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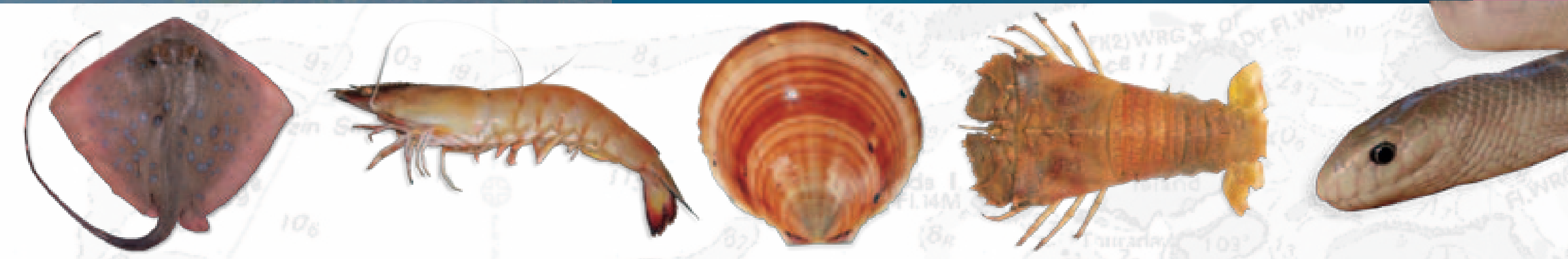
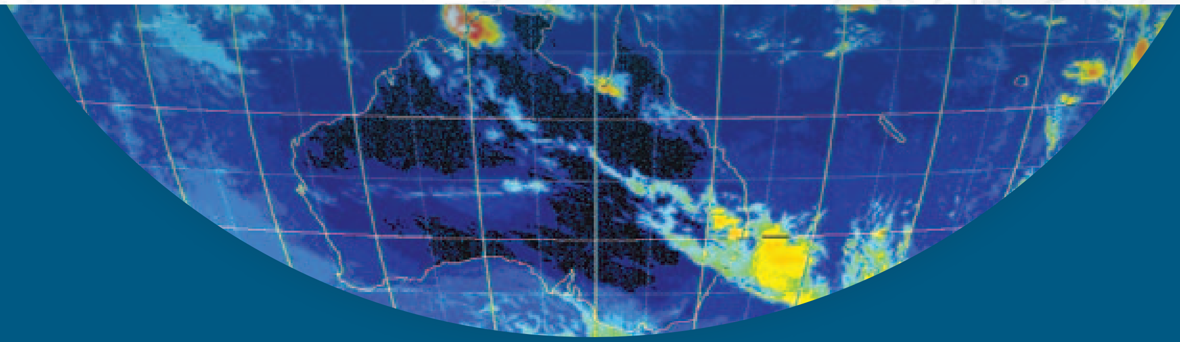
Marine Park Authority

Assessment of the ecological vulnerability of the East Coast Otter Trawl Fishery to climate change

A brief synthesis of information and results of an expert workshop





2012

Alexander K Morison and Rachel J Pears

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Expert workshop participants were Neil Cliffe (facilitator), David Cobon, Grant Stone, Vanessa Hernaman, Eddie Jebreen, John Kung, Anthony Roelofs, Brad Zeller, Richard Taylor, Steve Murphy, Geoff Tilton, Nick Schulz, Clive Turnbull, Rob Coles, Tony Courtney, Michael O'Neill, Ryan Donnelly, Chloe Schauble, Rachel Pears, Sandy Morison, Eric Perez, Sian Breen, John Beumer and Julie Robins. Appendix 2 of the report lists participants' organisations.

We would also like to acknowledge advice and input throughout the development process from additional experts at the GBRMPA, including Peter McGinnity, Paul Marshall, Roger Beeden and Mark Read. Tony Courtney (the Department of Agriculture, Fisheries and Forestry, DAFF) and Mark Read also reviewed and improved an earlier draft of the sea snake assessment included here. We also received valuable guidance from members of the Ecosystem Reef Advisory Committee (for the Great Barrier Reef Marine Park).

The section on global climate change projections within Section 3 of this report is a contribution by Ryan Donnelly of Pro-vision Reef and has been modified from a recent Climate Change Vulnerability Assessment for the Queensland Marine Aquarium Supply Industry (Donnelly 2011), which in turn is based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (IPCC 2008).

The assessment of sharks and rays has relied on a published vulnerability assessment (Chin et al. 2010).

Expert workshop participants provided comments on an earlier draft of the report, and Ian Jacobsen (DAFF) undertook a scientific review of the report. David Cobon reviewed the section on climate change projections and assisted with developing the summary material about climate variables. We are thankful also to Jenny Zadkovich and Suzie Davies (GBRMPA) for assisting with preparation of the bibliography. The photographs of rays are by Ian Jacobsen and the sea snake photograph is from the FRDC 2005/053 sea snake project. The image in section 14 was sourced from www.deepocean.org .

This report is an output of Phase I of adaptation planning for the Queensland East Coast Otter Trawl Fishery, which is a collaboration between GBRMPA, DAFF (specifically Fisheries Queensland and Agri-Science Queensland), the Queensland Climate Change Centre of Excellence and the Queensland Seafood Industry Association. Preparation of the report was funded by GBRMPA under the Great Barrier Reef Climate Change Action Plan 2007-2012.

Executive Summary

This vulnerability assessment report is a synthesis of information and a preliminary assessment of the ecological vulnerability to climate change of selected components of the Queensland East Coast Otter Trawl Fishery (ECOTF). The report also incorporates results from an expert workshop, which refined the assessment. The vulnerability assessment is an output of Phase I of adaptation planning for this fishery. This report will inform the development of a Climate Risk Management Matrix (Cobon et al. 2009) for the fishery, in which risks and adaptation options will also be identified.

The climate change scenarios used in this report are those described by the Intergovernmental Panel on Climate Change (IPCC 2008) and summarised by Donnelly (2011) for the Queensland marine environment. The risk assessment method used follows the exposure/sensitivity/adaptive capacity framework widely used in climate change vulnerability assessments, including for the Great Barrier Reef (Johnson and Marshall 2007).

The ecological components of the fishery included in this report are the main target species (eastern king prawns, tiger prawns, saucer scallops, banana prawns, endeavour prawns, red-spot and blue-legged king prawns, and Moreton Bay bugs) and the components of the Great Barrier Reef ecosystem identified in a recent ecological risk assessment (Pears et al. 2012) as being at potential risk from the fishery (Balmain bugs, sharks and rays, sea snakes and a poorly known upper slope habitat in the southern Great Barrier Reef referred to as 'Habitat 10'). The report also considered the effects of future climate change on critical habitats for each of these species. Moreton Bay, the Stout Whiting fishery and the Beam Trawl sector were not included in the scope of this project.

An initial review was undertaken to determine what climate variables were most likely to have a direct impact on the above ecological components. As a result of this review, the following climate variables were included in the assessment: higher sea surface temperature, ocean acidification, sea level rise, changed rainfall patterns and nutrient inputs, changed light spectra or intensity, increased tropical storm intensity and flooding, climate variability driven by El Niño-Southern Oscillation (ENSO) events, altered ocean circulation, and higher peak wind speeds. After the expert workshop and other consultations, climate variability driven by ENSO events was dropped because: a) it was not regarded as particularly relevant to the key species, b) a review of the expected changes indicated there was not a consensus on how ENSO frequency and intensity will change, and c) changes will more than likely be indirect and mediated through changes to other variables (such as rainfall) that are included in the assessment.

All of the ecological components were assessed as having a high level of ecological vulnerability to at least one of the selected climate change variables in the 20 to 50 year timeframe of the assessment. Saucer scallops were assessed as having a high vulnerability to five of the climate change variables, some species of sea snakes to three variables, red-spot king prawns, Balmain bugs and Habitat 10 to two variables, and the other components to a single variable. The biology and habitat associations of each species influences which climate variables are most important.

The projected climate change variables with greatest influence on ecological components of the fishery, as determined by the number of components with a high level of vulnerability, were in order of decreasing importance: ocean acidification (eight components with a high vulnerability), altered ocean circulation (four components), increased tropical storm intensity and flooding (three components), higher sea surface temperature, changed rainfall patterns and nutrient inputs, sea level rise and higher peak wind speeds (one component each). No components were identified as having a high vulnerability to changed light spectra or intensity.

Table 1 is a summary of the vulnerability scores assigned to each ecological component for each of the climate change variables. The scoring process used is fully documented in the report, and this included explicit consideration of 'certainty'.

Climate change science is a rapidly expanding area, however there are still many knowledge gaps for this fishery. Therefore, unexpected outcomes are possible. Well directed research, monitoring and adaptive management are important to increase the ability of fishers and managers to respond in an appropriate way.

Table 1. Summary of ecological vulnerability assessment findings. The table shows the vulnerability scores assigned to each ecological component for each of the climate change variables (L = Low, M = Medium, H = High).[1]

Summary of ecological vulnerability to climate change	Eastern king prawns		Tiger prawns		Saucer scallops	Banana prawns	Endeavour prawns		King prawns		Moreton Bay bugs	Balmain bugs		Sea snakes (varies by species)	Habitat 10
	Inshore	Offshore	Inshore	Offshore			Inshore	Offshore	Red-spot	Blue-legged		Smooth bugs	Other species		
Ocean acidification	L	L	H	H	H	L	H	H	H	H	H	H	H	M-H	H
Altered ocean circulation	H	H	L	L	H	L	L	L	L	L	M	H	H	L-M	H
Increased tropical storm intensity and flooding	M	L	M	L	H	L	M	L	H	M	M	L	L	M-H	L
Higher sea surface temperature	M	L	M	L	H	M	M	L	M	L	L	M	L	L	L
Changed rainfall patterns and nutrient inputs	M	L	M	L	H	M	M	L	L	L	L	L	L	L	L
Sea level rise	L	L	M	L	L	H	M	L	M	L	L	L	L	L	L
Higher peak wind speeds	L	L	L	L	L	L	L	L	L	L	L	L	L	M-H	L
Changed light spectra	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L

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[1] For sharks and rays, the overall ecological vulnerability to climate change was low to medium, depending on the species, but sharks and rays are not included in the summary table because a different assessment framework was used. See Section 12 for details.

CONTENTS

1. Introduction

Developing an information summary and preliminary assessment of ecological vulnerability to climate change for selected components of the East Coast Otter Trawl Fishery

Introduction

Assessing fisheries vulnerability to climate change is essential to prioritise systems in greatest need of intervention, understand the drivers of vulnerability to identify future research directions and, more importantly, to review current fisheries management with the view to developing management responses that will be effective in securing the future sustainability of marine fisheries (Johnson and Welch 2010).

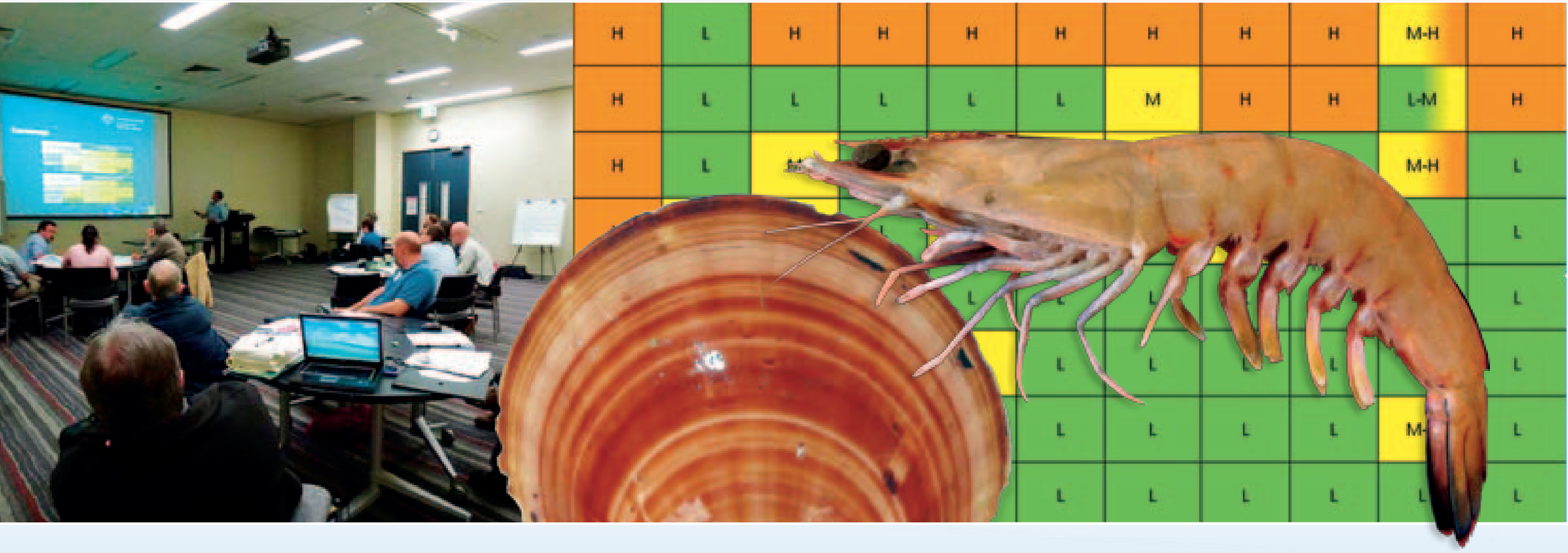
The overall outlook for the Great Barrier Reef has recently been assessed as poor, in the light of serious threats, especially from climate change (GBRMPA 2009). Although efforts are being made to reduce the effects of climate change on the Great Barrier Reef ecosystem, some level of impact from climate change is unavoidable. The nature of potential climate change impacts has not been considered for the Queensland East Coast Otter Trawl Fishery (ECOTF) in any detail, and therefore the trawl industry has limited awareness and understanding of its vulnerability to climate change. This report is intended to help fill this gap and support adaptation planning initiatives for the fishing industry. There may also be some opportunities as a result of positive climate change effects and increased awareness of potential changes may help industry to be more prepared to realise potential benefits.

The report outlines the expected impacts of climate change on selected components of the ECOTF and identifies information gaps. Ecological components of this report were based on the main target species of the fishery, as well as any species and habitat type identified as being at potential risk from trawling in a recent ecological risk assessment of the ECOTF in the Great Barrier Reef Marine Park (Pears et al. 2012). The main target species (in order of decreasing catch) are eastern king prawns, tiger prawns, saucer scallops, banana prawns, endeavour prawns, red-spot king prawns and blue-legged king prawns, and Moreton Bay bugs. These species are known as Principal Species in this fishery. The components identified at potential risk are Balmain bugs, some species of sharks and rays, two species of sea snakes and a poorly known upper slope habitat (100 to 300 metres depth) in the southern Great Barrier Reef referred to as 'Habitat 10' (the main deepwater area of the fishery from which eastern king prawns are caught). Moreton Bay, the Stout Whiting fishery and the Beam Trawl sector were not included in the scope of this project.

The climate change variables selected for inclusion were based on those already identified in other studies, particularly Johnson and Marshall (2007) and Hobday et al. (2008). Not all variables were considered likely to be important for the ECOTF but were initially listed to avoid the premature exclusion of a climate change variable that may be important to a component of this fishery even though not important on a national scale. The time horizon of the report also retained a degree of flexibility with information considered (potentially) referring to any year up until 2100. However the timeframe used for the assessment of ecological vulnerability was 20 to 50 years.

This vulnerability assessment report is an output of Phase I of adaptation planning for the ECOTF, which is a collaboration between the Great Barrier Reef Marine Park Authority, the Department of Agriculture, Fisheries and Forestry (specifically Fisheries Queensland and Agri-Science Queensland), the Queensland Climate Change Centre of Excellence and the Queensland Seafood Industry Association. Funding under the Great Barrier Reef Climate Change Action Plan 2007-2012 supported preparation of this report. The information synthesised here is now being used to complete a Climate Risk Management Matrix (Cobon et al. 2009) for the fishery through expert input and stakeholder workshops, where potential ecological, economic and social impacts and adaptation options for the fishery will be considered.

2. Methods



Ecological vulnerability derived from exposure, sensitivity and adaptive capacity to climate change

Methods

The approach adopted is to follow the exposure/sensitivity/adaptive capacity framework widely used in climate change vulnerability assessments (Figure 1). **Exposure** is used here as a measure of how much of a change in climate and associated problems a species or habitat type is likely to experience. **Sensitivity** is a measure of whether and how individuals of a species or habitat type are likely to be affected by, or responsive to, climate changes (for example, tolerance of prawns to changes and/or variability in such things as sea temperature, rainfall patterns, or other key processes). Here we use **adaptive capacity** to describe the capacity of populations of a species or habitat type to accommodate or cope with climate change impacts with minimal disruption. Adaptive capacity is influenced by inherent traits (such as ability of a species to move in search of more favourable habitat conditions, evolve, or modify its behaviour as climate changes) and external factors (such as man-made barriers to movement or overfishing that limits the genetic diversity available for evolutionary adaptation) (Glick et al. 2011).

Species-level sensitivities are often characterised by physiological factors, dependence on sensitive habitats, ecological linkages (e.g. predator-prey relationships, competition between species), changes to the timing or sequence of life cycle events (e.g. breeding, migration), population growth rates, degree of specialisation, reproductive strategy and interaction with other stressors (Glick et al. 2011). Even if a particular species or system is inherently sensitive to climate change, its vulnerability also depends on the character, magnitude, and rate of changes to which it is exposed. Therefore, exposure and sensitivity are combined to determine the potential impact, and this in turn is modified by the level of adaptive capacity of the species/habitat to give an **ecological vulnerability**.

Eastern king prawns, for example, are highly migratory species and exposure to any strengthening of the south-flowing East Australian Current may result in a potential impact through a change to their current recruitment patterns and a southward shift in their spawning grounds. For this species, the adaptive capacity has previously been assessed as being good to all climate change variables (Gibbs 2011), which would tend to reduce its ecological vulnerability.

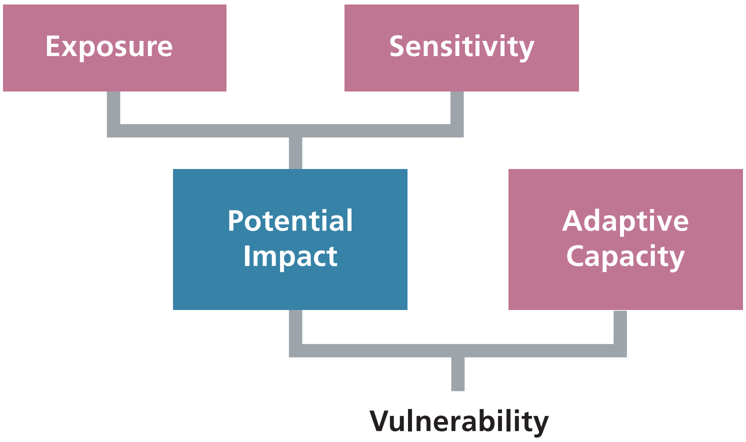
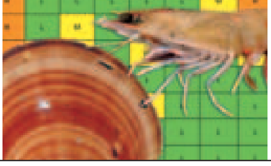


Figure 1. Relationship between exposure and sensitivity to potential climate change impact and influence of adaptive capacity in determining vulnerability.

A draft of this report provided a brief synthesis of available information and preliminary assessments of vulnerability to climate changes. This draft was provided as background information for participants in an expert workshop held in Brisbane on 28 and 29 July 2011. Participants at the expert workshop provided additional information and reviewed the preliminary assessment scoring and revised it where needed. The report of this expert workshop is provided in Appendix 2.



The initial draft of this report relied on information already summarised in other documents. Information on basic biology of eastern king prawns, brown tiger prawns, saucer scallops and Moreton Bay bugs was extracted from the East Coast Otter Trawl Fishery Annual Status Report (DEEDI 2010). Other key sources of information used in compiling this synthesis were: Hobday et al. 2008, which covers the implications of climate change for all fisheries and aquaculture industries in Australia; Johnson and Marshall 2007, which contains a vulnerability assessment for the whole of the Great Barrier Reef; and Donnelly 2011, which details a climate change vulnerability assessment for Queensland's marine aquarium supply industry. The preliminary assessment gave only limited consideration to indirect effects on a species as a consequence of climate effects to other species (e.g. predators, prey or competitors). The final report has drawn on additional reference material identified by a range of contributors to the workshop, the outcomes of the expert workshop, and subsequent reviews of the scoring by the report authors. Material available up until September 2011 was considered.

The trawl fishery area and Great Barrier Reef Marine Park are shown in Figure 2. It had been intended that information would be presented for separate broad regions of the fishery where available: **southern region** (south of 22 degrees S); **central region** (between 16 and 22 degrees S); and **northern region** (north of 16 degrees S). There were few instances, however, where information was available even at this fairly broad level of resolution.

