100 it predicted that suitable habitat would move further south by ~450 km on the east coast and ~390 km on the west coast (Hobday 2010) (M).	Extension
Western king prawns		Elevated temperature may increase period for growth and reproduction in SA (M) Recruitment to the West Coast Fishery (SA) may be negatively affected by an increase in the frequency of upwelling events associated with El Niño (Carrick 2007). Influxes of cold water may adversely affect reproductive capacity and larval development.	Extension in gulfs, contraction on West Coast
Yellowtail kingfish	Have increased in abundance in S Tas, appearing to shift southward (Last et al. 2011) (M)		Extension

Table 1.7: Summary of key climate change drivers, current and predicted, outlined in descriptive analysis. Relative level of impact: **high (***)**, **medium** (**), **and low** (*). '?' indicates a high level of uncertainty.

Species or species group	Temperature	Salinity	Upwelling	Winds & currents	pH	Nutrients/ plankton	Freshwater flows	Biological
Abalone	***				***?			*** sea urchins & pathogens
Australian salmon	*			***	*?			
Black bream	*	*			*?		***	* yellowfin bream, HABs
Blue grenadier	**?			*	*?			
Blue swimmer crab	***	***			*?			
Commercial scallops	**?				***?			
Eastern king prawn	**	*?		**	*?		**	
Flatheads	*	*?		*	*?	*	*	* seagrass
Gummy shark	*?				*?		*?	
King George whiting	**			**	*?	**?		** seagrass
School prawn		*?			*?		***	
Small pelagics	***		***	***	*?	***		** **jack mackerel:** krill
Snapper	**			**	*?			
Southern bluefin tuna	**		***	*	*?			** small pelagics
Southern calamari	***	*			*?			* seagrass & macroalgae
Southern garfish					*?			*** seagrass
Southern rock lobster	***			**?	*?			*** sea urchins, macroalgae, octopus, ERL
Spanner crabs	**			*	*?			
Striped marlin	**			**	*?			
Tunas, other	**			***	*?			
Western king prawns	***	*	***	*	*?			
Yellowtail kingfish	**			**	*?			

Qualitative risk assessment to rank sensitivity of species to climate change

Analysis at the attribute-level

Overall, no species were classed as extremely high or low risk (e.g. all scores at 3 or 1), with averaged scores for each attribute ranging from 2.75 to 1.25 (Figure 1.1) from a possible range of 3 to 1. The abundance attribute showed the least resolution between species with only four unique scores generated for the 35 risk assessments. The distribution attribute showed the highest level of resolution, with seven unique scores, showing the greatest amount of variation among species, with risk assessment scores ranging from 2.75 to 1.25. In terms of abundance, all 35 species were relatively low risk, with only three species receiving a score of <2 (mean: 1.61 ± 0.04). On average, species were most at risk in regards to phenological attributes (mean: 2.11 ± 0.05). There was no significant correlation between any attribute pair (i.e. A&D, A&P, D&P) indicating each attribute was independent from the other two and provided additional information to the analysis.

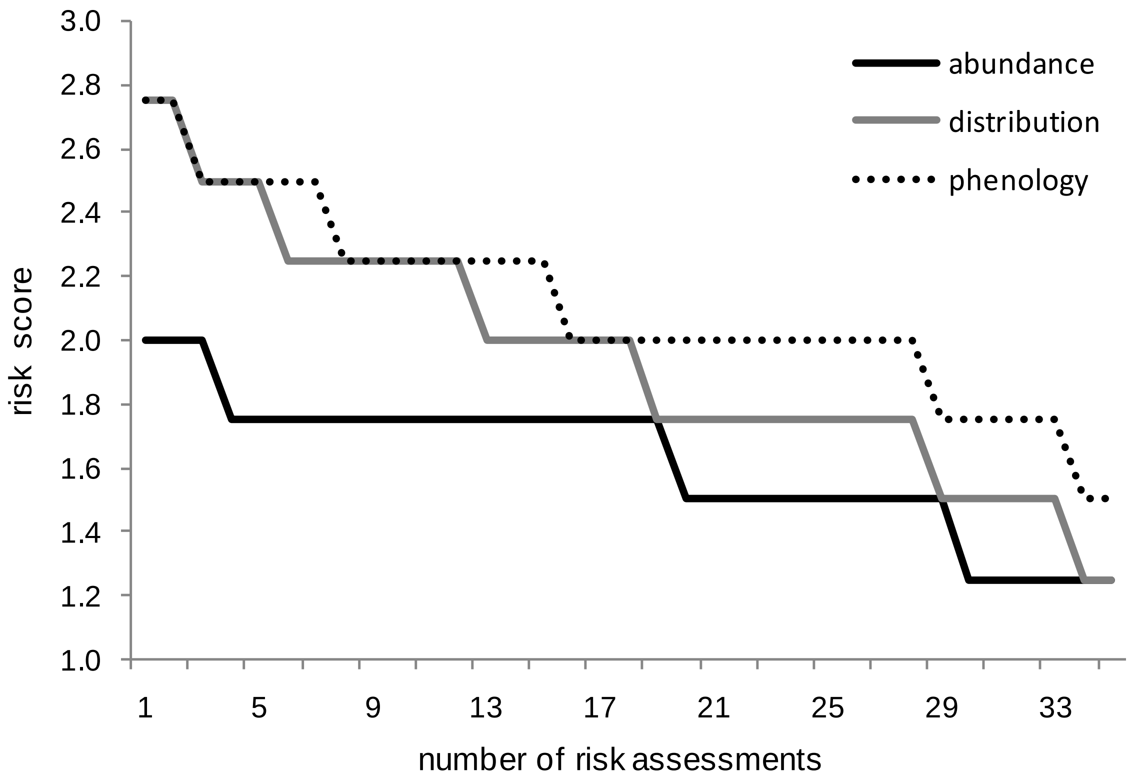

Figure 1.1: Risk scores plotted from highest to lowest for each of the three attributes. 3 = most sensitive/high risk, 1 = least sensitive/low risk. See table 3 for the criteria used to define each attribute.

Analysis at species-level: Abundance, distribution and phenology

Abundance: The abundance attribute grouped species into four discrete levels (Figure 1.3). Black bream, blue grenadier and gummy shark were ranked the most sensitive or high risk in regards to abundance; in other words, their capacity to increase in abundance is comparatively poor. A diverse range of species, from abalone to snapper, were moderately sensitive, while large pelagic, some small pelagic and short-lived crustaceans like prawns and blue swimmer crabs were the least sensitive (i.e. with the greatest capacity to increase in abundance).

Distribution: Scores for the distribution attribute were grouped into seven levels providing additional resolution for ranking (Figure 1.4). The four most sensitive species in regards to distribution were all benthic invertebrates (green and black lip abalone, southern rock lobster and scallops), which, except for scallops, are associated with rocky reefs. Other benthic invertebrates (prawns and crabs) had moderate to low sensitivity. Apart from the large pelagics which were the least sensitive, there was little pattern among species groups. Although 'spatial availability of unoccupied habitat' is a criterion within the distribution attribute, known 'range extenders and range contractors' sometimes remained clustered together (eg. snapper and garfish).

Phenology: The phenology attribute provided six levels of differentiation among the species (Figure 1.5). All three prawn species and one crab species had high risk scores in relation to phenology. In contrast, spanner crabs were positioned at the other end of the spectrum; however, there was a high degree of uncertainty associated with this species. Species groups, such as the small pelagics and flatheads, were also clustered together.

Species overall sensitivity was ranked by summing and ordering the distribution, abundance or phenology scores for the 35 species (1 = lowest sensitivity, 35 = highest sensitivity).

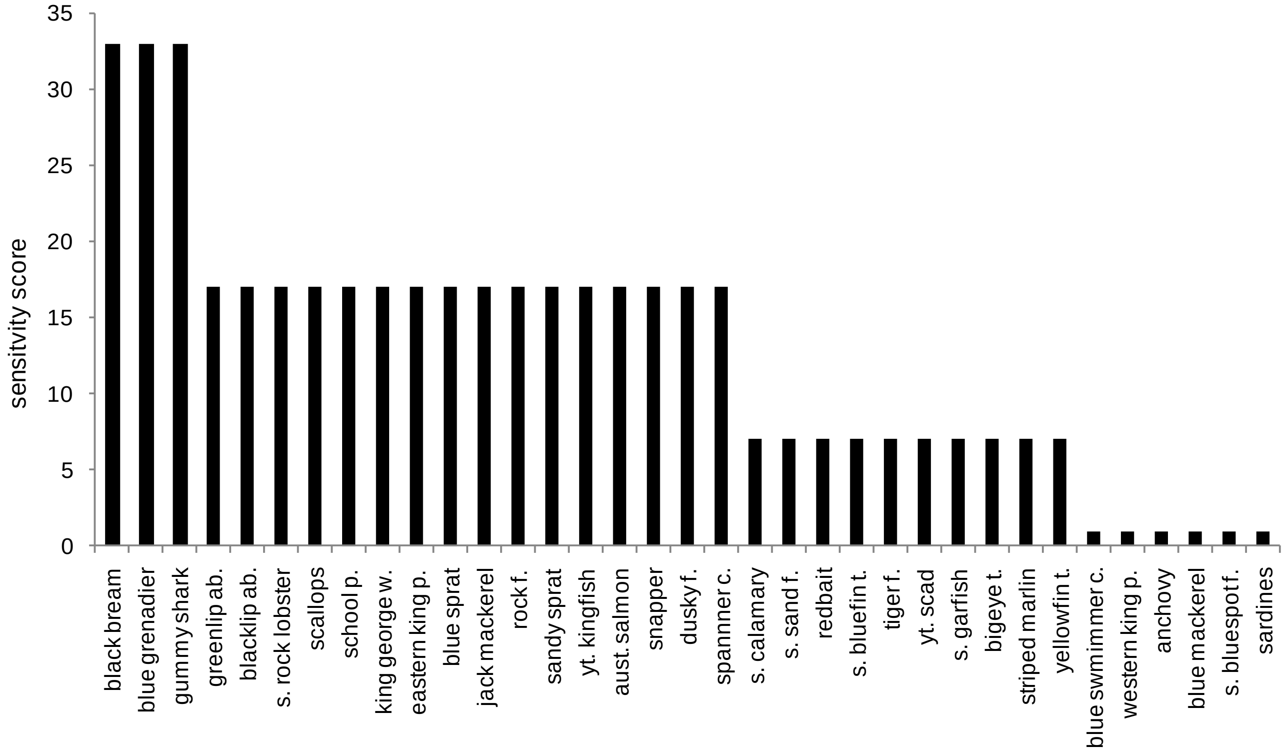

Figure 1.3: Ranking of species sensitivity based on the 'Abundance' attribute. See Table 1.3 for the criteria used to define the abundance attribute; higher score is more sensitive. s = southern, w = whiting, f = flathead, t = tuna, YT = yellowtail, p = prawn

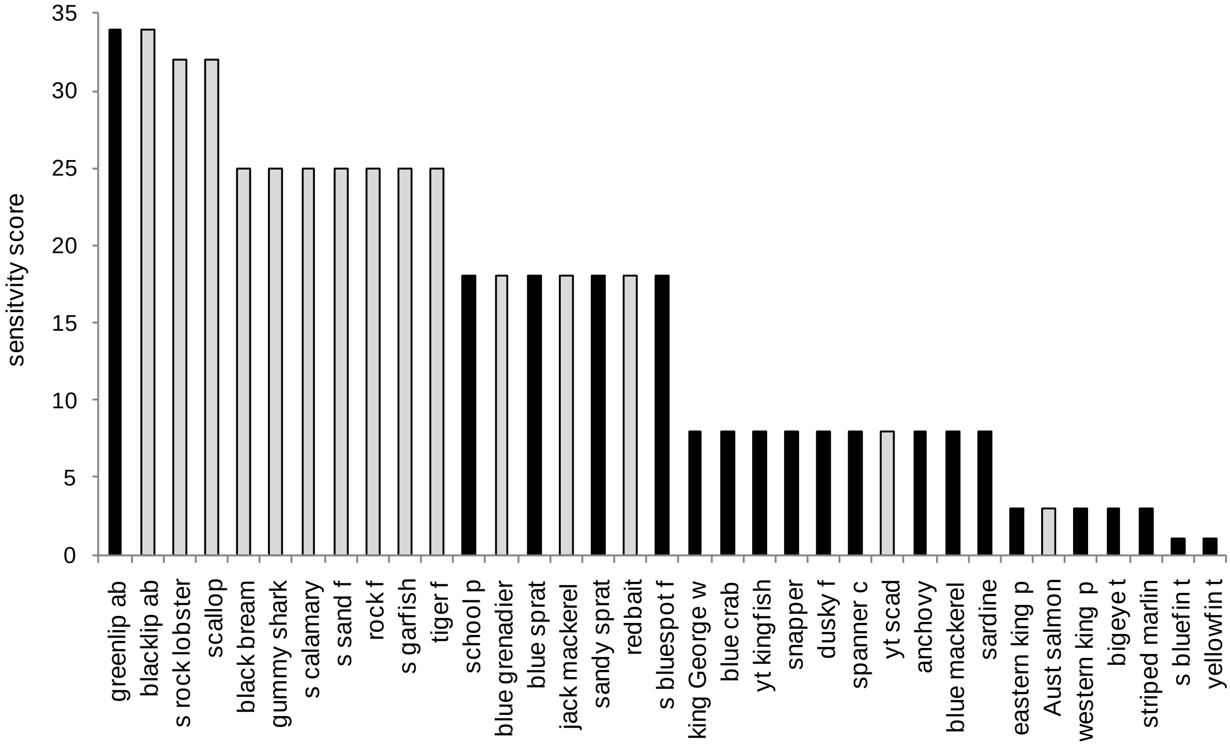

Figure 1.4: Ranking of species sensitivity based on the 'Distribution' attribute. Black columns = species which are predicted to undergo a range extension; grey columns = species which are predicted to undergo a range contraction. See Table 3 for the criteria used to define the distribution attribute.

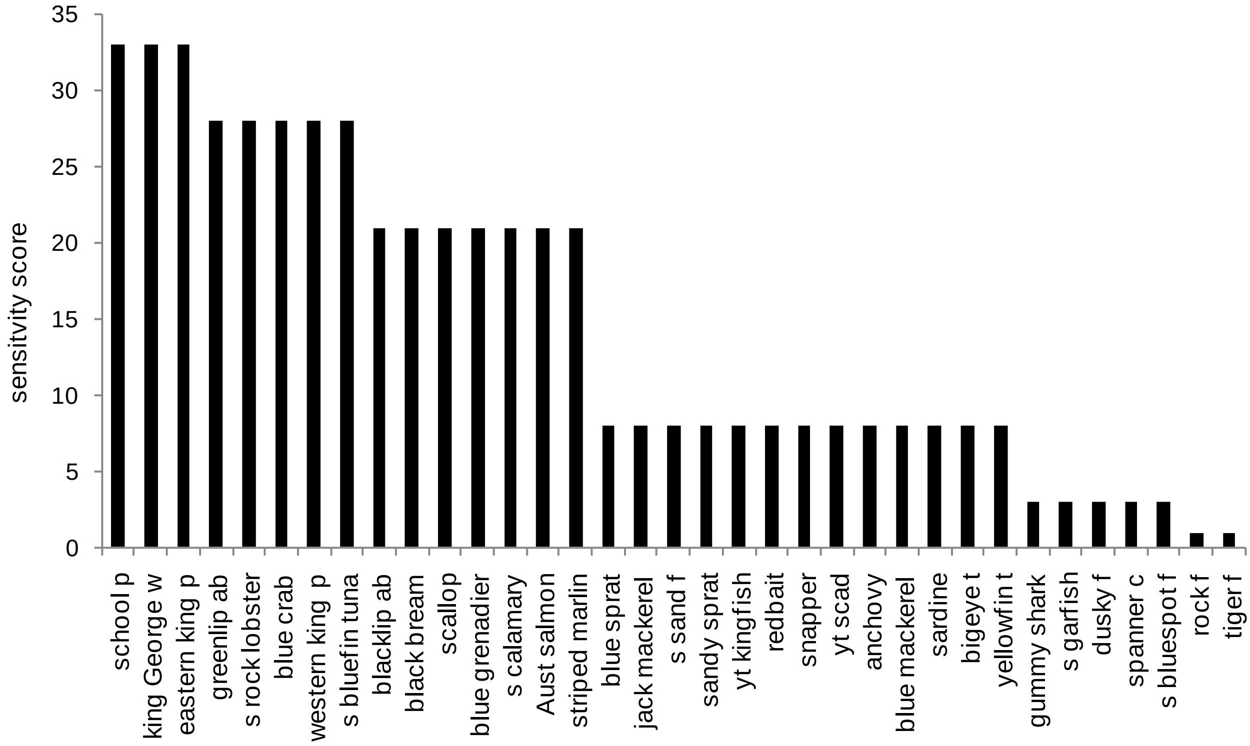

Figure 1.5: Ranking of species sensitivity based on the 'phenology' attribute. See Table 1.3 for the criteria used to define the phenology attribute.

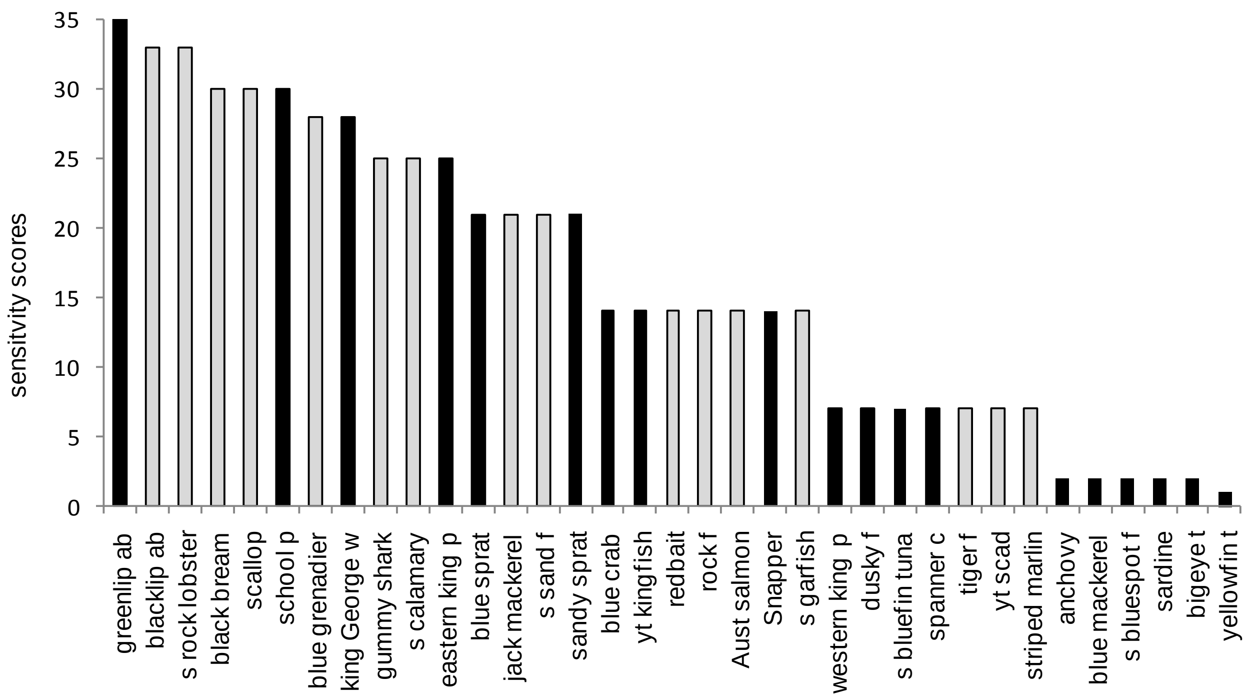

Figure 1.6: Overall ranking of wild capture fishery species based on an average of all attributes (distribution, abundance and phenology). Black columns = species which are predicted to undergo a range extension; grey columns = species which are predicted to undergo a range contraction.

Combining all three attributes of distribution, abundance and phenology, yielded 10 discrete levels of risk (Figure 1.6). Species were allocated a final risk designation, based on splitting the group of 35 species into approximate quarters using clear breaks in the rankings as a guide (see Figure 1.7, Table 1.8). The top eight most sensitive species represent a diverse range of taxa, including gummy sharks, abalone, and prawns, from a diverse range of habitats, including rocky reef, estuaries, and the deep sea (Table 1.8). Several of the species in this high-risk group, such as abalone, southern rock lobster, black bream and King George whiting, are already being impacted by climate change, some with a high degree of certainty (e.g. southern rock lobster). Other species in this high risk group, including scallops and grenadier, were associated with large data gaps and a large degree of uncertainty due the lack of information available to underpin allocation to risk categories. The small pelagic fishes group were generally split into two groups in all the attribute rankings – with the sprats, jack mackerel and redbait, designated as moderately sensitive and the anchovy, sardines and blue mackerel allocated as the least sensitive.

Table 1.8: Mean risk scores for each attribute (A = abundance, D = distribution, P = phenology), and the sum of all attributes combined. Qualitative indication of data availability (high, medium, low) on which risk scores were based is given,. The regional priority (10=highest) and final risk designation of each species is also indicated (* note ranking of regional priorities included aquaculture species as well as commercial fisheries.)

Species	A	D	P	Total (A+D+P)	Regional priority (top 10)*					Data availability
					NSW	Vic	SA	Tas	CW	
HIGH RISK										
Greenlip abalone	1.75	2.75	2.5	7	5	7	6	10		M
Blacklip abalone	1.75	2.75	2.25	6.75	5	7	6	10		M
Southern rock lobster	1.75	2.5	2.5	6.75		9	9	9		H
Black bream	2	2.25	2.25	6.5	4	6				H
Commercial scallop	1.75	2.5	2.25	6.5				7		M
School prawn	1.75	2	2.75	6.5	9					H
Blue grenadier	2	2	2.25	6.25					4	L
King George whiting	1.75	1.75	2.75	6.25		8	7			H
MEDIUM-HIGH RISK										
Gummy shark	2	2.25	1.75	6					10	M
Southern calamari	1.5	2.25	2.25	6		2		2		H
eastern king prawn	1.75	1.5	2.75	6	10					H
Blue sprat	1.75	2	2	5.75						M
Jack mackerel	1.75	2	2	5.75					8	M
Sand flathead	1.5	2.25	2	5.75				4	6	M
Sandy sprat	1.75	2	2	5.75						M
MEDIUM RISK										
Blue swimmer crab	1.25	1.75	2.5	5.5			4			H
Yellowtail kingfish	1.75	1.75	2	5.5	1		1			M
Redbait	1.5	2	2	5.5					8	M
Rock flathead	1.75	2.25	1.5	5.5				4	6	L
Australian salmon	1.75	1.5	2.25	5.5	6	3		3		M
Snapper	1.75	1.75	2	5.5	8	10	8			H
Southern garfish	1.5	2.25	1.75	5.5			3			M
Western king prawn	1.25	1.5	2.5	5.25			4			H
MEDIUM-LOW RISK										
Dusky flathead	1.75	1.75	1.75	5.25				4	6	M
Southern bluefin tuna	1.5	1.25	2.5	5.25					9	M
Spanner crab	1.75	1.75	1.75	5.25	3					M
Tiger flathead	1.5	2.25	1.5	5.25				4	6	L
Yellowtail scad	1.5	1.75	2	5.25						L
Australian anchovy	1.25	1.75	2	5						M
Blue mackerel	1.25	1.75	2	5					8	M
Bluespot flathead	1.25	2	1.75	5				4	6	L
Australian sardine	1.25	1.75	2	5	2		5			M
Bigeye tuna	1.5	1.5	2	5					7	L
Striped marlin	1.5	1.5	2.25	5.25					5	M
Yellowfin tuna	1.5	1.25	2	4.75					7	L

Discussion

Species at risk

Our two-stage approach to identifying and then comparing potential risks to the key commercial species in south-eastern Australia suggested that that the three species that underpin the region's most valuable fisheries – southern rock lobster, greenlip abalone and blacklip abalone – are also the species at the greatest risk to potential climate change impacts. Other species identified as being at high-risk included black bream, commercial scallops, school prawns, blue grenadier and King George whiting. However, catches of almost half of the species considered in this study have declined in recent years. Other stressors that may have been associated with these decreases in catch could also reduce the capacity of these species to cope with effects of climate change. Examples of these additional stressors include: overfishing (e.g. blue grenadier), recruitment failure (southern rock lobster), habitat loss (garfish), degradation of seagrass beds (flatheads and black bream), and pollution in intertidal zones (blue swimmer crabs and western king prawns) or juvenile nursery areas (snapper). In light of major knowledge gaps identified for most species, including environmental tolerances of key life stages, sources of recruitment and population linkages, critical ecological relationships (predator-prey etc), phenological relationships, and likely responses to lowered pH, it would be imprudent to conclude that, from an ecological perspective at least, any species is at low risk to potential climate change impacts.