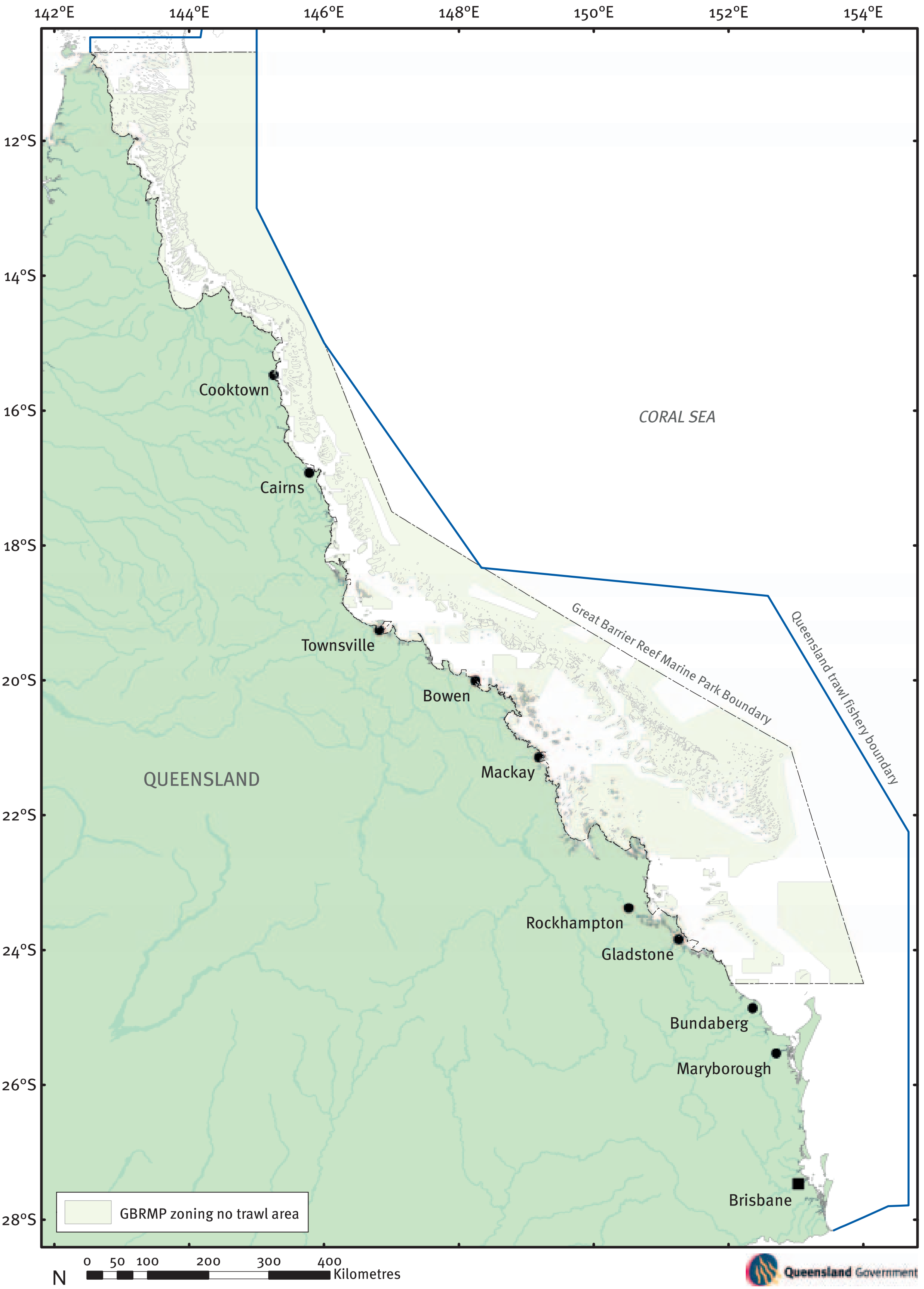
Projecting future climate conditions is inherently uncertain (Donnelly 2011). There is incomplete understanding of the physical processes of the climate system and how they work together and interact, and this adds uncertainty to mathematical modelling. Predicting future greenhouse gas concentrations is complicated by a range of socioeconomic factors linking human population growth, levels of affluence, intensity of energy use and the implementation of strategies designed to mitigate future emissions (Lough 2007).

Predicting regional consequences of climate change is further complicated by the coarse spatial resolution used by the models. The ability to predict the effects of climate change is also typified by uncertainty. This does not imply that we do not face significant challenges brought about by climate change; it means that the range of future climate conditions and subsequent impacts, particularly on a regional or local scale, cannot be accurately forecast (Donnelly 2011). Being explicit about the level of certainty in predictions is also important when determining priorities for responses.

The level of certainty of projected impacts and outcomes is explicitly categorised, where possible, using the following definitions:

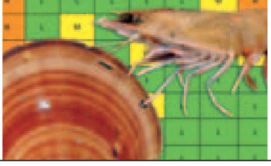
High (H)	Strong clear evidence, e.g. backed by several studies with solid datasets with little confounding interactions
Medium (M)	Some evidence, e.g. evidence supported by one or more studies, conclusions may be partially ambiguous or confounded
Low (L)	Limited evidence, e.g. anecdotal evidence, limited data and/or predicted conclusions based on theoretical knowledge.

Information was not always available for individual species and some species were assessed as a group. Where assessments are thought likely to vary among species this has been identified.



© State of Queensland, Fisheries Queensland, a service of the Department of Employment, Economic Development and Innovation 2011. This map incorporates data which is: © Commonwealth of Australia (Great Barrier Reef Marine Park Authority and Geoscience Australia) 2011; and © Pitney Bowes Mapinfo. GDA - 1994.

Figure 2. Map of east coast of Queensland showing trawl fishery area and Great Barrier Reef Marine Park.



For each species and each climate change variable, scores for exposure and sensitivity were combined to provide a score for potential impact using the following matrix (L = Low, M = Medium, H = High).

Potential Impact		**Sensitivity**		
		L	M	H
Exposure	L	L	L	M
	M	L	M	H
	H	M	H	H

Similarly, these derived scores of potential impact were combined with scores for adaptive capacity to produce a score for vulnerability using the following matrix.

Vulnerability		**Adaptive Capacity**		
		H	M	L
Potential Impact	L	L	L	L
	M	L	M	M
	H	M	H	H

Scores assigned for certainty for exposure and sensitivity were used to derive a combined certainty score for the potential impact using the following matrix.

Certainty of Potential Impact		**Exposure**		
		L	M	H
Sensitivity	L	L	L	L
	M	L	M	M
	H	L	M	H

Scores assigned for certainty for potential impact and adaptive capacity were used to derive a combined certainty score for the vulnerability using the following matrix.

Certainty of Vulnerability		**Potential Impact**		
		L	M	H
Adaptive Capacity	L	L	L	L
	M	L	M	M
	H	L	M	H

The climate change variables selected for consideration and the rationale for their use are outlined in Table 2.

Table 2. Climate change variables used and the reasons for their choice.

Variable	Rationale for use
Higher sea surface temperature	Changes to sea temperatures will have direct effects on all marine organisms and especially those unable to regulate their body temperature.
Ocean acidification	Changes to water acidity will have direct effects on many marine organisms and especially those that produce calcareous shells.
Sea level rise	Changes to sea levels will have indirect effects on many marine organisms through changes to the distribution and area of habitats.
Changed rainfall patterns and nutrient inputs	Changes to the level, frequency and quality of terrestrial inputs will have direct and indirect effects on many inshore marine organisms (especially those with an estuarine life history stage).
Changed light spectra or intensity	Changes to the light spectra or light intensity may have direct effects on some marine organisms or indirect effects through its effect on photosynthetic organisms.
Increased tropical storm intensity and flooding	Changes to the frequency, timing or severity of storms or other causes of physical disturbance will have direct or indirect effects on many marine organisms.
Altered ocean circulation	Changes to ocean currents could have direct effects on many marine organisms and especially those with planktonic phases to their life cycles.
Higher peak wind speeds	Changes to wind patterns could have indirect effects on some marine organisms through its effect on ocean currents and waves and as a source of physical disturbance.

It is acknowledged that these variables are not entirely independent and that high scores for one variable may be associated with high scores for another. For example, increased tropical storm intensity and flooding may also be linked to higher peak wind speeds, and changed rainfall patterns and nutrient inputs. Despite the potential for some 'double-counting' it was decided to score these variables separately so that the potential impacts of each climate change variable could be explicitly recognised. For example, sea snakes were thought to have a vulnerability to the physical turbulence from storms but not generally to the nutrient or other inputs associated with flooding.

3. Climate change projections

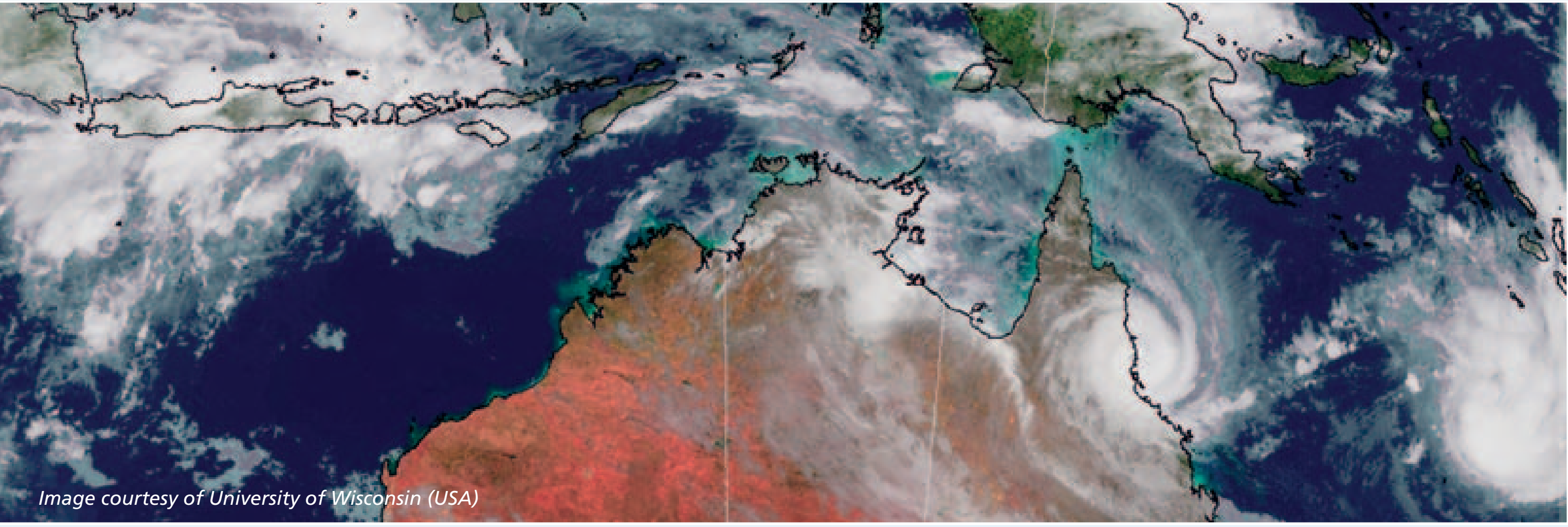


Image courtesy of University of Wisconsin (USA)

Summary of projected changes to climate that may influence marine life.

Global climate change projections — by Ryan Donnelly

The text in this section on global climate change projections is a contribution by Ryan Donnelly of Pro-vision Reef (www.pro-visionreef.org) and is from a recent Climate Change Vulnerability Assessment for the Queensland Marine Aquarium Supply Industry (Donnelly 2011) with minor modification, which in turn is based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (IPCC 2008).

The IPCC Special Report on Emissions Scenarios (SRES) grouped scenarios into four storyline families (A1, A2, B1, and B2) (Table 3) that explore alternative development pathways. The SRES scenarios covered a wide range of demographic, economic, and technological driving forces and resulting greenhouse gas emissions. All scenarios suggest there will be significant challenges by the middle of the century.

Table 3. IPCC scenarios are projections (initialised with observations for 1990) of possible future emissions for four scenario families, A1, A2, B1, and B2, which emphasise globalised vs. regionalised development on the A,B axis and economic growth vs. environmental stewardship on the 1,2 axis (Raupach et al. 2007).

Storyline	Description
A1	A future world of very rapid economic growth, global population peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.
A2	A very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.
B1	A convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures towards a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
B2	A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Importantly, the SRES scenarios do not include additional climate policy to mitigate greenhouse gas emissions above that which currently applies. The emission projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socioeconomic, demographic and technological change, serve as inputs to many recent climate change vulnerability and impact assessments.

Adopting a human development storyline in order to determine a climate change scenario is influenced by critical assumptions about the future pathways of human development. These include global population dynamics, technological advancement that results in production efficiencies, and the global transferability and take up of those technologies.

Medium variant predictions in the United Nations State of the World Population report (Engelman and UNFPA 2009) state that the world's population will reach about 9.15 billion in 2050 (the latest official figure for mid-2009 was 6.98 billion) but that the global fertility rate (average number of children per woman) will reduce from 2.56 (current level) to 2.02. The replacement rate is 2.13, which means that Storylines A1 and B1, whereby population peaks mid-century then declines thereafter, have merit. However, this fertility rate prediction is dependent on achieving substantially increased access to and uptake of voluntary family planning for women in developing countries. High variant predictions are for a population of 10.46 billion and a fertility rate of 2.51 in 2050, which is comparable to the current trend. Population growth is driven by the developing world where economic expansion and production inefficiencies are highest. Fertility in many parts of the industrialised world is below replacement, even in traditionally Catholic countries of southern Europe and South America.

Storyline A1 (globalised, economically oriented) contains various scenarios relating to technological development. The three variants lead to different emissions trajectories (Figure 3): A1FI (intensive dependence on fossil fuels), A1T (alternative technologies largely replace fossil fuels), and A1B (balanced energy supply between fossil fuels and alternatives) (Raupach et al. 2007). Figure 3 has been included to indicate that there are wide ranging consequences for the future based on the manner in which humanity develops.

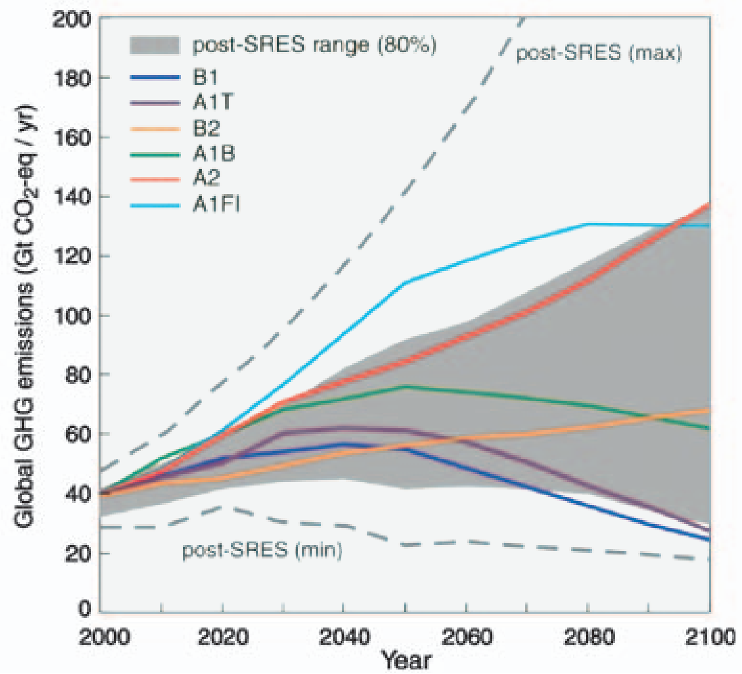
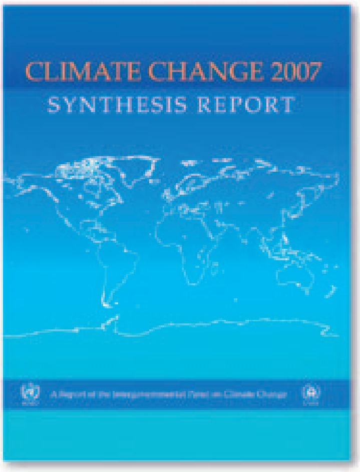


Figure 3. Predicted global greenhouse gas emissions by SRES scenario, demonstrating the wide disparity of outcomes determined by the pathway of human development adopted in the 21st century. None of these scenarios include global agreement on carbon mitigation policy, which is expected but as yet not developed (IPCC 2008).



The foreseeable future will be characterised by change brought about by an enhanced greenhouse effect.

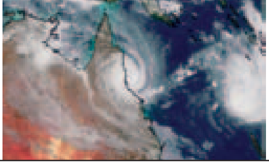
Scenario A1B includes a balance of energy technologies and makes the assumption that similar improvement rates apply to all energy supply and end-use technologies. Whilst this development pathway may yield improvement in the latter half of the century, greenhouse gas emissions are expected to be marginally less than the A2 storyline until mid-century. Consequently, for predicting the impacts of enhanced greenhouse effect to 2050, little separates A1B from A2 despite major differences in predicted population dynamics.

Whilst the IPCC states that the world is committed to a changing climate on the basis of emissions already in the atmosphere following industrialisation, painting an accurate picture of the future is difficult. The scenarios presented, which do not include international policy to mitigate greenhouse gas pollution, deliver various outcomes, all of which suggest there will be substantial challenges as we move toward the middle of the century. Beyond that, the scenarios diverge. However, the state of knowledge is evolving as more research is undertaken. Current observations lead to various and sometimes dire conclusions – we are already operating outside our worst case scenario in terms of starting points for trajectories. Raupach et al. (2007) for example, has shown that emissions growth rate since 2000 was greater than for the most fossil-fuel intensive of the IPCC emissions scenarios (A1F1 and A2) developed in the late 1990s.

Despite debate at the margins, there is widespread agreement that the foreseeable future will be characterised by change brought about by an enhanced greenhouse effect. Whichever development pathway manifests through the 21st century, critical parameters of atmospheric carbon dioxide (CO_2) and air temperature are expected to rise appreciably, with consequences for sea level, ocean chemistry and extremes of weather. Consequently, it may be instructive to be guided by the predictions emanating from the best (B1) and worst (A2) case scenarios when considering to what extent our world will be affected by climate change (Table 4), bearing in mind the inherent uncertainty attached to the future range of possible impacts relating to predicted scenarios.

Table 4. Atmospheric concentration of carbon dioxide (CO_2 parts per million), global temperature rise (T°C) above 1961 to 1990 average, and sea level rise (SL cm) above 1961 to 1990 level for four SRES storylines for projections to 2020, 2050 and 2080.

Storyline	2020			2050			2080		
	CO_2	T	SL	CO_2	T	SL	CO_2	T	SL
B1	421	0.6	7	479	0.9	13	532	1.2	19
B2	429	0.9	20	492	1.5	36	561	2.0	53
A1	448	1.0	21	555	1.8	39	646	2.3	58
A2	440	1.4	38	559	2.6	68	721	3.9	104



Regardless of which identified development pathway manifests through the 21st century, the predicted consequences of climate change will vary regionally. The impacts will be felt initially and to a greater extent at higher latitudes and inland from the coast, particularly at higher altitudes. The northern hemisphere has a greater proportion of landmass than the southern hemisphere and is expected to warm sooner. However, Australia is the hottest and driest continent with unique biophysical characteristics, limited water resources and a growing population that is mostly nestled on the eastern seaboard. Importantly, global climate change impact is an aggregation of many local scale impacts (IPCC 2008).

A summary of the expected changes in the Great Barrier Reef region is given in Table 5.

Table 5. Projected changes in climate for the Great Barrier Reef region for 2020 and 2050 based on SRES A2 and B1 storylines (from Lough 2007).

Projected change	2020		2050	
	A2	B1	A2	B1
Air temperature (relative to 1961 to 1990 average and on basis that tropical and coastal areas of Australia will warm at approximately global average)	+1.4°C	+0.6°C	+2.6°C	+0.9°C
Sea surface temperature for Great Barrier Reef (relative to 1961 to 1990 average 25.9°C)	+0.5°C	+0.5°C	+1.2°C	+1.1°C
Sea level rise (relative to 1961 to 1990 baseline)	+38 cm	+7 cm	+68 cm	+13 cm
Ocean chemistry (estimated decrease in ocean pH based on projections of 0.3 to 0.5 decrease by 2100)	-0.10	-0.06	-0.25	-0.15
CO2 parts per million (pre-industrial = 270 ppm)	440	421	559	479

Climate change projections for the Queensland marine environment

The following are projected changes to the marine environment off Queensland, with a focus on the areas of the east coast where the otter trawl fishery occurs. A summary of these climate change projections is provided in Table 6. However, these variables do not work in isolation to one another. For example, as more carbon dioxide is released into the atmosphere, the sea temperature is likely to rise, melting glaciers in the polar regions and, in turn, causing the sea level to rise. The level of certainty about these changes is indicated as either high (H), medium (M) or low (L) as outlined in the Methods.

Webpage resources about climate change in Queensland

Information on climate change for the Great Barrier Reef is available from www.gbrmpa.gov.au.

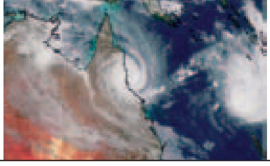
Regional climate change summaries: www.climatechange.qld.gov.au/whatsbeingdone/climatechangestrategy/impactsonqueenslandsregions.html

What the science is telling us: www.climatechange.qld.gov.au/whatthescienceistellingus.html

Further details on the ClimateQ program 'Helping Primary Producers to Adapt to Climate Change' are available at www.climatechange.qld.gov.au/pdf/factsheets/5primind-n4.pdf.

Table 6. Summary of climate change projections for the Queensland marine environment

Climate variable	Projected changes for the Queensland marine environment
Higher sea surface temperature	Sea surface temperatures for the Great Barrier Reef are projected to increase by 0.5°C by 2020 and 1.1°C to 1.2°C by 2050.
Ocean acidification	Ocean pH is expected to decrease by a further 0.2 to 0.3 units by 2100.
Sea level rise	On the Queensland Coast, sea level is expected to rise 30 cm by 2050 and 80 cm by 2100.
Changed rainfall patterns and nutrient inputs	There are expected to be more extremes in rainfall, and associated changes in the level, frequency and quality of inputs from the land.
Changed light spectra or intensity	Changes to spectral range and light intensity are expected.
Increased tropical storm intensity and flooding	There could be a 10% decrease in the frequency of cyclones by 2070, a 20-50% increase in the proportion of severe cyclones by 2050 and a 10% increase in cyclone intensity.
Altered ocean circulation	Ocean circulations are expected to change, including a possible intensification of the East Australian Current.
Higher peak wind speeds	Wind patterns are expected to change, with higher peak wind speeds and more extreme wind patterns (e.g. tropical cyclones).