There was a high level of qualitative agreement between the two stages of the risk assessment that we conducted; i.e. species that were identified as being higher risk in the comparative risk assessment were also identified in the detailed species profiles as exhibiting evidence of current climate change impacts or considered by experts as likely to be affected. Although the two stages of the risk assessment provided similar insights, both stages were essential and caution is needed when interpreting the relative risk levels derived from the comparative framework in isolation. The species-specific information presented in the individual species assessment profiles was a critical input to, and should be considered in conjunction with, the outcomes of the comparative risk assessment. For example, in the scoring presented for all three attributes combined (Figure 1.6), garfish was ranked as a medium risk species. However, the risk assessment does not take into account the impacts of fishing and other factors on population resilience. Garfish habitat has been reduced and the species is overfished throughout most of SE Australia; the resulting truncated age structures probably make garfish more vulnerable to environmental change than identified in the comparative analysis (McGarvey et al. 2009). Similarly, some species which available evidence suggests are already being impacted by climate change (e.g. the five species considered to be undergoing range-shifts with a high degree of certainty), were only classified as medium to medium-low risk in the comparative analysis. Most of these range-shifts would be considered 'opportunities' in the new regions into which these species are expanding. However, our limited understanding of the potential flow-on or indirect effects that range extensions may have in their new environments (e.g. predation on other commercial species, etc) means that this simplistic interpretation should be treated cautiously.

The attributes of distribution, abundance and phenology varied in their value as individual measures for assessing the relative sensitivity of fisheries species to climate change. For example, the abundance scores for the fisheries species considered were consistently high, reflecting the high productivity potential which is a characteristic of most commercially exploited species. As only a few of the suite of fishery species considered in this analysis were at the lower end of abundance potential, this attribute alone provided limited resolution of the relative sensitivity of these species to climate change. Evidence to suggest recruitment of rock lobster may have been reduced by climate change further emphases the value of using information collated in the species assessments to inform interpretation of the assessments of relative sensitivity.

The greater variation observed in distribution scores compared to abundance scores may reflect the wider range of traits that underpin the distribution attribute. The major existing impact of climate change documented in this report, and the most consistently predicted impact in the individual species assessments, was a change in distribution. Five of the eight species identified as high risk have ranges that are expected to contract with ongoing climate change, whereas three of the species are considered likely to undergo range extensions. However, some species with a high potential for range shifts will be negatively impacted as the amount of suitable habitat is reduced (e.g. species that can only contract due to a lack of suitable habitat south of Tasmania); others in this category may represent opportunities as they shift from sub-tropical regions further south to Victoria, Tasmania and parts of South Australia. Thus, it is important to note that designation as high risk or high sensitivity to changes in distribution does not automatically imply negative consequences if other stressors can be managed (e.g. fishing, pollution) and critical life history or ecological process (e.g. predator-prey relationships) are not impacted negatively.

Understanding the factors that limit species' geographical ranges is a central aim of both ecology and biogeography – and is now more important than ever. Unravelling the determinants of both stable and unstable range limits requires consideration of individual physiology, behaviour, population dynamics, community interactions and ecosystem feedbacks. The complexity of marine systems and the often large data requirements for comprehensive quantitative models, suggests that qualitative modelling may be needed to generate greater understanding and test key ecological relationships and linkages. Range shifting fish species tend to have smaller body sizes, faster maturation and smaller sizes at maturity than species with stable range boundaries (Perry et al. 2005). Species that successfully extend their distributions (i.e. range shifting species) also commonly have traits of successful introduced species, such as competitive and predatory superiority, life histories with short generation times and broad environmental tolerances (see summaries in Lodge 1993; Rejmánek and Richardson 1996; Vermeij 1996; Kolar and Lodge 2001). There are some indications that specialists and generalists are more prone to contractions and expansions, respectively (Rivadeneira and Fernández 2005). Obligate interactions such as specialist mutualists and predators will be subject to stronger impacts from climate change.

Phenology scores indicated greater sensitivity to climate change than the abundance or distribution attributes. This may be because the experts to tended to score phenology attributes as more sensitive in the face of the uncertainty stemming from the lack of information available for most species. Changes in the timing of life cycle events may be very important because the level of response to climate change drivers may vary across trophic levels - resulting in mismatches between predator and prey for example (Edwards and Richardson 2004). If current patterns and rates of phenological change are indicative of future trends (Thackeray et al. 2010), trophic mismatching may disrupt the functioning, persistence and resilience of many ecosystems and increase the risk of population extinctions. Temperate marine environments may be particularly vulnerable to phenological changes as recruitment success of higher trophic levels is usually dependent on synchronization with planktonic production (Edwards and Richards 2004). Resolution of the mechanisms and drivers underpinning rates of phenological change is crucial to projecting the impacts of these changes and should be a focus of future research (Thackeray et al. 2010).

Possible phenological responses to climate change (e.g. mismatches between predator and prey) are examples of potential 'deal breakers' – where the response of one attribute of a species or population may over-ride any other capacity to cope or respond positively to climate change. With the data available at hand for the species examined, it is not possible to consider where such responses are likely, adding uncertainty to our analysis. Likewise, it is not possible to include in our risk assessment a consideration of where and how climate change may lead to crossing of ecological thresholds. In addition to incremental or linear responses to climate change, small changes in physical parameters can elicit major responses when a threshold is crossed (CCSP 2009). An ecological threshold is the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon, or where small changes in one or more external conditions produce large and persistent responses in an ecosystem (Groffman et al. 2006). Sudden changes to ecosystem structure or function are not well understood, and therefore not usually predictable.

The application of more complex analytical approaches, for example differential weighting of individual attributes in the risk assessment using pair-wise comparisons within an Analytical Hierarchy Process (Saaty 1980), was considered during the course of the project. In this approach an attribute such as 'capacity for larval dispersal' could be weighted more heavily than 'adult movement range', or vice versa. Uncertainty in the relative importance of different attributes for each species precluded differential weighting of attributes. However, other techniques to make the risk assessment more robust, such as bootstrapping, could be included in future assessments although it was considered beyond the scope of this preliminary assessment to add this level of complexity. In the absence of information on the relative importance of our measures of sensitivity (abundance, distribution or phenology) across all species, our sensitivity scores for abundance, distribution and phenology were added to obtain a cumulative overall score for sensitivity. An alternative approach could be to look across the values for all three measures of sensitivity and take the score that indicates highest sensitivity (e.g. greenlip abalone was allocated 1.75 for abundance, 2.75 for distribution and 2.5 for productivity, giving this species a maximum sensitivity score of 2.7). Assigning species with a score of say, 2.5 or over, as high risk would have resulted in eastern and western king prawn, blue swimmer crab and southern blue fin tuna being included in the high risk group and black bream, commercial scallop and blue grenadier (currently designated as high risk) being re-allocated to the medium-high risk group.

The main weaknesses of the approach taken in this risk assessment were 1/ the simple additive nature of the approach (i.e. it does not account for the possibility of 'game breakers'); 2/ incomplete consideration of possible variations in exposure across species and/or sub-regions; and 3/ difficulties incorporating vulnerabilities to climate change related 'surprises' (see also ecological threshold discussion above). For example, around 15% (350 t) of the Tasmanian catch is obtained from a relatively restricted reef area along approximately 30 km of the coast (the Aceteons in Tasmania). Similarly, a single reef in Spencer Gulf (Tippara Reef) produces approximately 100 tonnes of greenlip abalone per year. If an unexpected event occurred in such an area (e.g. a disease outbreak) then the impact on the region's fishery production and value would be large. The approach taken in the current risk assessment has captured species sensitivity to climate change based on attributes that we know enable species persistence in the face of incremental environmental and ecological changes. However, it is quite possible that south eastern Australia will experience changes to the system that challenges species persistence in ways that we do not yet understand and cannot predict.

Ecological risk assessment can play an important role in natural resource management based on adaptive principles (see http://www.environment.gov.au/ssd/research/ecol-risk.html). However, predicting ecological responses to environmental changes is challenging and predictions are necessarily laden with caveats. Workshop discussions and broader consultation indicated that there was a high degree of confidence among participating scientists that the assessment methodology developed in this study was applied consistently across the 22 fishery species and species groups and provided a robust approach for comparing the relative risks to climate change. It seems likely that the methodology developed here would also be suitable for application to other species and/or regions. Analysis of ecological risks within a strategic framework does not eliminate the potential for controversy, but it does provide transparency and the process can be repeated as more information becomes available. Indeed, the iterative nature of risk assessment means that results are ideally updated periodically as new knowledge is generated and/or more monitoring is done. Risk-reduction strategies developed from this improved understanding can play an important role in best-practice natural resource management.

Key gaps in knowledge

Gaps in our current knowledge and areas where additional data are required to either achieve a more thorough assessment of potential risk, or to constructively inform adaptation planning, are listed in Table 1.9.

Where feasible, we also identify potential data sources and/or analytical tool developments that would be required to address these gaps. This table should be viewed as a starting point to elicit the wider feedback necessary from regional managers, scientific experts, and importantly, stakeholders, to collaboratively develop the best approach that could be taken to address each particular data or knowledge gap. Additionally, this table addresses physical and ecological gaps only and future adaptation planning would benefit from concurrent consideration of social, economic and governance issues.

Table 1.9: Identified critical knowledge or data gaps for south-eastern Australian commercial fishery species generally and the eight highest risk species specifically. Indications of the magnitude of the task required to address knowledge or data gaps are approximate and should be used as a general guide only.

Knowledge gap	Benefit for future adaptive planning	Methodology or data required	Indication of potential project magnitude
Physical environment			
Likely changes in current systems, particularly the region where knowledge is weakest, from south east South Australia to southern Tasmania	With potential changes in currents, dispersal of some species, especially those with extended or long ranging planktonic larval phases, may be enhanced in regions where warming alone might cause recruitment decline. Currents and upwelling events are likely to lead to water temperature changes with associated impacts from species to ecosystems. Understanding the change in dispersal patterns will assist in identifying source and sink areas for populations, which will aid spatial planning (for example fishery management tools).	Dispersal modelling using outputs from nested regional climate models (e.g. Bluelink) nested in future Global Climate Model (GCM) runs.	6–12 month desktop analysis of existing data products (Bluelink nested in 2060s, for one scenario), although generating several future scenarios would be advisable.
Likely changes in regional upwelling	Productivity may be enhanced in some regions, which could allow increased harvest of some species. This could allow adaptation strategies such as effort shifts from fisheries/species that are likely to be negatively impacted.	Examination of models nested in future GCM runs, as for current systems. For South Australia, this could include SAROM or Bluelink, and for other regions this feature is identified in Bluelink future projections.	A 3–6 month desktop analysis of existing data products (Bluelink nested in 2060s, for one scenario), although generating several future scenarios would be advisable. SAROM – would require coupling with GCM and validation stage, 12 months.
Multi-species			
Potential impacts of lowered ocean pH, particularly molluscs and larval stages of all commercial species. Impacts on calcareous phyto- and zoo-plankton and the disruption of food chains and associated productivity.	Impacts of lowered pH appear to be very species specific with some species potentially majorly affected and others less so. Lowered pH can impact physiological processes like calcification and respiration. Ultimately, broader pH impacts are likely to override regional temperature responses.	Empirical studies on physiological responses under varying pH, including interactions with other climate change drivers such as temperature.	Large 3–5 year laboratory research program per species.

Source of recruits to major fishery regions– population linkages and connectivity, dispersal of larvae	May result in adaptation strategies that provide greater protection of regional sources of larvae. Greater variance in dispersal abilities among interacting species will lead to more broken linkages and novel interactions – understanding linkages and dispersal will assist in assessing future risks to species persistence.	A combination of bio-physical modelling of larval transport processes and DNA or chemical marker research to directly establish connections between key population units.	Large-scale multi-year modelling and field program per species.
Establishment of good ecological indicators to detect changes in patterns and trends within ecosystems	Imperative we develop a greater understanding of what specific ecosystem components to monitor to elucidate changes in ecosystem structure and function to inform management. Need to consider cost-benefits in selection of ecosystem indicators	Large-scale and long-term regional monitoring of key commercially and ecologically important species. Evaluation of new and novel methods for monitoring ecosystems including biochemical tracers and image capture.	Collaborative and on-going investment in scientific and stakeholder monitoring of key species distributions or ecosystem variables.
Direct and indirect flow-on consequences of range shifting species moving into new ecosystems	What new species characterise an 'opportunity' versus a 'threat' may not be intuitively apparent – understanding how a new species will operate within an existing ecosystem will help avoid potentially maladaptive management responses.	Quantitative and complex ecosystem models could be one approach; however, many key interactions would be adequately captured and explored with inexpensive qualitative models. Both approaches depend on a good understanding of ecological and trophic linkages (see point below).	Quantitative: large-scale multi-year modelling projects by research team. Qualitative: one year desktop investigation supported by expert workshops.
Key ecological and trophic linkages, trophic importance of species	Specific structure of food webs and position of species in this structure will control the degree to which species risk extinction through direct and indirect effects. For instance, less diverse food webs should be more susceptible to climatic iterations. Ultimately, accurate predictions for patterns of biological diversity under warmer conditions will require a more sophisticated understanding of the realized niche and food web interactions in theoretical and empirical research.	Predator-prey relationships and the importance of trophic linkages can be examined using a variety of methods including immunological techniques, DNA dietary analysis, direct observations of foraging behaviour, and chemical tracers such as stable isotope and fatty acid analyses.	1 year desktop analysis to synthesise known information, followed by large-scale multi-year program to examine linkages in key systems, e.g. inshore reefs, inshore waters, pelagic system, soft-bottom habitats, deep water systems.
Environmental tolerances of larval stages	For most species we do not understand the tolerances and sensitivities of key life stages,	Empirical laboratory studies to examine physiological tolerances to temperature,	Once a dedicated environmental laboratory system has been

	particularly larval stages. The lack of quantitative data prevents estimation of dispersal rates and potential for successful establishment in new environments.	salinity and pH.	established and larval production methods are available, environmental tolerances will be achieved relatively quickly (months for each species).
Influence of environmental parameters on spawning and recruitment	Environmental factors like temperature, salinity, feeding conditions for larvae and predation of eggs and larvae, result in considerable recruitment variability	Statistical analysis and modelling using spatial and temporal data on stock and recruitment indices and environmental parameters. Longer time-series of data needs to be utilised as the risk of spurious correlations increases if a large number of environmental variables are tested and time series are short. For relationships to be most useful in a predictive context, statistical relationships need to be developed with mechanistic understanding.	1-2 year modelling project per species, informed by comprehensive empirical data on thresholds and tolerances.
Phenological relationships of key species	This is a significant knowledge gap as changes in phenology are critically important, species' life cycles are interconnected and changes in the timing of the life cycle of one species can affect many others, potentially resulting in an asynchrony between dependent species (i.e. decoupling of phenological relationships).	A challenge in phenology studies is understanding what constitutes background variation vs. phenological change. Unfortunately, phenological changes are not easily observable in marine systems and long term datasets are generally lacking in Australia. For a robust approach to detecting long term phenological change, full time series, not just dates of specific events (e.g. peak spawning) is required.	Time series analyses if data is available.
Emergent diseases and stress indicators	While it is unlikely that diseases can be predicted, it is likely that increased stress on animals due to either rapid changes in environmental conditions (i.e. inability to adjust to change) or prolonged exposure to sub-optimal conditions could lead to outbreaks of disease.	Development of techniques to monitor stress (e.g. endocrine, DNA) and routine sampling of animals at the fringes of their distributions for increased incidence of diseases	Requires evaluation of generic as well as species specific methods. Possibly 1–2 years per species.

Southern rock lobster			
1) Improved knowledge of the variability in temperature and currents from southern Tasmania to south-eastern SA. This should also include variability in bottom temperature with depth.	1) Improved understanding of the currents and temperature is required to enable predictive modelling. Downscaled climate models use SST as the predictor. An understanding of the linkages between SST and bottom temperature throughout the species range will enable improved assessments of likely growth responses to climate change drivers.	1) Some work is currently underway (Matear – CSIRO and Middleton – SARDI) but there is a need for observational data. Unfortunately IMOS is limited in the western and southern regions of Tasmania and alternative cost effective ways of collecting the data is required.	1) Observational data will require at least 3 years and should be on-going if possible.
2) Improved knowledge on the response to temperature including growth, selectivity and recruitment. This should include the rate of temperature change as experienced in upwelling systems.	2) This follows on from (1) and enables the outputs from (1) to be used to predict changes in the regional productivity of the resource in response to climate warming.	2) This research would involve a combination of both laboratory (aquarium) and field trials. Recent advances in tagging and tag models could be used for the field program.	2) Potentially 3-5 years for field research and 1-2 years for laboratory work (can be done simultaneously)
3) Increased understanding of the fleet dynamics so that effort distribution can be predicted as productivity of regional biomasses change.	3) Fleet dynamic models that incorporate economic variables have been developed for the Tasmanian rock lobster fishery (QMS – PhD project) and should be incorporated into the Vic and SA fisheries models.	3) Primary need is access to fisher/vessel catch records and improved individual vessel economic data. Tasmanian fleet dynamics model can easily be incorporated into regional lobster model.	3) 1-2 years to collect data and 6 months to populate regional fleet dynamics model and link to assessment model.
4) An understanding of predator-prey relationships with an emphasis on octopus, although new range extending species (e.g. snapper) that are known lobster predators need also to be considered	4) Rock lobster mortalities in traps have shown a positive increase with rising temperatures. With diminishing lobster stocks, this source of mortality could become significant. Understanding whether the increased mortality is due to larger populations of octopus or increased frequency of predation by the existing population is required. Similarly, the predation of lobsters (all settled life history stages) by octopus needs to be determined. Mortality needs to be incorporated into assessment model.	4) This could be achieved through the use of molecular dietary techniques (predation outside traps). Understanding population changes with temperature will require regional field projects.	4) Field work, which should include dietary analysis, should take 3-4 years.
5) Dispersal patterns of larvae, source of recruits and drivers of puerulus settlement (see multi-species section above)			

Blacklip & greenlip abalone			
1) Improved knowledge on the impacts of increasing water temperature and water column stratification on the growth, emergence and mortality of abalone.	1) There is increasing evidence, including fisher observations, that blacklip abalone are more productive in cooler waters. Recent "die-offs" have occurred in shallow waters in southern Tasmania during periods of continuously still days. Understanding the probability of these events occurring (hot still days) and the longer-term productivity of stocks will become an issue for assessment and sustainability of future harvests.	1) Data from BOM for predictive modelling of hot still days (link with Climate Future Tasmania project). Empirical field studies on effects of temperature on growth, emergence and mortality (however see recently completed QMS PhD project on abalone growth).	1) Predictive modelling – 6 months. Field studies – 3 years (possibly through PhD project).
2) Improved understanding of the prey requirements (algae) of abalone and how these are impacted by declining nutrients associated with an increasing EAC.	2) Southern Tasmania is the most productive fishing region for blacklip abalone. This region is high in primary productivity due to the influence of nutrient rich southern ocean waters mixing with warmer EAC waters – the sub-tropical front. This mixing zone is predicted to move further south as the EAC increases in southern penetration and magnitude. Understanding the linkages between these nutrient rich waters, primary production (benthic algae) and abalone diet and productivity will assist in the longer-term prediction of future harvests.	2) Studies on abalone diet (within and between regions), including studies on the productivity of the diet (i.e. algal species) under differing temperature and nutrient regimes.	2) Abalone diet – 1–2 years, algal productivity 1–2 years.
3) Effects of elevated temperature on biology (e.g. growth, reproductive timing and success, larval survival).	3) Assists in the prediction of changes in regional productivity in response to warming	3) Data on relationships between growth, reproduction, larval survival and temperature	3) Large field and laboratory research program.
4) The potential impact of invasive and range-extending species, and disease.	4) To determine allowable harvests all forms of mortality need to be understood.	4) Link with MPA and reef surveys to obtain data on the frequency of invasives. Link with DNA abalone marker to determine dietary intake. Routine sampling, especially at fringes of populations for increases in disease frequency.	4) Disease sampling should be routine (e.g. every [say] 3 years). Surveys for invasive and range extending species should be undertaken at increased frequency if these animals are noted through other

			existing programs (REDMAP, Reef Life Surveys, MPA monitoring etc)
5) Potential impacts of increasing ocean acidification on abalone, which has shown to have negative impacts on other marine calcifiers (see multi-species section above)			
Black bream			
1) Black Bream complete their life cycle within estuarine environments, and they rely on specific physico-chemical conditions (i.e. salt wedge formation) to trigger spawning and facilitate larval survival. Understanding of the environmental flow requirements for maintaining a sustainable black bream population in important estuaries in south eastern Australia is required.	1) An improved understanding of how reliant black bream populations are on environmental flows in a range of estuary types. If black bream life cycle requirements are understood for key estuaries, then guidance for optimal freshwater flows regimes for enhancing bream recruitment could be provided. Guidance could also be provided for expectations on future recruitment strength based on predicted climate change scenarios.	1) Examine physico-chemical profiles and black bream populations from a range of estuaries across south eastern Australia. Time series of year-class strength, freshwater flow and salinity stratification could be analysed to determine if the strong relationship found in the Gippsland Lakes also applies in other estuaries. Years where estuaries show high stratification would be expected to result in strong year-class strength, but strong years will vary between each estuary depending on their unique characteristics.	1) 2 year desktop and field based assessment
2) Key habitat conditions essential for survival and growth of juvenile black bream. The relationships between stratification, flow, key habitat availability and recruitment in estuaries is unknown. It is likely to vary substantially depending on the specific physical features of the estuary.	2) An improved understanding of habitat needs for black bream for incorporation with environmental flow requirements	2) During spring, examine densities of black bream eggs/larvae in a range of estuary types. A comprehensive post-larvae sampling program across a range of potential settlement habitats and examination of isotopic signatures of larvae would determine their reliance on each habitat type (i.e. refuge and/or food source)	2) 3 year field research project
Commercial scallops			
1) Impact of ocean acidification on *Pecten fumatus*. Acidification has been reported to affect larval survival and development in another species of scallop	1) It will be important to investigate the effects of acidification on *Pecten fumatus*, so that adaptation responses can be developed accordingly. Lowered pH can	1) Empirical studies on physiological responses under varying pH, temperature and salinity ranges.	1) 3 to 4 year laboratory project

	impact physiological processes like calcification, respiration and larval survival.		
2) Influence of environmental factors on basic biological parameters (growth, reproduction, recruitment)	2) Lack of knowledge on the relationships between biological parameters and physical climate change drivers limits the capability of modellers to predict the impacts of climate change on scallops, and thus the industries' ability to mitigate and adapt to impacts.	2) Examination of historical records on basic parameters such as growth if available, to determine any correlations with climate change trends.	2) Requires both field and intensive laboratory research
3) Understanding the impacts of climate variability and exposure on health and condition of scallops. There has been recent substantial "die offs" and the cause is unknown. Increased winter temperatures are considered to be a possibility	3) Understanding the links between condition and environmental variables could provide predictions on the timing and spatial allocation of harvests	3) Development of stress indicators followed by empirical studies on environmental conditions and stress.	3) 1-3 year project for development of stress indicators followed by 1-2 year project that includes both laboratory and field studies
4) Larval dispersal patterns and population structure (see multi-species section)			
School prawns			
1) Understanding of the impacts of environmental flows and altered current systems on the recruitment and early life survival of prawn sub-stocks associated with each of the major estuaries fished (given adult school prawns do not migrate far from the estuary they leave when they enter the ocean).	1) Understanding of the impacts of climate related variables on the recruitment and early-life survival of prawns at the sub population level could significantly improve the confidence in the outcomes of available models (Ives et al. 2009).	1) & 2) Initial study to relate environmental changes to harvests. Predictive modelling of the potential for environmental change (e.g. see Climate future for Tasmania project) in the future.	3 to 5 year project requiring both field, laboratory and modelling research
2) Impact of change in environmental variables on the catchability of school prawns by different harvest methods	2) Given that these populations are known to school at specific stages in their life cycle, understanding of the environmental drivers for schooling and its resultant impact on catchability at different life stages is required.		

Blue grenadier			
The proportion of mature fish that spawn each year is unknown. Recruitment seems to have a regular pattern, with strong year classes recruiting every few years. However, the drivers for these strong recruitment years are unknown.	It is essential to determine how key climate change drivers effect recruitment patterns and annual spawning migrations to assist in developing predictions of stock biomass.	Examine historical relationships between recruitment patterns and climate records. Develop a correlative model to establish a statistical relationship between climate change drivers (e.g. temperature) and recruitment.	2 year project involving desktop analysis and modelling
King George whiting			
1) Recruitment sources for King George whiting, and establishing movement and migration patterns.	1) This will provide a basis for determining how King George whiting stocks are likely to respond to change oceanic conditions linked to climate change projections. The fishery is cross-jurisdictional and distribution of stock may alter under climate change.	1) In conjunction with improved oceanographic understanding, otolith micro-chemical analysis could be used to determine the origin of fish to support model outputs, and could also be combined with ichthyoplankton (fish egg and larvae) studies.	1) 3 to 5 year project requiring both field, laboratory and modelling research.
2) Determine if the link between juvenile whiting and seagrass is direct or indirect (ie. via the detrital pathway).	2) Although relationships between KGW and seagrass are well understood in the early post-settlement stage, knowledge of linkages between older juveniles and seagrass is poor but necessary to understand the consequences of future changes to seagrass under climate change.	2) Under water video deployment to determine the depth of seagrass preferred by different age-classes of juvenile King George whiting. Otolith microchemistry analysis (as above) would help determine the areas of seagrass that are most important for producing juvenile King George whiting and stable isotopes analysis would allow assessment of the relative importance of the seagrass-based food chain in comparison to other primary producers (e.g. algae) in different areas.	2) 2 year project requiring both field and laboratory analysis. .