HIGHER SEA SURFACE TEMPERATURE

This report uses the term ‘sea surface temperature’ to refer to surface temperatures of the ocean and ‘sea temperature’ to refer to water temperatures of the ocean at a range of depths. The usage of these terms matches the source of information available and the topic being discussed. Temperature datasets and projections are more readily available for surface waters than for deeper waters. In the well mixed waters of the Great Barrier Reef lagoon, changes to the temperature of waters shallower than 20 metres will reflect changes to surface temperatures. Waters deeper than 20 metres would be impacted less due to the buffering effects of water depth (Waycott et al. 2007).

Sea temperatures around Australia have warmed by 0.7°C since 1910-1929, with south-western and south-eastern waters warming fastest (Poloczanska et al. 2009) (H).

Sea surface temperatures for the Great Barrier Reef are projected to increase by 0.5°C by 2020 and 1.1°C to 1.2°C by 2050 (relative to 1961 to 1990 average 25.9°C, Table 5 above from Lough 2007).

The increase in annual mean sea surface warming in Figure 4 (source: www.bom.gov.au) is given for degrees Celsius (°C) per decade. For the waters off the east coast of Queensland there has been an annual mean increase of 0.11 °C per decade, which is a total of about 0.7 °C for the 60 years from 1950 to 2010.

Temperatures will continue to rise this century. Annual sea surface temperature (SST) is projected to rise by 1.6-1.8°C in northern and north-eastern Australia by the 2070s (McInnes et al. 2006). SST rises are expected to be greater in the southern Great Barrier Reef and in winter (Lough 2007) (H).

A warming in SST around Australia of 1-2°C is projected by the 2030s and 2-3°C by the 2070s with the greatest warming off south-eastern Australia, but at a depth of 500 metres the warming would be only 0.5-1°C (Hobday et al. 2008).

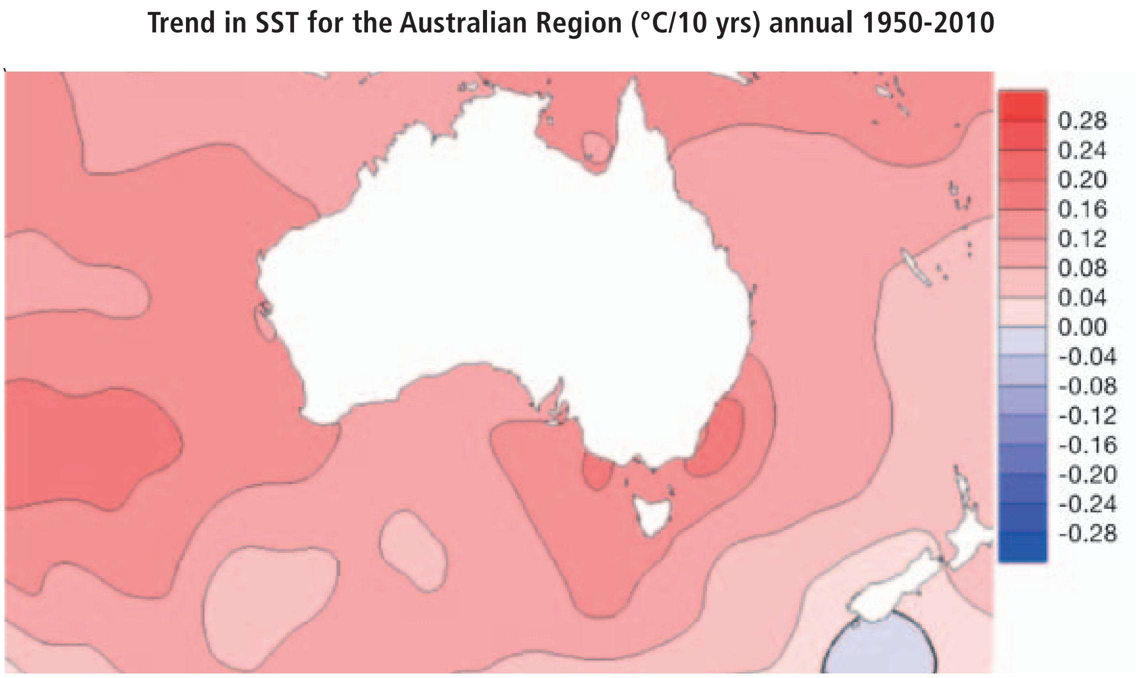

Trend in SST for the Australian Region (°C/10 yrs) annual 1950-2010

Figure 4. Trends in annual SST for the Australian region (1950-2010).

Annual Australian SST trends are available from http://www.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi?map=sstandarea=ausandseason=0112andperiod=1950

Absolute temperatures are available from
http://www.bom.gov.au/cgi-bin/climate/change/averagemaps.cgi?map=sstandseason=0112

Temperature trends are also available seasonally, as reported in the Lough (2009) report card, for consideration in assessment of species vulnerability and impacts:
http://www.oceanclimatechange.org.au/content/images/uploads/Temperature.pdf

Increased temperatures are likely to reduce productivity in most tropical and subtropical oceans, however effects may vary regionally (Cochrane et al. 2009). Increased temperatures will also affect physiological processes of many marine species, with positive and negative effects on fisheries depending on the location (Cochrane et al. 2009). Climate change is affecting the seasonality of some life cycle events, with flow on effects for marine food webs and unpredictable consequences for fish production (Cochrane et al. 2009). Predicted effects of increased temperatures on reproduction may be positive or negative and include increasing rates of embroyonic development, larval growth, development rates and survival, and decreasing rates of spawning and hatching success, leading to either increasing or decreasing recruitment success, depending on other environmental parameters (Pankhurst and Munday 2011). For most organisms, an increase in temperature above their normal thermal range reduces their metabolic activity causing stress and increasing their susceptibility to disease and predation.

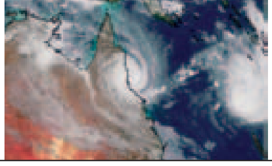
OCEAN ACIDIFICATION

Ocean acidification (lowering of pH and carbonate saturation state) is likely to be a more significant variable for marine life than any other changes in ocean chemistry (which are second-order modifications primarily as a result of changes in sea surface temperature, and climate induced changes in dissolved inorganic carbon concentrations) (Cao et al. 2007). Coral reefs, calcareous plankton and other marine organisms whose skeletons or shells contain calcium carbonate may be particularly affected (Caldeira and Wickett 2003).

The ocean is becoming more acidic (Figure 5), but there are differences in the reports of the speed of this change. Carbon dioxide dissolving in the oceans has been reported to have lowered pH by 0.1 units since 1750, representing a 30 per cent increase in hydrogen ion (acid) concentration (Poloczanska et al. 2009) (H). Average sea surface pH, however, has also been reported to have declined by 0.1 units, from 8.2 to 8.1, in the last 40 years (Pandolfi and Greenstein 2007) (H).

There is also a range of predictions about future trajectories for pH:

- For the Great Barrier Reef, ocean pH is projected to decrease by 0.06 to 0.1 units by 2020 and 0.15 to 0.25 units by 2050 (based on projections of 0.3 to 0.5 unit decrease by 2100, Table 5 above from Lough 2007).
- It is predicted that if CO2 emissions are not regulated then this could result in the average pH of sea water decreasing by 0.5 to a value of 7.5 by the year 2100 (Raven et al. 2005, cited by Hobday et al. 2008).
- Ocean pH will decrease by a further 0.2 to 0.3 units by 2100 (Poloczanska et al. 2009) (M).
- Ocean pH is projected to decline by between 0.2 and 0.3 units by the 2070s (Hobday et al. 2008) and by between 0.3 to 0.5 units over the next 100 years (Fabricius et al. 2007).



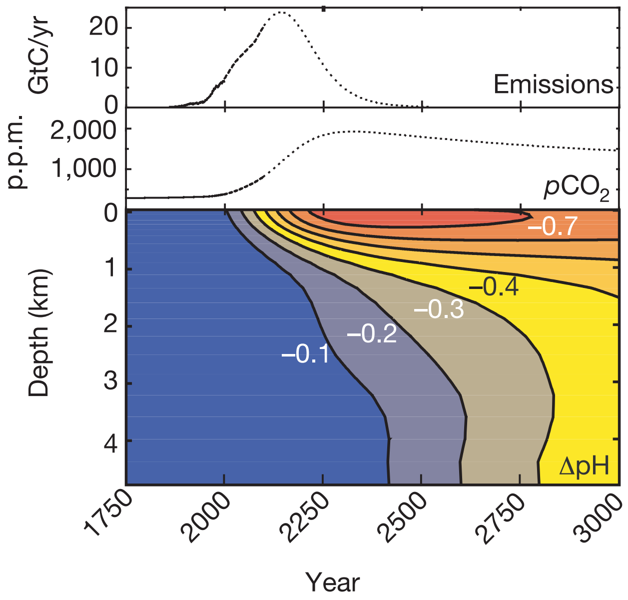


Figure 5. Atmospheric CO_2 emissions, historical atmospheric CO_2 levels and predicted CO_2 concentrations from this emissions scenario, together with changes in ocean pH based on horizontally averaged chemistry. Source: Caldeira and Wickett 2003.

In the long term, ocean acidification is likely to be the most significant climate variable affecting the Great Barrier Reef ecosystem (GBRMPA 2009). Although the process of ocean acidification is well understood, its effect on marine life is currently much less well known. However, even relatively small increases in ocean acidity can have substantial effects on some marine life.

Studies of ocean acidification have generally focused on calcification, fertilisation and larval development. Experimental studies have been conducted on a wide range of taxa including crustaceans, molluscs, echinoderms, fish, corals, and algae. Although some of the effects are subtle for individuals, over longer time frames there may be far-reaching effects for populations. Early life history stages are often more sensitive to change than adults.

Ocean acidification induced changes in marine biodiversity will be driven by differential vulnerability within and between different taxonomical groups: indirect effects that occur within multispecies assemblages may also be important in determining the effects of ocean acidification and global warming on marine communities (Hale et al. 2011).

The effects of predicted progressive acidification of the ocean will differ among reefs depending on natural cycles and the degree of flushing (Hutchings et al. 2007). Presumably, effects will also differ among other habitats. There is, however, little detailed information about high-resolution spatial patterns (e.g. cross-shelf) of change in ocean chemistry for the Great Barrier Reef (Lough 2007). It has been proposed that the decrease in pH of sea water will be greatest in shallow water and so populations of some species living at greater depth may be less affected by ocean acidification (Hutchings et al. 2007). Nevertheless, there is a large degree of uncertainty as to how ocean acidification will vary spatially including by depth, inshore compared to offshore, and whether some habitats may be able to buffer the expected change. Therefore, in the vulnerability assessment a single score has been assigned to ocean acidification for each species or species group. Participants at the expert workshop considered that the different life history stages, or the different population components in inshore and offshore habitats, may have different levels of exposure. For consistency, however, and in recognition of the current uncertainty over spatial variability, all species have been assigned a high level of exposure with a medium level of certainty.

Recent field experiments found some winners under more acidic oceanic conditions, such as seagrasses which increased in cover (Fabricius et al. 2011). It has also been noted that reef degradation from global warming and ocean acidification may occur less uniformly from place to place and over time than current projections suggest (Pandolfi et al. 2011). This is now an active area of scientific research and the knowledge base is expected to develop rapidly.

SEA LEVEL RISE

Global sea levels have risen by 20 cm in the period 1870-2004 (Poloczanska et al. 2009) (H).

Global sea levels will continue to rise 5-15 cm by 2030 and 18-82 cm by 2100 (Poloczanska et al. 2009) (M). However, ice sheet contributions to sea level rise, that cannot be quantified at this time, may substantially increase the upper limit of sea level rise (CSIRO 2007).

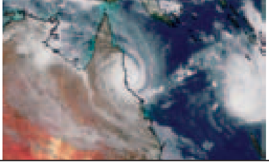
Sea level is projected to rise around Australia, and modelling has predicted localised sea level rise along the east coast of Queensland by up to a further 5 cm by 2070 (on top of the global average rise) due to strengthening of the East Australian Current.

Sea levels for the Great Barrier Reef are projected to rise between 7 and 38 cm by 2020 and 13 to 68 cm by 2050 (relative to 1961 to 1990 baseline, Table 5 above, from Lough 2007).

Rising sea levels will impact low-profile shores such as mangroves, increasing extent in some areas and decreasing mangrove extent in others (Hobday et al. 2008). There has been an expansion of mangroves into freshwater wetlands in northern Australia driven in part by sea level rise. Mangrove areas are likely to expand further landward, driven by sea level rise and soil subsidence (Poloczanska et al. 2009) (M).

Seagrasses may also be impacted by sea level rise; they may be able to colonise newly inundated lands but may also lose habitat at the deeper edges. There is not documented evidence of seagrass loss due to sea level rise and no relevant experimental results — net outcomes are uncertain (Waycott et al. 2007).

Seagrass meadows are important habitat for many species. Photo by Dieter Tracey



CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Rainfall is projected to slightly decrease in some parts of northern Australia and to slightly increase in others (Hobday et al. 2008). For example, some CSIRO models predict the percentage change in annual mean rainfall for northern Australia by 2070 compared to the year 2000 will be less than 10 per cent in most of the region (Hobday et al. 2008). For the Townsville region, CSIRO and the Bureau of Meteorology have projected a range of rainfall impacts from an annual increase of 19 per cent to a decrease of 32 per cent by 2070.

No consensus has been reached on projected change in average precipitation, however:

1) the intensity of drought will be increased due to higher air temperatures
2) the intensity of high rainfall events will increase (e.g. January 1998 Townsville flood event more frequent)
3) there will be more extremes (Lough 2007).

There are expected to be more extremes in rainfall for Queensland.

Queensland rainfall patterns are influenced by cyclone activity, and the frequency of cyclones is influenced by ENSO events, but the future pattern of ENSO is not known (see below). However, there are predicted to be more intense drought periods (exacerbated by warmer air temperatures) during El Niño events and more intense high rainfall events with increased freshwater flow and nutrient inputs to coastal environments during La Niña events (Poloczanska et al. 2009).

Floodwaters carry most of the terrestrial sediment and nutrients that reach the Great Barrier Reef (Furnas 2003). The size, movement and persistence of river plumes in the Great Barrier Reef lagoon changes with the volume of discharged fresh water and the strength of oceanographic forces which move and mix coastal waters (Furnas 2003). These low-salinity plume waters with their associated sediment and nutrients are usually forced into a narrow coastal band by the Coriolis force and dominant south-east trade winds but may extend to mid-shelf reefs during extreme flood events and to outer-shelf reefs under extreme cyclonic conditions (Furnas 2003).

CHANGED LIGHT SPECTRA

Species living in intertidal and shallow waters will be most vulnerable to changes in light attenuation and exposure to ultraviolet radiation, especially those with symbiotic algae such as giant clams, sponges, anemones and those spawning in intertidal habitats exposed to full sun (Hutchings et al. 2007).

There is only expected to be a small potential loss of seagrass in the Great Barrier Reef due to changes to light spectra under predicted climate change scenarios (Waycott et al. 2007) (L).

Changes to the light environment include both changes to the spectral range and light intensity. Participants at the expert workshop considered that it was difficult to separately assess the expected direct effects from the indirect effects for this variable, as the indirect effects may be greater than the direct ones.

INCREASED TROPICAL STORM INTENSITY AND FLOODING

The number of severe cyclones is likely to increase in Queensland (Lough 2007) (M-H). Recent projections by CSIRO and the Bureau of Meteorology are there could be a 10 per cent decrease in the frequency of cyclones off the east coast of Australia by 2070, a 20 to 50 per cent increase in the proportion of severe cyclones by 2050 and a 10 per cent increase in cyclone intensity.

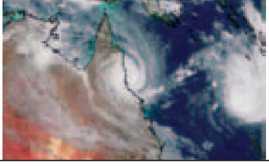
In period 1969 to 1997, the number of cyclones affecting the Great Barrier Reef may have declined, but those that occurred were more intense (Lough 2007). In the last few years, the number of cyclones has been higher, and included some of the most powerful cyclones to have affected the Great Barrier Reef since records commenced. Tropical cyclones are not equally likely over the area considered in this assessment, being less prevalent in the most northerly and most southerly areas of the fishery, and the impacts are therefore also likely to vary regionally.

There will be an increased threat from storm tides, inundation and flooding associated with tropical storms/cyclones. Storm surges are likely to penetrate further inland and extreme coastal inundation (e.g. 1 in 100 year events) could become more frequent.

Tropical cyclones can be major structuring forces for marine habitats such as coral reefs. Severe cyclones have caused major physical disturbance, including extensive structural damage to reef habitats of the Great Barrier Reef and other regions. For example, Tropical Cyclone Yasi in 2011 caused severe damage to six per cent of the coral reef area within the Great Barrier Reef Marine Park, and over 15 per cent sustained some level of coral damage (GBRMPA 2011).

Physical disturbance from storms and cyclones is expected to cause both loss and intermittent gains and community shifts in seagrass habitats, but these changes are expected to be localised (Waycott et al. 2007) (H). Shallow seagrass habitats (e.g. less than 5 metres) would be most affected.

A diver surveying damage to reef habitats of the Great Barrier Reef following a cyclone.



Understanding of the effects of extreme weather events such as cyclones and floods on coral reef and shallow seagrass habitats has been improved through recent monitoring and research (e.g. Puotinen 2007, Fabricius et al. 2008, Devlin et al. 2010, GBRMPA 2011, Osborne et al. 2011). Much less is known about physical disturbance from extreme weather events for trawled habitats such as continental shelf seabed habitats (without emergent coral reefs). However, it is expected that depth and proximity to rivers may have some influence on the level of any impacts.

Floods, as well as carrying nutrients, also create plumes of fresh water. The thickness of the low salinity layer can vary considerably, from 5-10 metres near the mouth of a flooding river to a thin layer only a few centimetres thick at the boundary of the plume (Furnas 2003). Average salinity is about 35 parts per thousand (ppt) for Great Barrier Reef waters. Salinity can be reduced to less than 24 ppt, and some degree of salinity changes may occur down to depths of 20 metres or more (Wolanski and Jones 1981). Areas affected by flood plumes may also experience high turbidity, with potential effects on habitats. Flood plumes are short term (hours to several weeks) and variable events. The composition of plumes is strongly event specific, varying over time and water depth, and influenced by mixing and other processes such as the biological uptake by phytoplankton and sedimentation of particulate matter. How habitats respond to flood plumes depends on several factors including the time and severity of exposure, the status of the ecosystem prior to exposure and other concurrent disturbance events.

CLIMATE VARIABILITY DRIVEN BY EL NIÑO-SOUTHERN OSCILLATION (ENSO) EVENTS

There is little evidence of observed change in ENSO variability due to global warming (Poloczanska et al. 2009) (L-M).

A background 'El Niño-like' pattern is projected this century (M), with no change in ENSO event amplitude or frequency (Poloczanska et al. 2009) (L).

Projections of how ENSO will change with continued climate change are considered to be unclear by some authors, but will continue to be a source of climate variability for this region (Lough 2007).

The effects of ENSO on regional climate are modulated by the Pacific Decadal Oscillation (PDO) with relationships between Australian rainfall and ENSO events being strong, significant and more predictable during PDO cool phases and weak, insignificant and less predictable during PDO warm phases.

ENSO and PDO are a source of climate variability from year to year in the Great Barrier Reef region, and tend to modulate rainfall and river flow, and tropical cyclones.

After the expert workshop and other consultations, climate variability driven by ENSO events was dropped because: a) it was not regarded as particularly relevant to the key species, b) a review of the expected changes indicated there was not a consensus on how ENSO frequency and intensity will change, and c) changes will more than likely be indirect and mediated through changes to other variables (such as rainfall). The effects of climate variability driven by ENSO events are therefore not considered further in this report. However, this does not mean that climate variability is not an important influence on the ECOTF, and further research on this topic would be valuable.

ALTERED OCEAN CIRCULATION

It is anticipated that climate change will result in an increase in thermal stratification (H). The depth of the thermocline is expected to rise and surface layer currents to increase (Steinberg 2007) (M).

The main driver of the Coral Sea circulation, the Southern Equatorial Current, shows only a small seasonal variation. However, it is projected that the relative contributions of the various zonal jets entering the Coral Sea will vary the location of the bifurcation and hence the relative strengths of the south-flowing East Australian Current and north-flowing Hiri Current (Steinberg 2007) (L-M).

The East Australian and Hiri currents are expected to increase in strength due to direct forcing from the Southern Equatorial Current, which will result in warmer waters extending further south. Central Great Barrier Reef currents may weaken and reverse if the bifurcation moves south (Steinberg 2007) (M).

The flow of the East Australian Current has strengthened, and is likely to strengthen by a further 20 per cent by 2100 (Poloczanska et al. 2009) (M). However, a more recent study showed differences in strengthening between regions, with most of the strengthening likely to occur south of the Great Barrier Reef (Sun et al. 2012).

With any increase in the Southern Equatorial Current, eddy activity is also expected to increase. Perturbations to the thermocline are likely to increase in magnitude (Steinberg 2007) (M).

Upwelling is expected to be highly variable and episodic. Shallowing of the thermocline due to increased stability of the surface may allow the thermocline to lift above the shelf edge (Steinberg 2007) (L).

Almost all areas of Australia will have greater stratification and a shallowing of the mixed layer by about 1 metre, reducing nutrient inputs from deep waters (Hobday et al. 2008).

Tidal currents are not expected to increase significantly, however, as sea levels rise tidal ranges will increase with sea level rises according to local shelf and coastal topography. Where waters can encroach on land, this effectively increases the shelf width, resulting in an amplification of the tidal range (Steinberg 2007) (H).

Changes to ocean circulation may also have indirect impacts on fishery resources through effects on seagrasses. Theoretical losses and gains and community shifts have also been suggested (Waycott et al. 2007).

HIGHER PEAK WIND SPEEDS

Climate models predict stronger south-east winds in the Coral Sea (Steinberg 2007) (M). These south-east trade winds are prevalent from April to November and characterise this season in the subtropical Great Barrier Reef.

Overall wind patterns and extreme wind patterns (e.g. tropical cyclones) may affect the marine environment. The average annual change in mean non-cyclonic wind speed is projected to increase up to six per cent in Brisbane by 2070 (CSIRO 2007). The proportion of severe tropical cyclones is likely to increase, intensity of cyclones is likely to increase, but frequency of cyclones is likely to decrease in Queensland.

4. Eastern King Prawns

Key facts

Species assessed: Eastern king prawn, a highly migratory species found between central Queensland and north-eastern Tasmania.

Habitats used: estuarine and inshore areas and continental shelf at depths of 1 to 220 metres.

Trawl fishery: most important target species taken in southern region of fishery.

Eastern king prawns	Vulnerability
Higher sea surface temperature	M-inshore
	L-offshore
Ocean acidification	L
Sea level rise	L
Changed rainfall patterns and nutrient inputs	M-inshore
	L-offshore
Changed light spectra	L
Increased tropical storm intensity and flooding	M-inshore
	L-offshore
Altered ocean circulation	H
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. All life history stages of eastern king prawns may be subject to a high level of ecological vulnerability from altered ocean circulation, which could: 1) alter distribution of adults, and 2) affect dispersion of eggs and larvae for this species. This vulnerability arises because the distribution of larvae and post larvae and the migration of adults are likely to be affected by prevailing currents. The entire distribution of the eastern king prawn stock from Victoria to central Queensland is in very close proximity to the East Australian Current, which is expected to increase in strength.

2. The inshore stages of the life cycle of eastern king prawns may be subject to a medium level of ecological vulnerability from higher sea surface temperature, changed rainfall patterns and nutrient inputs and increased tropical storm intensity and flooding, which could result in impacts on the survival and distribution of this species. This vulnerability arises because of direct potential effects on individuals and indirectly because these factors are likely to alter potentially important attributes of their inshore habitats.

Background

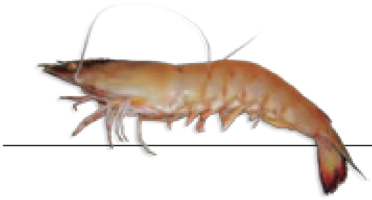
The eastern king prawn *Melicertus plebejus* is endemic to eastern Australia, inhabiting sandy sediments of the continental shelf at depths of 1–220 metres between Mackay in Queensland and north-eastern Tasmania. While juveniles tend to be found in shallow water environments, eastern king prawn undertake northerly sea migrations sometimes in excess of 1000 kilometres to spawn in waters between northern New South Wales (NSW) and Swains Reefs in central Queensland (Kailola et al. 1993). Adult eastern king prawns spawn from January through to August in water depths (generally) greater than 90 metres.

Eastern king prawns live for a maximum of three years with adult females able to carry upwards of 200,000 eggs (Gibbs 2011). Larvae move up the water column during the night-time period and down the water column by day. At three weeks, larvae undergo a change in body shape and settle in estuarine waters as post-larvae. Post-settlement, larvae grow quickly nearing adulthood in about six months. Older juvenile prawns then migrate seaward; reaching sexual maturity at 12–18 months of age (DEEDI 2010, Gibbs 2011).

Post-larval to adolescent eastern king prawns inhabit bare and vegetated substrates in areas of marine (rather than freshwater) influence within estuaries and probably within shallow embayments in ocean waters. They emigrate from estuaries over spring and summer and then move northwards over long distances prior to spawning (Gibbs 2011).

The role of seagrass beds in the life history of the eastern king prawn is complex. Proximity of seagrass beds to mangroves has been shown to be important in Moreton Bay (Skilleter et al. 2005) but reduction in seagrass density was found to be associated with increased numbers of prawns in Tin Can Bay (Halliday 1995). Modelling of the Queensland fishery (O’Neill et al. 2005) suggested that eastern king prawns had been fished to the limit of maximum sustainable yields, but that population sizes prior to 2001 may have been lower than this. This result was, however, sensitive to the uncertainty relating to the spawner-recruitment relationships, the estimates of annual increases in fishing power and the accuracy of the logbook catch data. Population modelling (Ives and Scandol 2007) of the NSW stock indicated that it was very resilient under the assumption of stable levels of recruitment from Queensland.

The broad geographic range, high fecundity and lower trophic level of the species and large variations in growth, mortality and recruitment of the species in both space and time suggest it is resilient to the predicted rate of change under most climate shift scenarios (Gibbs 2011).



Exposure, sensitivity, potential impact and adaptive capacity of eastern king prawns

HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Eastern king prawns will be exposed to the predicted effects of climate change on sea surface temperatures (SST) over their entire range. Changes to SST are predicted to be greater, however, than those to temperatures of deeper waters (Waycott et al. 2007, Hobday et al. 2008) and hence the juvenile stages that rely on shallower inshore habitats will be exposed to the largest changes in sea temperature.

Inshore nursery habitats for eastern king prawns, such as seagrasses, are also exposed to the effects of elevated sea temperatures (Waycott et al. 2007).

Prawns have a medium sensitivity to sea temperature, as temperature may influence factors such as growth rates and the timing or sequence of life cycle events (e.g. breeding, migration).

Under increasing temperatures, eastern king prawns may emigrate from estuaries earlier in the year than at present; they may spawn earlier in the year and spawn further south; and there may be an overall southward extension of their geographic distribution (Montgomery 1990, cited in Gibbs 2011).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore L-offshore	H	M	H	H-inshore L-offshore	H

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011). The population of eastern king prawns on the east coast of Australia has been subject to relatively high fishing pressure.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L- offshore	M

OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: Eastern king prawns will be exposed to the effects of ocean acidification over their entire range.

As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

It has been proposed that the decrease in pH of sea water will be greatest in shallow water and so populations of some species living at greater depth may be less affected by ocean acidification (Hutchings et al. 2007), however what is meant by 'shallow' in this context is unclear and may actually include all of the water depths fished in the ECOTF (to over 200 metres depth). In the initial draft of this report it was thought that for eastern king prawns, juveniles inhabiting shallow water may therefore have high exposure to more acidic oceanic conditions, whereas adults are found in a range of depths from shallow inshore waters to over 200 metres, and hence exposure was expected to be lower in deeper offshore waters.

It has also been suggested that estuarine fauna (presumably including the estuarine stages of prawns) routinely encounter much greater fluctuations in pH and dissolved CO_2 than projected to occur over the next century as a result of climate change (Hobday et al. 2008). It could be inferred therefore that eastern king prawns, which have an estuarine phase in their life cycle, are likely to be relatively insensitive to changes in ocean chemistry.

Nevertheless, it has also been proposed that "crustaceans may be particularly vulnerable to ocean acidification because of their dependence on the availability of calcium and bicarbonate ions for mineralisation of a new exoskeleton after moulting" (Raven et al. 2005, cited in Hobday et al. 2008).

Prawns, however, are among the groups of organisms that exert high biological control over calcification, typically accumulating intracellular stocks of carbonate ions gradually, hardening their chitin and protein exoskeletons by depositing calcium carbonate ($CaCO_3$) from within, and therefore require less specific seawater chemistry to form shells (Cooley and Doney 2009).

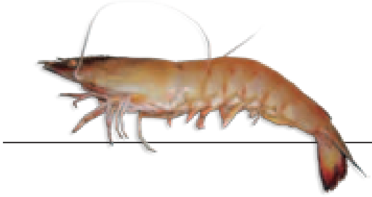
Laboratory experiments on another species of prawn in Japan found effects on the reproduction of females under more acidic conditions (females produced fewer eggs etc.) (Kurihara et al. 2008).

The cause of ocean acidification, the rise in atmospheric CO_2 levels, may itself have an indirect but positive effect on prawn populations. "Growth of mangroves and seagrasses .... may be stimulated by additional CO_2 levels in the atmosphere and ocean respectively .... and these form essential habitat for prawns" (Hobday et al. 2008).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	L	M	M	M

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011). Nevertheless, Hutchings et al. (2007) stated that the impact of ocean acidification on calcifying marine invertebrates will depend on species' adaptability and that there are few experimental data on this.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M



SEA LEVEL RISE

Exposure, sensitivity and potential impact: Eastern king prawns will be exposed to the effects of sea level rise over their entire range, but much of the adult population is not likely to experience a big change in sea level given the depths inhabited and level of projected changes.

Changes to sea levels may indirectly affect eastern king prawns through predicted changes to the distribution and extent of mangrove and seagrass habitats. The impacts on prawn populations from these habitat changes are difficult to predict and are likely to vary locally as the areas of mangroves and other habitats on low profile shores are expected to increase their extent in some areas and decrease in others.

The juvenile stages that rely on these inshore habitats will be the most sensitive to any changes. Participants at the expert workshop, however, considered that there was a low level of certainty to the estimation of sensitivity.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	M-inshore L-offshore	L	M-inshore L-offshore	L

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	L

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Exposure, sensitivity and potential impact: The estuarine phase in the life cycle of eastern king prawn is the most exposed to freshwater and other terrestrial inputs to the estuaries.

The estuarine phase in the life cycle of eastern king prawn is also the most sensitive to freshwater and other terrestrial inputs to the estuaries. Recruitment of the larval prawns to estuaries is reduced during high freshwater input or floods (Gibbs 2011). However, the level of impact is likely to vary substantially among estuaries, due to differing physical attributes and levels of anthropogenic modification (Pecl et al. 2011). Participants at the expert workshop considered that there was a medium level of certainty to the estimate of sensitivity.

It is not certain which estuaries produce the juveniles that contribute most adults back to the effective spawning stock (Montgomery et al. 2007).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore L-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Eastern king prawns will be exposed to the direct effects of changes to light spectra over their entire range. However, as this species only makes limited use of intertidal and shallow water habitats, it will only experience moderate effects of changes to light spectra. There may also be indirect impacts if the expected increases in turbidity decrease the area of seagrass habitats and reduce the productivity of inshore areas in which juvenile prawns live.

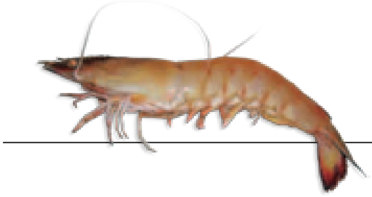
Spectral changes associated with increased turbidity, sedimentation, and storm frequency are predicted to have an impact on benthic invertebrates that obtain at least part of their nutrition from photosynthetic symbionts (e.g. giant clams and anemones) (Hutchings et al. 2007). Eastern king prawns, however, do not fall into this category of organisms and prawn populations are expected to have low sensitivity to direct effects of changes to light spectra.

There are potential indirect effects on eastern king prawns through effects of changes to light spectra on seagrasses but, given the uncertainty over the role of seagrasses for recruitment of eastern king prawns, this is expected to be minor.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	M	L	M

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M



INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Eastern king prawn populations are exposed to the direct and indirect impacts of such events especially in the northern part of their range. The juvenile stages that live in inshore habitats will be the most exposed to these physical disturbances.

Eastern king prawns may be sensitive to changes in physical disturbance regimes caused by tropical storms. The northern areas of their distribution have the greatest reproductive potential (Montgomery et al. 2007) and may also be the most important source of recruitment to nursery areas.

Predicted positive and negative local effects on seagrass habitats from this climate variable may also impact indirectly on eastern king prawn populations.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore M-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Eastern king prawns are highly migratory and will be particularly exposed to any effects of changes to the strength of the East Australian Current.

Under most climate scenarios, the East Australian Current moves south and this may change current recruitment patterns for eastern king prawns and shift spawning grounds southward (Gibbs 2011).

The oceanic sources of larvae that contribute to recruitment in each nursery area remain uncertain (Montgomery et al. 2007) so impacts of changes to the East Australian Current are uncertain.

The northward pre-spawning movement of adults may also be affected by any increase in the strength of the East Australian Current.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	M	H	H	H

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011). Nevertheless, for a species like eastern king prawn, for which migration is such a key aspect of the life history, participants at the expert workshop considered that the adaptive capacity may still be only moderate.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	H	M

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Eastern king prawn populations would be exposed to any effects of changes to wind patterns over their entire range. However, the projected changes are minor, so the overall exposure is considered to be medium. Participants at the expert workshop considered there to be only a medium level of certainty to this estimate of exposure.

There is no information to suggest that eastern king prawns are sensitive to the proposed changes to wind patterns.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	M	L	M

Adaptive capacity and vulnerability: Adaptive capacity has been assessed as being good to all climate change variables (Gibbs 2011).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

5. Tiger Prawns

Key facts

Species assessed: brown tiger prawn and grooved tiger prawn assessed as a species-group because they are similar species. Life cycle includes inshore and offshore components.

Habitats used: juveniles use inshore nursery areas including seagrass beds, adult brown tiger prawns prefer coarse sediments, while grooved tiger prawns prefer muddy seabed areas.

Trawl fishery: important target species, particularly in northern and central regions of fishery.

Tiger prawns	Vulnerability
Higher sea surface temperature	M-inshore
	L-offshore
Ocean acidification	H
Sea level rise	M-inshore
	L-offshore
Changed rainfall patterns and nutrient inputs	M-inshore
	L-offshore
Changed light spectra	L
Increased tropical storm intensity and flooding	M-inshore
	L-offshore
Altered ocean circulation	L
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. The inshore life history stages of tiger prawns may be subject to a high level of ecological vulnerability from ocean acidification, which could result in direct effects on these species such as changes to larval development, survival and fecundity, leading to changes in key life history stages and recruitment success for this species. This vulnerability arises because there is a high level of potential impact on the species and only a medium level of capacity to adapt to changes in pH. However, the level of certainty is low due to the high variability of the natural environment and the lack of studies on tolerance of the species to chronic acidification.
2. Inshore juvenile tiger prawns may be subject to a medium level of ecological vulnerability from higher sea surface temperature, sea level rise, changed rainfall patterns and nutrient inputs, and increased tropical storm intensity and flooding, which could result in direct detrimental effects on the survival of juveniles and indirect impacts on critical inshore habitats. This vulnerability arises because this species has an inshore component of its life cycle, where exposure and impact is thought to be higher. This is mitigated by a high level of adaptive capacity (e.g. historical capacity to adapt to an already highly variable ecosystem/habitat).

Background

There are two main species of tiger prawn caught in the fishery: the brown tiger prawn *Penaeus esculentus* and the grooved tiger prawn *P. semisulcatus*. Participants at the expert workshop considered these species were sufficiently similar, however, for the results of this assessment to be equally applicable to both species.

The brown tiger prawn is endemic to northern Australia, inhabiting coarse sediments to depths of over 100 metres but are mostly trawled in depths of 10–20 metres (Kailola et al. 1993). Spawning occurs from July to March; larvae are planktonic for three weeks before settling on inshore nursery areas (DEEDI 2010). Coastal and estuarine seagrass beds were found to be important nursery areas for tiger prawns in the Turtle Island Group north of Cairns but deepwater seagrass beds were not (Derbyshire et al. 1995). Brown tiger prawns are sexually mature at 5 to 7 months old and 26 mm carapace length and reach a maximum carapace length of 55 mm for females and 40 mm for males; females can produce over 300,000 eggs; juveniles of both species are found in shallow waters associated with seagrass beds (Kailola et al. 1993). This association is mainly with intertidal and slightly subtidal seagrass areas (C. Turnbull pers. comm.). Brown tiger prawns migrate offshore at about 20 mm carapace length (DEEDI 2010).

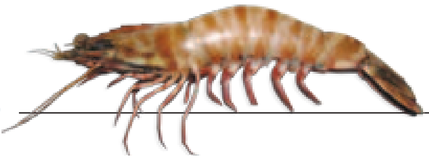
Brown tiger prawns are associated with slightly sandier habitats compared to grooved tiger prawns, the latter have a higher association with muddy seabed areas (C. Turnbull pers. comm.).

The species composition of commercial prawns for the east coast of Queensland varies by region with brown tiger prawns being more common in the north and grooved tiger prawns more common in central and southern areas (details of species composition of commercial prawns are provided in Turnbull et al. 2004, see Figures 5 and 6).

Tiger prawns probably share many of the climate change risks identified for eastern king prawns.

"The broad geographic range, high fecundity and lower trophic level of the species [eastern king prawn] and large variations in growth, mortality and recruitment of the species in both space and time suggest it is resilient [not sensitive] to the predicted rate of change under most climate shift scenarios." (Gibbs 2011). Tiger prawns share similar attributes and could be expected to have similar resilience.

A simulation study using an ecosystem model of the Gulf of Carpentaria predicted that the abundance of tiger prawns would decline in response to climate change (Brown et al. 2010). This was attributed to the indirect effect of high predation rates from, or strong competition with, other functional groups following increases in primary productivity.



Exposure, sensitivity, potential impact and adaptive capacity of tiger prawns

HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Tiger prawns will be exposed to the predicted effects of changed sea surface temperatures over their entire range. Tiger prawns are associated with fine sediments and such faunas have been predicted to be primarily affected by changes in temperature (Hutchings et al. 2007).

Inshore nursery habitats for prawns, such as seagrasses, are also exposed to the effects of elevated sea temperatures (Waycott et al. 2007). Participants at the expert workshop considered that the life history stages occupying the more offshore habitats would also have a medium level of exposure due to the level of mixing of waters within the Great Barrier Reef, but that there was only a medium level of certainty to this assessment.

In aquaculture situations, maximal growth rates of giant tiger prawns (*P. monodon*) has been shown to occur during sustained periods of warmer pond water (Jackson and Wang 1998, cited in Hobday et al. 2008). Therefore, increasing SST may increase growth rates of at least one species of tiger prawns in the wild (M).

As identified for eastern king prawn (Gibbs 2011), increased SST may also hasten larval development of tiger prawns and reduce the time spent in estuarine nursery habitats, resulting in the prawns emigrating earlier in the year.

A more rapid transit through the more vulnerable larval and juvenile stages may also lead to reduced natural mortality and increased rates of survival to adult stages. Spawning may also occur earlier in the year. Earlier development, however, may reduce the coincidence of migrations and the development of favourable habitat conditions, if the timing of their development is not similarly shifted.

Sea temperature is a major factor controlling seagrass photosynthesis and elevated temperatures

generally increase photosynthesis in tropical species over a wide range of temperatures (Waycott et al. 2007). Increased sea temperatures may therefore have a positive effect on the productivity of these habitats for juvenile prawns.

Overall, the sensitivity has been assessed as medium rather than high as some of the predicted effects may be positive for the species.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore M-offshore	M	M	M	H-inshore M-offshore	M

Adaptive capacity and vulnerability: Prawns have both mobile adults and planktonic larvae, both of which are features that allow movement of populations into colder and deeper water or into cooler waters of higher latitudes (Hutchings et al. 2007).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

OCEAN ACIDIFICATION/CHEMISTRY

Exposure, sensitivity and potential impact: Tiger prawns will be exposed to the effects of ocean acidification over their entire range. Participants at the expert workshop considered that indirect effects of ocean acidification may be important for tiger prawns, that larval stages may be more exposed to the effects than adults, and that inshore impacts may be buffered by the respiration of seagrasses although diurnal cycles may override these effects. However, as explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

According to information provided to Australian prawn aquaculturists (who mainly produce *P. monodon*), prawns prefer slightly alkaline waters, with the optimum pH of the water source in the range of 7.5 to 8.5.

The projected changes to pH levels appear to be within acceptable levels for at least *P. monodon* over the next 100 years, but over longer periods ocean acidification levels may cause stress.

It has been suggested that estuarine fauna (presumably including the estuarine stages of prawns) routinely encounter much greater fluctuations in pH and dissolved CO_2 than projected to occur over the next century as a result of climate change (Hobday et al. 2008). It could be inferred therefore that *P. monodon*, which is more of an estuarine species, is likely to be relatively insensitive to changes in ocean chemistry, but other species of tiger prawns may exhibit greater sensitivity.

Nevertheless, it has also been proposed that “crustaceans may be particularly vulnerable to ocean acidification because of their dependence on the availability of calcium and bicarbonate ions for mineralisation of a new exoskeleton after moulting” (Raven et al. 2005, cited in Hobday et al. 2008).

Prawns, however, are among the groups of organisms that exert high biological control over calcification, typically accumulating intracellular stocks of carbonate ions gradually, hardening their chitin and protein exoskeletons by depositing $CaCO_3$ from within, and therefore require less specific seawater chemistry to form shells (Cooley and Doney 2009).

The cause of ocean acidification, the rise in atmospheric CO_2 levels, may itself have an indirect but positive effect on prawn populations. “Growth of mangroves and seagrasses .... may be stimulated by additional CO_2 levels in the atmosphere and ocean respectively .... and these form essential habitat for prawns” (Hobday et al. 2008).

Participants at the expert workshop considered that there was likely to be a medium level of sensitivity of tiger prawns to ocean acidification but that there was a low level of certainty to this assessment.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	M	L	H	L

Adaptive capacity and vulnerability: The impact of ocean acidification on calcifying marine invertebrates will depend on species' adaptability and there are few experimental data on this (Hutchings et al. 2007).