Research priorities and issues for further investigation

High priority, immediate issues

Improved predictions for the physical environment off the south coast of mainland Australia and the west and south-west coast of Tasmania

Relatively robust projections are available for changes in the physical environment along the east coast of Australia (SST increases, extension of EAC), whereas there are few projections for the south coast (western Tasmania, western Victoria and eastern South Australia). Oceanography of the southern coast is highly complex; e.g. intrusion of the Leeuwin Current, and the large upwelling system (Flinders Current) which is further complicated by the impacts of westerly winds that can bring cooler nutrient rich southern ocean waters to western and southern Tasmania. Physical changes are unlikely to be simple increases in temperature (except in embayments, such as the SA gulfs, Port Phillip Bay, etc.). A high priority would be to investigate the likely changes in oceanographic conditions in the shelf waters off the south coast (western Tasmania, western Victoria and eastern South Australia) due to variations in the relative influence of the Leeuwin Current, upwelling (Flinders Current) and magnitude and duration of westerly winds. This could be achieved by extending the existing regional model (SAROM) to include western Victoria and western/south western Tasmania. Outputs from GCMs could be used as inputs to the regional model to produce projections for future averages in physical parameters (temperature, currents) under particular emissions scenarios and at various time periods (e.g. 2020, 2050). Linkages with BoM data and existing wind predictions (e.g. Climate Futures Tasmania project) would enhance understanding of the complexity of these currents in driving productivity. This would be particularly relevant for abalone, southern rock lobster and King George whiting.

Southern rock lobster (SRL)

Rocky reefs support the most valuable fisheries in the south-eastern Australian region. SRL is the region's highest value fishery species, occurs in multiple jurisdictions and is likely to be a good indicator of the general health of our reef systems. The majority of SRL biomass production occurs on the south coast of Australia and it is suspected that the south coast is also responsible for the bulk of larval recruits (Bruce et al. 2007). While increasing temperatures due to the EAC are predicted to increase catchability and growth rates in the eastern regions of the fishery, there is some evidence that temperature changes along the western regions of the fishery (e.g. SA, western Victoria and north-western Tasmania) through increased upwelling bringing cooler water onto the shelf, will reduce catchability, growth rates, juvenile survival and/or recruitment (Linnane et al. 2010). There are ongoing monitoring programs including fishery dependent and independent at-sea sampling in each jurisdiction that provide relevant data and a current FRDC project is investigating the implications of temperature-induced changes in population dynamics for stock assessment and fishery productivity.

A recent vulnerability assessment for the east coast Tasmanian rock lobster fishery suggested major impacts would vary latitudinally across the state (Pecl et al. 2009), primarily influenced by changes in the EAC. A high priority would be to investigate the effects of likely changes in temperature, currents and nutrients for the western portion of the fishery from SA to south-west Tasmania on SRL biomass and productivity. Outputs from regional climate ocean models (e.g. temperature) could be utilised as inputs to population models to project likely changes to rock lobster population dynamics and biomass off eastern SA, western Victoria and western Tasmania similar to that undertaken for eastern Tasmania (Pecl et al. 2009). In addition to SST, there is a need to link SST with bottom temperature to determine if SST is an appropriate indicator of benthic and sub-surface conditions. Additional field and laboratory studies may be required to examine the relationship between temperature, growth and survival for all settled stages of SRL.

Abalone

Abalone exhibit complex behavioural patterns, such as aggregating to spawn, that may be affected by temperature and productivity. Recent mortalities in south-eastern Tasmania have been associated with several days of low winds and high temperature (Tarbath, FRAG Report, 2011). Increased periods of calm, hot days during summer may impact on the productivity of abalone in shallow waters. Changes in abalone growth through time have been observed which may result in change in productivity (Tarbath, pers. comm.). The most productive and resilient region of the black lip abalone fishery is in south-eastern Tasmania, which is influenced by nutrient rich southern ocean waters (Harris et al. 1988). Reductions in productivity associated with a declining influence of southern ocean waters (due to a strengthening of the EAC) may adversely impact the productivity of abalone in this region.

As herbivores, abalone are dependent on algae, although the contribution of different species or groups (e.g. reds or browns) and origin (local attached or drift algae) remain uncertain (Guest et al. 2008). Productivity changes may affect abalone through changes in the type (species) and condition of available algae. Understanding the influence of coastal processes and productivity on abalone behaviour and growth and survival are key issues in understanding the impacts of climate change on abalone harvests.

Understanding the likely impacts of ocean acidification on key species

We have virtually no information on the likely impacts of acidification on any of the commercial species in the south-eastern Australian region. This is a significant knowledge gap severely hindering our capacity to assess likely future species-specific or ecosystem-level changes (Langer et al. 2006). The consequences of lowered pH may include reductions in calcification rates and increased physiological stress (Fabry et al 2008). This will obviously affect calcifying organisms and some other species directly but will also have indirect effects on other species through loss of prey. Importantly, lowered pH may also impact non-calcifying species directly – there is evidence to suggest that olfactory discrimination and therefore settlement cues of fish can be severely disrupted under pH levels expected to be reached by *ca*. 2100 (Munday et al. 2009). There is a need for further laboratory studies that examine the effects of acidification on a range of species, under realistic future pH profiles, and throughout the entire life cycle (Kaplan et al. 2010).

Understanding the implications of range extending species

Species of commercial or recreational value that undergo range extensions or shifts can provide new opportunities, but also confer ecological risks to their new ecosystems. There are also social and economic challenges for communities that gain or lose species. Optimising the management and allocation of these resources will be a challenge for resource managers. As range extensions associated with increases in temperature are likely to be a major issue in south-eastern Australia, understanding of ecological implications and management options is a priority.

Understanding the links between climate change, stress and disease

Climate change is expected to increase the range of environmental conditions that species are exposed too. This could be through more prolonged periods of adverse conditions (e.g. elevated temperatures) and increased variability (e.g. more frequent flushing of estuaries, rapid change in temperature in inshore waters). These stressful conditions are likely to make animals more vulnerable to disease, or could impact on the quality or quantity of reproductive output. While conclusive attribution of disease to climate change has not been proven there have been documented increases in the diseases of commercially important invertebrates including lobsters (*Homarus americanus, Panulirus argus*) and abalone (*Haliotis rubra*).

Other considerations for determining research priorities

One approach to utilising the outcomes of an ecological risk assessment is to focus attention on species or groups that are most at risk. However, other factors, including social and economic importance also need to be considered. Issues that may warrant consideration when prioritising species/fisheries for the allocation of limited resources include but are limited to:

- Importance for the region (GVP, socio-economic value/investment, cultural value, recreational value);
- Identified risks which may be amenable to management;
- Likely availability of data available to measure effectiveness of adaptation actions;
- A range of case studies that includes species with different expected responses, for example;
    - Likely decline in local abundance.
    - Opportunities that may arise from an increase in abundance.

    - Likely shift across jurisdictional boundaries.
- Cases where modest advance action could significantly reduce future costs;
- Avoiding investment in species where significant effort may deliver minimal benefit;
- Case studies that include a range of taxonomic or functional groups and/or regions;
- Case studies that include species with potential roles as an ecological indicators;
- Case studies that focus on key aspects of the environment (i.e. current systems);
- Case studies with capacity to illustrate to stakeholders the potential for constructive climate change adaption, particularly given evidence of non-acceptance of climate change by many stakeholders (Pecl et al. 2009).

Focusing on management options

The ultimate focus of the SEAP program is to prepare governments and industry for climate change through the identification of clear adaptation pathways. While there will be a number of species-specific and population-level responses as a function of climate change, three recurring scenarios associated with changes in distribution and abundance which could require management or industry responses were evident:

(1) A predicted decline in resource abundance through declines in recruitment or productivity.

(2) Shifts in resource distribution at both small spatial scales (between fishing communities) and larger scales (over jurisdictional boundaries).

(3) A predicted increase in resource abundance through increased recruitment (any life history stage) or productivity.

Resource managers require knowledge of the types of adaptive responses that can be applied in the three cases above. The risk assessment could be used to identify species with potential as case studies to examine likely solutions and/or pathways to maximise the benefits arising from opportunities.

Taking a systems approach

The risk assessment identified large gaps in basic biological and ecological knowledge of most species. Population responses to climate change are not only going to result from direct impacts. Ecological interactions will also be critical in limiting, allowing or facilitating changes in distribution or abundance. It would therefore be prudent to build a more comprehensive knowledge of our major ecosystems, through research focussing on high and medium risk species within those ecosystems.

Inshore reefs and marine invertebrates

Inshore reefs have been identified as being under immediate threat. High priority species including greenlip and blacklip abalone and southern rock lobster are key components of these systems and there is a strong case for focusing research on this system and these species (see pages 50 and 51).

Inshore waters and continental shelf: finfish

Snapper ($12M) and King George whiting ($8M) are economically important. Both of these species and Australian salmon are also important recreational fishing species. All occur in multiple jurisdictions and are potentially good indicators of ecological health. The key spawning areas for snapper are in coastal embayments, e.g. the SA gulfs and Port Phillip Bay, where water temperatures are likely to increase during the summer spawning period. Spawning and recruitment success may be linked to temperature and predictions of the response to climate change would be aided by understanding potential implications of increases in water temperature on spawning and recruitment success. The SA spawning grounds for KGW are likely to be a critical source of recruits for Victoria and there is the potential for significant phenological impacts if environmental cues for spawning and the timing of currents supporting larval transport cease to align. There are spawning grounds off Western Australia and northern NSW for western and eastern Australian salmon, respectively. Adults migrate to the spawning grounds and larvae are transported to the nursery grounds by the Leeuwin and East Australian Current. Again, there is the potential for phenological changes resulting for mismatch of temperature cues and current systems.

Pelagic system: finfish (tuna and coastal pelagic fishes)

The pelagic system supports the most valuable finfish fishery in the south-eastern region (SBT – $122M). Juvenile SBT migrate into the GAB during each summer and autumn to feed on small pelagic fishes, especially sardines and anchovy. Fisheries for coastal pelagic fishes are of low to moderate economic value, but are among the highest volume fisheries in several jurisdictions (SA, Tas, NSW, Commonwealth). Pelagic community structure is strongly influenced by changes in upwelling strength and productivity, (e.g. shifts in the relative abundance of key species such as anchovy and sardine). Long-term data sets and plankton collections are available for southern Australia and it would be possible to examine the effect of variations in upwelling strength on pelagic community structure and flow on productivity to coastal pelagic fishes.

Soft bottom habitats: invertebrates - spanner crabs, blue swimmer crabs, eastern king prawns, western king prawns, scallops

Invertebrate species from soft-bottom habitats support moderately valuable fisheries in several jurisdictions. However, the key species vary regionally, e.g. spanner crabs, blue swimmer crabs and eastern king prawns of the east coast, scallops off Tasmania and Victoria; blue swimmer crabs and western king prawns in the SA gulfs. The potential of these species to act as regional indicators of climate change impacts in soft bottom environments is unclear. Several species of crabs and prawns have sub-tropical affinities and there is some data to suggest that there have been range shifts and biomass increases within the region, and possibly increased growth rates (potential 'opportunity' species). Some species, e.g. spanner crabs in southern Queensland and northern NSW, may provide good case studies for assessing trans-boundary management issues, underpinned by a desktop examination of changes in the distribution and abundance of soft-bottom invertebrates in south-eastern region.

Deep water habitats (continental slope): blue grenadier

This high risk species is a moderate value fishery ($33M) mainly taken in a single jurisdiction (Commonwealth). The fishery targets the only known spawning ground off eastern Tasmania and there is considerable potential phenological sensitivity as the annual migration to the spawning ground could be temperature related. There is a need to understand the effect of environmental factors on recruitment variability and success as there is little understanding of larval dispersal and changes in the currents could have significant impact.

Estuary associated species: black bream, school prawns

School prawns are a moderate value species on the east coast (NSW) and black bream are of low commercial value but recreationally very important. Both of these high risk species are very dependent on fresh water flows for recruitment and impacts of variable rainfall and associated human and agricultural water demands, could be significant.

SECTION B: AQUACULTURE RISK ASSESSMENT

Introduction

Aquaculture provides significant social and economic benefits globally and accounts for approximately 43% of aquatic animal food produced for human consumption (Bostock et al. 2010). In Australia, aquaculture is an increasingly important component of the country's seafood production, accounting for 40% of the total commercial value in 2007–08 (up from 29% in 1998–99), and 37% of total employment in 2006 (ABARE 2009). In the south-eastern region alone, aquaculture contributes 55% of the total value of seafood production in the region (excluding Commonwealth fisheries) and 74% of the total value of aquaculture production in Australia (2007–08 data, ABARE 2009). Salmonids and southern bluefin tuna (SBT) are the two most valuable aquaculture species in Australia, respectively, and are both farmed solely in the south-eastern region. Pacific oyster and abalone are also economically important and are produced mostly from this region.

Although climate variability, defined as an inter-annual change in environmental conditions, has always been a factor for many Australian aquaculture industries, such 'natural' variability is now accompanied by a directional, human-mediated change in climate (Battaglene et al. 2008), which is likely to have direct and indirect impacts on all Australian aquaculture environments (Hobday et al. 2008). In addition to a directional change in climate, changes in the frequency, duration and intensity of extreme climatic events will also critically impact some farming systems. Evidence suggests that the south-eastern region will be significantly impacted by climate change and it is essential that our valuable aquaculture industries have the best information available to develop constructive adaptation strategies to maximise positive outcomes. Key aquaculture species in south-eastern Australia are based on a wide range of species and involve a diversity of farming methods, which cross terrestrial, intertidal and offshore environments. Furthermore, there are four main jurisdictions within the region relevant to aquaculture: Tasmania, South Australia (SA), New South Wales (NSW) and Victoria, with each having different physical environments and environmental and management legislation systems. As such, climate change impacts, and the degree to which farming methods can be adapted to mitigate the effects of climate change, are likely to vary significantly between species, farming methods and jurisdictions.

Financial allocations to natural resource management are never unlimited, and investment in adaptation research, planning and implementation is no exception. Therefore, an analysis of comparative risks to climate change among aquaculture species is important for identifying regional priorities for future action and planning (Battaglene et al. 2008), and thus allowing scientists, policy makers, marine resource managers and stakeholders to optimally focus financial and human resources to address the most pressing concerns.

This study was initiated to provide scientific advice to marine resource managers and stakeholders regarding the likely impacts of climate change on aquaculture species in south-eastern Australia and to identify research required to develop and subsequently refine 'projections' of likely climate change scenarios for key species. In this report, we develop and adopt a two-stage screening-level assessment to examine the relative risk of climate change impacts on the key species in south-eastern Australia. The first stage involves producing detailed 'species profiles' , which describe the industry, life history stages, farming methods, likely climate change impacts, key physical drivers responsible for those impacts and data gaps. Subsequently, these species profiles were used to inform, in conjunction with an expert panel, the second stage of the project. The second stage entailed producing qualitative ecological risk assessments for each species, to establish a relative risk level among the relevant aquaculture species. The risk assessments focus on the biology of the aquaculture species and the environment in which they are farmed, and do not cover social or economic impacts.

Methods

Study region

See Part 1, Section A

Ranking and selecting priority aquaculture species in the south-eastern region

Forty-four species or species groups, both from wild fishery (n = 36) and aquaculture industries (n = 8), were originally selected by resource managers and researchers from across all jurisdictions for potential inclusion in the SEAP study (see Appendix 2 for written rationales for each aquaculture species). Based on economic importance (and also ecological and recreational importance for the wild fishery species), each jurisdiction assigned a rank to their 10 most important species, out of the original 44, with 10 being the most important and 1 being the least (see Appendix 3). All of the originally selected aquaculture species, except native oyster, were ranked and selected for inclusion in this study, leaving a total of six species and one species group (abalone) (see Table 2.1).

Table 2.1: Aquaculture species selected for potential inclusion in the SEAP study, with associated jurisdictions, total value in the south-eastern region, and regional priority (higher number equals greater priority).

Common name	Scientific name	Value ($, m)*	Regional priority (rank)
Abalone - blacklip - greenlip - tiger (hybrid)	 *Haliotis rubra* *Haliotis laevigata*	16.8	28 (inc. wild fishery)
Atlantic salmon	*Salmo salar*	291	8
Blue mussel	*Mytilus galloprovincialis*	6.6	6
Pacific oyster	*Crossostrea gigas*	49.5	8
Southern bluefin tuna	*Thunnus maccoyii*	186.8	10
Sydney rock oyster	*Saccostrea glomerata*	39	7
Yellowtail kingfish	*Seriola lalandi*	17.7[1]	2 (inc. wild fishery)
Native oyster	*Ostrea angasi*	unknown – insignificant production	unranked

*2007/08 financial year (ABARE 2009). [1] value includes mulloway, though majority represents YTK (see species profile for more information).

Expertise-based species profiles

Seven comprehensive expertise-based 'species profiles' were produced for each of the species or species group detailed in Table 2.1. The profiles were based on a set template and collated existing data, published and grey literature and expert opinion on the industry, production, the species' life history, farming process, current and potential climate change impacts, and critical data gaps. The profiles were produced by a panel of expert authors and reviewers across all four jurisdictions (see Part 2 to view individual profiles). Information on Atlantic salmon was largely drawn from Battaglene et al. (2008). The key results from each of these descriptive species profiles were subsequently summarised and tabulated.

Risk assessment approach

A qualitative risk assessment, to rank species according to their sensitivity to climate change, was conducted. For each species, risk (defined as level of sensitivity or inability to respond to change) was assessed for nine key aquaculture attributes. The species profiles, together with the authors' broader knowledge of marine climate change impacts, were used to select appropriate attributes which could be used to test the sensitivity of all aquaculture species and relevant farming processes to climate change. Attributes were designed around the basic farming, business, and life history stages, including broodstock conditioning, spawning, and larval and juvenile rearing, with the last five attributes focused solely on the growout or adult stage (see Table 2.2). Three risk categories or scores were assigned to each attribute, low (1), medium (2) and high (3), in relation to level of sensitivity to climate change. For example, a high score of 3 would indicate that the aquaculture activity in question has a relatively high sensitivity to climate change and thus at a higher risk of being impacted. The second step in the risk assessment involved providing a 'weighting' for each attribute based on the level of known or predicted impacts of climate change. Weightings were scored for each species and attribute as follows: strong negative impact (2), moderate negative impact or level of impact unknown (1) and mild negative impact, positive impact, or no impact anticipated (0). Again, the unweighted sensitivity scores and impact scores were based on information derived from the species profiles. To calculate the overall weighted score for each species, the unweighted score was multiplied with the impact score for each attribute; the scores from each of the nine attributes were then added together. If a species was farmed using more than one method a risk assessment was conducted for each method (e.g. abalone, SRO and BM). In total, 11 risk assessments were performed.

Table 2.2: Attributes and risk categories used assess level of sensitivity to climate change for aquaculture species in south-eastern Australia.

Attributes	Risk category (level of sensitivity)		
	Low risk (1)	Medium risk (2)	High risk (3)
1. Broodstock availability & conditioning – degree of environmental control	Broodstock are completely aquacultured, held at-sea or in indoor growout conditions; increased use of selective breeding	Broodstock collected from the wild but bred in a hatchery	Breed in the wild
2. Spawning & fertilisation – degree of difficulty and environmental control	Occurs in a fully controlled environment; spawning triggers well known; easy to hold large numbers of broodstock and/or differentiate their sex	Occurs in a fully controlled environment; spawning triggers are poorly known; difficult to hold large numbers of broodstock and/or differentiate their sex	Occurs naturally in the wild
3. Larval rearing – degree of complexity and environmental control	Occurs in fully controlled environment; few larval steps or stages; no live feeds required	Occurs in a fully controlled environment; longer or more complex series of steps during larval development; live feeds required	Occurs naturally in the wild
4. Juvenile rearing (to stage stocked into growout system) – degree of complexity and environmental control	Occurs in a fully controlled environment; manufactured feeds required	Occurs in a partially controlled environment; some natural feeds required	Occurs naturally in the wild
5. Growout: connectivity to natural environment – degree of environmental control	Almost fully closed, highly controlled environmental system (e.g. intensive recirculation system)	Partially closed and environmentally controlled system (e.g. ponds, tanks, raceways)	Open system in the natural environment (e.g. sea cages, longlines)
6. Growout: availability of alternative farm sites & systems – capacity to relocate farm site or use of alternative farming system	Readily identifiable alternative farm areas, some which may already have been allocated for another form of aquaculture	Some potential to move to alternative sites, but requires new area to be allocated through the relevant resource allocation process, or to use alternative farming systems	No identifiable potential for alternative sites or changed farming systems

7. Growout: feed – wild verses manufactured sources; frequency of manual feeding	Manufactured feeds used	Live feeds from wild, used but with some capacity to vary species or use manufactured feeds	Natural productivity
8. Growout: farm operations – level of exposure to the natural environment and environmental extremes	Full farm cycle and infrastructure onshore, readily accessible and not subject to environmental extremes	Part of farming cycle in areas subject to occasional flooding, king tides or storm damage, but generally easy to access with good environmental conditions	Full farm cycle at sea requiring frequent site visitation in a challenging operating environment (e.g. sea and swell conditions)
9. Growout: diseases and pests – management and susceptibility	Published papers on diseases/pests suggesting some natural resistance and no existing major disease/pest issue(s)	Published papers on diseases/pests suggesting some natural disease resistance, but with some existing disease/pest issue(s) that are being managed	Extensive documented disease and pest issues for farmed taxa/related taxa and current major disease/pest issue(s) that are not well managed and likely to be exacerbated by climate change

Results

Summary of key elements emerging from the individual species profiles

A diverse array of farming methods were represented among the seven selected species, from sea-ranching to intensive land-based aquaculture (see Table 2.3). There were two broad taxonomic groups represented, namely finfish and shellfish species. Three species were farmed using more than one method, with abalone farmed using both land and sea-based aquaculture, and SRO and BM reliant on both hatchery-produced and wild-caught spat. Although SBT is currently farmed using sea-ranching methods, hatchery production is currently being developed. Four species were multi-jurisdictional, however, no species were farmed in all four jurisdictions.

Table 2.3. Summary of farming methods and the current location of farms or hatcheries (jurisdictions) for each species.

Species	Farming methods	Jurisdictions
Abalone *Haliotis rubra*, *H. laevigata*, tiger (hybrid)	hatchery (broodstock, larvae, spat); land-based tanks/raceways (adults) or sea cages (adults)	SA, Vic, Tas
Atlantic salmon *Salmo salar*	hatchery (broodstock, fry, parr); brackish & marine sea cages (smolts, adults)	Tas
Blue mussel *Mytilus galloprovincialis*	hatchery (broodstock, larvae, spat) or collection from wild using longlines (spat); longlines (adults)	SA, Vic, Tas
Pacific oyster *Crossostrea gigas*	hatchery (broodstock, larvae, spat); intertidal baskets (adults)	SA, Tas, NSW
Southern bluefin tuna *Thunnus maccoyii*	collection from wild, sea-ranching (juveniles & adults); hatchery in development	SA
Sydney rock oyster *Saccostrea glomerata*	hatchery (broodstock, larvae, spat) or collection from wild using stick culture (spat); adults (stick or tray culture)	NSW
Yellowtail kingfish *Seriola lalandi*	hatchery (broodstock, larvae, juveniles); marine sea cages (adults)	SA, NSW (hatchery only)

For all species, there were few current climate change impacts highlighted, and those identified were also solely associated with biological impacts. Furthermore, current climate change impacts were generally regarded with a low-medium certainty with few having direct or highly certain linkages to climate change (e.g. for YTK 'flukes present greater problems in increased water temperature') (Table 2.4). Temperature was the most common cited driver of climate change, commonly linked to stress and immune-suppression and increases in pests and diseases in regards to biological impacts, and changes in farm husbandry practices (e.g. increased cleaning of infrastructure and reduced fallowing periods) in regards to industry-related impacts. Ocean acidification was another key driver highlighted, predicted to impact the growth, development, and survival of the four shellfish species, with low to medium certainty. Increases in the severity, duration and frequency of extreme climatic events and sea-level rise were also predicted to impact farm infrastructure, the suitability of current farming locations and farming operations. In regards to industry-related impacts, most were described with low certainty and based on anecdotal evidence and expert opinion.