Participants at the expert workshop considered that tiger prawns had only a medium level of adaptive capacity to ocean acidification.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	H	L

SEA LEVEL RISE

Exposure, sensitivity and potential impact: Tiger prawns will be exposed to the effects of sea level rise over their entire range, but much of the adult population is not likely to experience a big change in sea level given the depths inhabited and level of projected changes. Population components in inshore habitats would, however, have a high level of exposure.

Changes to sea levels may indirectly affect prawns through predicted changes to the distribution and extent of mangrove and seagrass habitats. The impacts on prawn populations from these habitat changes are difficult to predict and are likely to vary locally as the areas of mangroves and other habitats on low profile shores are expected to increase their extent in some areas and decrease in others. For tiger prawns, changes to seagrass habitats may affect juveniles.

Participants at the expert workshop considered that offshore population components would have a low sensitivity to any sea level rise.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore L-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of tiger prawns at a species level and different species may have different adaptive capacities to sea level rise.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Exposure, sensitivity and potential impact: Changes to rainfall levels and to subsequent river flows are most likely to impact on prawn populations by altering water quality in the estuarine and inshore habitats occupied by juvenile stages. Any impacts on prawn production are likely to vary regionally.

"The estuarine phase in the life cycle of eastern king prawn is the most sensitive to climate change, especially in relation to freshwater input to the estuaries. Recruitment of the larval prawns to estuaries is reduced during high freshwater input or floods" (Gibbs 2011). Juvenile tiger prawns occupy similar habitats and could be expected to have a similar sensitivity. In Western Australia, periods of heavy rainfall following cyclones may reduce the catches of tiger prawns[2].

Participants at the expert workshop considered that the offshore components of the population would still have a medium exposure and a medium sensitivity to the changes in rainfall patterns and nutrient inputs, and that the level of certainty to the estimate of exposure was also medium.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore M-offshore	H	M-inshore M-offshore	M	H-inshore M-offshore	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of each species of tiger prawns and different species may have different adaptive capacities.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Tiger prawns will be exposed to the direct effects of changes to light spectra over their entire range. There may also be indirect impacts if the expected increases in turbidity decrease the area of seagrass habitats and reduce the productivity of inshore areas in which juvenile prawns live.

Spectral changes associated with increased turbidity, sedimentation, and storm frequency are predicted to have an impact on benthic invertebrates that obtain at least part of their nutrition from photosynthetic symbionts (e.g. giant clams and anemones) (Hutchings et al. 2007). Prawns, however, do not fall into this category and changes to light spectra are expected to have minimal direct impact on prawn populations.

Tiger prawn populations are unlikely to be sensitive to the expected small potential loss of seagrass in the Great Barrier Reef due to changes to light spectra.

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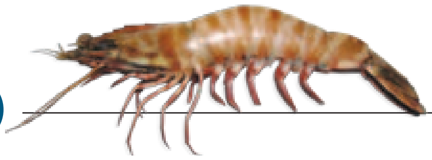
[2] (Western Australian Fisheries website http://www.fish.wa.gov.au/docs/cf/Prawns/index.php?0206 . Accessed 16 May 2011)



Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of tiger prawns to changed light spectra but their adaptive capacity is probably not important given the low potential impact.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Tiger prawn populations are exposed to the direct and indirect impacts of such events throughout their range.

Tiger prawns may be sensitive to changes in physical disturbance regimes caused by tropical storms.

In Western Australia, cyclones have had both significant positive and negative effects on the recruitment of tiger prawns later that year depending on their timing and severity (Caputi et al. 2010). For example, the category 5 Cyclone Vance in 1999 had a negative effect on the juvenile tiger prawn habitat (seagrass/algal communities) which negatively affected the tiger prawn recruitment the following two years, 2000 and 2001 (Sporer et al. 2008). It is uncertain whether this effect is the result of physical disturbance or rainfall associated with cyclones.

Predicted positive and negative local effects on seagrass habitats may also impact indirectly on tiger prawn populations.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore M-offshore	H	H-inshore L-offshore	M	H-inshore L-offshore	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of tiger prawns to increased storm intensity and flooding.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Tiger prawn populations will be exposed to the range of predicted changes to ocean circulation and currents over their entire range but, as a mainly inshore species, this exposure will be less than for species inhabiting more offshore habitats, and was assessed as medium.

Some species of benthic invertebrates may benefit from ocean circulation changes through recruitment, providing such changes increase favourable conditions for larvae. For example, populations of the seashell *Strombus luhuanus* on the Great Barrier Reef showed consistently high recruitment for two years following ENSO events, likely due to ocean circulation changes and upwelling of nutrient-rich waters (Hutchings et al. 2007).

There is no information on whether tiger prawns are likely to benefit in a similar way.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of tiger prawns to altered ocean circulation.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Tiger prawn populations would be exposed to any effects of changes to wind patterns over their entire range. However, the projected changes are minor, so the overall exposure is considered to be medium.

There is no information to suggest that tiger prawns are sensitive to the proposed changes to wind patterns.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of tiger prawns to higher peak wind speeds.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

6. Saucer Scallops

Key facts

Species assessed: saucer scallop, which have a pelagic larval phase but do not move far as adults, and are found south of Innisfail in Queensland.

Habitats used: bare sand, rubble or soft sediments in depths from 10 to 75 metres.

Trawl fishery: target species in southern and central regions of fishery.

Saucer scallops	Vulnerability
Higher sea surface temperature	H
Ocean acidification	H
Sea level rise	L
Changed rainfall patterns and nutrient inputs	H
Changed light spectra	L
Increased tropical storm intensity and flooding	H
Altered ocean circulation	H
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. Saucer scallops may be subject to a high level of ecological vulnerability from changed rainfall patterns and nutrient inputs, and increased tropical storm intensity and flooding, which could result in reduced health and recruitment failure from greater input of pollutants and sediments and from episodes of lowered salinity that reduce the amount or quality of available habitat. This vulnerability arises because saucer scallops are relatively sedentary as adults, have a limited core population range that is often exposed to the discharge from large rivers, and are highly dependent on the successful settlement of larvae on hard substrates. Potential increases in coastal sources of pollution and sedimentation and increased coastal development may contribute to these changes. However, the level of certainty is low because of information gaps.

2. Saucer scallops may be subject to a high level of ecological vulnerability from higher sea surface temperature and ocean acidification, which could result in disruptions to triggers for spawning and developmental effects on larvae and a greater prevalence of fragile shells for this species. This vulnerability arises because adults have a low capacity to move and all life stages occur above the thermocline, and these waters will continue to warm this century. How well saucer scallops would cope with higher temperatures is uncertain.

3. Saucer scallops may be subject to a high level of ecological vulnerability from altered ocean circulation where the south-flowing East Australian Current becomes stronger (or the Hiri Current split moves south into the main species distribution area), which could result in larvae being distributed into unsuitable settlement areas. This vulnerability arises because saucer scallop are broadcast spawners and the distribution of larvae is dependent on ocean currents and circulation patterns. However, the level of certainty is low because of information gaps.

Background

The saucer scallop (*Amusium balloti*) is distributed from Innisfail to Jervis Bay on the east coast of Australia, in the waters of New Caledonia and off Western Australia. Saucer scallops tend to inhabit bare sand, rubble or soft sediment environments in water depths of 10 to 75 metres (Kailola et al. 1993). Spawning occurs from May to September in Queensland when mature scallops broadcast eggs and sperm into the water column to be fertilised. Research indicates that saucer scallop larvae float in the water column for 12–18 days before settling to the sea floor where they are capable of independent swimming movement (Kailola et al. 1993). Saucer scallops can reach their minimum legal shell length of 90 mm in 33–42 weeks but can reach up to 140 mm in length and live for up to 3–4 years (DEEDI 2010)**.** In Queensland, saucer scallops in deeper waters with swift tidal flows grow more slowly when compared to scallops in shallower water with less tidal flow (Kailola et al. 1993).

Exposure, sensitivity, potential impact and adaptive capacity of saucer scallops

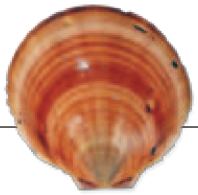
HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Saucer scallops will be exposed to the predicted effects of changed sea surface temperatures over their entire range. Deeper populations will be exposed to the smaller changes expected in deeper waters. The planktonic larvae may be more exposed as they may spend time in the upper parts of the water column.

No information was found in the literature on the sensitivity of saucer scallops to sea temperature but, like other invertebrates, rates of larval development are likely to be faster in warmer waters. At the expert workshop, industry participants reported that scallops from areas of higher sea temperatures were generally smaller and had more fragile shells. Temperature is thought to be a trigger for spawning so increased sea temperatures may alter the timing of spawning events.

A significant positive correlation between recruitment and increasing temperature in the Irish Sea has been observed in *Pecten maximus* over a 16-year period (Shephard et al. 2010, cited in Doubleday 2011). The study indicated that greater gamete production was the key underlying cause of increased recruitment, which was probably due to greater food availability. It is uncertain whether a similar relationship with sea temperature would be found for tropical species.

In a mesocosm experiment (i.e. designed to provide an experimental system with close to natural conditions, in which environmental factors can be realistically manipulated) in temperate waters, molluscs as a group (including bivalves) showed the greatest reduction in abundance and diversity in response to low pH and elevated temperature but closely related species showed different responses (Hale et al. 2011).



For scallops in south-eastern Australia, elevated temperatures may shift timing of spawning, and impact larval development, recruitment, and growth rates (Pecl et al. 2011) (L).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	H	H	H	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of saucer scallops but the extensive latitudinal range of the species suggests an inherent capacity to cope with a range of sea temperatures.

Participants at the expert workshop considered that the adaptive capacity of saucer scallops would be enhanced by the mobility of the larvae and by them being a short-lived species.

Suspension-feeding molluscs have exhibited the highest extinction rates among groups of Southern Hemisphere molluscs during the Cretaceous-Tertiary extinction event (Hutchings et al. 2007). Whether this is a good indicator of the poor adaptive capacity of saucer scallops to rising sea surface temperatures, however, is unclear.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	H	L

OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: Saucer scallops will be exposed to the predicted effects of changed acidity over their entire range.

As a shell-forming animal, saucer scallops are likely to be sensitive to the effects of ocean acidification. The predicted decrease in ocean pH may impact on the ability of invertebrates to secrete protective skeletons, negatively affecting shell and skeleton formation, development and strength, and thereby affecting their primary function, as protection from physical damage, including predation (Hutchings et al. 2007).

The first direct impact on humans of ocean acidification may be through declining harvests and fishery revenues from shellfish (Cooley and Doney 2009). The giant scallop (*Pecten magellanicus*) showed decreases in fertilisation and development at pH levels below 8 (Fabry et al. 2008, cited in Cooley and Doney 2009).

Some organisms may also show indirect effects of ocean acidification by diverting resources from their shells towards improving physiological function. For example, the bivalve *Mytilus galloprovincialis* dissolves its calcium carbonate shell during periods of prolonged hypercapnia (excess carbon dioxide in the blood) in order to increase haemolymph bicarbonate and limit acidosis (Hutchings et al. 2007).

Increased levels of CO^2, predicted to occur later this century, are reported to have significantly decreased larval size and survivorship (>50 per cent) and delayed metamorphosis in the scallop *Argopecten irradians* (Talmage and Gobler 2009, cited in Doubleday 2011).

In south-eastern Australia, decreased pH may have a profound impact on development and survival of commercial scallops (Pecl et al. 2011) (L).

In a mesocosm experiment in temperate waters, molluscs as a group (including bivalves) showed the greatest reduction in abundance and diversity in response to low pH and elevated temperature but closely related species showed different responses (Hale et al. 2011).

Calcification rates of other benthic molluscs, the mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*), have been predicted to decline linearly with increasing acidification, by 25 per cent and 10 per cent respectively, by the end of the century, with early life stages of molluscs being particularly sensitive (Guinotte and Fabry 2008).

As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	H	M	H	M

Adaptive capacity and vulnerability: Recent modelling suggests that molluscs evolved optimal shell morphologies in response to predators (Hutchings et al. 2007) but the ability of scallops to adapt to weakened shells sufficiently rapidly to avoid potentially increased predation pressures is uncertain.

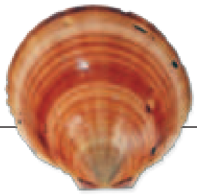
Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	M	H	M

SEA LEVEL RISE

Exposure, sensitivity and potential impact: Saucer scallops will be exposed to the effects of sea level rise over their entire range. They do not, however, inhabit those shallow inshore habitats that are predicted to be most directly affected by sea level changes.

Sea level rise may affect benthic communities that are relatively isolated by geographical barriers by facilitating larval dispersal. The effect of geographical barriers could be reduced with heightened sea level, resulting in recruitment of invader species to a formerly isolated area. Alternatively, increased larval dispersal between previously semi-isolated intraspecific populations could also help to maintain genetic continuity (Hutchings et al. 2007). Participants at the expert workshop considered that there was a medium level of certainty as to whether saucer scallops will be sensitive to these types of hypothesised changes.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	M	L	M



Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of saucer scallops but participants at the expert workshop considered that they were likely to have a high adaptive capacity to a rise in sea levels.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	H	L	M

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Exposure, sensitivity and potential impact: Saucer scallops do not inhabit the inshore waters that are most likely to experience the effects of altered rainfall and river flows although reduced salinities can extend to offshore waters during extreme floods and down to depths of 20 metres (Wolanski and Jones 1981, Furnas 2003). At the expert workshop industry participants reported that there has been a loss of beds of saucer scallops nearer the coast in Hervey Bay, which was thought to be an effect of increased sedimentation or other terrestrial inputs. Participants at the expert workshop considered that larvae, which are found from late May to July when there is less likelihood of flooding, are less likely to be exposed to the effects of changed rainfall patterns and nutrient (or other) inputs but that adults and subadults would have a medium level of exposure.

Marine benthic invertebrates can be highly sensitive to changes in salinity (e.g. encapsulated molluscs) and many species have, at best, a limited ability to osmoregulate in the presence of fresh water (Hutchings et al. 2007). No information is available on whether saucer scallops are among those species that are highly sensitive to salinity levels.

Participants at the expert workshop considered that there was the possibility that increases in nutrient inputs would increase food levels for scallops but were not sufficiently confident about this to reduce the sensitivity below the level of high.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	H	M	H	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of saucer scallops to changed rainfall patterns and nutrient inputs. Participants at the expert workshop, however, considered adaptive capacity to be low, given the reported loss of the nearshore beds of saucer scallops.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	H	L

CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Saucer scallops live deeper than the intertidal and shallow waters most exposed to the predicted changes in light spectra.

Saucer scallops are not photosynthetic symbionts, the group of benthic invertebrates identified as being most sensitive to predicted spectral changes (Hutchings et al. 2007).

Participants at the expert workshop considered that there may be indirect impacts of changes to light spectra through its potential effect on algae, which forms part of the diet of scallops.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of saucer scallops to changed light spectra.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L

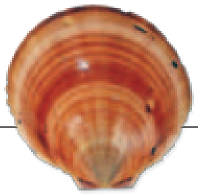
INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Scallops will be exposed to the predicted effects of changes to storms and extreme weather events, particularly those populations living in waters that are closer to the coast.

Saucer scallops are not among the following groups of benthic organisms that have been identified as being the most vulnerable to storm activities, with associated increased river flow and sedimentation: sessile species or egg masses in the intertidal or shallow subtidal zones which are physically torn from the substrate or buried, and infaunal organisms that are physically dislodged by wave action that erodes the habitat (Hutchings et al. 2007).

Nevertheless, some participants at the expert workshop considered that saucer scallops could be exposed to, and would be highly sensitive to, increased storm intensity and flooding. This sensitivity was considered to be from the potential for sediments and pollution to adversely affect populations.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	H	L	H	L



Adaptive capacity and vulnerability: Scallops are locally mobile as adults but no information was found in the literature on the adaptive capacity of saucer scallops to these changes. Participants at the expert workshop considered that individual adult saucer scallops would have a low level of adaptive capacity because of their limited ability to move away from affected areas. Nevertheless, at the population level, the planktonic larval stage does confer a level of mobility that, as for sea surface temperature, would provide a medium level of adaptive capacity.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	H	L

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Saucer scallops will be exposed to the range of predicted changes to ocean circulation and currents over their entire range but it is only the larval stages that would be expected to be directly affected.

Some species of benthic invertebrates may benefit from ocean circulation changes through recruitment, providing such changes increase favourable conditions for larvae. For example, populations of the seashell *Strombus luhuanus* on the Great Barrier Reef showed consistently high recruitment for two years following ENSO events, likely due to ocean circulation changes and upwelling of nutrient-rich waters (Hutchings et al. 2007).

In Western Australia, the strength of the Leeuwin Current has a significant negative influence on the larval life of the scallop *Amusium balloti* in Shark Bay and at the Abrolhos Islands (Pearce and Caputi 1994, cited in Hobday et al. 2008). Changes to ocean currents may have similar effects on the larval life of the species in Queensland waters, though no such relationships have yet been identified. Changes in ocean currents have been identified as a potentially important impact of climate change on commercial scallops (*Pecten fumatus*) in southern Australia (Doubleday 2011).

Participants at the expert workshop considered that saucer scallops would have a substantial exposure and sensitivity to changes to the strength of the East Australian Current given the planktonic larval stage.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	M	M	H	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of saucer scallops to changes in ocean circulation.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	H	L

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Saucer scallops would be exposed to any effects of changes to wind patterns over their entire range. However, the projected changes are minor, so the overall exposure is considered to be medium.

There is no information to suggest that saucer scallops are sensitive to the proposed changes to wind patterns.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	L	L	L	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of saucer scallops to higher peak wind speeds.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L

7. Banana Prawns

Key facts

Species assessed: white banana prawn, an inshore species.

Habitats used: estuarine and inshore waters to a depth of 45 metres, nursery areas are mangrove-lined, muddy estuaries and juveniles are tolerant of a broad range of salinities.

Trawl fishery: target species in southern and central regions of fishery.

Banana prawns	Vulnerability
Higher sea surface temperature	M
Ocean acidification	L
Sea level rise	H
Changed rainfall patterns and nutrient inputs	M
Changed light spectra	L
Increased tropical storm intensity and flooding	L
Altered ocean circulation	L
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. Banana prawns may be subject to a high level of ecological vulnerability from sea level rise, which could result in more variability in the survival of larvae and juveniles, in recruitment of individuals to the fishery and in the subsequent catches in the fishery. This vulnerability arises through indirect effects of sea level rise because banana prawns are an inshore species with a dependence on shallow waters and mangrove habitats. These habitats are vulnerable to climate change and have varying capacity to adapt along the Queensland east coast due to natural and man-made constraints. However, the level of certainty is low because the sensitivity of banana prawns to these habitat changes has not been studied.

2. Banana prawns may be subject to a medium level of ecological vulnerability from higher sea surface temperature and changed rainfall patterns and nutrient inputs, which could result in variable growth and survival of juveniles for this species, or alter the distribution and abundance of banana prawns, and possibly alter the timing of prawn aggregations. This vulnerability arises because banana prawn juveniles inhabit shallow estuarine waters that are likely to experience the largest rise in sea surface temperatures and they are an inshore species whose biology is intimately linked to the timing and amount of rainfall. Both positive and negative effects from higher temperatures and more extremes in rainfall (as projected) are possible for this species and this has been considered in the assessment of sensitivity.

Background

In Australia, banana prawns (*Penaeus merguiensis*) are distributed from Shark Bay and Exmouth Gulf in Western Australia along the Northern Territory, the Gulf of Carpentaria and the Queensland coasts to northern New South Wales; they usually inhabit estuarine and inshore waters to a depth of 45 metres and are typically associated with turbid waters over mud or muddy sand substrates; adults inhabit medium and low energy coastlines but can withstand cyclonic events (Kailola et al. 1993). Adults are trawled in schools in depths between 16 and 25 metres.

Adult females become mature at about six months of age; spawning occurs throughout the shallow coastal zones inhabited by adults; they are batch spawners and can produce between 100,000 and 400,000 eggs which are thought to be demersal; these hatch to a pelagic nauplius stage in approximately 15 hours (Kailola et al. 1993). Over the next 2–3 weeks, the young prawns develop through a protozoea stage, followed by a mysis stage and a post-larval stage that settles out of the water column into a benthic phase; post-larval banana prawns settle in mangrove-lined, muddy estuaries and over the following 2–3 months grow into juveniles; these are tolerant of a broad range of salinities and may travel several kilometres upstream to almost fresh water; when about half the length of adult size they leave the estuary and continue to grow, mature, mate and spawn in open offshore waters (Tanimoto et al. 2006).

Exposure, sensitivity, potential impact and adaptive capacity of banana prawns

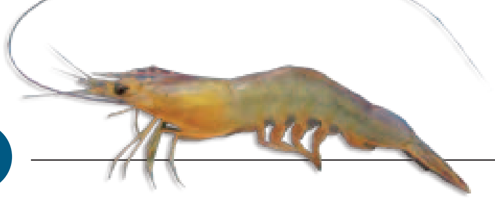
HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Banana prawns will be exposed to the predicted effects of changed sea surface temperatures over their entire range. Immature stages in particular, that inhabit shallow inshore habitats, would be exposed to the larger temperature changes predicted for these habitats.

Experiments on banana prawns suggested an optimum temperature of 28°C taking both survival and growth into account (Staples and Heales 1991). In the wild, growth rates of juvenile banana prawns were positively influenced by sea temperature over the range of 24.4 to 30.9°C but mortality rates also increased with increasing temperatures (Haywood and Staples 1993).