Table 2.4: Summary of current and predicted climate change impacts outlined in species profiles, with level of certainty of the associated information. Level of certainty is divided into high (H) = strong clear evidence, backed by several studies with solid datasets with little confounding interactions; medium (M) = evidence supported by one or more studies, conclusions may be partially ambiguous or confounded; low (L) = anecdotal evidence, limited data and/or predicted conclusions based on theoretical knowledge. * indicates a current climate change impact, or current impacts which may be linked to climate change

Species	Current & predicted impacts (biological)	Current & predicted impacts (industry-related)
Abalone	• 'Summer mortality', which is linked to reproductive stress, elevated temperatures, poor water quality, and disease, is common on farms which experience high summer temperatures (Vandepeer 2006) (M)* • Increased severity and duration of 'summer mortality' (M) • Ocean acidification may lead to increased larval and spat mortality, decreases in growth and abnormal shell development, especially at sea-based farms (Harris et al. 1999; Gazeau et al. 2007) (L) • Increases in storms may lead to reduced growth at sea-based farms (Oulton 2009)(M)	• Increases in temperature may lead to a need for increased water flow to land-based growout systems (H), greater use of shading for nursery and growout areas (M), increased use of cultured diatom species to seed settlement plates (L), increases in fouling organisms (L), refrigeration during live transport (M), improved measures to store manufactured feed (M) • Increases in flood events and fluctuating salinity levels and sea-level rise (Oulton 2009) may affect farm site suitability in land-based systems (L)
Atlantic salmon	• High summer temperatures in Tas already affect productivity and health, and cause an increases in disease outbreaks (M)* • Southward range shift of the harmful microalgae, *Noctiluca*, threatens salmon health (Hallegraeff et al. 2008)(M)* • Further increases in diseases due to increased stress and immune-suppression (M) and reduced efficacy of vaccines (L) • Increase in jellyfish and harmful microalgae (M)	• All hatcheries are expected to become temperature regulated (H) • Sea cages may be moved to cooler offshore waters (L) • Increased reliance on selective breeding programmes (M) • Temperature increase may impact final product (i.e. poorer colour) (L) *Unless otherwise indicated, see Battaglene et al. (2008) for all points relating to Atlantic salmon.*
Blue mussel	• Decline in wild spatfall in Vic has been linked to prolonged drought (L)* • Increases in temperature may have negative impacts on growth, reproduction and health (Fearman and Moltschaniwskyj 2010) (Anestis et al. 2007; Ferreira et al. 2008)(M) • Ocean acidification may lead to increased larval and spat mortality, decreases in growth and abnormal shell development (Gazeau et al. 2007; 2010)(M) • Increases in disease (Anestis et al. 2010)(M)	• Increases in harmful microalgae which cause shellfish poisoning (Hallegraeff et al. 2009)(M) • Increased reliance on hatchery production (L) • Storm increases may lead to increased mechanical damage to infrastructure (L) • Increased cleaning of infrastructure due to biofouling (L) • More rigorous product transport, processing and packaging standards (L)
Pacific	• Flatworm infestations, which can devastate oyster spat, have been linked to prolonged drought and high salinities (O'Connor and Newman 2001) (M)*	• Intertidal leases may become less suitable for farming due to sea level rise (M)

oyster	• Ocean acidification may lead to increased larval and spat mortality, decreases in growth and abnormal shell development (Gazeau et al. 2007)(M) • Increased severity of 'summer mortality', which is linked to temperature, salinity, O_2 levels, reproductive stress, and disease (Li et al. 2007; 2010)(M) • Adults may spawn earlier in the year due to increased temperature	• Increases in harmful microalgae which cause shellfish poisoning (Hallegraeff et al. 2009)(M) • Increased cleaning of infrastructure due to biofouling (L) • More rigorous product transport, processing and packaging standards (L)
Southern bluefin tuna	• Southward range shift of natural population (Hobday 2010) • Increases in upwelling in SA may lead to increases in prey/feed availability (small pelagics) • Increases in growth rates and production • Reduced O_2 levels in sea cages due to elevated temperatures (L) • Increases in parasites, disease and harmful microalgae (L)	• Storm increases may lead to increased mechanical damage to infrastructure and reduce the time available for operational tasks (L) • Temperature increase may impact final product (L) • Increased cleaning of infrastructure due to biofouling (L) • More rigorous product transport, processing and packaging standards (L) • Reduced fallowing periods (L)
Sydney rock oyster	• Decline in fertilisation success due to changes in pH and temperature (Parker et al. 2009; 2010) (H) • Ocean acidification may lead to increased larval and spat mortality, decreases in growth and abnormal shell development (Watson et al. 2009)(M) • Increase in 'winter mortality' and QX disease due to increased stress (M)	• Intertidal leases may become less suitable for farming due to sea level rise (H) • Increased cleaning of infrastructure due to biofouling (L) • Increased costs associated with the quality assurance programme • More rigorous product transport, processing and packaging standards (L)
Yellowtail kingfish	• Gill and skin flukes present greater problems in increased water temperatures (Mooney et al. 2006) (H)* • Increases in parasitic infections, microalgal and jellyfish blooms (M) • Elevated temperatures may lead to increased growth (Poortenaar et al. 2003) (H), but this may be offset by increases in salinity which may reduce growth (Oulton 2009) (M)	• Increased use of parasite control measures (i.e. bathing) (H) • Reduced working time on offshore cages • Reduced fallowing periods (L) • Increases in net replacements due to increased biofouling (L) • New harvesting strategies (to avoid 'burnt muscle' at high temperatures (Arroyo Mora et al. 2007)) (L) • More rigorous product transport, processing and packaging standards (L)

Regardless of the diverse array of farming systems represented key data gaps, areas of uncertainty, relevant to climate change impacts, were strikingly similar between species (Table 2.5). Key data gaps included impacts of climate change on the physiology and immunology of critical developmental stages, ability of selective breeding to counteract the impacts of climate change, impacts of climate change on the interactions between aquaculture species and organisms which affect performance and survival (such as parasites, viruses, and microalgae), and the limited availability of fine-scale climate change monitoring and modelling relevant to the spatial scales of aquaculture farms and lease sites. Impacts of ocean acidification were also highlighted as a key data gap for finfish species.

Table 2.5: Summary of key data gaps outlined in species profiles. CC = climate change.

Species	Data gaps
Abalone	• Impacts of climate change on the physiology and immunology of critical developmental stages • Precise cause of summer mortality • Impacts of ocean acidification • Fine scale climate change modelling and monitoring relevant to aquaculture farms • Impacts of CC on the interactions between abalone and other species which affect performance and survival (e.g. mudworms and AVG) • General biology of tiger (hybrid) abalone • Ability of selective breeding/genetic variation to counteract the impacts of CC
Atlantic salmon	• Effects of CC impacts (elevated temperature) on salmon health in Australia • Effect of elevated temperature on vaccine efficacy, immune response, and disease-causing species • Impacts of ocean acidification • Fine scale climate change modelling and monitoring relevant to aquaculture farms
Blue mussel	• Factors influencing the reproductive cycle, timing of spawning and larval development. • Impacts of CC on the interaction between spat variability and availability and fouling organisms such as ascidians in the wild • Effects of CC impacts (temperature and pH) on Australian mussel populations • Ability of selective breeding/genetic variation to counteract the impacts of CC
Pacific oyster	• Fine scale climate change modelling and monitoring relevant to aquaculture farms • Impacts of climate change on the physiology and immunology of critical developmental stages • Precise cause of summer mortality • Ability of selective breeding/genetic variation to counteract the impacts of CC • Impacts of CC on the interactions between PO and other species which affect performance and survival (e.g. mudworms and flatworms)
Southern bluefin tuna	• Fine scale climate change modelling and monitoring relevant to aquaculture farms • Impacts of climate change on the physiology and immunology of critical developmental stages • Ability of selective breeding to counteract the impacts of CC • Impacts of CC on the interactions between SBT and other species which affect performance and survival (e.g. parasites, biofoulers and microalgae) • Impacts of ocean acidification
Sydney rock oyster	• Fine scale climate change modelling and monitoring relevant to aquaculture farms • Ability of selective breeding to counteract the impacts of CC (temperature and pH)
Yellowtail kingfish	• Fine scale climate change modelling and monitoring relevant to aquaculture farms • Impacts of climate change on the physiology and immunology of critical developmental stages • Ability of selective breeding to counteract the impacts of CC • Impacts of CC on the interactions between YTK and other species which affect performance and survival (e.g. fluke, biofoulers) • Impacts of ocean acidification

Qualitative risk assessment

There was good resolution among the 11 risk assessments, with weighted sensitivity scores ranging from 9 to 34 and with only two species receiving the same score. The weighted scores indicated that the edible oyster industry in south-eastern Australia is the most sensitive aquaculture industry in regard to climate change impacts (Figure 2.1). This is primarily due to the situations in SA and NSW where summer or heatwave related mortalities are already an issue. Strong and moderate impacts were also scored for both oyster species for most of the other attributes (see Appendix 6 for complete scoring by attribute for each species). SRO farmed from wild spatfall (which is currently much more common than hatchery produced spat) was the most sensitive of the oyster group, and, overall, out of all the risk assessments, receiving a score of 34. Hatchery produced SRO and PO had similar scores, differing by only 2 points.

Abalone was a moderately sensitive aquaculture group, with land-based systems being the most sensitive. Unweighted scores were relatively low for land-based farming, which is largely due to the level of environmental control which can be applied throughout the lifecycle. However, climate change impacts were generally rated as strong to moderate, which increased the scores, due to the existing temperature and disease impacts experienced in summer on many farms in SA and Victoria.

Blue mussel farmed from wild-caught spat was the second most sensitive group (alongside Pacific oysters) and was substantially different to the hatchery-produced blue mussel, with each scoring 27 and 15 respectively. Strong climate change impacts are associated with the early life history stages (attributes 2–4) in blue mussel (wild), with natural spatfall already showing signs of decline in Victoria and SA. It is thought that the declines are related to drought conditions and atypical weather conditions affecting microalgae productivity in Victoria and SA respectively. However, the mussel growout stage, which is the same for both farming methods, is less sensitive than other shellfish species farmed in natural environmental conditions. Mussels are less prone to disease and are farmed in deeper sub-tidal wave-protected regions, where heatwave impact is less serious.

The finfish species, on average, were ranked as less sensitive to climate change compared to the shellfish species. SBT was assessed as relatively resilient, for both sea-ranching and hatchery production methods. SBT may be impacted by climate change both positively (e.g. increases in prey species for juvenile stock) and negatively (e.g. increases in the occurrence of algal blooms), but there is a great uncertainty with regard to potential impacts. For Atlantic salmon, the moderately high sensitivity score and moderate to strong climate change impacts were primarily related to the growout stage, with increases in disease and the lack of future suitable farm locations being key concerns. YTK had the lowest sensitivity score of 9, which was considerably different to the unweighted score (16). Climate change impacts were only considered to be moderate, mild, or positive as environmental conditions are well controlled in hatcheries, and temperature increases are expected to increase growth rates and productivity during the growout stage.

The risk assessment scores indicated that hatchery production substantially reduces risk to climate change impacts in Sydney rock oyster and blue mussel. The less pronounced effect that finfish hatcheries appeared to have on risk scores (e.g. Atlantic salmons and SBT) is probably that most finfish aquaculture is based on hatchery production and the level of uncertainty in regard to climate change impacts on early life stages and processes, which subsequently increases the risk.

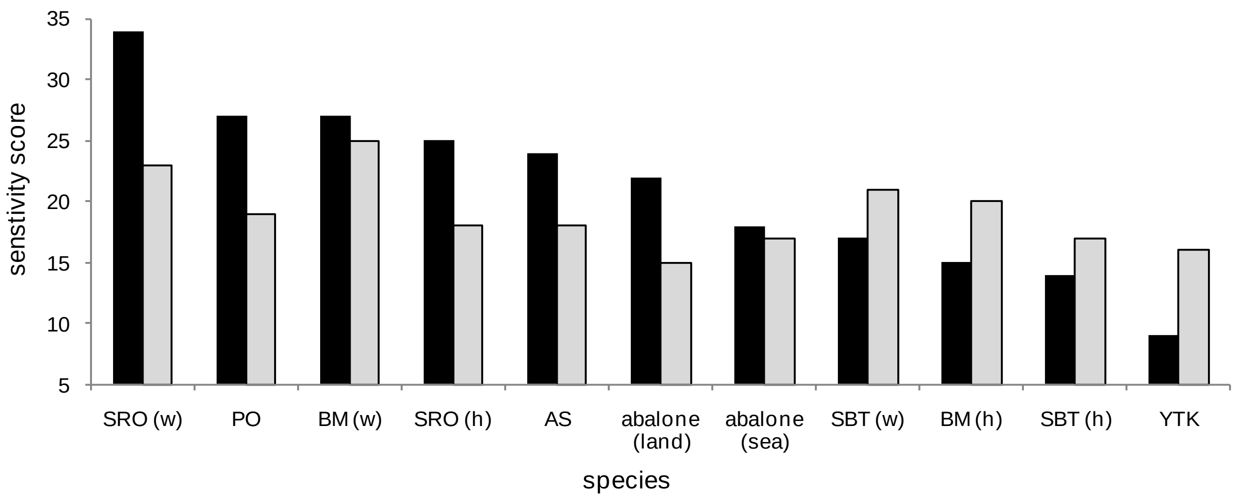

Figure 2.1: Total sensitivity scores for each species and farming system, from most sensitive (high risk) to least sensitive (low risk) based on the weighted score. Weighted score = black columns, unweighted = grey columns. SRO = Sydney rock oyster, PO = Pacific oyster, BM = blue mussel, YTK = yellowtail kingfish, SBT = southern bluefin tuna, AS = Atlantic salmon. w = juveniles or larvae sourced from the wild, h = larvae produced in hatcheries.

The total weighted scores for each attribute, across all species, showed that attribute 5 (level of connectivity of growout to the natural environment) and attribute 9 (disease and pest management) were the most vulnerable to climate change impacts (Figure 2.2). Attribute 3 (larval rearing) had a moderately high weighted score, which was primarily associated with the shellfish-related risk assessments, with all scoring an impact score of 2 (strong anticipated climate change impact). Attribute 6 (availability of alternative farm sites and systems) had the lowest score, with AS being the only species receiving an impact score of 2. All other attributes, for both weighted and unweighted scores, showed relatively moderate levels of sensitivity.

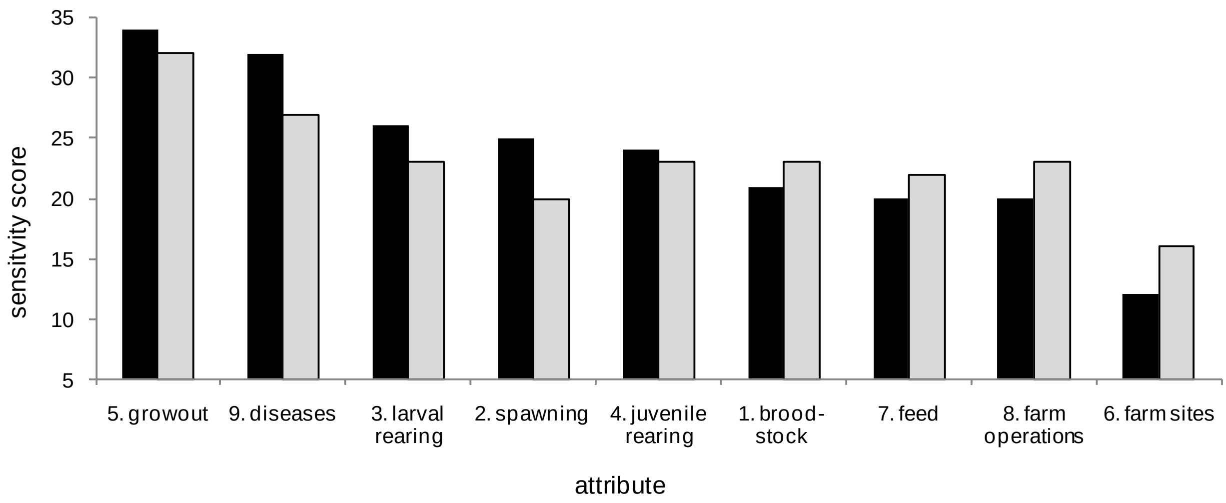

Figure 2.2. Total sensitivity scores for each aquaculture attribute, from most sensitive (high risk) to least sensitive (low risk) based on the weighted score. Weighted score = black columns, unweighted score = grey columns.

Discussion

The risk assessment approach involved a simple and repeatable methodology, which was appropriate for a divergent range of different aquaculture systems and taxa. The weighting component of the risk scoring system allowed each attribute to be weighted according to the anticipated severity of the climate change impact. This allowed 'deal-breakers' (e.g. the relative inability of salmon farms to shift further south to avoid increasing water temperatures) to be incorporated into the risk analysis to a certain extent. For example, if a climate change impact was anticipated to be severe for a particular attribute, an impact score of 2 was given, overriding the original unweighted score. The weighting categories also allowed uncertainty and positive impacts to be incorporated into the risk analysis, which produced, overall, a more realistic picture of relative risk among species and farming systems. The unweighted scores, for instance, indicated that abalone (land) and mussels (wild) were the least sensitive and most sensitive species to climate change impacts respectively. This contradicts some of the overall descriptive conclusions outlined in Table 4, which clearly indicate that mussels (wild) are more resilient than SRO (wild) and less resilient than YTK, and vice versa for abalone (land). Like the wild fisheries risk assessment method the aquaculture assessment also did not directly address exposure to climate change and variations in climate change impacts at regional scales (e.g. the degree of temperature increase and changes in the intensity and frequency of extreme events are likely to vary between jurisdictions). This issue is more relevant to multi-jurisdictional species, such as abalone and Pacific oyster, where farms range from southern Tasmania to SA. The authors note that a key limitation of the risk assessment approach was that the attributes were based on biological information and the environment in which the species were farmed and did not include a full supply-chain business analysis, which is required to incorporate economic and social risk.

However, this report's main aim was to produce a screening-level assessment to help advise future research priorities and provide direction for more detailed analyses.

There was a reasonable level of qualitative agreement between the two stages of the qualitative assessment, the descriptive synthesis (species profiles) and comparative scoring assessment (weighted scores), but also, importantly, each of the stages provided a critical and complementary set of information. Even though the descriptive syntheses provided the necessary information to develop the attributes and scoring level for each species, the risk scores provided a framework in which to compare a large and complex range of associated risks among species. For instance, it would be difficult to rank species according to level of predicted impacts based on the information given in the species profiles and synthesis tables (Tables 3-5). In comparison, the descriptive syntheses additionally highlighted the key climate change drivers behind the associated impacts, such as temperature, pH, extreme climatic events, and sea level rise, current and anticipated impacts, regional variability in production and the physical environment, and the *level* of uncertainty in regard to anticipated impacts. As such, the risk scores should not be treated as the final end-product of the results, but interpreted in combination with the descriptive information.

The way that risk or sensitivity to change was perceived was also different between the descriptive and scoring components. The descriptive component generally described impacts as biological or industry-related and the scoring component focused on the level of environmental control which can be applied throughout the farming process and capacity of the farming process to adapt to change. For example, potential relocation of farming sites, due to temperature increase and sea-level rise, is seen as an industry-related impact in the descriptive syntheses, but in the risk scoring system, farm relocation is deemed a positive outcome and a means to mitigate such climate change impacts. These differing perspectives both provide complementary information on two intrinsically linked concepts (i.e. what can be done to mitigate impacts verses what is the impact of the mitigation/adaptation strategy itself).

Key gaps in knowledge

In undertaking this screening-level risk assessment, gaps in our current knowledge were highlighted, indicating areas where additional data would be required to either achieve a more thorough assessment of potential risk, or to constructively inform adaptation planning. Here we list these knowledge gaps and where feasible we identify the data and/or analytic tool that would be required to address these gaps (Table 2.6).

Table 2.6: Identified critical knowledge or data gaps for south-eastern Australian aquaculture species. Indications of the magnitude of the task required to address knowledge or data gaps are approximate and should be used as a general guide only.

Knowledge gap	Benefit for future adaptive planning	Methodology or data required	Indication of magnitude
The effects of climate change on the full supply-chain business activities of the aquaculture sectors and adaptation strategies to address the issues identified are largely unknown.	Adaptation strategies to address identified climate change issues on the business of aquaculture must involve industry and be developed and incorporated within a business framework; without this they are unlikely to be implemented. The above aquaculture industry data will better inform climate change scientists and government regulators of what are the key climate change drivers and parameters of most relevance to aquaculturists and which adaptation strategies industry is most likely to support and implement.	1. Close and extensive liaison is required with aquaculture industry sectors to inform them of the general nature of climate change so as to increase their involvement and ownership in developing cost effective and targeted business-based adaptation strategies. 2. This can effectively be achieved by engaging with each aquaculture sector to map their whole-of-chain business activity, identifying the specific issues most likely to be affected by climate change, prioritising their risks and business impacts, and developing business based adaptations that address each of the above.	Aquaculture sector based projects could be achieved within a 12 month time frame and much can be learned from the outcomes of previous projects (e.g. edible oysters, Leith and Haward 2010; Atlantic salmon, Battaglene et al 2008).
Physiological and immunological responses to key climate change drivers at different developmental stages (e.g. temperature, salinity, pH and pCO_2 ranges)	Lack of knowledge on these critical biological factors limits the capability to predict the impacts of climate change on aquaculture species, and thus the industries' ability to mitigate impacts.	1. Individual and synergistic impacts of key drivers related to climate changes on physiology and immunology of farmed species at different developmental stages. 2. Synergistic impacts of key climate change drivers and other external and internal environmental changes on physiology, immune health of farmed species at different developmental stages.	It is anticipated these physiological and immunological responses might be species specific and a 3–4-year study would thus be required for each species involving laboratory and field work.
Fine-scale climate change monitoring and modelling	There is limited or no information available on climate change impacts and predictions relevant to the spatial scale of aquaculture farming. This increases the challenge for the industry, resource managers and policy makers to accurately	1. Develop models that can better incorporate the finer spatial and temporal scales relevant to aquaculturists. 2. Increase interaction between climate change scientists and aquaculture industry sectors to	At least a 5-year study involving field work and subsequent modelling of various scenarios. Its progress will rely on other related

	assess and establish methods to mitigate climate change impacts.	better identify and quantify the importance of key climate change drivers. 3. Collect and incorporate into climate change models the relevant biological, chemical and physical field data and species' physiological and immunological data.	research, such as physiological and immunological responses.
Impacts of climate change on parasite, pathogen and pest interactions	Disease/pest outbreaks can have devastating consequences for aquaculture species. Climate change may result in an increase or decrease in the severity and frequency of a disease already present or facilitate the emergence of novel diseases. It is imperative for future adaptation planning, to improve our knowledge of these ecological interactions.	1. Prevalence, intensity and site preference of disease species. 2. Interaction between disease species and cultured species. 3. Interaction between these organisms and the surrounding fouling organisms. 4. Changes in climate change related drivers on the above parameters and their interactions.	The responses and interaction of these organisms are very difficult to predict or to simulate in controlled or natural environments. Research will be challenging.
Ability of selective breeding to counteract the impacts of climate change	Increased reliance on selective breeding programs is a potential adaptation strategy for aquaculture industries to changing environmental conditions and pest/disease interactions. It will be important to determine the potential efficacy of selective breeding against climate change impacts.	1. Genetic variations in traits related to climate changes in the existing breeding population or populations potentially available to address climate change impacts. 2. Genetic correlation between traits of economic importance and those related to climate changes. 3. Evaluation of if selective breeding could be used effectively and efficiently to mitigate the predicted climate change impacts according to the data collected above and economical data of operating a breeding business in a species of interest.	It is anticipated that the required genetic parameter analyses will be population specific and require study over more than 2 generations (laboratory and field work will be necessary).

Research priorities and issues for further investigation

This was a screening level assessment designed to be inexpensive, repeatable and transparent in order to identify which important aquaculture species and industries are at high risk to climate change, and subsequently define future research priorities, which includes more detailed and focussed species risk assessments, for adaptation action and planning. As discussed earlier, future case studies would need to include a full supply chain business analysis, which would incorporate economic and social risks. It must be noted that recommendations below are designed to provide a starting point for discussion and that further consultation with managers, researchers and industry will be required.