Overall, the sensitivity has been assessed as medium rather than high as some of the predicted effects may be positive for the species. Some participants at the expert workshop, however, considered the sensitivity to be low given that this species lives in a highly variable environment.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	M	M	H	M



Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of banana prawns to higher sea surface temperatures.

Prawns have both mobile adults and planktonic larvae, both of which are features that allow movement of populations into colder and deeper water or into cooler waters of higher latitudes (Hutchings et al. 2007).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M	M

OCEAN ACIDIFICATION/CHEMISTRY

Exposure, sensitivity and potential impact: Banana prawns will be exposed to the effects of ocean acidification over their entire range.

It has been suggested that estuarine fauna (presumably including the juvenile stages of banana prawns) routinely encounter much greater fluctuations in pH and dissolved CO_2 than projected to occur over the next century as a result of climate change (Hobday et al. 2008). Therefore, juvenile banana prawns at least, are likely to be relatively insensitive to changes in ocean chemistry.

Nevertheless it has also been proposed that "crustaceans may be particularly vulnerable to ocean acidification because of their dependence on the availability of calcium and bicarbonate ions for mineralisation of a new exoskeleton after moulting" (Raven et al. 2005, cited in Hobday et al. 2008).

The cause of ocean acidification, the rise in atmospheric CO_2 levels, may itself have an indirect but positive effect on prawn populations. "Growth of mangroves and seagrasses .... may be stimulated by additional CO_2 levels in the atmosphere and ocean respectively .... and these form essential habitat for prawns" (Hobday et al. 2008).

As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

See other text under tiger prawns.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	L	M	M	M

Adaptive capacity and vulnerability: The impact of ocean acidification on calcifying marine invertebrates will depend on species' adaptability and there are few experimental data on this (Hutchings et al. 2007).

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

SEA LEVEL RISE

Exposure, sensitivity and potential impact: Banana prawns will be exposed to the direct effects of sea level rise over their entire range, and part of their life cycle includes shallow waters and mangrove habitats that will experience the greatest effects of sea level rise.

Changes to sea levels are not expected to directly affect banana prawns but they are likely to be sensitive indirectly through changes to the distribution and extent of mangrove and seagrass habitats.

The impacts on prawn populations from these habitat changes are difficult to predict and are likely to vary locally as the areas of mangroves and other habitats on low profile shores are expected to increase their extent in some areas and decrease in others.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	M	L	H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of banana prawns to sea level rise.

Participants at the expert workshop considered banana prawns to have only a medium level of adaptive capacity to sea level rise because of their strong linkages to the habitats most likely to be affected.

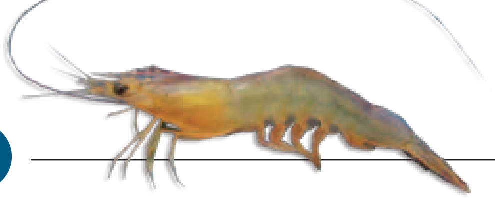
Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	H	L

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Exposure, sensitivity and potential impact: Changes to rainfall levels and to subsequent river flows may impact on banana prawn populations by altering water quality in the estuarine and inshore habitats occupied by juvenile stages. Growth and survival of juvenile stages may also be affected. Any impacts on banana prawn production are likely to vary regionally.

Banana prawn recruitment in some areas of the Gulf of Carpentaria has been shown to be positively related to summer rainfall (Vance et al. 1985, Staples et al. 1995). This relationship has also been identified in banana prawn stocks in Nickol Bay (Kangas et al. 2008), Onslow and the Kimberley. Examination of the trend in summer (December-March) rainfall and banana prawn catch in Nickol Bay since 1966 shows no significant long-term trend.

Catches of banana prawns are highly positively correlated with rainfall in the south-eastern Gulf of Carpentaria (Hobday et al. 2008). The influence of rainfall and river flow (and other environmental factors) on banana prawns on the east coast of Queensland, however, is not well known (Tanimoto et al. 2006). Nevertheless, increased river flows have generally resulted in an immediate increase in otter trawl catch rates, possibly because the flow promotes the downstream movement of prawns to areas fished by the otter trawlers, thus increasing their catchability (Tanimoto et al. 2006). A study of the growth rates of juvenile banana prawns sampled from the Fitzroy, Calliope and Boyne River estuaries on the east coast of



Queensland found freshwater flows significantly increased the growth rates of juvenile banana prawns, leading to a greater biomass of banana prawns in the estuary, prior to their recruitment to coastal and offshore fisheries (Halliday and Robins 2007). The influence of more extremes in rainfall (as projected) on banana prawn populations is uncertain, but may alter the distribution and abundance of banana prawns, and possibly alter the timing of prawn aggregations.

A modelling study of the possible effects of climate change on the commercial catch of school prawns (*Metapenaeus macleayi*), a mostly estuarine species with a response to river flow that is similar to banana prawns, indicated that both the growth and movement of prawns were affected by the rates of river discharge, and that higher rates of river discharge usually generated increased commercial catches, but this outcome was not certain (Ives et al. 2009).

The demonstrated positive effects of rainfall on banana prawns was considered by workshop participants to indicate that they have a low sensitivity to changed rainfall patterns.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	L	H	M	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of banana prawns to changes in rainfall patterns and nutrient inputs. Participants at the expert workshop considered that banana prawns had a medium level of adaptive capacity to more extremes in rainfall patterns and changed nutrient inputs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	M	M

CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Banana prawns will be exposed to the direct effects of changes to light spectra. There may also be indirect impacts if the expected increases in turbidity decrease the area of mangrove habitats and reduce the productivity of inshore areas in which juvenile banana prawns live. Participants at the expert workshop also noted that there may be an indirect and positive effect on banana prawns by a reduction in the level of predation.

Spectral changes associated with increased turbidity, sedimentation, and storm frequency are predicted to have an impact on benthic invertebrates that obtain at least part of their nutrition from photosynthetic symbionts (e.g. giant clams and anemones) (Hutchings et al. 2007). Banana prawns, however, do not fall into this category and changes to light spectra are expected to have minimal direct impact on prawn populations.

Banana prawn populations are unlikely to be sensitive to the expected small potential loss of seagrass in the Great Barrier Reef due to changes to light spectra.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of banana prawns to changes in the light spectra. Participants at the expert workshop considered them to have a medium adaptive capacity to the predicted changes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	L	M

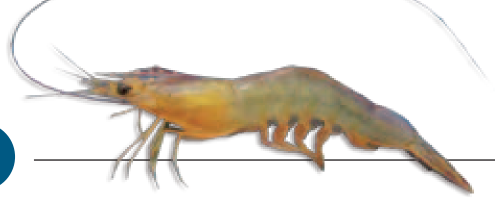
INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Banana prawn populations are exposed to the direct and indirect impacts of such events throughout their range.

Banana prawns may be sensitive to changes in physical disturbance regimes caused by tropical storms. Freshwater flows associated with flood events may increase growth rates of juvenile banana prawns (Halliday and Robins 2007). The effects on banana prawn populations may be both positive (flooding may enhance recruitment) and negative (banana prawns displaced from estuaries may become more vulnerable to trawling).

Predicted positive and negative local effects on seagrass habitats may also impact indirectly on banana prawn populations.

The biology of some marine species such as banana prawns is intimately linked to the timing and amount of rainfall.



Participants at the expert workshop considered that overall banana prawns have a low sensitivity to the predicted changes given that they occupy very variable habitats. They also noted, however, that there would be indirect impacts on banana prawns through possible adverse effects on the inshore habitats that banana prawns occupy.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	L	H	M	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of banana prawns to increased storm intensity and flooding. Participants at the expert workshop, however, considered that they would have a high adaptive capacity to direct impacts of these changes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Participants at the expert workshop considered that banana prawn populations will have a low level of exposure to the range of predicted changes to ocean circulation and currents because they mainly occupy estuarine and inshore habitats.

Some species of benthic invertebrates may benefit from ocean circulation changes through recruitment, providing such changes increase favourable conditions for larvae. For example, populations of the seashell *Strombus luhuanus* on the Great Barrier Reef showed consistently high recruitment for two years following ENSO events, likely due to ocean circulation changes and upwelling of nutrient-rich waters (Hutchings et al. 2007).

There is no information on whether banana prawns are likely to benefit in a similar way.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	H	L	H

Adaptive capacity and vulnerability: No information found on adaptive capacity.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Banana prawn populations would be exposed to any effects of changes to wind patterns over their entire range. Participants at the expert workshop considered them likely to have a high level of exposure given that they occupy inshore habitats.

There is no information to suggest that banana prawns are sensitive to the proposed changes to wind patterns.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found on the adaptive capacity of banana prawns to high peak wind speeds.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

8. Endeavour Prawns

Key facts

Species assessed: blue endeavour prawn and red endeavour prawn assessed as a species-group because they are similar species. Life cycle includes inshore and offshore components.

Habitats used: juveniles occupy a wide range of inshore habitats including seagrass beds, adults found over sandy, sand-mud or muddy seabed areas.

Trawl fishery: target species, particularly in northern and central regions of fishery.

Endeavour prawns	Vulnerability
Higher sea surface temperature	M-inshore L-offshore
Ocean acidification	H
Sea level rise	M-inshore L-offshore
Changed rainfall patterns and nutrient inputs	M-inshore L-offshore
Changed light spectra	L
Increased tropical storm intensity and flooding	M-inshore L-offshore
Altered ocean circulation	L
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. The inshore life history stages of endeavour prawns may be subject to a high level of ecological vulnerability from ocean acidification, which could result in direct effects on this species such as changes to larval development, survival and fecundity, leading to changes in key life history stages and recruitment success for this species. This vulnerability arises because there is a high level of potential impact on the species and only a medium level of capacity to adapt to changes in pH. However, the level of certainty is low due to the high variability of the natural environment and the lack of studies on tolerance of the species to chronic acidification.

2. Inshore juvenile endeavour prawns may be subject to a medium level of ecological vulnerability from higher sea surface temperature, sea level rise, changed rainfall patterns and nutrient inputs, and increased tropical storm intensity and flooding, which could result in direct detrimental effects on the survival of juveniles and indirect impacts on critical inshore habitats. This vulnerability arises because this species has an inshore component of its life cycle, where exposure and impact is thought to be higher. This is mitigated by a high level of adaptive capacity (e.g. historical capacity to adapt to an already highly variable ecosystem/habitat).

Background

Blue endeavour prawns (*Metapenaeus endeavouri*) and red endeavour prawns (*M. ensis*) are distributed from Shark Bay in Western Australia, across northern Australia to New South Wales; juvenile blue endeavour prawns are most commonly associated with seagrass beds in shallow estuaries and juvenile red endeavour prawns occupy a wide range of habitats including seagrass beds, mangrove banks, mud flats and open channels; adult blue endeavour prawns are found from inshore waters to depths of 60 metres and red endeavour prawns may be found to depths of 95 metres in some areas; larger blue endeavour prawns live over sandy or sand-mud substrates; red endeavour prawns prefer muddy substrates; endeavour prawns spawn all year round; juveniles are more common on inshore nursery grounds in October and November suggesting that movement to adult habitats occurs at a small size (Kailola et al. 1993).

Both species tend to be caught with tiger prawns and are principally taken in waters of less than 20 metres and northward from Cairns (Zeller 2004). Participants at the expert workshop considered that the two species of endeavour prawns were sufficiently similar to be assessed together, and that the likely effects were the same as for tiger prawns. Therefore, comments regarding tiger prawns are considered relevant for endeavour prawns.

Exposure, sensitivity, potential impact and adaptive capacity of endeavour prawns

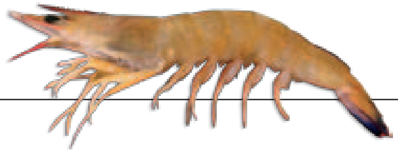
HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Endeavour prawns will be exposed to the predicted effects of changed sea surface temperatures over their entire range. Immature stages in particular, that inhabit shallow inshore habitats, would be exposed to the larger changes predicted for these habitats. Individuals in waters deeper than 20 metres would be impacted less due to the buffering effects of water depth.

Inshore nursery habitats for prawns,, such as seagrasses are also exposed to the effects of elevated sea temperatures (Waycott et al. 2007). The expert workshop considered that the life history stages occupying the more offshore habitats would also have a medium level of exposure due to the level of mixing of waters within the Great Barrier Reef, but that there was only a medium level of certainty to this assessment.

No information specifically for endeavour prawns but general comments for tiger prawns are relevant.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore M-offshore	M	M	M	H-inshore M-offshore	M



Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of endeavour prawns to higher sea surface temperatures.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: Endeavour prawns will be exposed to the effects of ocean acidification over their entire range. No information found specifically for endeavour prawns but general comments under tiger prawns are also relevant.

As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	M	L	H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of endeavour prawns to ocean acidification.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	H	L

SEA LEVEL RISE

Exposure, sensitivity and potential impact: Endeavour prawns will be exposed to the predicted rises in sea level over their entire range, but much of the adult population is not likely to experience a big change in sea level given the depths inhabited and level of projected changes. Population components in inshore habitats would, however, have a high level of exposure.

Changes to sea levels may indirectly affect prawns through predicted changes to the distribution and extent of mangrove and seagrass habitats.

The impacts on prawn populations from these habitat changes are difficult to predict and are likely to vary locally as the areas of mangroves and other habitats on low profile shores are expected to increase their extent in some areas and decrease in others.

Participants at the expert workshop considered that offshore population components of tiger prawns would have a low sensitivity to any sea level rise and that endeavour prawns would share these attributes.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore L-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of endeavour prawns to sea level rise.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Exposure, sensitivity and potential impact: Changes to rainfall levels and to subsequent river flows are most likely to impact on prawn populations by altering water quality in estuarine and inshore habitats occupied by juvenile stages. Any impacts on prawn production are likely to vary regionally.

No information found specifically for endeavour prawns, but comments under tiger prawns are relevant.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore M-offshore	H	M-inshore M-offshore	M	H-inshore M-offshore	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of endeavour prawns to changed rainfall patterns and nutrient inputs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Endeavour prawns will be exposed to the direct effects of changes to light spectra over their entire range. There may also be indirect impacts if the expected increases in turbidity decrease the area of seagrass habitats and reduce the productivity of inshore areas in which juvenile prawns live.

Predicted changes to light spectra are expected to have minimal direct impact on prawn populations.

Endeavour prawn populations are unlikely to be sensitive to the expected small potential loss of seagrass in the Great Barrier Reef due to changes to light spectra.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of endeavour prawns to changed light spectra but their adaptive capacity is probably not important given low potential impact.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Endeavour prawn populations are exposed to the direct and indirect impacts of such events throughout their range.

Endeavour prawns may be sensitive to changes in physical disturbance regimes caused by tropical storms, but effects on their populations are uncertain. In Western Australia, endeavour prawn catches reached an all-time high after a period of intense cyclone activity[3].

Predicted positive and negative local effects on seagrass habitats may also impact indirectly on endeavour prawn populations.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-inshore M-offshore	H	H-inshore L-offshore	M	H-inshore L-offshore	M

Adaptive capacity and vulnerability: No information was found on adaptive capacity.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-inshore L-offshore	M

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[3] (WA Fisheries website http://www.fish.wa.gov.au/docs/cf/Prawns/index.php?0206 . Accessed 16 May 2011)

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Endeavour prawn populations will be exposed to the range of predicted changes to ocean circulation and currents over their entire range.

Some species of benthic invertebrates may benefit from ocean circulation changes through recruitment, providing such changes increase favourable conditions for larvae. For example, populations of the seashell *Strombus luhuanus* on the Great Barrier Reef showed consistently high recruitment for two years following ENSO events, likely due to ocean circulation changes and upwelling of nutrient-rich waters (Hutchings et al. 2007).

There is no information on whether endeavour prawns are likely to benefit in a similar way.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of endeavour prawns to altered ocean circulation.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Endeavour prawn populations would be exposed to any effects of changes to wind patterns over their entire range. However, the projected changes are minor, so the overall exposure is considered to be medium.

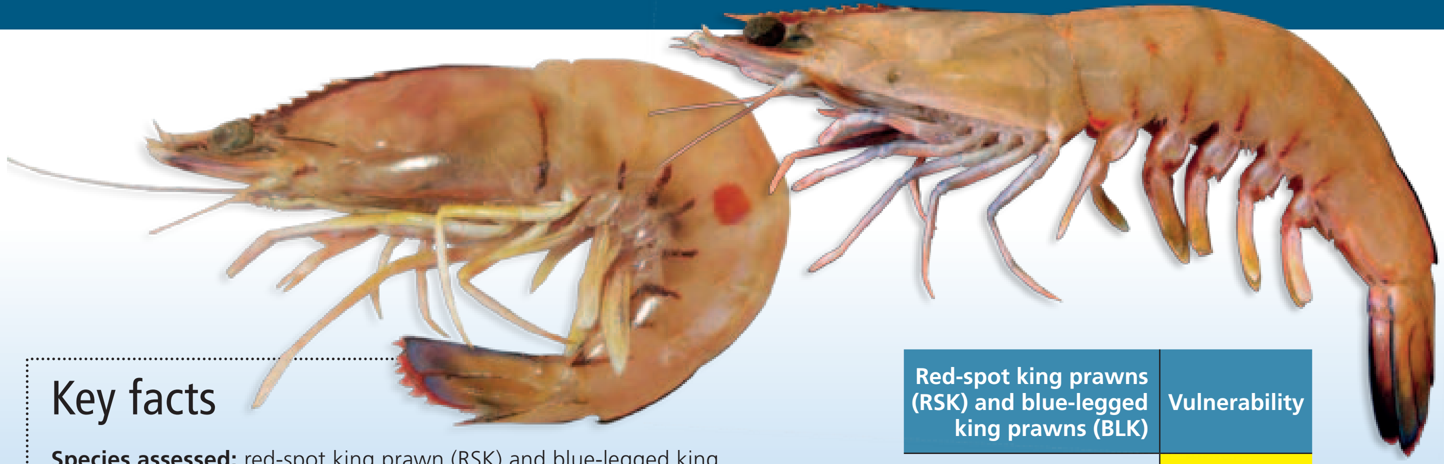
There is no information to suggest that endeavour prawns are sensitive to the proposed changes to wind patterns.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of endeavour prawns to higher peak wind speeds.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

9. Red-spot King Prawns and Blue-legged King Prawns



Key facts

Species assessed: red-spot king prawn (RSK) and blue-legged king prawn (BLK), which have different life histories and distributions.

Habitats used: nursery areas for red-spot king prawns include reef tops, and adults occur in inter-reef channels and adjacent waters. Blue-legged king prawns use inshore nursery areas including seagrass beds, and adults are found further offshore.

Trawl fishery: target species, with red-spot king prawns most important species in central region of fishery.

Red-spot king prawns (RSK) and blue-legged king prawns (BLK)	Vulnerability
Higher sea surface temperature	M-RSK L-BLK
Ocean acidification	H
Sea level rise	M-RSK L-BLK
Changed rainfall patterns and nutrient inputs	L
Changed light spectra	L
Increased tropical storm intensity and flooding	H-RSK M-BLK
Altered ocean circulation	L
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. Red-spot king prawns may be subject to a high level of ecological vulnerability from increased tropical storm intensity and flooding, which could result in a critical loss of juvenile reef-top habitats for prolonged periods through storm damage for this species. This vulnerability arises because the juvenile phase of red-spot king prawns is particularly dependent on reef-top habitats. The main fishery is concentrated in the Townsville region, which is expected to be impacted by this increased tropical storm intensity scenario.

2. Blue-legged king prawns may be subject to a medium level of ecological vulnerability from increased tropical storm intensity and flooding, which could result in lower survival of juveniles and indirect impacts on critical inshore nursery habitats through storm damage for this species. This vulnerability arises because the juvenile phase of blue-legged king prawns is dependent on inshore and estuarine habitats.

3. Red-spot and blue-legged king prawns may be subject to a high level of ecological vulnerability from ocean acidification, and red-spot king prawns may be subject to a medium level of ecological vulnerability from higher sea surface temperatures and sea level rise, which could result in population declines. This vulnerability arises because of potential direct impacts on these king prawns and indirect effects of the predicted changes in these climate variables on the availability of their preferred habitats. Red-spot king prawns are assessed as being vulnerable to additional variables because they have stronger links to coral reef habitats, which are particularly vulnerable to climate change. The level of certainty relating to vulnerability of these king prawns to ocean acidification is low because of a lack of ocean acidification experiments for this species.

Background

Red-spot king prawns (*Melicertus longistylus*) are common from Shark Bay in Western Australia along northern Australia to near Yepoon in Queensland; in Queensland waters they are rarely found more than 30 kilometres from coral reefs; through much of Queensland juveniles inhabit coral reef lagoons in depths of 1-3 metres, yet in north-eastern Queensland they live in estuaries and on reef tops (Kailola et al. 1993). Reef tops, including those with little or no vegetation on the seabed, are important nursery areas for red-spot king prawns (Derbyshire et al. 1995). Adults inhabit inter-reef channels and adjacent waters in depths of 18 to 60 metres; spawning occurs between May and October; they do not require estuarine or coastal environments to complete their life cycle; adults are sedentary (Kailola et al. 1993).

Blue-legged king prawns (*M. latisulcatus*) are widely distributed throughout the Indo-Pacific and in Australia are found on the west, north and east coasts from Cape Leeuwin (in Western Australia) to Ballina (in NSW) as well as in the gulfs and adjacent waters of South Australia. Spawning times vary regionally and may occur throughout the year. Spawning occurs offshore and larvae remain in offshore waters for about two weeks before moving into high-salinity, sheltered, inshore and estuarine waters. Juvenile prawns remain in these shallow nursery areas for 3 to 12 months and then move offshore (Kailola et al. 1993).