In consideration of the risk assessment outcomes, likely resource limitations, current data availability and knowledge, and value of the industry, we suggest that abalone would be a suitable candidate for a full case study analysis. The logic for selection is as follows:

- SBT was classed as a relatively resilient species and currently lacks suitable data for a full case study analysis. To achieve a more thorough assessment of climate change risk, it will be important to gain a better understanding of the effects of climate on the biology and physiology of wild SBT populations, sea-ranching operations, and pest/disease interactions.
- Although blue mussels farmed from wild-spat was ranked the third most sensitive group, hatchery production is expected to increase in the near future and mussels farmed from hatchery-produced spat was ranked the third most resilient group. The mussel industry was also the least valuable of the seven aquaculture species.
- YTK was ranked the most resilient species and climate change is anticipated to have an overall positive impact.
- The edible oyster and salmon industries are both highly valuable and are ranked as highly and moderately sensitive species respectively. However, a full supply chain business analysis has already been done to a large degree for edible oysters (Leith and Haward 2010) and salmon (Battaglene et al. 2008). Also, for the salmon industry, future climate change research needs are being met in a number of ways following the initial scoping study.
- Abalone aquaculture, therefore, appears to be the logical target for the next SEAP project, which should include a full supply chain business analysis for SE Australia. Land-based abalone farming was the next most sensitive group after edible oysters, mussels (wild), and salmon. Although sea-based abalone farming was scored as relatively resilient, land-based farming systems produce most of the farmed abalone in SE Australia. Additional rationale for suggesting abalone include: a) abalone aquaculture is of significant economic importance and occurs across most of the SE region, b) the main farming system is land-based and as such is of a different type than previously studied (i.e. salmon and edible oysters are both farmed at sea) and one where a move from raceways to intensive

environmentally controlled recirculation systems might be feasible (c.f. South Africa), c) increased summer temperatures have strongly impacted the performance of farmed abalone and the practices used to farm them at some locations, d) information developed might also be applicable to the abalone wild fishery, which is of considerable importance in the SE region and e) the southern Australian industry has a unified industry association, the Australian Abalone Growers Association. The latter will help facilitate a strong industry involvement in the next SEAP project. This is important as an economic and broad social context will be essential to establishing the priorities of industry and effectively addressing and/or adapting to climate change. Finally, involvement of government regulatory agencies is recommended as this will facilitate consideration and resolution of any changes required to policy and regulation to facilitate adaptation by industry.

Other aquaculture-related issues requiring further investigation include: 1) the development of low stress farming practices, 2) understanding the key genetic and economic parameters required to evaluate if selective breeding could be applied to address climate change impacts effectively and efficiently, and 3) the development of industry sector or regional environmental monitoring systems to enable avoidance or early warning of mortality outbreaks. Such a system will be dependent on incorporating both environmental data and species' immunological and physiological information.

Further development

This risk assessment accounts only for the sensitivity dimension to ecological risk and does not distinguish between differential levels of exposure that might occur as a result of intra-regional and/or species differences. Many challenges associated with climate change will be common to all jurisdictions within the south-eastern region, and a coordinated and collaborative approach to addressing those challenges is essential. However, the south-eastern region covers a broad area with complex, heterogeneous, and in some respects poorly understood oceanography. It would be wise to build on the current assessment by examining regional and species-specific levels of exposure to key climate change drivers for high and medium risk species. Additionally, the current risk assessment does not consider sensitivity of the broader socio-ecological system to climate change induced effects. This requires extension of the assessment to include sensitivity of social, economic and governance components of the system to changes in species distribution, abundance and phenology that are anticipated as a consequence of climate change. We need to interpret the results of this ecological risk assessment in the broader context of the social-ecological system, in which ability to cope with effects of climate change will depend on sensitivities and adaptive capacities of the linked human system. Understanding sensitivities and critical linkages/feedbacks in marine socio-ecological systems generally, and in specific regard fisheries, is therefore critical. Climate change is a complex and confronting issue and it is absolutely vital that stakeholders are engaged and well informed on how climate change is expected to alter the physiology, life cycles, distribution and abundance of commercial species.

Planned outcomes and benefits

This project is one of a suite of projects that will contribute to the outcomes of the SEAP plan:

- Effective incorporation of fisheries in marine ecosystem based management arrangements
- Fisheries and aquaculture management that is responsive to climate change
- A community that is supportive of fisheries management arrangements
- A fishing and aquaculture industry that is adapting to climate change

The key outcome of the current project is a sound risk-based approach for addressing the potential impacts of climate change on marine resources through a thorough assessment of the sensitivity and tolerances of critical life history stages of key species to climate change drivers for fisheries, aquaculture and marine ecosystems. In turn, this will support the development of policies that allow industry to adapt in the most optimal way possible to projected impacts, both positive and negative. A sound risk-based approach to informing the decisions of sectors and management arrangements will be critical in preparing for climate change. Outcomes will benefit all key fishing sectors and fishery managers for the south-eastern Australia region, and also provide a platform for further research into adaptive capacity, vulnerability, adaptation options and climate change.

Conclusion

Significant climate change impacts on key species in the south-eastern Australian region have already been demonstrated and this trend is expected to continue, with impacts likely increasing in severity over time. It is therefore imperative that the issue of climate change, including investment in research priorities, is the subject of extensive discussion and consultation with stakeholders who will be the individuals most affected by necessary adaptation actions – i.e. the participants in our south-eastern Australian commercial and recreational fishing and aquaculture industries. A key aspect of consultation and engagement of stakeholders concerning the likely impacts of climate change must involve discussing the potential constructive adaptation actions that could be undertaken to minimise losses and maximise opportunities.

Achieving the first objective of this project, i*dentifying the life history stages, habitats and aquaculture systems of key species that may be impacted by climate change,* has provided the basis for accomplishing the other three aims:

Identify the physical and chemical parameters that may determine the potential impacts of climate change on key species.

- Temperature was the most commonly cited driver of current or potential climate change impacts on both fisheries and aquaculture species.
- Impacts of ocean acidification, or lowered pH, were associated with a high degree of uncertainty for all species, both fisheries and aquaculture. Effects of acidification are likely to be species-specific but can include increased larval mortality, decreases in growth, abnormal shell development, and altered behavioural responses.
- Potential changes in currents, freshwater flows and salinity were of importance for fisheries species whilst any increases in the severity, duration or frequency of extreme events were a major concern for aquaculture species.

Conduct a screening-level risk assessment of each key species to the potential impacts of climate change.

- The fisheries species designated as highest risk from an ecological perspective were coincidently the south-eastern regions highest value fisheries – blacklip and greenlip abalone and southern rock lobster. Southern rock oysters, pacific oysters and blue mussels were the aquaculture species assessed as highest risk.
- Every jurisdiction represented in the south-eastern region had at least one of its top two priority species classified as high risk. The challenges posed by adequately managing large-scale climate change impacts are multi-jurisdictional in scope and we face many common difficulties. A coordinated approach such as that commenced by the SEAP is sensible and continued regional planning and collaboration is highly recommended.

- Climate change is expected to put additional stress on species and their ecosystems and exploited species are more likely to be sensitive to climate change (Hsieh et al. 2008). Other stressors such as overfishing, pollution, disease and habitat loss are likely to exacerbate climate related stressors. Determining attribution of impacts and taking a holistic approach that captures all potential stresses is ideal if achievable.
- As temperature was the most frequent driver of climate change impacts, a major biological response is, and will continue to be, the shifting of species distributions and abundances that will bring both ecosystem and management challenges.
- This report was concerned with commercial species caught in NSW, VIC, SA, Tasmania and the Commonwealth. As such we did not examine or consider species that may be range-shifting into NSW from southern Queensland. To be prepared for opportunities arising from new species and/or prepared to best manage negative direct or indirect effects of range extending species, NSW needs to ensure collaborative arrangements with the Northern Tropical Australia Adaptation program.

Highlight critical knowledge and data gaps, relevant to future assessments of climate change impacts on key species and development of adaptation strategies.

- Major data gaps were evident for most fisheries species, including environmental tolerances of key life stages, sources of recruitment and population linkages, critical ecological relationships (predator-prey etc), phenological relationships, and likely responses to lowered pH.
- Key data gaps for aquaculture species included: impacts of climate change on the physiology and immunology, ability of selective breeding to counteract impacts, interactions between aquaculture species and organisms which affect performance and survival (such as parasites, viruses, and microalgae), and the limited availability of fine-scale climate change monitoring and modelling relevant to the spatial scales of aquaculture farms and lease sites.
- It is important to note that investment in improved physical data will not improve the risk assessment process for all species. Without basic knowledge of sources of recruitment, understanding of critical ecological and trophic linkages, and phenological associations and responses (relationship of timing of spawning and moulting to temperature versus day length for example), such physical information has value but cannot be *fully* utilised. For example, while species distribution models can be populated with fine-scale data, without mechanistic understanding based on biological processes that we know will alter with climate change, results from such models would be of limited predictive value. Furthermore, despite recent investment in large-scale oceanographic monitoring (e.g. IMOS), there has been notably less investment in ecological monitoring to understand the flow-on effects of altered oceanographic regimes to biodiversity, ecosystems, and fisheries.

Adaptation actions are taking place across a range of sectors and regions in Australia in response to existing climate impacts, and in anticipation of future unavoidable impacts. However, it is imperative to note that climate change will unfortunately be an ongoing issue for the foreseeable future. While we may well be able to adapt to a 1–2°C temperature rise over the coming decades, adaptation to a 4°C rise or greater (Parry et al. 2009), for example, would be an incredible challenge (Schneider 2009).

The information derived from this project will allow development of a prioritised framework for future research that is based on species' relative sensitivities to climate change drivers, recognises likely resource limitations and highlights the range of values and issues that could be considered for further work.

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Appendix 1: Intellectual property

This is not applicable to this project.

Appendix 2: Selection and ranking of key species for detailed assessment

Below is a copy of the advice circulated to resource managers and research institutions in each jurisdiction

This is the DRAFT species list for discussion and prioritisation by each jurisdiction's management agency in consultation with the relevant PMC representative. The 25 species collectively ranked the most highly will be selected for individual assessment (sensitivities and tolerances to climate change drivers) and the risk assessment.

Can each jurisdiction please add a rationale/comment on the importance of each species to their area – this can include ecological, recreational, commercial or cultural information (please also see criteria suggested below). The rationale for selecting species will be included in our final report.

If a species occurs in your jurisdiction, but you do not envisage you would rank it highly (or at all), please still fill out some information on its occurrence/importance for your area.

If a particular species ONLY occurs in one jurisdiction you must highlight why this is still an important species for SEAP to consider – i.e. with warming it is expected that the distribution may extend into state x and may therefore represent a potential opportunity to that area.

IF WE ARE MISSING AN IMPORTANT SPECIES OFF THIS LIST PLEASE ADD IT!

Criteria to consider when prioritising species:

The commercial wild catch fishery provides a significant total economic value (please provide GVP in the table).

Recreational fisheries that provide significant economic activity (through fisher participation and associated recreational fishing industry sectors) and/or social benefits.

Target species for aquaculture production that provide high value including those that are either currently in operation or have demonstrated potential as a high value production species.

The species is of significant ecological importance with links to other recreational or commercial species, and/or has the potential to be an indicator species for ecosystem response to climate change.

Fisheries species
Arrow squid (Tas, CMAR)
Banded morwong
Barracouta
Black bream (Vic & NSW)
Black lip abalone (Tas, SA, NSW, Vic)
Blue grenadier (CMAR)
Blue swimmer crabs
Blue warehou
Commercial scallops (Tas, Vic, CMAR)
Eastern Australian salmon (NSW, Vic and Tas)
Eastern and/or western gem fish (CMAR)
Eastern king prawns (NSW)
Flatheads (dusky, sand, tiger, rock)
Garfish (SA and Tas)
Giant crabs (Tas and SA?)
Green lip abalone (Tas, SA?)
King George whiting (Vic, SA)
Orange roughy (CMAR)
Sardine (SA and NSW)
School prawn (NSW)
Silver trevally (CMAR)
Spanner crabs (NSW)
Snapper (Vic and SA and NSW)
Snook
Southern calamari (Tas and SA)
Southern rock lobster (Tas, SA, Vic)
Striped trumpeter (Tas, Vic)
Tailor (NSW)
Tunas
Western Australian salmon (SA and Vic)
Western king prawns

Added species (Commonwealth)
Broad billed swordfish
Gummy shark
Ling
Small pelagic species (Tas & CMAR)
Striped marlin

Added species (SA)
Australian herring

Aquaculture species
Atlantic salmon (Tas)
Greenlip, blacklip and hybrid abalone (SA, Tas, Vic)
Mussels (SA, Vic, Tas)
Native oyster (Tas)
Pacific oysters (NSW, SA and Tas)
Southern bluefin tuna (SA)
Sydney rock oysters (NSW)
Yellowtail kingfish (SA, NSW)

Rationale for wild and aquaculture species selection

* indicates both aquaculture and wild fishery species

Wild Fisheries

Arrow squid (*Nototodarus gouldi*)

Tasmania – Sporadic high volume and highly seasonal fishery. Ecologically very important as predator and prey, species with potential for increasing abundance under changing environmental conditions. 694 t were caught in 2006/07 and 46 t in 2007/08.

NSW – A mixed species fishery with poor catch records though the majority of the 9 tonne fishery in 07/08 is thought to be *N. gouldi*.

Victoria – n/a

South Australia – No reported commercial catch in SA managed fisheries. Very small recreational harvest.

Commonwealth – Ecologically a very important species. Provides a recreational benefit. The commercial wild catch fishery provides a low total economic value of $6,217,610 between 2005/06 and 2007/08.

Australian herring (*Arripis georgianus*)

Tasmania – Occurs along the north and west coasts of Tas. May be mis-identified as juvenile Australian salmon.

NSW – n/a

Victoria – Taken in small quantities in central and western Vic, both recreational and commercial fisheries.

South Australia – A previously important part of the inshore commercial net fishery in the two gulfs. Catches have steadily dropped since the late 1980s from 500 t to 100 t, partly due to decreasing effort by the commercial fishery. In 2000/01, it was the most commonly caught marine finfish species by recreational fishers, and in 2007/08 its importance dropped to one third. In similarity with Western Australian salmon, recruitment variability of herring to SA and its fishery is influenced by ENSO events, and so recruitment might be influenced by climate change.

Commonwealth – n/a

Australian sardine (*Sardinops neopilchardus*)

Tasmania – Whilst no commercial fishery, it is found in Tasmanian waters and considered an important component of pelagic ecosystem.

NSW – Important commercial pelagic fishery extending to SA, previously impacted by mass mortality apparently caused by a herpes virus. Landings in NSW have increased significantly since 2004/05 and in 2007/8 exceeded 2,000 t.

Victoria – Recent increase in catch to 1589 tonnes in 07/08, value of $1.4 million. Ecologically important

South Australia – The SA Sardine Fishery is the largest single species fishery (by weight) in Australia. The Total Allowable Commercial Catch is currently 30,000 t and GVP is approximately $18 million. Sardines mainly occur in southern gulfs and in ocean-shelf waters. Changes in the strength or duration of upwelling events due to climate change could impact on sardines and other components pelagic ecosystem.

Commonwealth – n/a

Banded morwong (*Cheilodactylus spectabilis*)

Tasmania – Long-lived inshore reef fish found in shallow exposed rocky reef areas, forms the basis of a live fish export market, returning a good price for local Asian restaurants.

NSW – n/a

Victoria – Very small commercial fishery for live fish export market. The fishery is primarily in far eastern Victoria using mesh nets. Habitat for this species may be affected by increasing *Centrostephanus* barrens in the area, potentially related to climate change.

South Australia – Very occasionally seen off south-east SA, mainly by recreational spear fishers. Southward extension of the EAC may enhance numbers in eastern SA; however, its biology is unknown in SA.

Commonwealth – n/a

Barracouta (*Thyrsites atun*)

Tasmania – Historically, barracouta was one of the most important species of the Tasmanian scalefish fishery; however, stocks collapsed in the 70s. Only 15 t were caught in 2000/01.

NSW – n/a

Victoria – Insignificant commercial/recreational catch, similar comment to Tasmania.

South Australia – This is a commercially and recreationally minor species in SA, with total harvest levels of about 5–10 t annually. It is taken as by-catch by both sectors when trolling for Australian salmon.

Commonwealth – n/a

Black bream (*Acanthopagrus butcheri*)

Tasmania – Important recreational species increasingly targeted as part of a sport fishery. As an estuarine species it will be highly dependent on river flows. Highly variable recruitment and year class strength, linked to environmental factors.

NSW – A species occurring in south coast estuaries of NSW with episodic recruitment and populations usually dominated by a small number of strong year classes. The species is likely to be on its northern distribution limit in NSW and susceptible to increasing water temperature under climate change scenarios for the NSW coast. This species is a likely climate change indicator in NSW.

Victoria – Very important commercial and recreational finfish fishery in Victoria. Most of the commercial catch comes from Gippsland Lakes where the catch has been declining for over a decade. Relatively specific requirements in terms of environmental factors such as temperature and salinity. Declines in catch may be related to reduced freshwater flows though an extended dry period affecting recruitment. Reduced rainfall in south-eastern Australia is consistent with climate change predictions.

South Australia – Total annual harvest of 15 t (equally shared between commercial and recreational fishers). Commercial harvest is mainly from the Coorong Lagoon, an area of high environmental risk, due to decreasing water flow from the River Murray. The recreational fishery also occurs in estuaries often already impacted by anthropogenic factors and may be impacted by climate related reductions in freshwater flows.

Commonwealth – n/a

Blacklip abalone (*Haliotis rubra*)*

Tasmania – The Tasmanian abalone industry is the largest wild abalone fishery in the world, providing around 25% of the annual global harvest. It is a key player in the Tasmanian commercial fishing sector and contributes significantly to the state's economy. Abalone is potentially threatened by the barren-forming urchin *Centrostephanus* along the east coast of Tasmania, which is predicted to spread further south with increasing temperatures.

NSW – The northern distributional limit of the species occurs in central NSW and recruitment is likely to be significantly impacted by a southern shift in the EAC. The implications of temperature stress on the incidence of the disease *Perkensis* sp. is an important factor when considering climate change. The interactions with sea urchins are similar to Tasmania.

Victoria – The most important marine commercial fishery by value in Victoria. Abalone stocks in western Victoria have been affected by the disease, abalone viral ganglioneuritis (AVG). It is possible that susceptibility to this virus is affected by environmental conditions such as water temperature, and therefore may be related to climate change. The increase in *Centrostephanus* barrens in eastern Victoria, potentially related to climate change, could also affect abalone habitat.

South Australia – Approximately 495 t are commercially harvested throughout the more wave exposed waters of the state. The recreational harvest comprises a very small fraction of the total harvest (~ 1%). Commercial GVP: $17 million.

Commonwealth – n/a

Blue crab (*Portunus pelagicus*)

Tasmania – n/a

NSW – n/a, a widely distributed species.

Victoria – n/a

South Australia – A significant commercial and recreational crustacean fishery for this state (950 t; 30% of total harvest is taken by recreational fishers). It is mainly harvested in the central and northern waters of both gulfs, with a small proportion from the far west coast. Catchability is highest during warmer summer months. Blue crab is mainly a tropical species and there is some evidence that the distribution of blue crabs is extending southwards, particularly in the Gulf St Vincent.

Commonwealth – n/a

Blue grenadier (*Macruronus novaezelandiae*)

Tasmania – n/a

NSW – n/a

Victoria – n/a

South Australia – n/a

Commonwealth – An ecologically important species, with a low recreational benefit. The commercial wild catch fishery provided a significant total economic value of $33 million between 2005/06 and 2007/08.

Blue warehou (*Seriolella brama*)

Tasmania – Commercial and recreational seasonally available species, currently overfished. Marked variability in catch and availability possibly linked to oceanographic conditions. 24.9 t was caught in 2007/08.

NSW – n/a, catch in 2007/8 was less than 1000 kg.

Victoria – n/a

South Australia – Insignificant catches taken in SA commercial and recreational fisheries. A similar species (spotted warehou, *S. punctata*) is subject to sporadic influxes of large numbers of juvenile fish into inshore waters of SA (1987); however, unknown relationship between these occurrences and ocean currents.

Commonwealth – Stocks are subject to a stock rebuilding strategy. The commercial wild catch fishery provided a low total economic value of $2 million between 2005/06 and 2007/08.

Broad billed swordfish (*Xiphias gladius*)

Tasmania – n/a

NSW – n/a

Victoria – n/a

South Australia – No commercial or recreational caught fish in SA managed fisheries. Occasional records of broadbill swordfish strandings in upper gulf waters; however, insufficient number of records to investigate any relationship between numbers and seasonality of strandings and oceanic current strengths off southern Australian coast.

Commonwealth – An important recreational species. The commercial wild catch fishery provided a significant total economic value of $21.6 million between 2005/06 to 2007/08 for the east.

Eastern king prawn (*Melicertus plebejus*)

Tasmania – n/a

NSW – Both eastern king and school prawns are valuable wild harvest commercial and recreational fisheries. The species occur from Queensland to Victoria/Tasmania, and in NSW both species are considered growth overfished. Northern recruitment areas and juvenile utilisation of estuaries and coastal lagoons suggest both species will be impacted by climate shifts.

Victoria – Climate change shift may see an increase in these in Victoria.

South Australia – n/a

Commonwealth – n/a

Eastern Australian salmon (*Arripis trutta)*

Tasmania – There is capacity for industry to expand production to the commercial catch limit should new markets be found. Australian salmon (eastern and western) represent the second most commonly caught species in the recreational fishery.

NSW – A recreational and commercial species, which occurs in estuaries and shelf waters of NSW. Tagging shows a one way movement from Tasmania. Few if any individuals of the western stocks, which overlap in Victoria and Tasmania with the eastern stock, occur in NSW.

Victoria – The two species overlap in Victoria and are not differentiated in catch statistics. Important for both commercial and recreational fishing. Changes to characteristics of both the Leeuwin and East Australian currents under climate change could affect transport of larvae and juveniles to Victorian waters, and also movement of adults.

South Australia – Indistinguishable with the western Australian salmon by commercial and recreational fishers; however, fishery-independent monitoring of juvenile salmon populations throughout SA in the late 1990s noted its occurrence in schools mixed with the western species throughout the SE part of SA. There is a potential for an increasing presence in SA through the southern shift of the EAC. Commercial GVP for combined eastern and western Australian salmon is $188 K.

Commonwealth – n/a

Flatheads (Family: Platycephalidae & Neoplatycephalidae)

General information provided

Tasmania – Most important marine recreational fish in Tasmania.

NSW – A mixed estuarine and ocean fishery for a variety of species harvested by both commercial and recreational fisheries. The 2007/08 commercial catch for all species was 2860 t, though prices for trawl caught fish are often very low.

Victoria – Flatheads are important to the recreational fishery as they are the most commonly caught species group. In contrast, they make up only a small proportion of the commercial catch, except for Rock flathead from Corner Inlet.

South Australia – Commercial and recreational harvest of the state managed flatheads is low (~20 t p.a.), of which 85% is harvested by recreational fishers. Commercial GVP for all flatheads in SA is $19 K.

Commonwealth – Ecologically important species, with recreational value. The commercial wild catch fishery provided a significant total economic value of $30,888,930 between 2005/06 and 2007/08 for tiger, sand, blue-spotted, toothy and yank flathead. (Flathead are not reported to species level).

Platycephalus speculator (southern blue-spotted or yank)

Tasmania – n/a

NSW – n/a

Victoria – Minor commercial and recreational fishery. Second most abundant flathead species in Port Phillip Bay.

South Australia – Southern blue-spotted flathead in commercial and recreational fisheries caught in small numbers; however, it is not distinguished from other flathead species by either groups of fishers reporting on their catches.

Commonwealth – Ecologically important species, with recreational value. The commercial wild catch is not distinguished from other flathead species when catches are reported for tiger, sand, blue-spotted, toothy or yank flathead.

P. caeruleopunctatus (blue-spotted)

Tasmania – n/a

NSW – Is primarily a recreational coastal species with a catch in excess of 400 t the commercial trawl catch is about 120 t.

Victoria – n/a

South Australia – n/a

Commonwealth – Ecologically important species, with recreational value. The commercial wild catch is not distinguished from other flathead species when catches are reported for tiger, sand, blue-spotted, toothy or yank flathead.

P. fuscus (dusky)

Tasmania – n/a

NSW – Is the main estuary species, commercial catch is about 130 t and recreational is about 650t.

Victoria - Low value commercial fishery but important recreational species in eastern Victoria. The most estuarine dependent of the flathead species and may be affected by reduced rainfall and freshwater flow under climate change. Eastern Victoria is the southern range limit for the species, which may extend westwards under climate change.

South Australia – n/a

Commonwealth – n/a

P. bassensis (southern sand)

Tasmania – Flathead are the most important recreational fish in Tasmania; 292 t were caught in 2007/08 – 95% was sand flathead. Sand flathead make up a smaller proportion of the commercial fishery.

NSW – n/a

Victoria – Low value commercial fishery but very important recreational fishery. Most recreational catch comes from Port Phillip Bay where sand flathead abundances have been declining for 20 years. The decline is thought to me environmentally mediated and may be related to climate change.

South Australia – Caught in commercial and recreational fisheries in small numbers; however, it is not distinguished from other flathead species by either groups of fishers reporting on their catches.

Commonwealth – Ecologically important species, with recreational value. The commercial wild catch is not distinguished from other flathead species when catches are reported for tiger, sand, blue-spotted, toothy or yank flathead.

P. laevigatus (rock)

Tasmania – n/a

NSW – n/a

Victoria – Medium value commercial fishery concentrated mainly in Corner Inlet. The species is highly dependent on seagrass habitat and any climate change impacts on seagrass cover would likely affect this species.

South Australia – Small commercial and recreational catches known to occur, however, it is not distinguished from other flathead species by either groups of fishers reporting on their catches.

Commonwealth – n/a

Neoplatycephalus richardsoni (tiger)

Tasmania – The commercial catch is dominated by tiger flathead, and a smaller extent sand flathead; 74 t was caught in 2007/08.

NSW – A commercial nearshore species in NSW with a 200 t harvest which has been stable in recent years; recreational catch is very low. Most tiger flathead on the NSW coast are caught in the Commonwealth, not NSW fishery.

Victoria – n/a

South Australia – n/a, not caught in SA

Commonwealth – Ecologically important species, with recreational value. The commercial wild catch is not distinguished from other flathead species when catches are reported for tiger, sand, blue-spotted, toothy or yank flathead.

N. aurimaculatus (toothy)

Tasmania – n/a

NSW – n/a

Victoria – n/a

South Australia – n/a

Commonwealth – Ecologically important species, with recreational value. The commercial wild catch is not distinguished from other flathead species when catches are reported for tiger, sand, blue-spotted, toothy or yank flathead.

Gemfish, eastern and western (*Rexea solandri*)

Tasmania – n/a

NSW – n/a

Victoria – n/a

South Australia – n/a

Commonwealth – The eastern stock is subject to a stock rebuilding strategy. The western stock of the commercial wild catch fishery provided a total economic value of $4,362,580 between 2005/06 to 2007/08.

Garfish (*Hyporhamphus melanochir*)

Tasmania – After a long period of stability, catch declines have been reported for all major fishing regions due to lack of resource; 30 t were caught in 2007/08.

NSW – n/a, different species (eastern sea garfish) caught in NSW.

Victoria – Low/moderate value commercial fishery, mainly from Corner Inlet; moderate value recreational fishery.

South Australia – This species has been a significant part of the commercial net fishery in SA for many years, with most catches are taken over seagrasses in the shallow northern waters of both gulfs. Annual commercial harvest levels have dropped from ~500 t in the 1990s to ~300 t since 2002, due to lower recruitment levels in Spencer Gulf and decreasing effort throughout the state. The recreational harvest is about 20% of the total harvest. This species could be vulnerable to climate change because of its high exploitation rate and truncated population age structure in the SA gulfs; however, it is not known how climate change will impact reproduction or recruitment.

Commonwealth – n/a

Giant Crab (*Pseudocarcinus gigas*)

Tasmania – The most productive fishing grounds are in waters adjacent to Tasmania, which have historically supported the largest fishery for the species. The giant crab fishery has an annual harvest set at 62.1 t, and has a comparatively high value, with the landed valued estimated to be around $2 million.

NSW – n/a

Victoria – Moderate value commercial fishery (26 t landed in 07/08) in western Victoria. Fishery is within the Bonney upwelling region so could be affected by any climate induced changes to upwelling.

South Australia – There is a small licence limited offshore commercial fishery in SA, producing 17–20 t p.a. ($0.25 million). No reported catch of giant crabs by recreational fishers.

Commonwealth – n/a

Greenlip abalone (*Haliotis laevigata*)*

Tasmania – Constitutes a smaller component of the wild abalone fishery in Tasmania; 122 t were harvested in 2008 (compared to 2,461 t of blacklip).

NSW – n/a

Victoria – n/a

South Australia – Approximately half the total commercial harvest of abalone in SA is greenlip, with higher TACCs and landings with westward progression along the state's coast. The recreational harvest is very small, compared with the commercial fishery. Commercial GVP is $13 million.

Commonwealth – n/a

Gummy shark (*Mustelus antarcticus*)

Tasmania – 13.9 t caught commercially in 07/08; also fished recreationally.

NSW – n/a

Victoria – Fairly small-scale fishery in Victoria with a value of $285,000 (07/08). Moderately significant recreational fishery. Thought to use bay and inlet seagrass habitats as pupping/nursery areas.

South Australia – Moderate commercial and recreational fisheries within state waters. Total harvest is 120 t, with about 15% taken by recreational fishers. GVP for commercial fishery is $518K.

Commonwealth – Ecologically an important species. Important recreational species. The commercial wild catch fishery provides a significant total economic value of $44 m between 2005/06 to 2007/08.

King George whiting (*Sillaginodes punctatus*)

Tasmania – n/a

NSW – n/a

Victoria – Highest value finfish fishery in Victoria and also a highly important recreational species. The main fishery is in the bays of central Victoria which depend on larval supply from far western Victoria and/or South Australia. Therefore, climate change induced changes to current patterns across southern Australia in winter could affect recruitment. There is also a positive correlation between sea temperature off western Victoria and recruitment in Port Phillip Bay, suggesting a possible positive effect of climate change. Juvenile whiting are strongly dependent on seagrass habitat and will be susceptible to climate change effects on seagrass cover. King George whiting spawn in late autumn/winter, so it is possible that increased SST could lead to contraction of spawning period and southward movement of the spawning area for this species.

South Australia – This SA iconic species is the highest valued in the commercial MSF fishery ($ 4.7 million). Commercial catches have steadily declined over the past 10 years from around 760 to 350 t, due to decreasing effort. It is now the most commonly caught species taken in the SA recreational fishery and comprises half the combined commercial and recreational harvest weight. Also, it is the second most commonly caught species in the SA recreational charter boat fishery. Recruitment to the fishery is dependent on surface driven currents transporting eggs and larvae up to several hundred kilometres distant from the nursery areas; however, the consequence of variation in these currents to recruitment is uncertain. It may also be physiologically vulnerable to changes in physical/environmental characteristics.

Commonwealth – n/a

Ling (*Genypterus blacodes*)

Tasmania – Only 0.4 t caught in 2007/08.

NSW – n/a

Victoria – n/a

South Australia – Very small commercial and recreational catches in SA (~1 t).

Commonwealth – Ecologically an important species. Recently assessed as subject to overfishing in the 2008 BRS Status Reports. The commercial wild catch fishery provided a total economic value of $19.6 million between 2005/06 and 2007/08.

Orange roughy (*Hoplostethus atlanticus*)

Tasmania – n/a

NSW – n/a

Victoria – n/a

South Australia – n/a

Commonwealth – Stocks are subject to a stock rebuilding strategy (Orange Roughy Conservation Programme) The commercial wild catch fishery provided a total economic value of $8.9 million between 2005/06 and 2007/08 for the cascade, east and GAB stock.

Scallops (*Pecten fumatus*)

Tasmania – The scallop fishery has historically exhibited boom and bust cycles in catch. 1330 t were caught in 2007, with an estimated value of $8 million.

NSW – n/a

Victoria – Increasingly important commercial fishery (historically variable). Scallop fishery in Bass Strait off Gippsland produced 907 tonnes in 07/08 with a value of about $1.9 million.

South Australia – There is a small recreational dive fishery for this species in SA (~5 t harvested). The commercial dive fishery is also small (confidential data, < 5 licence holders).

Commonwealth – The Commonwealth scallop fishery recently reopened this year after being closed for several years. The commercial wild catch fishery will provide a significant total economic value in 2009/10.

School prawn (*Metapenaeus macleayi*)

Tasmania – n/a

NSW – Both eastern king and school prawns are valuable wild harvest fisheries. The species occur from Queensland to Victoria / Tasmania and in NSW both species are considered growth overfished. Northern recruitment areas and juvenile utilisation of estuaries and coastal lagoons suggest both species will be impacted by climate shifts.

Victoria – n/a

South Australia – n/a

Commonwealth – n/a

Silver trevally (*Pseudocaranx dentex*)

Tasmania – Valued as a recreational species.

NSW – Widely distributed species harvested in both the commercial and recreational sectors.

Victoria – Low to moderately important commercial and recreational fishery. Catch is mainly from bays and inlets which is the primary juvenile habitat.

South Australia – The small recreational fishery in SA (~12 t) is made up of two species that are indistinguishable to recreational fishers. Similarly, a small commercial line fishery exists, but is normally taken as by-product when targeting snapper. Little is known about their biology in this state and hence there is no understanding of the effect of climate change on their population biology.

Commonwealth – n/a

Snapper (*Pagrus auratus*)

Tasmania – Highly valued as a recreational species although only low numbers caught by rec fishers in Tasmanian waters.

NSW – Important recreational and commercial fishery with a general northern movement of tagged individuals. The stock is shared with Qld and is likely to be impacted by a southern shift in the EAC.

Victoria – Moderately important commercial fishery but the recreational catch is much higher, probably the most valuable recreational fishery along with King George whiting. Two stocks occur in Victoria either side of Wilsons Promontory; the eastern stock shared with NSW and Queensland and the western stock, possibly shared with South Australia (unknown). Eastern stock individuals spawn offshore and larvae are likely to be transported southward by the EAC, therefore the dispersal may be affected by a stronger EAC under climate change. Western stock individuals spawn primarily in Port Phillip Bay (PPB). Recruitment in PPB is episodic and is determined early in the larval stage. Environmental conditions in PPB are likely to be affected by factors such as rainfall and freshwater flow that are expected to be affected by climate change. PPB has become hypersaline in recent years as a result of continuing rainfall deficit.

South Australia – A highly important commercial and recreational species in SA, with up to 1000 t in total harvest p.a.; 20% of the harvest is taken by the recreational sector. It is the most important species taken in the SA recreational charter boat fishery and is also the key species for an annual national fishing tournament in northern Spencer Gulf, which has a significant interstate component. Population dynamics are driven by recruitment variation, which is affected by physical environmental characteristics. As yet, this is not well understood, but potentially makes them vulnerable to climate change. Two genetically distinct populations occur in SA – one in the south-east of SA which is also found in western Victoria, and the more common central and western SA population, which is also found in southern WA.

Commonwealth – The commercial wild catch fishery provided a total economic value of $2,612,010 between 2005/06 and 2007/08.

Small pelagic species (redbait, Jack mackerel, blue mackerel)

Tasmania – Redbait is the dominant species of the Tasmanian small pelagics fishery; however, it was historically jack mackerel. In 2007/08, 297 t and 201 t of redbait and JM were caught respectively. Primary market is for the bluefin tuna industry and for use as fish meal. Stock availability probably influenced, in part, by climatic and oceanographic conditions and krill availability. Important component of the pelagic ecosystem.

NSW – n/a

Victoria – n/a

South Australia – n/a

Commonwealth – The small pelagic species group is considered ecologically and recreationally significant by AFMA. The commercial wild catch redbait fishery provides a total economic value of $3.6 million between 2005/06 and 2007/08. The commercial wild catch blue mackerel fishery provided a total economic value of $2.2 million between 2005/06 and 2007/08.

Snook (Sphyraena novaehollandiae)

Tasmania – Taken by recreational fishers.

NSW – n/a

Victoria –Insignificant commercial and recreational fishery.

South Australia – A species of medium importance in the commercial and recreational fisheries with an annual total harvest of about 180 t (equally shared between commercial & recreational sectors). It is mainly harvested in the two gulfs and is a second level predator. Their distribution may be influenced by changes in the distribution of their prey species (small bait fish).

Commonwealth – n/a

Southern bluefin tuna (*Thunnus maccoyii*)*

Tasmania – Important recreational fishery; preferred game fishery species of iconic value. Highly variable availability linked to environmental conditions. Stocks under considerable stress.

NSW – n/a

Victoria – A sport fishery for the species has developed off western Victoria in recent years indicating a shift in distribution

South Australia – There is a state-based annual recreational harvest of about 40 t. The recreational charter boat fishery has seen a rise in numbers harvested since 2005, when catch recording began. The interstate component of the recreational catch in this state is unclear; however, anecdotal information suggests it could be a significant. Variation in catchability of the species in the recreational fishery could be influenced by distribution of prey species at the edge of the continental shelf.

Commonwealth – A very important recreational species. The commercial wild catch fishery provided a significant total economic value of $122.8 million between 2005/06 and 2007/08, and provides the Commonwealth's highest GVP.

Southern calamari (*Sepiotheuthis australis*)

Tasmania – Over the last few years, catch and effort has tripled, recently fluctuating around 80–100 t. This expansion of the fishery is most likely due to growing markets, rising prices and increased use of squid jigs. Important recreational species. Cephalopods respond rapidly to environmental change and have extremely plastic life histories and are likely to be influenced by changing climatic conditions.

NSW – Very variable bycatch in the commercial fishery of about 40 t (2007/08) and a recreational catch estimated at 10 t.

Victoria – Low to moderate value fishery of 61 t in 2007/08.

South Australia – Approximately 500 t are harvested annually in SA; 40% of this catch taken by recreational fishers. Annual commercial catches fluctuate markedly (300–500 t). Most of the fishery (both sectors) occurs in the two gulfs. Southern calamari is a rapid growing, short-lived species, dependent on suitable seagrass/algal habitat in inshore waters to lay their eggs. Juveniles are more commonly found in the more offshore waters of the two gulfs, and monitoring of by-catch from the western king prawn trawl fisheries has successfully been used to monitor recruitment into the inshore fisheries.

Commonwealth – n/a

Southern rock lobster (*Jasus edwardsii*)

Tasmania – Second most important commercial fishery in Tasmania and also highly valued by recreational fishers. Worth $72 million in 2007/08. Changes in growth and puerulus recruitment are occurring along the east and south coasts, thought to be in response to rising temperatures.

NSW – n/a, Eastern Rock Lobster in NSW

Victoria – Second most valuable fishery in Victoria; worth $13.8 million in 2007/08. Recent catch declines have been attributed to affects of currents on larval recruitment or affects of changing water temperature/upwelling on physiological processes such as moulting. These environmental factors may be linked to climate change.

South Australia – This is most highly valued crustacean fishery in SA (~2400 t in 2007/08; value of $91 million). The majority is taken commercially in the southern zone, with only 4% of the commercial harvest taken by the recreational sector. In both fishing zones, catch and CPUEs have declined in recent years, resulting in reduced TACCs. There is some evidence from the southern zone to suggest that growth rates have reduced in recent seasons possibly in response to exceptionally strong upwelling events.

Commonwealth – n/a

Spanner crabs (*Ranina ranina*)

Tasmania – n/a

NSW – Joint fishery dependant monitoring of this shared stock occurs with Qld and a southern shift in the fishery may occur under most predicted climate change scenarios.

Victoria – n/a

South Australia – n/a

Commonwealth – n/a

Striped marlin (*Tetrapturus audax*)

Tasmania – Occasionally taken by recreational game fishers. Highly valued by this sector.

NSW – n/a

Victoria – n/a

South Australia – Very occasionally seen in offshore SA waters. No targeted recreational or commercial fishery in SA.

Commonwealth – A very important recreational species. The commercial wild catch fishery provided a total economic value of $6,579,620 between 2005/06 and 2007/08.

Striped trumpeter (*Latris lineata*)

Tasmania – 15.5 t were harvested in 2007/08. Important recreational species. Recruitment is highly variable.

NSW – n/a

Victoria – n/a

South Australia – n/a

Commonwealth – n/a

Tailor (*Pomatomus saltatrix*)

Tasmania – Taken by recreational fishers in limited numbers from specific areas (eg. Georges Bay).

NSW – n/a

Victoria – n/a

South Australia – Occasionally, small numbers of tailor (10s) are caught in SA waters by recreational fishers; however, it is unknown whether they are derived from WA or eastern Australian populations.

Commonwealth – n/a

Tunas, other (*Thunnus* sp.)

Tasmania – Important recreational species; approximately 144 t were taken in 2007/08. Mainly albacore and skipjack tuna.

NSW – n/a

Victoria – n/a

South Australia – Albacore and yellowfin tuna are the only other thunnid species (apart from SBT) reported in recreational catches in this state. Low annual recreational harvest levels (hundreds of fish, combined species).

Commonwealth – A very important recreational species. The commercial wild catch fishery provided a significant total economic value of $63.5 million between 2005/06 and 2007/08 for yellowfin, bigeye, albacore and skipjack tuna.

Western king prawns (*Melicertus latisulcatus*)

Tasmania – n/a

NSW – n/a

Victoria – n/a

South Australia – The western king prawn fishery in SA is the largest for this species in Australia, producing 2300 t annually (value of $36 million). Spencer Gulf produces the bulk of the harvest with smaller harvests in Gulf St Vincent (GSV) and West Coast (WC) fisheries. The recreational catch is insignificant. The three regions display very different catch histories. The Spencer Gulf Fishery has a stable history of commercial catch due to stable recruitment and sound management practices. The GSV Fishery has had two periods of increasing then declining catch. Recent improvements in management strategies for the fishery have led to a substantial stock recovery. The West Coast Prawn Fishery has a highly variable catch history, likely reflecting variable recruitment associated with the oceanic environment it encompasses. Recent studies suggest that recruitment to this fishery is highly susceptible to environmental change, in particular coastal upwellings associated with El Niño. This is another relic tropical species, which could potentially benefit from climate change.

Commonwealth – n/a

Western Australian salmon (*Arripis truttaceus*)

Tasmania – See comments for Eastern Australian salmon

NSW – n/a

Victoria – See comments for eastern Australian salmon

South Australia – In SA, this is probably the more commonly caught of the two species of Australian salmon. However, the two species are not distinguished by commercial nor recreational fishers. In 2007/08, there was a total harvest of 200 t (45% recreational). Since the introduction of a 1000 t TACC in 1983, the commercial harvest has always been well below the catch limit, but has decreased even more since 2002/03, due to a decrease in fishing effort. Recruitment of the western species to SA is influenced by the strength of eastward-directed surface currents across the GAB and ENSO events. As such, recruitment might be influenced by climate change.

Commonwealth – n/a

Yellowtail kingfish (*Seriola lalandi lalandi*)*

Tasmania – Highly valued as a recreational species. Although only low numbers caught by rec fishers in Tasmanian waters, being increasingly targeted.

NSW – A widely distributed recreational and commercial species with a minimum legal length of 65 cm the catch by both sectors is estimated as equal at 150 t each.

Victoria – n/a

South Australia – The recreational harvest is moderate (~100 t); however, appears to be increasing in the SA recreational charter boat fishery. There is both an inshore (gulf) and offshore light game fish component to the recreational fishery. The gulf fishery is made up of smaller and larger fish, whereas the offshore fishery occurs mainly for larger fish. Currently, some research is being undertaken on the biology of kingfish in SA waters.

Commonwealth – n/a

Aquaculture

Atlantic Salmon (*Salmo salar*)

Tasmania – Tasmanian salmonid farming industry is Australia's largest and most valuable seafood producer, currently producing 26,000 tonnes of Atlantic salmon at an estimated farm gate value of $272 million. There is concern that ocean warming could result in the thermal limit being exceeded in some Tasmanian regions. Additional impacts of climate change, such as availability of freshwater, extreme storm events and increases in jellyfish blooms, may also have consequences for the salmon industry.

NSW – n/a

Victoria – n/a

South Australia – Previous small operations in south east SA (< 50 tonnes per year).

Barramundi (*Lates calcarifer*) (added by SA on the 25/1/2010 after rankings)

While barramundi is a tropical species, it has been farmed in South Australia in intensive recirculation systems and flow-through systems using geothermal groundwater. Annual farm gate value was about $4.5 million dollars in 2007/08, compared to about $1.3 million in New South Wales and $24.3 million in Queensland. Stock are obtained from hatcheries in South Australia or interstate.

Climate change will potentially have less effect on the production of barramundi in South Australia because of the close environmental control possible in the hatchery and grow-out phases. However, water shortages are likely to negatively impact on groundwater supplies (either directly or because of changed government regulated allocations) at some stage, whereas higher air temperatures may reduce water heating costs at times or require greater insulation and cooling costs at other times.

Abalone - blacklip (*Haliotis rubra*), greenlip (*H. laevigata*) and hybrid*

Tasmania – Tasmania's production is primarily blacklip abalone and hybrids between black and greenlip abalone. 170 tonnes were farmed in 2007/08, which was worth approximately $5.5 million.
NSW – No commercial hatchery or growout permits for abalone exist, but a research hatchery is operating at Tomaree Head, Port Stephens.
Victoria – Abalone farming is now Victoria's most valuable marine aquaculture industry with a grow-out value of about $4.3 million in 2006/07.
South Australia – A species farmed in South Australia since the late 1980s, primarily in onshore 'tank' systems but with increasing production and interest in offshore cage systems. All farmed production in SA is greenlip abalone, with an annual farm gate production value being around $5.2 million in 2007/08; compared to between $5–6 million in Tasmania and Victoria in the same year.

Production levels are predicted to continue to increase in each of these states over the coming years. However the industry has also been facing a range of issues including those associated with disease and summer mortalities that seemed to be a stress-related factor, linked, amongst a range of things, to elevated water temperature. Climate change is seen as having potential to cause significant impact.

Dunaliella salina (microalgae) (added by SA on the 25/1/2010 after rankings)

The green microalgal species *Dunaliella salina* is farmed extensively in ponds in South Australia, near Whyalla to produce beta carotene, which is used widely in human health foods and as a colouring agent in aquafeeds. While formal government statistics do not identify the farm gate value of this industry sector in South Australia as it is represented by a single company, it is cited in various publications as around a few million dollars per annum (greater production value originates from Western Australia).

Microalgal production is strongly influenced by such factors as the quantity and intensity of sunlight, levels of various nutrients and minerals and availability of $C0_2$, and wind for natural mixing; these factors have the potential to be significantly influenced by climate change.

Blue mussels (*Mytilus galloprovincialis*)

Tasmania – Tasmanian marine farmers have been growing mussels commercially for over 20 years but only recently has production expanded to a level where Tasmanian mussels are now available year round and in significant quantity. The Tasmanian mussel industry was worth $3.5 million in 2006/07.

NSW – n/a

Victoria – Blue mussels are an important marine aquaculture species in Victoria, primarily located in Port Phillip Bay. The Victorian mussel industry was worth about $2.3 million in 2006/07. Spatfall in Port Phillip Bay has been inconsistent in recent years and this has affected the productivity of the industry. Variability in spatfall is likely to be environmentally mediated and may be linked to climate change; for example, the prolonged rainfall deficit in Victoria may be affecting the ecology of Port Phillip Bay. Recent developments in hatchery rearing of spat are now helping to circumvent this problem.

South Australia – Mussel farming began in South Australia in the mid to late 1990s and is based on the longline system. Production has since grown steadily over the last seven years and is predicted to continue to increase. Annual farm gate production value was about $2.5 million in 2007/08 (1400 t), an amount comparable to Tasmania and Victoria. Spat are obtained from the wild in South Australia.

Climate change induced pH changes are of concern to bivalve mussel farmers; recent publications have also suggested spat survival and growth as well as production can be negatively impacted.

Native oyster (*Ostrea angasi*)

Tasmania – Native oysters were fished out in the 1800s; there is a small fishery in one location in Tasmania where native oyster reef exists. Native oysters make up a tiny proportion (about 1%) of harvested oysters in Tasmania.

NSW – n/a

Victoria – n/a

South Australia – in the 1800s and early 1900s, a large dredge fishery existed for this species in the gulfs and west coast bays (at the time, probably the most highly valued fishery in the state). Since the 1930s, the fishery has collapsed probably due to a population crash, caused by over-fishing and habitat changes due to dredging. The species is now not harvested commercially and is rarely taken in recreational diving operations. Attempts to culture the species in SA have not been economically successful.

Pacific oysters (*Crassostrea gigas*)

The Pacific oyster is becoming the second most valuable bivalve in Australia.

Tasmania –The Tasmanian oyster industry, which is mainly based on Pacific oysters, was worth $23.7 million in 2006/07.

NSW – Introduced noxious species in NSW with restricted distribution and subject to fishing closures to prevent establishment in areas outside of Port Stephens. However, production from Port Stephens was 216,000 dozen in 2007/2008, which was worth about $1 million.

Victoria – n/a

South Australia – Pacific oyster farming was the first form of aquaculture in South Australia, but only began to develop in a significant way from the mid to late 1980s. Pacific oyster is the primary species farmed today, primarily intertidally on longlines using baskets or racks, and is the second most valuable aquaculture industry sector in the state. Production mainly occurs in west coast bays and one embayment in Spencer Gulf. Annual farm gate value of Pacific oyster farming in South Australia was about $32 million in 2007/08, compared to Tasmania’s ~$19 million and ~$1-2 million in New South Wales.

Climate change effects on summer water and air temperatures, salinity, freshwater-run-off and sea level changes have the potential to negatively impact on Pacific oyster farming. Climate change induced pH changes are also of concern to bivalve mussel farmers; recent publications have also suggested spat survival and growth as well as production can be negatively impacted.