In the ECOTF, red-spot and blue-legged king prawns are taken in waters of the Great Barrier Reef lagoon, northward from Mackay in water depths of 20-50 metres (Zeller 2004).

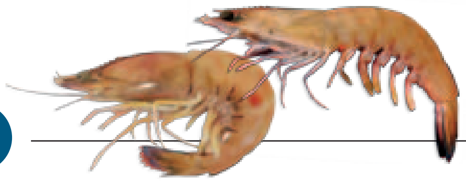
Participants at the expert workshop considered that the differences in the life histories of the two species might lead to differences in their vulnerabilities to changes to some climate change variables. These species have therefore been assessed separately where necessary.

Exposure, sensitivity, potential impact and adaptive capacity of red-spot king prawns and blue-legged king prawns

HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: These king prawns will be exposed to the predicted effects of changed sea surface temperatures over their entire range. Immature stages of blue-legged king prawns in particular, that inhabit shallow inshore habitats, would be exposed to the larger changes predicted for these habitats. Similarly, juvenile red-spot king prawns generally inhabit shallow waters and would therefore be exposed to the larger changes predicted for these habitats.

Participants at the expert workshop considered that red-spot king prawns would be more exposed to increases in sea surface temperature than blue-legged king prawns because their juveniles occupy habitats on the tops of coral reefs.



The length of the larval stage of blue-legged king prawns depends on sea temperature, with faster development in warmer water (Dixon 2011). Sea temperature, among other factors, influences the distribution and abundance of larvae (Carrick 2003, cited in Dixon 2011).

Elevated temperature may increase the period for growth and reproduction of western king prawns in South Australia (Pecl et al. 2011) (M). But influxes of cold water may adversely affect reproductive capacity and larval development (Pecl et al. 2011).

No information was found on sea surface temperature effects specifically for red-spot king prawns but general comments for tiger prawns may also be relevant. Also the wide latitudinal range of blue-legged king prawns in particular indicates that the species is able to survive in a broad range of temperatures (and see Figure 6). General comments for tiger prawns may also be relevant.

Participants at the expert workshop considered that both species had a medium rather than a high level of sensitivity – red-spot king prawns because of the variable environments they inhabited and blue-legged king prawns because of the wide thermal tolerance.

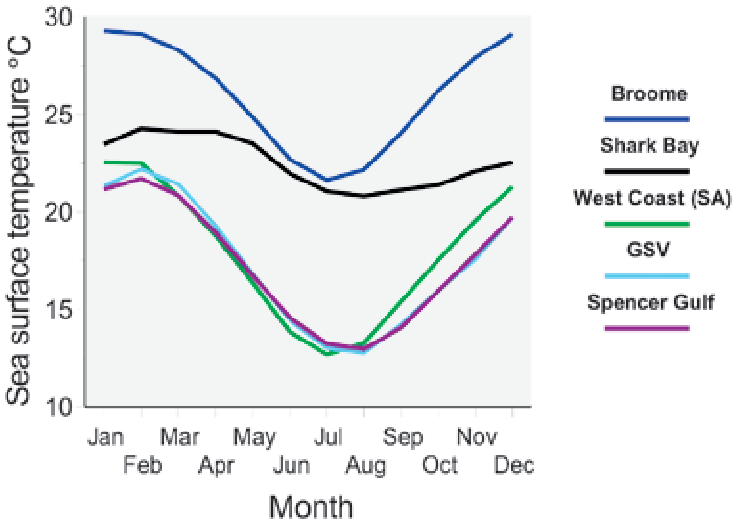


Figure 6. Comparison of mean monthly sea surface temperature (SST, °C) for the Australian prawn fisheries that target blue-legged king prawns (from Dixon 2011). Key: GSV = Gulf St Vincent.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H-RSK M-BLK	M	M	M	H-RSK M-BLK	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of these species but the wide latitudinal range of blue-legged king prawns in particular would suggest that the species has an ability to adapt to a broad range of sea temperatures.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M-RSK L-BLK	M

OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: These king prawns will be exposed to the effects of ocean acidification over their entire range. General comments under tiger prawns are also likely to be relevant.

These king prawns are reef associated for at least part of their life cycles and may therefore be more sensitive to the indirect effects of ocean acidification on their reef habitats. No other information found specifically for these king prawns but general comments under tiger prawns are also likely to be relevant.

As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	M	L	H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of these king prawns.

Participants at the expert workshop considered that these king prawns had only a medium level of adaptive capacity to ocean acidification.

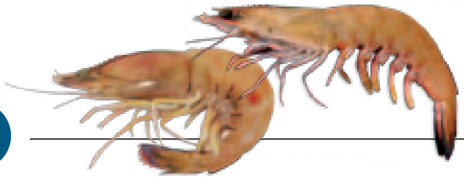
Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	H	L

SEA LEVEL RISE

Exposure, sensitivity and potential impact: These king prawns will be exposed to the predicted rises in sea level over their entire range, and part of their life cycle includes shallow waters that will experience the greatest effects of sea level rise.

Changes to sea levels may be less likely to affect these king prawns than other prawn species because their juveniles are not associated with the mangrove and seagrass habitats that may be affected. Nevertheless, seagrasses may still be an important potential detrital food source (for blue-legged king prawns at least) even though the adults prefer sandy substrates (Dixon 2011).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	M	M	M	M



Adaptive capacity and vulnerability: No information found on adaptive capacity specifically for these king prawns.

Participants at the expert workshop considered that red-spot king prawn was more of a habitat specialist than blue-legged king prawn and that its adaptive capacity was at a medium rather than a high level.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M-RSK H-BLK	M	M-RSK L-BLK	M

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Exposure, sensitivity and potential impact: Except for the juvenile stages of blue-legged king prawns in some areas, these king prawns will not be exposed to the predicted changes in rainfall and river flow.

Changes to rainfall levels and to subsequent river flows are less likely to impact on populations of red-spot king prawns in particular than other prawn species because their juveniles are not associated with the inshore habitats affected by such flows. Juveniles of blue-legged king prawns do inhabit inshore areas and their development may be affected by the predicted changes to rainfall and river flow. In Western Australia, movement of juvenile blue-legged king prawns out of nursery areas may be intensified by the flushing action of winter rains (Kailola et al. 1993). Salinity, among other factors, influences the distribution and abundance of larvae (Carrick 2003, cited in Dixon 2011) and rainfall may therefore also indirectly influence this. Juvenile blue-legged king prawns, however, are more efficient osmoregulators than adults, tolerating greater variation in salinity (Dixon 2011).

General comments under tiger prawns may also be relevant.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	M	L	M

Adaptive capacity and vulnerability: No information found on adaptive capacity specifically for these king prawns but the broad geographic range of blue-legged king prawns in particular suggests an ability to adapt to a variety of conditions.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: These king prawns will be exposed to the direct effects of changes to light spectra over their entire range. However, as this species only makes limited use of intertidal and shallow water habitats, it will only experience limited effects of changes to light spectra.

Predicted changes to light spectra are expected to have minimal direct impact on prawn populations.

Populations of these king prawns are unlikely to be sensitive to the expected small potential loss of seagrass in the Great Barrier Reef due to changes to light spectra.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	M	L	M

Adaptive capacity and vulnerability: No information found on adaptive capacity but probably not important given low potential impact.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Populations of these king prawns will be exposed to the direct and indirect impacts of such events throughout their range.

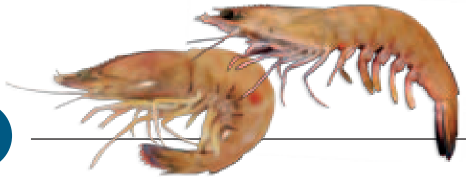
These king prawns may be sensitive to changes in physical disturbance regimes caused by tropical storms, through effects on the survival of juveniles and indirect impacts on critical inshore or reef habitats.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	H	M	H	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of these species to this variable.

Participants at the expert workshop considered that red-spot king prawn was more of a habitat specialist than blue-legged king prawn and that its adaptive capacity was at a medium rather than a high level.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M-RSK H-BLK	M	H-RSK M-BLK	M



ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Populations of these king prawns will be exposed to the range of predicted changes to ocean circulation and currents over their entire range.

Larvae of blue-legged king prawns in South Australia are generally dispersed by wind-driven and tidal currents (Carrick 2003, cited in Dixon 2011). In South Australia, oceanographic patterns of water movement are critical to larval advection and adult movement of blue-legged king prawns (Dixon 2011). Changes to such patterns may have a positive or negative effect on these processes. There is some evidence to suggest that recruitment to part of the South Australian fishery is negatively affected by upwelling events associated with El Niño years (Carrick 2007, cited in Dixon 2011) possibly through the influx of cold water on one or more processes important to successful recruitment. Participants at the expert workshop, however, considered that these findings were not relevant to the species in Queensland. In particular, the levels of exposure and sensitivity were less and warranted scores of low. Lower levels of information also reduced the certainty for exposure to a medium level.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	M	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of these prawns to altered ocean circulation.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	M	L	M

Queensland may experience more intense tropical storms and higher peak wind speeds, which could increase the effects of wind-driven waves and storm seas on marine habitats and species.

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Populations of these king prawns would be exposed to any effects of changes to wind patterns over their entire range. However, the projected changes are minor, so the overall exposure is considered to be medium.

Larvae of blue-legged king prawns in South Australia are generally dispersed by wind-driven and tidal currents (Carrick 2003, cited in Dixon 2011).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	M	M	M	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of these prawns to higher wind speeds.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

10. Moreton Bay Bugs

Key facts

Species assessed: two species of Moreton Bay bugs assessed as a species-group. These bugs have an extended pelagic larval phase and are highly mobile as adults.

Habitats used: mud bugs are found in turbid inshore waters from 10 to 30 metres deep, whereas reef bugs are found over hard coarse sand between reefs at depths of 30 to 60 metres.

Trawl fishery: target species caught in all regions of the fishery.

Moreton Bay bugs	Vulnerability
Higher sea surface temperature	L
Ocean acidification	H
Sea level rise	L
Changed rainfall patterns and nutrient inputs	L
Changed light spectra	L
Increased tropical storm intensity and flooding	M
Altered ocean circulation	M
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. Moreton Bay bugs may be subject to a high level of ecological vulnerability from ocean acidification, which could result in direct effects on larval health and exoskeleton development and in indirect effects on the abundance of a preferred food (scallops). This vulnerability arises because of the potential impairment of their ability to form a strong exoskeleton band because of Moreton Bay bugs' dietary preferences for scallops and other bivalves which may also have a reduced capacity to produce calcareous shells. However, the level of certainty is low because of a lack of ocean acidification experiments for this species.
2. Moreton Bay bugs may be subject to a medium level of ecological vulnerability from increased tropical storm intensity and flooding and altered ocean circulation, which could result in altered distribution of larvae and increase or decrease the number of bugs that settle to preferred seabed habitats. This vulnerability arises because they have an extended pelagic larval stage, and are therefore likely to be sensitive to changes in physical disturbance regimes caused by tropical storms and to ocean circulation patterns. The broad geographic range of Moreton Bay bugs is likely to mitigate this vulnerability to some degree.

Background

Moreton Bay bugs caught in the ECOTF include two species: the reef bug (*Thenus australiensis*) and the mud bug (*T. parindicus*). Mud bugs are found in turbid inshore waters from 10 to 30 metres deep in eastern Queensland (Kailola et al. 1993). Reef bugs are bay lobsters and are generally found in coarse sand environments between reefs at depths of 30 to 60 metres (DEEDI 2010). The majority of the Moreton Bay bug catch retained in the ECOTF consists of the reef bug (DEEDI 2010).

Reef bugs spawn throughout spring and into summer; the female carries fertilised eggs beneath her abdomen for 10 weeks before the planktonic larvae hatch; the larvae are carried by ocean currents for three months before settling to the sea floor; growth is rapid in the early life stages, reaching 45–50 mm carapace length in 9–12 months; sexual maturity occurs at 1–2 years of age and 58 mm carapace length (DEEDI 2010). Moreton Bay bugs can live for over seven years and females reach a carapace length of 90 mm, whereas males do not grow as large reaching a maximum carapace length of 78 mm (DEEDI 2010).

Moreton Bay bugs are highly mobile and show a preference for bivalve molluscs in their diet (Kailola et al. 1993).

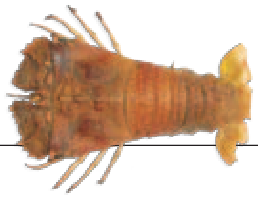
Exposure, sensitivity, potential impact and adaptive capacity of Moreton Bay bugs

HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Moreton Bay bugs will be exposed to the predicted effects of changed sea surface temperatures over their entire range. Waters deeper than 20 metres would be impacted less due to the buffering effects of water depth (Waycott et al. 2007).

No information found specifically for Moreton Bay bugs but, like other crustaceans, the rate of larval development is likely to be dependent on temperature. This may influence their mortality during the larval phase and the timing of settlement. Participants at the expert workshop considered that Moreton Bay bugs had a low level of sensitivity to higher sea surface temperatures because they were regarded as a very hardy animal that already experienced a large range of sea temperatures over their broad geographic range.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	L	M	M	M



Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Moreton Bay bugs. Participants at the expert workshop considered them to have a high level of adaptive capacity because they were mobile and inhabited multiple habitats over broad geographic and depth ranges.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: Moreton Bay bugs will be exposed to the effects of ocean acidification over their entire range. No information found specifically for Moreton Bay bugs but general comments under tiger prawns may be relevant.

There may be indirect impacts on the growth of Moreton Bay bugs through their dietary preference for bivalve molluscs, whose populations may be potentially reduced by ocean acidification.

As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	M	L	H	L

Adaptive capacity and vulnerability: No information found on adaptive capacity specifically for Moreton Bay bugs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	H	L

SEA LEVEL RISE

Exposure, sensitivity and potential impact: Moreton Bay bugs will be exposed to the predicted rises in sea level over their entire range.

Moreton Bay bugs do not, however, inhabit the very shallow inshore habitats that are predicted to be most directly affected by sea level changes.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity specifically for Moreton Bay bugs. Participants at the expert workshop considered Moreton Bay bugs to have a high adaptive capacity to sea level rise because they were mobile and inhabited multiple habitats over broad geographic and depth ranges.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

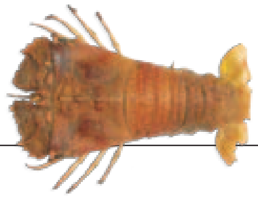
Exposure, sensitivity and potential impact: Adult mud bugs live in a range of habitats including the turbid inshore coastal waters that are likely to be impacted by changes to rainfall and river flow.

No information was found in the literature on the sensitivity of Moreton Bay bugs to changed rainfall patterns and nutrient inputs.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	L	M	M	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Moreton Bay bugs to changed rainfall patterns and nutrient inputs. Participants at the expert workshop, however, considered them to have a high adaptive capacity for the reasons outlined above for other variables: they were mobile and inhabited multiple habitats over broad geographic and depth ranges.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	L	M



CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Moreton Bay bugs will be exposed to the predicted effects of changes in light spectra over their entire range, however these bugs will only experience limited effects of changes in light spectra.

Moreton Bay bugs are not likely to be sensitive to the direct effects predicted from changes in light spectra or to the indirect effects through impacts on seagrasses.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Moreton Bay bugs but this is probably not important given the low potential impact.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L

INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Moreton Bay bug populations are exposed to the direct and indirect impacts of such events throughout their range.

Moreton Bay bugs may be sensitive to changes in physical disturbance regimes caused by tropical storms, particularly in the pelagic larval phase. Participants at the expert workshop did not think the Moreton Bay bugs would be very sensitive to the impacts of increased flooding.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	M	M	M	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Moreton Bay bugs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	M	L

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Moreton Bay bugs will be exposed to any effects of changes to ocean circulation patterns particularly during the extended larval phase.

Changes to ocean circulation patterns may potentially alter (either positively or negatively) the distribution of larvae and the numbers that settle to preferred benthic habitats.

Participants at the expert workshop agreed that Moreton Bay bugs had only a medium level of sensitivity to altered ocean circulation given the broad geographic range.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	M	H	H	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Moreton Bay bugs. Participants at the expert workshop considered that the broad geographic range of Moreton Bay bugs also conferred a high adaptive capacity to altered ocean circulation.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	M	M	M

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Moreton Bay bugs will be exposed to any effects of changes to wind patterns over their entire range but especially during the extended larval phase.

Moreton Bay bugs may be sensitive to these changes indirectly through the effects of wind on ocean currents (see above).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	L	L	M	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Moreton Bay bugs.

Information from participants at the expert workshop on the adaptive capacity of Moreton Bay bugs to other variables suggests that they would also have a high adaptive capacity to higher peak wind speeds.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	L	L	L

11. Balmain Bugs

Balmain bugs	Vulnerability
Higher sea surface temperature	M-Smooth bug L-other species
Ocean acidification	H
Sea level rise	L
Changed rainfall patterns and nutrient inputs	L
Changed light spectra	L
Increased tropical storm intensity and flooding	L
Altered ocean circulation	H
Higher peak wind speeds	L

Key facts

Species assessed: three species of Balmain bugs assessed separately where necessary.

Habitats used: soft seabed substrates such as sand, mud, and clay, in depths of about 50 to 260 metres depending on the species.

Trawl fishery: by-product species caught in southern region of the fishery.

VULNERABILITY TO CLIMATE CHANGE

1. Balmain bugs may be subject to a high level of ecological vulnerability from ocean acidification, which could result in detrimental effects on larval survival, fertility and exoskeleton formation for this species. This vulnerability arises because biological/physiological processes may be disrupted by more acidic sea water. However, the level of certainty is low because of a lack of ocean acidification experiments for this species.
2. Balmain bugs may be subject to a high level of ecological vulnerability from altered ocean circulation, which could result in changed dispersion of larvae and possibly also in changed adult migration for this species. This vulnerability arises because Balmain bugs have an extended larval stage that increases its exposure to changed circulation patterns. However, the level of certainty is low because of information gaps.
3. Smooth bugs (a type of Balmain bug) may be subject to a medium level of ecological vulnerability from higher sea surface temperature, which could result in unknown effects (both positive and/or negative) including a southwards shift in its distribution, increased growth rate, or increased biomass for this species. This vulnerability arises because growth and distribution are potentially affected and these effects are not mitigated by low sensitivity or high adaptive capacity. However, the level of certainty is low because of information gaps.

Background

There are three species of Balmain bugs caught in the ECOTF: the smooth bug (*Ibacus chacei*), the deepwater bug (*Ibacus altricrenatus*) and the shovel-nosed bug (*Ibacus brucei*). Balmain bugs typically inhabit soft seabed substrates such as sand, mud, and clay, which allow the lobsters to bury. Smooth bugs have been recorded in depths of 58–238 metres, deepwater bugs in depths of 118–258 metres and shovel-nosed bugs in depths of 117–230 metres (Haddy et al. 2005). Balmain bugs (unlike other scyllarid lobsters) appear to exploit local currents and biotic systems to restrict larval dispersal and maintain their ecological niche (Booth et al. 2005). Smooth bugs migrate to spawn, with larvae being distributed southwards via the East Australian Current (Stewart and Kennelly 1998).

Seasonal reproductive data indicates that shovel-nosed bugs and smooth bugs have an annual reproductive cycle with monthly length-frequency distributions showing smooth bugs display multi-modality. Smooth bugs have a prolonged recruitment period with recruits moulting 3–4 years post-recruitment. Female smooth bugs reach sexual maturity at 1.7–2 years with individuals attaining their maximum length within 5–7 years (Haddy et al. 2005).

Records held by Fisheries Queensland indicate that the vast majority of Balmain bugs landed in the ECOTF are smooth bugs (approximately 80 per cent). At present, there is insufficient biological information to classify the sustainability status of Balmain bugs as other than ´uncertain´ (DEEDI 2010).

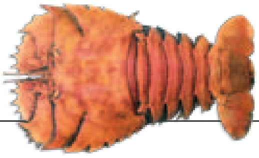
Exposure, sensitivity, potential impact and adaptive capacity of Balmain bugs

HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Balmain bugs will be exposed to the predicted effects of changed sea surface temperatures over their entire range. Changes to SST are predicted to be greater, however, than those to sea temperatures at greater depths (Waycott et al. 2007, Hobday et al. 2008) and hence populations occupying deeper habitats will be exposed to smaller changes in sea temperature.

Participants at the expert workshop considered that the level of exposure will vary among the three species of Balmain bugs and will be greatest for smooth bugs, which are found in shallower waters than the other two species. The depths at which the other species are found suggests that they would have a low exposure to higher sea surface temperatures.

Participants at the expert workshop considered that the level of sensitivity will be medium, but there was a low certainty associated with this.



No information was found specifically for Balmain bugs but, like other crustaceans, the rate of larval development is likely to be dependent on temperature. This may influence their mortality during the larval phase and the timing of settlement.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M–Smooth bugs L–Other species	M	M	L	M–Smooth bugs L–Other species	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Balmain bugs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	M–Smooth bugs L–Other species	L

OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: Balmain bugs will be exposed to the effects of ocean acidification over their entire range. General comments under tiger prawns may also be relevant.

The decrease in pH of sea water will be greatest in shallow water and so populations of some species living at greater depth may be less affected by ocean acidification (Hutchings et al. 2007). However, as explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

No information found specifically on sensitivity for Balmain bugs but general comments under tiger prawns may be relevant.

No information was found about the food of Balmain bugs but if they prey extensively on molluscs, as do Moreton Bay bugs, there may be indirect impacts on their growth if populations of molluscs are reduced by ocean acidification.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	M	L	H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity specifically for Balmain bugs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	H	L

SEA LEVEL RISE

Exposure, sensitivity and potential impact: Balmain bugs will be exposed to the predicted rises in sea level over their entire range.