Southern bluefin tuna (*Thunnus maccoyii*)*

Tasmania – n/a

NSW – n/a

Victoria – n/a

South Australia – Southern bluefin tuna aquaculture was initiated in about 1990, occurs only in South Australia, and is based on wild capture of stock that are subsequently fattened in sea cages (ranching). Aquaculture operations are focused in the SW region of Spencer Gulf; however, wild fish harvested for ranching are captured by Commonwealth licensed vessels in the GAB and are transported by towed cages to the SW Spencer Gulf aquaculture sites. Annual farm gate production value was about $187 million in 2007/08, down from a high of about $250 million in 2003/04 and with the potential to decline further due to recent quota reductions. While experimental manufactured feeds have been developed, the commercial industry feed is a range of baitfish, about 50% southern Australian caught sardines and 50% imported species. One company, Clean Seas Tuna Ltd, is in the process of propagating southern bluefin tuna; to date they have been very successful with their research and development having spawned the fish and reared some larvae through to a juvenile size of some 60–80cm total length.

The physiology of southern bluefin tuna is difficult to study in the sea and as such the effects of climate change on this species' aquaculture is largely unknown. Suggestions have been made that climate change might impact the species because higher summer water temperatures have the potential to cause greater physiological stress, whereas higher winter temperatures might increase growth rates and negatively impact product condition.

Sydney rock oysters (*Saccostrea glomerata*)

Tasmania – n/a

NSW – Major aquaculture species with a distribution centred on the NSW coast. The 2007/08 production was 6,350,078 dozen oysters.

Victoria – n/a

South Australia – n/a

Commonwealth – n/a

Yellowtail kingfish (*Seriola lalandi lalandi*)*

Tasmania – n/a

NSW – Small-scale commercial farming has been attempted in NSW in the past. A hatchery currently exists in Port Stephens.

Victoria – n/a

South Australia – Yellowtail kingfish are cultured in South Australia in sea cages, with stock coming from a couple of hatcheries. Annual farm gate value was about $17.6 million in 2007/08. There is also interest in farming this species in New South Wales and Western Australia, with a small level of production from the former in 2007/08.

Low winter temperatures have the potential to cause stress-related issues in some parts of South Australia when the growth rates of this species are low, and as such climate change may have a positive impact.

Appendix 3: Species prioritisation by jurisdiction

Table A3.1: Resource managers in consultation with their PMC representative and researchers in each jurisdiction were asked to identify and rank their 10 most important wild fisheries and aquaculture species, numbering from 10 to 1 (with 10 the most important). The 25 species with the highest number of points were suggested for detailed individual assessment and selected subject to PMC approval. GVP = annual gross value of production ($, K), RI = recreational importance (H, M, L), EI = ecological importance (H, M, L). Five most important for each jurisdiction marked in red, next five marked in yellow. W = wild fishery, a = aquaculture.

	NSW				Vic				SA				Tas				CMAR/AFMA			
	GVP	RI	EI	Rank	GVP	RI	EI	Rank	GVP	RI	EI	Rank	GVP	RI	EI	Rank	GVP	RI	EI	Rank
Arrow squid (*Nototodarus gouldi*)	79	L	L											M	H		1 – L 6217	4 - M	10 - H	3
Atlantic salmon (*Salmo salar*)													271823	L	L	8				
Australian herring (*Arripis georgianus*)									394											
Australian sardine (*Sardinops neopilchardus*)	4000	bait	M	2	1414	L	H		17546			5 (+ sml pelagics)			M					
Banded morwong (*Cheilodactylus spectabilis*)					103	L	M						539	L	M	1				
Barracouta (*Thyrsites atun*)					8	L	L		7					L	M					
Black bream (*Acanthopagrus butcheri*)	180	H	H	4	1303	H	M	6	22					H	M					
Blacklip abalone (*Haliotis rubra*)	4075	H[1]	M	5	37774	L	L	7	29483[2]			6 (both species)	105977 (w), 5307 (a)[2]	M	M	10				
Blue crab (*Portunus pelagicus*)	1004	H	L						5472			4 (and/or WKP)								
Blue grenadier (*Macruronus novaezelandiae*)																	8 – H 33098	1 - L	6 - M	4
Blue warehou (*Seriolella brama*)					9	L	M							M	M		2056			
Broad billed swordfish																	5 – M	5 -	2.5	2

(*Xiphias gladius*)																	21648	M	L	
Eastern Australian salmon (*Arripis trutta*)	2050	H	H	6	607[1]	H	M	3	118[1]				248[1]	H	H	3				
Eastern king prawn (*Melicertus plebejus*)	14732	H	H	10	200	M	M													
Flatheads (Family: Platycephalidae)	17367	M	M		622[2]				19					H	M	4	7 – H 30888	3 - L	6 - M	6
Flathead, dusky					102	H	M													
Flathead, sand					39	H	M	5						H	M					
Flathead, rock					423	M	M													
Flathead, tiger														M	M					
Flathead, bluespot																				
Flathead, southern bluespot					58	M	M													
Flathead, toothy																				
Garfish (*Hyporhamphus melanochi*)					510	H	M		1971			3	330	L	M					
Gemfish, eastern and western (*Rexea solandri*)																	4362 west			
Giant crab (*Pseudocarcinus gigas*)					724	L	M		340				1535							
Gummy shark (*Mustelus antarticus*)									518					L	M		9 – H 44071	6 - M	8 - H	10
Greenlip abalone (*Haliotis laevigata*)					209	L	L		29483[2]			6 (both species)	105977 (w), 5307 (a)[2]	L	M					
King George whiting (*Sillaginodes punctatus*)					3028	H	M	8	4944			7								
Ling (*Genypterus blacodes*)																	4 – M 19580	2 - L	6 - M	1
Mussels (*Mytilus* sp.)					2308[3]	L	M	1	2500 (a)				2360			5				
Native oyster (*Ostrea angasi*)																				
Orange roughy (*Hoplostethus atlanticus*)																	8976			
Pacific oysters	1897	L	M						30000			2	15746			6				

(*Crassostrea gigaswas*)									(a)											
Scallops (*Pecten fumatus*)					1881	L	L		n/a				7562	M	L	7	Not Avail			
School prawn (*Metapenaeus macleayi*)	5322	H	H	9	39	L	M													
Silver trevally (*Pseudocaranx dentex*)	674	H	M		224	M	M		34					L	L					
Snapper (*Pagrus auratus*)	3293	H	H	8	806	H	M	10	5637			8		L	L		2612			
Small pelagic species (redbait, mackerels, pilchard)												5 (+ sardines)			H		2 – L 5848	7 - H	9 - H	8
Snook (*Sphyraena novaehollandiae*)					83	L	M		253					L	L					
Southern bluefin tuna (*Thunnus maccoyii*)									186000 (a)			10		M	L		10– H 122941	9 - H	2.5 - L	9
Southern calamari (*Sepiotheuthis australis*)	456	M	M		672	H	H	2	2606					M	H	2				
Southern rock lobster (*Jasus edwardsii*)					13880	M	H	9	104702			9	59162	H	H	9				
Spanner crabs (*Ranina ranina*)	989	H	M	3																
Striped marlin (*Tetrapturus audax*)																	3 – L 6579	10 - H	2.5 - L	5
Sydney rock oysters (*Saccostrea glomerata*)	36064	H	H	7																
Tailor (*Pomatomus saltatrix*)	521	H	L		125	M	H													
Tunas (*Thunnus* sp.)														M	M		6 – M 63496	8 - H	2.5 - L	7
Western king prawns (*Melicertus latisulcatus*)									34289			4 (and/or b crab)								
Western Australian salmon (*Arripis truttaceus*)					607[1]	H	M	4	118[1]				248[1]	M	M					
Yellowtail kingfish (*Seriola lalandi lalandi*)	1174	H	M	1					3 (w) 17600 (a)			1		L	L					

Comments from Victoria

NOTE: 2007/08 financial year
[1] Species are not separated in commercial catch statistics
[2] Dusky $102K, Rock $423K, Southern blue-spotted $58K, Sand $39K
[3] 2006/07 financial year (low compliance therefore not included 07/08)

Comments from NSW

NOTE: value is for 2007/08 and is based on the monthly average price for the species at the Sydney Fish Markets multiplied by monthly catch from the commercial catch database. This is a minimum value as most high price catch is sold direct to Registered fish receivers for which we do not have prices.
[1] for special sector

Comments from CMAR

NOTE: The "ecological importance" column separates squid, small pelagics and chondrychthians then groups demersal and pelagic. The three demersal species (Blue Grenadier, Flatheads and Ling) were each given 6 points (sum of 7+6+5 divided by 3) and the four pelagic species (Southern Bluefin Tuna, Other tunas, Broad Billed Swordfish and Striped Marlin) were each given 2.5 points (sum of 4+3+2+1 divided by 4).

Comments from SA

NOTE: 2008/09 financial year for commercial wild fisheries (w), 2007/08 for aquaculture species (a).
[1] Eastern and western Australian salmon GVP not separated here.
[2] Blacklip and greenlip abalone GVP not separated here.
n/a: confidential data for scallops, < 5 commercial fishers.

Comments from Tas

NOTE: 2006/07 financial year, commercial wild fisheries = (w), for aquaculture species = (a).
[1] Eastern and western Australian salmon GVP not separated here, [2] Blacklip and greenlip abalone GVP not separated here.

Appendix 4: Selection and ranking of key species for detailed assessment

Table A4.1: Summary of rankings numbering from 10 to 1 (with 10 the most important). Note that abalone, Australian salmon, and flathead are being treated as single 'species' groups and sardines have been combined with the small pelagics. Green = species which are unranked but occur in the jurisdiction, yellow=ranked species, red= assessments CMAR to coordinate.

Species (total = 30)	**NSW**	**Vic**	**SA**	**Tas**	***Total (states)***	**CMAR**	**Wild**	**Aqua**	
Abalone, blacklip/greenlip (*Haliotis laevigata, H. rubra*)	5	7	6	10	28	-	x	X	**Two assessments**, one aquaculture (Vic to coordinate, input from SA and TAS), one wildfish (TAS, with from input all other States)
Southern rock lobster (*Jasus edwardsii*)	-	9	9	9	27	-	x		TAS to coordinate, input from all States except NSW
Snapper (*Pagrus auratus*)	8	10	8	-	26	-	X		Vic to coordinate, major input from NSW & SA, includes comments from TAS
King George whiting (*Sillaginodes punctatus*)	-	8	7	-	15	-	X		VIC or SA to coordinate, input from other
Australian walmon, eastern/ western (*Arripis trutta, A. truttaceus*)	6	3	-	3/4	13	-	X		NSW to coordinate, major input VIC and TAS, include comments from SA
Black bream (*Acanthopagrus butcheri*)	4	6	-	-	10	-	X		VIC or NSW to coordinate, input from others
Eastern king prawn (*Melicertus plebejus*)	10	-	-	-	10	-	X		NSW to coordinate
Southern bluefin tuna (*Thunnus maccoyii*)	-	-	10	-	10	9	x	x	**Two assessments**, one wildfish (CMAR, input from States), one culture (SA)
Flatheads (Family: Platycephalidae)	-	5 (sand)	-	4	9	6	x		VIC to coordinate, major input from TAS and CMAR – (will be a large assessment)
School Prawn (*Metapenaeus macleayi*)	9	-	-	-	9	-	X		NSW to coordinate
Atlantic salmon (*Salmo salar*)	-	-	-	8	8	-		x	TAS to coordinate
Pacific oysters (*Crassostrea gigaswas*)	-	-	2	6	8	-		X	SA to coordinate with input from TAS
Scallops (*Pecten fumatus*)	-	-	-	7	7	-	x		TAS to coordinate
Small pelagic species (redbait, mackerels, sardines)	2	-	5	-	7	8	x		SA to coordinate, major input from CMAR and TAS
Sydney rock oysters (*Saccostrea glomerata*)	7	-	-	-	7	-		x	NSW to coordinate

Mussels (*Mytilus* sp.)	-	1	-	5	6	-		X	TAS to coordinate, input from VIC and SA
Blue crab (*Portunus pelagicus)*	-	-	4	-	4	-	X		SA to coordinate
Southern calamari (*Sepiotheuthis australis*)	-	2	-	2	4	-	x		SA/TAS , input VIC and NSW
Western king prawns *(Melicertus latisulcatus)*	-	-	4	-	4	-	x		SA to coordinate
Garfish (*Hyporhamphus melanochi)*	-	-	3	-	3	-	X		SA to coordinate, input TAS and VIC
Spanner crabs (*Ranina ranina*)	3	-	-	-	3	-	x		NSW to coordinate
Yellowtail kingfish (*Seriola lalandi lalandi*)	1	-	1	-	2	-	x	X	**Two assessments,** NSW to coordinate wildfish one, SA to coordinate aquaculture
Banded morwong (*Cheilodactylus spectabilis*)	-	-	-	1	1	-	X		
Arrow squid (*Nototodarus gouldi*)	-	-	-	-	0	3	x		
Blue grenadier (*Macruronus novaezelandiae*)	-	-	-	-	0	4	X		CMAR to coordinate
Broad billed swordfish (*Xiphias gladius*)	-	-	-	-	0	2	X		
Gummy Shark (*Mustelus antarticus*)	-	-	-	-	0	10	x		CMAR to coordinate, input VIC, SA & TAS
Ling (*Genypterus blacodes*)	-	-	-	-	0	1	X		
Striped marlin (*Tetrapturus audax*)	-	-	-	-	0	5	x		CMAR to coordinate, input TAS and SA
Tunas, other (*Thunnus* sp.)	-	-	-	-	0	7	x		CMAR to coordinate, input TAS and SA

Appendix 5: Raw risk assessment scores for wild fisheries species

Table 1. Australian anchovies

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Serial batch spawners, ~ 15,000 per batch
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on neither habitat or prey	1	
			Av = 1.25	
Distribution	Larval duration	> 2 months	1	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Potential increase in population size in Tasmania only.
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	
			Av = 2.00	
Total Risk Ranking			**5.00**	

Table 2. Australian salmon

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Certain assessment
	Recruitment	Occasional and variable recruitment period	2	Certain assessment
	Maturity	2-10 yrs	2	Certain assessment
	Generalist vs. specialist	Reliance on either habitat or prey	2	Certain assessment
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	Certain assessment
	Adult/juvenile range	> 1,000 km	1	Certain assessment
	Physiological tolerance	> 20 degrees latitude	1	Certain assessment
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Certain assessment
			Av = 1.50	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Uncertain judgement. Current-driven by Leeuwin Current in the east and the East Australian Current in the west.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Uncertain judgement. Current-driven by Leeuwin Current in the east and the East Australian Current in the west.
	Life-cycle events	Wide duration, 2-4 months	2	Uncertain judgement. And variable between States
	Migration	Migration is common for the whole population	3	Certain assessment
			Av = 2.25	
Total Risk Ranking			**5.50**	

Table 3. Australian sardine

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Batch fecundities approx 15,000 per female, spawning fraction 0.156 during spawning season
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on neither habitat or prey	1	Highest abundances occur in association with upwelling areas, characterised by high productivity (zooplankton food for sardines)
			Av = 1.25	
Distribution	Larval duration	> 2 months	1	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	Ranges between sthn Qld and SA
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Possible potential to increase in abundance off eastern Tasmania, dependent upon existing small pelagic species occupying similar pelagic habitat (e.g. redbait)
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	Spawning in SA occurs between January and March
	Migration	Migration is common for some of the population	2	Movement of sardines poorly understood.
			Av = 2.00	
Total Risk Ranking			**5.00**	

Table 4. Bigeye tuna

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Fishbase
	Recruitment	Occasional and variable recruitment period	2	Poorly known
	Maturity	2-10 yrs	2	Farley, J. H., N. P. Clear, B. Leroy, T. L. O. Davis and G. McPherson (2006). Age, growth and preliminary estimates of maturity of bigeye tuna, *Thunnus obesus*, in the Australian region. Marine and Freshwater Research 57.
	Generalist vs. specialist	Reliance on neither habitat or prey	1	Pretty general…
			Av = 1.50	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	> 1,000 km	1	Evans, K., A. Langley, N. P. Clear, P. Williams, T. A. Patterson, J. R. Sibert, J. Hampton and J. Gunn (2008). Behaviour and habitat preferences of bigeye tuna (*Thunnus obesus*) and their influence on longline fishery catches in the western Coral Sea. Canadian Journal of Fisheries and Aquatic Sciences 65: 2427-2443.
	Physiological tolerance	> 20 degrees latitude	1	Moderates this with changes in depth distribution
	Spatial availability of habitat	Substantial unoccupied habitat, >6 degrees latitude (or longitude).	1	Personal judgement
			Av = 1.50	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Highly uncertain.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Highly uncertain.
	Life-cycle events	Wide duration, 2-4 months	2	Farley et al (2006).
	Migration	Migration is common for some of the population	2	Evans et al (2008).
			Av = 2.00	
Total Risk Ranking			**5.00**	

Table 5. Blacklip abalone

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	2-10 yrs	2	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.75	
Distribution	Larval duration	< 2 weeks or no larval stage	3	
	Adult/juvenile range	< 10 km	3	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	No opportunity for southward change in distribution.
			Av = 2.75	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Temperature. Judgement not verified with data.
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Temperature. Judgement not verified with data.
	Life-cycle events	Wide duration, 2-4 months	2	Not much known about spawning period. Duration of spawning season may vary spatially.
	Migration	No migration	1	
			Av = 2.25	
Total Risk Ranking			**6.75**	

Table 6. Black bream

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	High certainty (See section 2.1 in species review)
	Recruitment	Highly episodic recruitment events	3	Some temporal variability e.g. variation was higher late 80s/early 90s than late 90s/early 2000s in Gippsland Lakes (Jenkins 2010).
	Maturity	2-10 yrs	2	High certainty (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on either habitat or prey	2	High certainty. Reliance on estuarine habitat, particularly strong halocline for spawning (Jenkins 2010)
			Av = 2.00	
Distribution	Larval duration	2-8 weeks	2	Moderate certainty, need more data (See sections 2.1 and 2.2 in species review)
	Adult/juvenile range	10 - 1000 km	2	Lifetime range most likely limited to one estuarine system (See section 2.2 in species review)
	Physiological tolerance	10 - 20 degrees latitude	2	High certainty (See section 4 in species review)
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	High certainty, Already in Tasmania, can't move south, limited estuarine habitat in SE Australia (See section 2.3 in species review)
			Av = 2.25	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Moderate certainty, lack of information, temperature, salinity structure and day-length all likely to contribute (See sections 2.1 and 2.5 in species review)
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Low certainty, little data available (See sections 2.1 and 2.5 in species review)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	No migration	1	High certainty. Generally restricted to one estuary, may move within estuary in relation to season/spawning (See section 2.3 in species review)
			Av = 2.25	
Total Risk Ranking			**6.50**	

Table 7. Blue grenadier

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	1 million eggs
	Recruitment	Highly episodic recruitment events	3	It does recruit ever year - but the magnitude varies enormously - regular episodic very good recruitment years about once every 8-10 years
	Maturity	2-10 yrs	2	4-5 years
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 2.00	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	> 1,000 km	1	Migrate to spawning grounds - only one major spawning ground
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	
			Av = 2.00	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature, but uncertain.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature, but uncertain.
	Life-cycle events	Wide duration, 2-4 months	2	Lasts from May/June -> August
	Migration	Migration is common for the whole population	3	Only for spawning
			Av = 2.25	
Total Risk Ranking			**6.25**	

Table 8. Blue mackerel

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on neither habitat or prey	1	
			Av = 1.25	
Distribution	Larval duration	> 2 months	1	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Potential to increase in population size off Tasmania only
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	
			Av = 2.00	
Total Risk Ranking			**5.00**	

Table 9. Blue sprat

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	100 - 20,000 eggs per year	2	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats,	2	
		2-6 degrees latitude	**Av = 2.00**	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	
			Av = 2.00	
Total Risk Ranking			**5.75**	

Table 10. Blue swimmer crab

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	0.6 - 1.2 million eggs per spawning (Kumar et al, 2000)
	Recruitment	Consistent recruitment events every 1-2 years	1	2 - 3 years of age
	Maturity	<= 2 yrs	1	Approx 1 yr of age (Dixon & Hooper, 2009)
	Generalist vs. specialist	Reliance on either habitat or prey	2	Blue crabs inhabit wide number of habitats in SA gulfs - seagrass, algal, sand or mud habitats (Dixon & Hooper, 2009)
			Av = 1.25	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	< 10 km	3	
	Physiological tolerance	> 20 degrees latitude	1	Wide ranging species; Qld - SA - high temperature and salinity tolerances
	Spatial availability of habitat	Substantial unoccupied habitat, >6 degrees latitude (or longitude).	1	Potential for species to expand to sthn SA Gulf waters
			Av = 1.75	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Temperature.
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	Peak spawning seasons differ by one month between the two SA gulfs (Oct & Nov, resp.), however, some spawning (female egg carrying) can occur throughout the year (Dixon & Hooper, 2009)
	Migration	Migration is common for some of the population	2	Juvenile migration.
			Av = 2.50	
Total Risk Ranking			**5.50**	

Table 11. Commercial scallop

Attribute	Criteria	Risk Ranking: Category	Risk Ranking: Score	Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Highly episodic recruitment events	3	
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	< 10 km	3	
	Physiological tolerance	10 - 20 degrees latitude	2	Distribution and species status of *Pecten fumatus* debated. We define *P. fumatus* distribution ranging between Shark Bay (WA) to mid NSW.
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	For populations with commercial densities
			Av = 2.50	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Temperature.
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	Duration of spawning season varies spatially. < 4 months in Tas, > 4 months in NSW and VIC (Young et al. 1999). Key fishery in Tas waters, so class as medium.
	Migration	No migration	1	
			Av = 2.25	
Total Risk Ranking			**6.50**	

Table 12. Dusky flathead

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	High certainty (See section 2.1 in species review)
	Recruitment	Occasional and variable recruitment period	2	Low certainty - little data on this (See section 2.4 in species review)
	Maturity	2-10 yrs	2	High certainty (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on either habitat or prey	2	High certainty - reliance on estuarine habitat (See sections 2.2 and 2.3 in species review)
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	Medium - high certainty (See sections 2.1 and 2.2 in species review)
	Adult/juvenile range	10 - 1000 km	2	Low - medium certainty, can move between estuaries, lack of data on this (See sections 2.1 and 2.2 in species review)
	Physiological tolerance	> 20 degrees latitude	1	High certainty (See section 2.2 in species review)
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Potential to expand to Tasmania, limited to estuarine habitats (See section 2.2 in species review)
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature - high certainty - spawning mainly related to increases in temperature and day length (See section 2.1 in species review)
	Settlement / metamorphosis cue	No apparent correlation to environmental variable	1	Temperature - low certainty, little or no information (See sections 2.1 and 2.2 in species review)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	Medium certainty - migration to estuary mouth for spawning, may move between estuaries (See sections 2.1 and 2.2 in species review)
			Av = 1.75	
Total Risk Ranking			**5.25**	

Table 13. Eastern king prawn

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Certain assessment
	Recruitment	Occasional and variable recruitment period	2	Certain assessment
	Maturity	2-10 yrs	2	Certain assessment
	Generalist vs. specialist	Reliance on either habitat or prey	2	Certain assessment
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	Uncertain assessment
	Adult/juvenile range	> 1,000 km	1	Certain assessment
	Physiological tolerance	> 20 degrees latitude	1	Certain assessment
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Certain assessment
			Av = 1.50	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Season, fresh water discharge and the East Australian Current.
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Season, fresh water discharge and the East Australian Current.
	Life-cycle events	Wide duration, 2-4 months	2	Certain assessment
	Migration	Migration is common for the whole population	3	Certain assessment
			Av = 2.75	
Total Risk Ranking			**6.00**	

Table 14. Greenlip abalone

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	2-10 yrs	2	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.75	
Distribution	Larval duration	< 2 weeks or no larval stage	3	
	Adult/juvenile range	< 10 km	3	
	Physiological tolerance	< 10 degrees latitude	3	
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	
			Av = 2.75	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Temperature. Judgement not verified with data.
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Temperature. Judgement not verified with data.
	Life-cycle events	Brief duration, <2 months	3	
	Migration	No migration	1	
			Av = 2.50	
Total Risk Ranking			**7.00**	

Table 15. Gummy shark

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	<100 eggs per year	3	
	Recruitment	Consistent recruitment events every 1-2 years	1	
	Maturity	2-10 yrs	2	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 2.00	
Distribution	Larval duration	< 2 weeks or no larval stage	3	
	Adult/juvenile range	> 1,000 km	1	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	
			Av = 2.25	
Phenology	Spawning cue	No apparent correlation of spawning to environmental variable	1	
	Settlement / metamorphosis cue	No apparent correlation to environmental variable	1	
	Life-cycle events	Wide duration, 2-4 months	2	2 month ovulation period
	Migration	Migration is common for the whole population	3	
			Av = 1.75	
Total Risk Ranking			**6.00**	

Table 16. Jack mackerel

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	2-10 yrs	2	Stevens et al (1984) suggest age at maturity 3 yrs or more for the GAB.
	Generalist vs. specialist	Reliance on either habitat or prey	2	Abundance of *Euphausiids* off east coast of Tas may influence fat production in jack mackerel, and ultimately egg production in following season (Williams & Pullen, 1993).
			Av = 1.75	
Distribution	Larval duration	> 2 months	1	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	
			Av = 2.00	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	
			Av = 2.00	
Total Risk Ranking			**5.75**	

Table 17. King George whiting

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	High certainty (See section 2.1 in species review)
	Recruitment	Occasional and variable recruitment period	2	High certainty (See sections 2.1 and 2.4 in species review)
	Maturity	2-10 yrs	2	High certainty, generally 3 - 5 years, high spatial variability (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on either habitat or prey	2	Seagrass dependence, moderate - high certainty, some spatial variability, some lack of data (See sections 2.2 and 2.3 in species review)
			Av = 1.75	
Distribution	Larval duration	> 2 months	1	High certainty, 3 - 5 months (See section 2.1 in species review)
	Adult/juvenile range	10 - 1000 km	2	potential lifetime range, moderate certainty, lack of data (See sections 2.1 and 2.2 in species review)
	Physiological tolerance	10 - 20 degrees latitude	2	High certainty (See section 2.2 in species review)
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Potential expansion to Tasmania only (See section 2.2 in species review)
			Av =1.75	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Moderate to high certainty, rearing studies, need more info on spatial variation (See section 2.1 in species review)
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	High certainty, see Jenkins and King 2006
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for the whole population	3	Some uncertainty, need more data on this, Victorian fish may migrate to SA for spawning (See sections 2.1 and 2.2 in species review)
			Av = 2.75	
Total Risk Ranking			**6.25**	

Table 18. Redbait

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Neira et al, 2008
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	2-10 yrs	2	2 yrs for east coast Tasmanian population, 4 yrs for SW Tas population
	Generalist vs. specialist	Reliance on neither habitat or prey	1	
			Av = 1.50	
Distribution	Larval duration	> 2 months	1	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	
			Av = 2.00	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	
			Av = 2.00	
Total Risk Ranking			**5.50**	

Table 19. Rock flathead

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Moderate certainty, little information (See section 2.1 in species review)
	Recruitment	Occasional and variable recruitment period	2	Low certainty - little data on this (See sections 2.1 and 2.4 in species review)
	Maturity	2-10 yrs	2	High certainty (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on either habitat or prey	2	High certainty, requires seagrass/reef-algal habitat (See sections 2.2 and 2.3 in species review)
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	Low certainty, little information (See section 2.1 in species review)
	Adult/juvenile range	10 - 1000 km	2	Low certainty, little information (See sections 2.1 and 2.2 in species review)
	Physiological tolerance	10 - 20 degrees latitude	2	High certainty (See section 2.2 in species review)
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	Already found throughout Tasmania (See section 2.2 in species review)
			Av =2.25	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature - low certainty - little information (See section 2.1 in species review)
	Settlement / metamorphosis cue	No apparent correlation to environmental variable	1	Temperature - low certainty, little or no information, some evidence for effect of river flow (See sections 2.1 and 2.4 in species review)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	No migration	1	Low certainty - little or no information (See sections 2.1 and 2.2 in species review)
			Av = 1.50	
Total Risk Ranking			**5.50**	

Table 20. Sand flathead

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Medium certainty, data lacking (See Brown 1977)
	Recruitment	Occasional and variable recruitment period	2	Medium - high certainty, need data on spatial variation (See sections 2.1 and 2.4 in species review)
	Maturity	2-10 yrs	2	High certainty (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on neither habitat or prey	1	High certainty (See sections 2.2 and 2.3 in species review)
			Av = 1.50	
Distribution	Larval duration	2-8 weeks	2	Temperature - high certainty (See section 2.1 in species review)
	Adult/juvenile range	10 - 1000 km	2	Low certainty, lack of data on this (See sections 2.1 and 2.2 in species review)
	Physiological tolerance	10 - 20 degrees latitude	2	High certainty (See sections 2.1 and 2.2 in species review)
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	Cool temperate species, already occurs throughout Tasmania, cannot move further south (See section 2.1 in species review)
			Av = 2.25	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Temperature - high certainty (See section 2.1 in species review)
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature - low to moderate certainty, -ve correlation with temp in Port Phillip Bay (Jenkins 2010)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	No migration	1	Low certainty, little data on this (See sections 2.1 and 2.2 in species review)
			Av = 2.00	
Total Risk Ranking			**5.75**	

Table 21. Sandy sprat

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	**Score**	
Abundance	Fecundity	100 - 20,000 eggs per year	2	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	
			Av = 2.00	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	
			Av = 2.00	
Total Risk Ranking			**5.75**	

Table 22. School prawn

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	100 - 20,000 eggs per year	2	Certain assessment
	Recruitment	Occasional and variable recruitment period	2	Certain assessment
	Maturity	<= 2 yrs	1	Certain assessment
	Generalist vs. specialist	Reliance on either habitat or prey	2	Certain assessment
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	Uncertain assessment based on general peneid data
	Adult/juvenile range	10 - 1000 km	2	Certain assessment
	Physiological tolerance	10 - 20 degrees latitude	2	Certain assessment
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Certain assessment
			Av = 2.00	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Season, fresh water discharge and the East Australian Current.
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Season, fresh water discharge and the East Australian Current.
	Life-cycle events	Wide duration, 2-4 months	2	Uncertain
	Migration	Migration is common for the whole population	3	Certain assessment
			Av = 2.75	
Total Risk Ranking			**6.50**	

Table 23. Snapper

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	High certainty (See section 2.1 in species review)
	Recruitment	Occasional and variable recruitment period	2	High certainty, higher level seen in SA (See section 2.5 in species review)
	Maturity	2-10 yrs	2	High certainty (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on either habitat or prey	2	High certainty (See sections 2.3 and 2.4 in species review)
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	High certainty (See section 2.1 in species review)
	Adult/juvenile range	10 - 1000 km	2	Lifetime range (See section 2.1 and 2.3 in species review)
	Physiological tolerance	> 20 degrees latitude	1	Aquaculture studies, moderate certainty (See section 4 in species review)
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Potential expansion to Tasmania only (See section 2.3 in species review)
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature. Strongly correlated in each location, but variable for distribution. (See section 2.1 in species review)
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature. Moderate certainty - need more data (See sections 2.1 and 2.5 in species review)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	Moderate certainty, need more data (See sections 2.1 and 2.3 in species review)
			Av = 2.00	
Total Risk Ranking			**5.50**	

Table 24. Southern bluespot flathead

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	**Score**	
Abundance	Fecundity	>20,000 eggs per year	1	Moderate - high certainty (See section 2.1 in species review)
	Recruitment	Occasional and variable recruitment period	2	Low certainty - little data on this (See sections 2.1 and 2.4 in species review)
	Maturity	<= 2 yrs	1	High certainty (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on neither habitat or prey	1	High certainty (See sections 2.2 and 2.3 in species review)
			Av = 1.25	
Distribution	Larval duration	2-8 weeks	2	Temperature - low certainty, little information (See sections 2.1 and 2.4 in species review)
	Adult/juvenile range	10 - 1000 km	2	Low certainty, little information (See section 2.1 and 2.2 in species review)
	Physiological tolerance	10 - 20 degrees latitude	2	High certainty (See section 2.2 in species review)
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Potential to expand to Tasmania only (See section 2.2 in species review)
			Av = 2.00	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature - high certainty - spawning mainly related to increases in temperature and day length (See section 2.1 in species review)
	Settlement / metamorphosis cue	No apparent correlation to environmental variable	1	Temperature - low certainty, little or no information (See sections 2.1 and 2.4 in species review)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	Low certainty - little or no information (See sections 2.1 and 2.2 in species review)
			Av = 1.75	
Total Risk Ranking			**1.25**	

Table 25. Southern calamari

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	100 - 20,000 eggs per year	2	
	Recruitment	Consistent recruitment events every 1-2 years	1	However, generations do not overlap, therefore recruitment failure in one year can result in population crashes.
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.50	
Distribution	Larval duration	< 2 weeks or no larval stage	3	Direct development
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	> 20 degrees latitude	1	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	
			Av = 2.25	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Direct development (no larval stage), but temperature correlated to rate of embryonic development (Steer et al. 2002 and 2003)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for the whole population	3	
			Av = 2.25	
Total Risk Ranking			**6.00**	

Table 26. Southern garfish

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	100 - 20,000 eggs per year	2	
	Recruitment	Consistent recruitment events every 1-2 years	1	
	Maturity	<= 2 yrs	1	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.50	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	
			Av = 2.25	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Spawning occurs during summer months, when water temperatures are 19 - 23 C
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	No information, however, larval development occurs when water temperatures are relatively high.
	Life-cycle events	Wide duration, 2-4 months	2	Oct - March spawning period
	Migration	No migration	1	Limited larval and adult movements. Several separate populations within SA gulfs
			Av = 1.75	
Total Risk Ranking			**5.50**	

Table 27. Southern bluefin tuna

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Farley, J. H. and T. L. O. Davis (1998). Reproductive dynamics of southern bluefin tuna, *Thunnus maccoyii*. Fishery Bulletin 96(2): 223-236.
	Recruitment	Consistent recruitment events every 1-2 years	1	Uncertain - based on Great Australian Bight aerial survey index, trouble is it is co-varying with changing population size. Definitely not "high"
	Maturity	> 10 yrs	3	Gunn, J. S., N. P. Clear, T. I. Carter, A. J. Rees, C. A. Stanley, J. H. Farley and J. M. Kalish (2008). Age and growth in southern bluefin tuna, *Thunnus maccoyii* (Castelnau): Direct estimation from otoliths, scales and vertebrae. Fisheries Research 92: 207-220.
	Generalist vs. specialist	Reliance on neither habitat or prey	1	Quite wide ranging, generalist; lots of refs on movement and food choice
			Av = 1.50	
Distribution	Larval duration	2-8 weeks	2	
	Adult/juvenile range	> 1,000 km	1	Bestley, S., T. A. Patterson, M. A. Hindell and J. S. Gunn (2010). Predicting feeding success in a migratory predator: integrating telemetry, environment, and modeling techniques. Ecology 91: 2373-2384.
	Physiological tolerance	> 20 degrees latitude	1	Caton, A. E. (1991). Review of aspects of southern bluefin tuna biology, population and fisheries. Proceedings of the first FAO Expert Consultation on interactions of Pacific tuna fisheries, Noumea, New Caledonia.
	Spatial availability of habitat	Substantial unoccupied habitat, >6 degrees latitude (or longitude).	1	Pelagic species, plenty of water
			Av = 1.25	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Matsura, H., T. Sugimoto, M. Nakai and S. Tsuji (1997). Oceanographic conditions near the spawning ground of southern bluefin tuna; northeastern Indian Ocean. Journal of Oceanography 53: 421-433.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Unknown….some aquaculture trials in SA may now show this as rate is faster….

	Life-cycle events	Wide duration, 2-4 months	2	Farley, J. H. and T. L. O. Davis (1998). Reproductive dynamics of southern bluefin tuna, *Thunnus maccoyii*. Fishery Bulletin 96(2): 223-236.
	Migration	Migration is common for the whole population	3	Caton, A. E. (1991). Review of aspects of southern bluefin tuna biology, population and fisheries. Proceedings of the first FAO Expert Consultation on interactions of Pacific tuna fisheries, Noumea, New Caledonia.
			Av = 2.50	
Total Risk Ranking			**5.25**	

Table 28. Southern rock Lobster

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	2-10 yrs	2	
	Generalist vs. specialist	Reliance on either habitat or prey	2	
			Av = 1.75	
Distribution	Larval duration	> 2 months	1	
	Adult/juvenile range	< 10 km	3	
	Physiological tolerance	< 10 degrees latitude	3	
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	
			Av = 2.50	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Current induced temperature changes. More relevant on eastern stocks. Pecl et al 2009
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Data showing month of settlement has been shifting over last 16 years. Pecl et al 2009
	Life-cycle events	Brief duration, < 2 months	3	Check to see if data is available.
	Migration	No migration	1	
			Av = 2.50	
Total Risk Ranking			**6.75**	

Table 29. Spanner crab

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Certain assessment
	Recruitment	Occasional and variable recruitment period	2	Certain assessment
	Maturity	2-10 yrs	2	Uncertain assessment
	Generalist vs. specialist	Reliance on neither habitat or prey	2	Certain assessment
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	Uncertain assessment
	Adult/juvenile range	10 - 1000 km	2	Certain assessment
	Physiological tolerance	10 - 20 degrees latitude	2	Certain assessment
	Spatial availability of habitat	Substantial unoccupied habitat, >6 degrees latitude (or longitude).	1	Certain assessment
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Uncertain judgement.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Uncertain judgement.
	Life-cycle events	Continuous duration, > 4 months	1	Certain assessment
	Migration	Migration is common for some of the population	2	Certain assessment
			Av = 1.75	
Total Risk Ranking			**5.25**	

Table 30. Striped marlin

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	High level of certainty. 3 million - 90 million oocytes per spawning season. Kopf. 2010.
	Recruitment	Consistent recruitment events every 1-2 years	1	Medium certainty. Analysis of data from the pelagic database in Tasmania (sample of 37,100 striped marlin caught in S QLD) indicates that there is a single annual spawning cycle with spawning generally occurring continually between approximately September to December and with the resulting cohort recruiting the fishery around 10 months later when they weigh around 11 kg (Robert Campbell AFMA brief 2010).
	Maturity	2-10 yrs	2	~1.4-3 years. Kopf. 2010.
	Generalist vs. specialist	Reliance on either habitat or prey	2	Medium to high certainty. They have a temperature dependant habitat. Some uncertainty as to necessity of sub-surface topography for habitat. Generalist feeder high certainty. Kopf 2010.
			Av = 1.50	
Distribution	Larval duration	2-8 weeks	2	Medium certainty. Transition of larvae to post larvae occurs in 1 to 2 weeks from hatching. There is some uncertainty of the duration of the post larval phase (Kopf pers comm 2010).
	Adult/juvenile range	10 - 1000 km	2	Satellite data indicates some individuals migrate over 3000nm however more than 80% tend to stay within 500nm range. Kopf 2010. High certainty.
	Physiological tolerance	> 20 degrees latitude	1	Highly migratory species. High certainty.

	Spatial availability of habitat	Substantial unoccupied habitat, >6 degrees latitude (or longitude).	1	Medium-high certainty. Species currently spawns in waters around the coral sea (10 S-30 S). Range goes as far South as NZ where resting and recovering females are found. There is room to move for spawning populations however it is unknown where southern part of the stock may move to. There is also possibility of vertical depth constriction limiting habitat (Prince and Goodyear; 2006).
			Av = 1.50	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	In Australia species prefer to spawn in waters 25-29 C. Temperature preferences seem to vary between regions. Some records as low as 16 C in California. (Kopf 2010; Bromhead et al 2004).
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	High certainty. Growth rates are temperature dependant. Larvae prefer warmer tropical/ sub tropical waters. (Bromhead et al 2004; Kopf 2010).
	Life-cycle events	Wide duration, 2-4 months	2	High certainty. Striped marlin generally spawn during late spring to early summer, peaking in November and December (Kopf 2010).
	Migration	Migration is common for the whole population	3	Striped marlin are a highly migratory species (travel up to 31.5nm/day) however some individuals migrate further than others. Most seem to stay within a few hundred (<500nm) range, some travel over 3000nm. (Bromhead et al 2004).
			Av = 2.25	
Total Risk Ranking			**5.25**	

Table 31. Tiger flathead

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	High certainty (See section 2.1 in species review)
	Recruitment	Occasional and variable recruitment period	2	Low certainty - little data on this (See sections 2.1 and 2.4 in species review)
	Maturity	2-10 yrs	2	High certainty (See section 2.1 in species review)
	Generalist vs. specialist	Reliance on neither habitat or prey	1	Moderate to high certainty (See sections 2.2 and 2.3 in species review)
			Av = 1.50	
Distribution	Larval duration	2-8 weeks	2	Temperature- low certainty, little information (See sections 2.1 and 2.4 in species review)
	Adult/juvenile range	10 - 1000 km	2	Low certainty, little information (See sections 2.1 and 2.2 in species review)
	Physiological tolerance	10 - 20 degrees latitude	2	High certainty (See section 2.2 in species review)
	Spatial availability of habitat	No unoccupied habitat, range constriction likely, 0-2 degrees latitude	3	Already found throughout Tasmania (See section 2.2 in species review)
			Av = 2.25	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature - low certainty - little information (See section 2.1 in species review)
	Settlement / metamorphosis cue	No apparent correlation to environmental variable	1	Temperature - low certainty, little or no information (See sections 2.1 and 2.4 in species review)
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	No migration	1	Low certainty - little or no information (See sections 2.1 and 2.2 in species review)
			Av = 1.50	
Total Risk Ranking			**5.25**	

Table 32. Western king prawn

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Consistent recruitment events every 1-2 years	1	1 year of age
	Maturity	<= 2 yrs	1	They begin to mature at 25 mm CL, 50% females inseminated at 34 mm CL.
	Generalist vs. specialist	Reliance on either habitat or prey	2	Prefers sandy to seagrass or vegetated habitats (Tanner and Deakin, 2001)
			Av = 1.25	
Distribution	Larval duration	2-8 weeks	2	Larval duration 15 - 34 days, dependent on water temperature (15 - 17 C).
	Adult/juvenile range	< 10 km	3	
	Physiological tolerance	> 20 degrees latitude	1	Wide ranging species; Qld - SA - high temperature and salinity tolerances
	Spatial availability of habitat	Substantial unoccupied habitat, >6 degrees latitude (or longitude).	1	Occupies most of SA gulf waters, limited habitat outside gulfs to expand
			Av = 1.50	
Phenology	Spawning cue	Strong correlation of spawning to environmental variable	3	Optimum temperature range for spawning is 17 - 25 C - spawning season in SA is early summer, whereas same species spawns in late Autumn, early winter in Qld, when temp drops below 25 C
	Settlement / metamorphosis cue	Strong correlation to environmental variable	3	Larval development rate increases with water temperature
	Life-cycle events	Wide duration, 2-4 months	2	Spawning frequency related to moult frequency. Moult interval about 30 - 40 days, and multiple spawning occurs during summer months
	Migration	Migration is common for some of the population	2	Juvenile migration.
			Av = 2.50	
Total Risk Ranking			**5.25**	

Table 33. Yellowtail kingfish

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	100 - 20,000 eggs per year	2	Certain Assessment
	Recruitment	Occasional and variable recruitment period	2	Variable between States ie NSW versus SA
	Maturity	2-10 yrs	2	Certain Assessment
	Generalist vs. specialist	Reliance on neither habitat or prey	1	Certain Assessment
			Av = 1.75	
Distribution	Larval duration	2-8 weeks	2	Temperature-dependent, 15-16 days.
	Adult/juvenile range	10 - 1000 km	2	Certain Assessment
	Physiological tolerance	> 20 degrees latitude	1	Certain Assessment
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	Certain Assessment
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Uncertain judgement. Current-driven by the East Australian Current in the west.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Uncertain judgement. Current-driven by the East Australian Current in the west.
	Life-cycle events	Wide duration, 2-4 months	2	Certain assessment
	Migration	Migration is common for some of the population	2	Certain assessment
			Av = 2.00	
Total Risk Ranking			**5.50**	

Table 34. Yellowtail scad

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	
	Recruitment	Occasional and variable recruitment period	2	
	Maturity	2-10 yrs	2	
	Generalist vs. specialist	Reliance on neither habitat or prey	1	
			Av = 1.50	
Distribution	Larval duration	> 2 months	1	
	Adult/juvenile range	10 - 1000 km	2	
	Physiological tolerance	10 - 20 degrees latitude	2	
	Spatial availability of habitat	Limited potential to expand to unoccupied habitats, 2-6 degrees latitude	2	
			Av = 1.75	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Temperature.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Temperature.
	Life-cycle events	Wide duration, 2-4 months	2	
	Migration	Migration is common for some of the population	2	
			Av = 2.00	
Total Risk Ranking			**5.25**	

Table 35. Yellowfin tuna

Attribute	Criteria	Risk Ranking		Comments : Reference to data source or publication; type and nature of uncertainty [incertitude, variability]
		Category	Score	
Abundance	Fecundity	>20,000 eggs per year	1	Fishbase
	Recruitment	Occasional and variable recruitment period	2	Variation into the Australian region
	Maturity	2-10 yrs	2	
	Generalist vs. specialist	Reliance on neither habitat or prey	1	Quite wide ranging, generalist; lots of refs on movement and food choice; Graham, B. S., D. Grubbs, K. Holland and B. N. Popp (2007). A rapid ontogenetic shift in the diet of juvenile yellowfin tuna from Hawaii. Marine Biology 150: 647-658.
			Av = 1.50	
Distribution	Larval duration	2-8 weeks	2	http://www.nmfs.noaa.gov/fishwatch/ species/pac_yellowfin_tuna.htm
	Adult/juvenile range	> 1,000 km	1	Klimley, A. P., S. J. Jorgensen, A. Muhlia-Melo and S. C. Beavers (2003). The occurence of yellowfin tuna (*Thunnus albacares*) at Espiritu Seamount in the Gulf of California. Fishery Bulletin 101(3): 686-692.
	Physiological tolerance	> 20 degrees latitude	1	Brill, R. W., B. A. Block, C. H. Boggs, K. A. Bigelow, E. V. Freund and D. J. Marcinek (1999). Horizontal movements and depth distribution of large adult yellowfin tuna (*Thunnus albacares*) near the Hawaiian Islands, recorded using ultrasonic telemetry: implications for the physiological ecology of pelagic fishes. Marine Biology 133(3): 395-408.
	Spatial availability of habitat	Substantial unoccupied habitat, >6 degrees latitude (or longitude).	1	Pelagic species, plenty of water; http://www.nmfs.noaa.gov/fishwatch/species/pac_yellow fin_tuna.htm
			Av = 1.25	
Phenology	Spawning cue	Weak correlation of spawning to environmental variable	2	Highly uncertain.
	Settlement / metamorphosis cue	Weak correlation to environmental variable	2	Highly uncertain.
	Life-cycle events	Wide duration, 2-4 months	2	http://www.nmfs.noaa.gov/fishwatch/species/pac_yellowfin_tuna.htm

	Migration	Migration is common for some of the population	2	http://www.nmfs.noaa.gov/fishwatch/species/pac_yellowfin_tuna.htm
			Av = 2.00	
Total Risk Ranking			**4.75**	

Appendix 6: Raw risk assessment scores for aquaculture species

See Table 2.2 for full description of attributes. US = unweighted sensitivity score, IS = impact score, WS = weighted sensitivity score. SRO = Sydney rock oyster, PO = pacific oyster, BM = blue mussel, YTK = yellowtail kingfish, SBT = southern bluefin tuna, AS = Atlantic salmon.

attribute	Abalone (land)			Abalone (sea)			AS			BM (hatchery)		
	US	IS	WS	US	IS	WS	US	IS	WS	US	IS	WS
1	2	1	2	2	1	2	1	1	1	2	1	2
2	1	1	1	1	1	1	2	1	2	1	1	1
3	1	2	2	1	2	2	2	0	0	2	2	4
4	2	2	4	2	2	4	1	0	0	2	1	2
5	2	2	4	3	1	3	3	2	6	3	0	0
6	2	1	2	2	0	0	3	2	6	1	0	0
7	1	1	1	2	1	2	1	1	1	3	1	3
8	1	0	0	2	1	2	2	1	2	3	1	3
9	3	2	6	2	1	2	3	2	6	3	0	0
Total	**15**		**22**	**17**		**18**	**18**		**24**	**20**		**15**

attribute	BM (wild)			PO			SRO (hatchery)			SRO (wild)		
	US	IS	WS	US	IS	WS	US	IS	WS	US	IS	WS
1	3	1	3	1	1	1	2	1	2	3	1	3
2	3	2	6	1	1	1	1	1	1	3	2	6
3	3	2	6	2	2	4	2	2	4	3	2	6
4	3	2	6	2	1	2	2	1	2	3	1	3
5	3	0	0	3	2	6	3	2	6	3	2	6
6	1	0	0	2	1	2	1	1	1	1	1	1
7	3	1	3	3	1	3	3	1	3	3	1	3
8	3	1	3	2	1	2	2	1	2	2	1	2
9	3	0	0	3	2	6	2	2	4	2	2	4
Total	**25**		**27**	**19**		**27**	**18**		**25**	**23**		**34**

attribute	SBT (hatchery)			SBT (wild)			YTK		
	US	IS	WS	US	IS	WS	US	IS	WS
1	2	1	2	3	1	3	2	1	2
2	2	1	2	3	1	3	2	1	2
3	2	0	0	3	0	0	2	0	0
4	2	1	2	3	1	3	1	0	0
5	3	1	3	3	1	3	3	0	0
6	1	0	0	1	0	0	1	0	0
7	1	1	1	1	1	1	1	1	1
8	2	1	2	2	1	2	2	1	2
9	2	1	2	2	1	2	2	1	2
Total	**17**		**14**	**21**		**17**	**16**		**9**

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