Balmain bugs do not inhabit those shallow inshore habitats that are predicted to be most directly affected by sea level changes and participants at the expert workshop therefore considered them to have a low level of exposure to sea level rise.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity specifically for Balmain bugs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

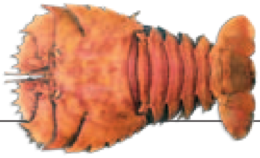
Exposure, sensitivity and potential impact: Adult Balmain bugs do not live in the turbid inshore coastal waters that are likely to be impacted by changes to rainfall and river flow.

No information was found in the literature for Balmain bugs but participants at the expert workshop considered that their more offshore distribution meant that they had only a low level of exposure to changed rainfall patterns and nutrient inputs.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Balmain bugs. Participants at the expert workshop considered that Balmain bugs would have a low adaptive capacity to changed rainfall patterns and nutrient inputs because they would not normally be exposed to such inputs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L



CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Balmain bugs will be exposed to the predicted effects of changes in light spectra over their entire range. However, as these species only make limited use of shallow water habitats, they will only experience limited effects of changes to light spectra. Participants at the expert workshop noted that the planktonic larval stages will have a higher exposure to changed light spectra than the bottom-dwelling adults.

Balmain bugs are not likely to be sensitive to the direct effects predicted from changes in light spectra or to the indirect effects through impacts on seagrasses.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M-larvae L-adult	M	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Balmain bugs but probably not important given low potential impact. Participants at the expert workshop, however, considered that Balmain bugs would have a low adaptive capacity to changed light spectra because they would not normally be exposed to changes in this variable.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L

INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Balmain bug populations are exposed to the direct and indirect impacts of such events throughout their range.

Balmain bugs may be sensitive to changes in physical disturbance regimes caused by tropical storms, particularly in the pelagic larval phase. Participants at the expert workshop, however, considered that Balmain bugs would have a low sensitivity to increased tropical storm intensity and flooding because of the depths at which they lived.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	M	L	M	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Balmain bugs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Balmain bugs will be exposed to any effects of changes to ocean circulation patterns particularly during the larval phase.

Changes to ocean circulation patterns may potentially alter (either positively or negatively) the distribution of larvae and the numbers that settle to preferred benthic habitats.

Under most climate scenarios, the East Australian Current moves south and this may change current recruitment patterns for smooth bugs whose larvae are believed to be distributed by the East Australian Current.

The northward pre-spawning movement of adults may also be affected by any increase in the strength of the East Australian Current.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	M	H	H	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity specifically for Balmain bugs. Participants at the expert workshop considered that Balmain bugs have low adaptive capacity to changed ocean circulation because the planktonic larval stages depend on being passively entrained by currents in areas that provide access to suitable habitats when ready to settle.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	H	L

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Balmain bugs will be exposed to any effects of changes to wind patterns over their entire range but especially during the extended larval phase. However, participants at the expert workshop considered that there was only a medium level of certainty to the assessed level of exposure.

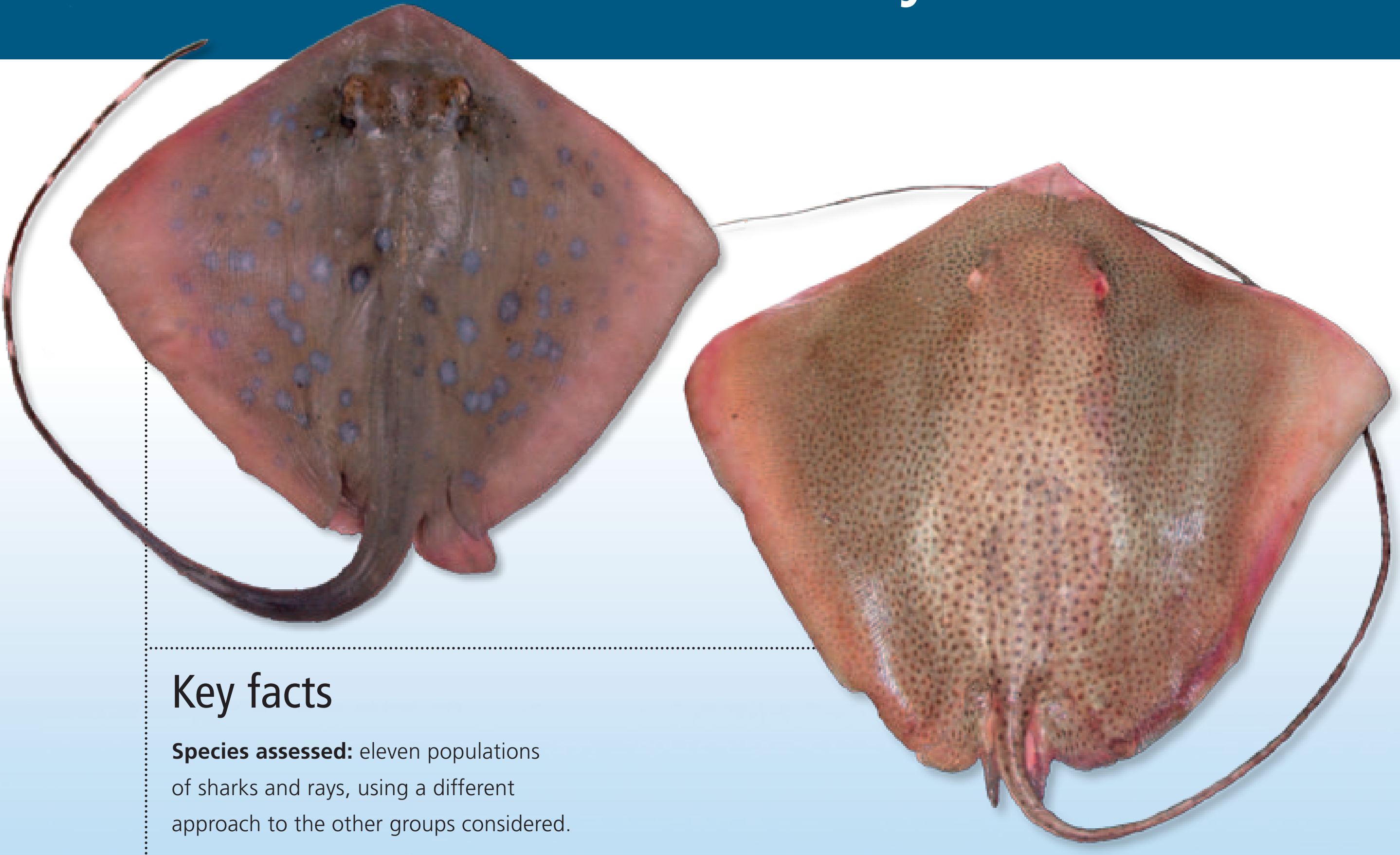
Balmain bugs may be sensitive to these changes indirectly through the effects of wind on ocean currents (see above).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	M	L	L	L	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Balmain bugs.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L

12. Sharks and Rays



Key facts

Species assessed: eleven populations of sharks and rays, using a different approach to the other groups considered.

Habitats used: these particular species are generally associated with trawl grounds for the fishery.

Trawl fishery: taken incidentally as by-catch and potentially at risk from otter trawling in the Great Barrier Reef.

	Eastern shovelnose ray	**Coffin ray**	**Blackspotted whipray**	**Bluespotted maskray**	**Speckled maskray**	**Patchwork stingaree** Bathyal (below about 200 m)	**Patchwork stingaree** Shelf	**Pale tropical skate**	**Argus skate** Bathyal (below about 200 m)	**Argus skate** Shelf	**Australian butterfly ray**
Vulnerability	L	L	L	L	L	L	M	L	L	L	M

VULNERABILITY TO CLIMATE CHANGE

1. Two populations of rays which are caught as by-catch by the otter trawl fishery may be subject to a medium level of ecological vulnerability from the overall effects of climate change, which could result in declines for these populations. This vulnerability arises because of a combination of direct and indirect effects of climate change and species attributes. The two populations are the shelf population of the patchwork stingaree and the Australian butterfly ray (which is found in coastal/inshore areas).

Background

Since 2001, no sharks or shark products (includes all species of chondrichthyans) have been permitted to be retained from trawl catches in the East Coast Trawl Fishery in recognition of conservation concerns for sharks and rays. However, at least 94 species of sharks, rays and chimaeras (chondrichthyans) occur in the area of the ECOTF (Kyne et al. 2007), and about half of these have been recorded as by-catch in the fishery on occasions.

This section only considers the species of sharks and rays (chondrichthyans) identified as being at high risk in the ecological risk assessment undertaken in 2010 for the East Coast Otter Trawl Fishery in the Great Barrier Reef Marine Park (Pears et al. 2012): eastern shovelnose ray *Aptychotrema rostrata*, coffin ray *Hypnos monopterygius*, blackspotted whipray *Himantura astra,* bluespotted maskray *Neotrygon kuhlii,* speckled maskray *Neotrygon picta,* common stingaree *Trygonoptera testacea,* patchwork stingaree *Urolophus flavomosaicus,* pale tropical skate *Dipturus apricus,* Argus skate *Dipturus polyommata,* endeavour skate *Dipturus endeavouri,* and Australian butterfly ray *Gymnura australis*.

Sharks and rays identified as being at potential risk from the ECOTF tend to inhabit environments that correspond with trawl grounds. In addition, the diet of a number of these species consists of crustaceans (including prawns) inhabiting soft sediment environments preferred for trawl fishing [e.g. the blackspotted whipray, (Jacobsen and Bennett 2011)]. The recent ecological risk assessment found current turtle excluder and by-catch reduction devices were not effective for most of these species, particularly for smaller individuals and species with smaller maximum disc widths.

While initially included, the endeavour skate and the common stingaree were removed from this assessment due to a lack of information. Assessments for the patchwork stingaree and the Argus skate were also subdivided into a bathyal population (i.e. below about 200 metres, essentially the continental slope) and shelf population to account for intraspecific differences in their geographical distributions. This means that, in total, eleven populations were assessed covering nine of the above species.

Assessment of climate change vulnerability for sharks and rays

Chin et al. (2010) provided an assessment of the vulnerability of sharks and rays to the effects of climate change which includes most of the species identified as being at high risk from the fishery in the Great Barrier Reef (endeavour skate *Dipturus endeavouri* and the common stingaree *Trygonoptera testacea* were not considered). Given this, it was determined that their assessment would be the basis for the assessment here, and therefore the results reported here are those of Chin et al. (2010) for the relevant populations.

The vulnerability assessment for sharks and rays uses exposure, sensitivity, and adaptability as the framework for assessing vulnerability (similar to the other assessments in this report), but has adopted Chin and co-workers' interpretation of adaptability, which is different to that used for other groups in this report. For sharks and rays, adaptive capacity attributes included physical/chemical tolerance, which was considered to be an attribute of sensitivity in other groups. The assignment of attributes is also somewhat arbitrary; trophic specificity was assessed as an attribute of adaptive capacity but habitat specificity was an attribute of sensitivity.

The difference in approach for sharks and rays is an acknowledgement that chondrichthyans as a group have relatively slow rates of evolutionary change: "Given the slow generation times and rate of genetic change of sharks and rays and the scope of this assessment (100 years), adaptation through genetic evolution is not considered here as an attribute of adaptive capacity" (Chin et al. 2010). The approach used by Chin and co-workers for sharks and rays is also used here but the difference in approach should be noted.

Table 7 shows the assigned vulnerability to each of the climate change attributes and the overall vulnerability for each population of sharks and rays considered in this report. The shelf population of the patchwork stingaree and the Australian butterfly ray (which occurs in coastal/inshore areas) had a medium overall vulnerability to climate change. The other nine populations assessed had a low overall vulnerability to climate change.

Chin et al. (2010) identified that, of the ecological groups of sharks and rays found within the Great Barrier Reef, freshwater/estuarine and reef-associated sharks and rays are most vulnerable to climate change, and that vulnerability is driven by case-specific interactions of multiple factors and species attributes.

Table 7. Summary of vulnerability assessment findings for selected sharks and rays from Chin et al. 2010.

Note: Eleven populations are considered in this report covering nine species. The bathyal population (i.e. below about 200 metres, essentially the continental slope) and shelf population were assessed separately for two species(*). For patchwork stingaree these two assessments gave different results (Bathyal = Low, Shelf = Medium), whereas for Argus skate the two assessments gave the same result (Bathyal and Shelf = Low).

Common Name	Scientific Name	Risk (from ERA)	Ecological group	Overall vulnerability to climate change	Direct			Indirect					
					Temperature	Ocean acidification	Freshwater input	Ocean circulation	Temperature	Sea level	Severe weather	Freshwater input	Light
Eastern shovelnose ray	*Aptychotrema rostrata*	HIGH	Coastal/ Inshore	L	L	L	L	L	L	L	L	L	L
Coffin ray	*Hypnos monopterygius*	HIGH	Reef	L	L	L	L	L	L	L	L	L	L
Blackspotted whipray	*Himantura astra*	HIGH	Coastal/ Inshore	L	L	L	L	L	L	L	L	L	L
Bluespotted maskray	*Neotrygon kuhlii*	HIGH	Coastal/ Inshore	L	L	L	L	L	L	L	L	L	L
Speckled maskray	*Neotrygon picta*	HIGH	Coastal/ Inshore	L	L	L	L	L	L	L	L	L	L
Patchwork stingaree	*Urolophus flavomosaicus*	HIGH	Bathyal*	L	M	L	L	M	L	L	L	L	L
			Shelf*	M	M	L	M	M	M	L	L	M	L
Pale tropical skate	*Dipturus apricus*	HIGH	Bathyal	L	L	L	L	L	L	L	L	L	L
Argus skate	*Dipturus polyommata*	HIGH	Bathyal and Shelf*	L	L	L	L	L	L	L	L	L	L
Australian butterfly ray	*Gymnura australis*	HIGH	Coastal/ Inshore	M	M	L	M	M	M	M	M	M	M

13. Sea Snakes

Key facts

Species assessed: all 16 species of sea snakes that occur in the area, mostly assessed at the species-group level.

Habitats used: generally shallow (< 60 m) inshore and estuarine areas.

Trawl fishery: taken incidentally as by-catch and four species potentially at risk from otter trawling in the Great Barrier Reef.

Sea snakes	Vulnerability
Higher sea surface temperature	L
Ocean acidification	M* H*
Sea level rise	L
Changed rainfall patterns and nutrient inputs	L
Changed light spectra	L
Increased tropical storm intensity and flooding	M* H*
Altered ocean circulation	L* M*
Higher peak wind speeds	M* H*

** Score varies by species*

VULNERABILITY TO CLIMATE CHANGE

1. Sea snakes may be subject to a medium to high level of ecological vulnerability (depending on the species) from ocean acidification, increased tropical storm intensity and flooding and higher peak wind speeds, which could result in increased mortality to sea snakes and possibly increased damage to estuarine and coralline habitats for these species. This vulnerability arises because sea snakes are shallow (< 60 m) inshore and estuarine species that may be prone to impacts from severe flooding and offshore storm and wave events. As an air breather they have both a high exposure and high sensitivity to such storms and the turbulence they create. However, the level of certainty is low because of information gaps.

2. Some species of sea snakes may be subject to a medium level of ecological vulnerability from altered ocean circulation, which could result in changed distribution or unknown effects on these species. This vulnerability only arises for some sea snake species that occur further offshore, however the level of certainty is low because of information gaps.

Background

The vulnerability of sea snakes within the Great Barrier Reef to climate change has been assessed by Hamann et al. (2007). Additional expert input to this assessment was provided by Tony Courtney (DAFF) and Mark Read (GBRMPA).

Sixteen species of sea snakes from the families Hydrophiidae and Laticaudidae occur within the Great Barrier Reef Marine Park, with 14 of these species maintaining permanent breeding populations. The Queensland otter and beam trawl fishery catch at least 12 different species of sea snakes (Courtney et al. 2010) of which the two most commonly caught species are the elegant sea snake *Hydrophis elegans* and the spine-bellied sea snake *Lapemis curtus*.

The overall levels of ecological risk to sea snakes from trawling in the Great Barrier Reef from a recent assessment included two sea snake species assessed as high (elegant *Hydrophis elegans* and ornate *Hydrophis ornatus*) and two species at intermediate risk (spectacled *Hydrophis/Disteira kingie* and small-headed *Hydrophis macdowelli*), and the other 11 species of sea snakes were at intermediate-low risk (Pears et al. 2012). One species was not assessed in that project as it was considered to have negligible interaction with the fishery.

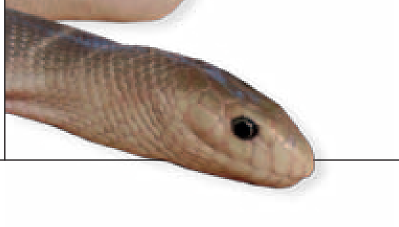
For a number of climate change variables, estimates of potential impact and vulnerability have been assigned as high on a precautionary basis because of the lack of information.

Exposure, sensitivity, potential impact and adaptive capacity of sea snakes

HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: Sea snakes will be exposed to the predicted effects of changed sea surface temperatures throughout their range.

There is little known about the fine-scale distribution of different species, thermal requirements, thermal tolerances, fine-scale aspects of dietary ecology (i.e. prey selectivity), or how preferred prey items will be influenced to assess their vulnerability to the projected rises in sea temperature of 1.1 to 1.2°C by 2050 (Hamann et al. 2007).



The yellow-bellied sea snake (*Pelamis platura*) is the most widespread of the sea snake species and its distribution has been empirically linked to sea surface temperature patterns. The distribution of this species is linked to thermal zones, and has upper and lower thermal tolerances of between 36.0 and 11.7°C. It is likely that other sea snake species have a thermal range within the boundaries of those of the yellow-bellied sea snake. It is possible that gradual shifts in the range of species will occur over the course of the next 50 to 100 years (Hamann et al. 2007).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	H	L	L	M	L

Adaptive capacity and vulnerability: There is insufficient information on thermal sensitivity of individual species of sea snake to estimate how particular species will respond to increased sea temperature. Potential changes could include changes in distribution of certain species and/or their prey, and timing of movements and reproductive events (Hamann et al. 2007). Nevertheless, the wide geographic range and thermal tolerances of the yellow-bellied sea snake suggest that this species at least has an ability to adapt to a broad range of sea temperatures. Other species may have lower adaptive capacities.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
H	L	L	L

OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: Sea snakes will be exposed to the effects of ocean acidification over their entire range.

As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

No information was found about the sensitivity of sea snakes to changes in water chemistry. There are no available data to indicate whether ocean acidification would have any effect on marine reptiles in the Great Barrier Reef (Hamann et al. 2007). Experts considered the sensitivity would be medium to low, depending on the species.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	L-M	L	M-H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of sea snakes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	M-H	L

SEA LEVEL RISE

Exposure, sensitivity and potential impact: Sea snakes have been reported to have a low probability of exposure to increased sea level (Hamann et al. 2007), but this seems to be a different interpretation of exposure than used for other groups and seems to be more about the sensitivity of the group to any changes. Experts considered the exposure would be low, because few species use very shallow coastal habitats.

Indirect effects on reef-dwelling species of sea snakes from sea level rises were considered possible if the fish communities they rely on for food are impacted by sea level rise (Hamann et al. 2007).

Experts considered the sensitivity to sea level rise would be medium to low, depending on the species.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L-M	L	L	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of sea snakes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

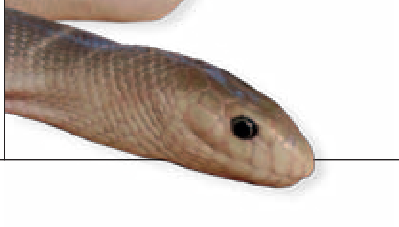
Exposure, sensitivity and potential impact: Sea snakes will have varied exposure to the impacts of the predicted changes in rainfall and river flow depending on their distribution and habitat preferences.

There are insufficient data on water quality requirements for sea snakes to determine whether or not increases in rainfall will have any impacts on sea snakes (Hamann et al. 2007), however experts considered the sensitivity is likely to be low.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	L	L	L	L	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of sea snakes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L



CHANGED LIGHT SPECTRA

Exposure, sensitivity and potential impact: Expert opinion was that sea snakes will have a medium level of exposure to the predicted changes in light spectra because in the depths of water that they inhabit it was considered that light conditions would be similar to present, but they are also exposed to surface conditions at times where change in this variable is expected to be greater.

No information was found in the literature on the sensitivity of sea snakes to the predicted changes in light spectra, however experts considered the sensitivity is likely to be low.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	L	L	L	L	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of sea snakes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L	L

INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Sea snakes will be exposed to the direct and indirect impacts of such events throughout their range.

No information was found in the literature on the sensitivity of sea snakes to these predicted changes. In the 1950s, there were anecdotal reports that large numbers of sea snakes were observed to be washed up on Fraser Island beaches after cyclones and other severe weather events suggesting that, as surface breathers, they have both a high exposure and a medium sensitivity to such storms. However, experts considered the sensitivity would be medium to low, depending on the species.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	L	L-M	L	M-H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of sea snakes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	M-H	L

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Expert opinion was that sea snakes will have only a medium level of exposure to any effects of changes to ocean circulation patterns because such changes will occur offshore and sea snakes are largely confined to shallow water.

No information was found on the sensitivity of sea snakes to these predicted changes. Experts considered the sensitivity would be medium to low, depending on the species.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
M	L	L-M	L	L-M	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of sea snakes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	L-M	L

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Sea snakes will be exposed to any effects of changes to wind patterns.

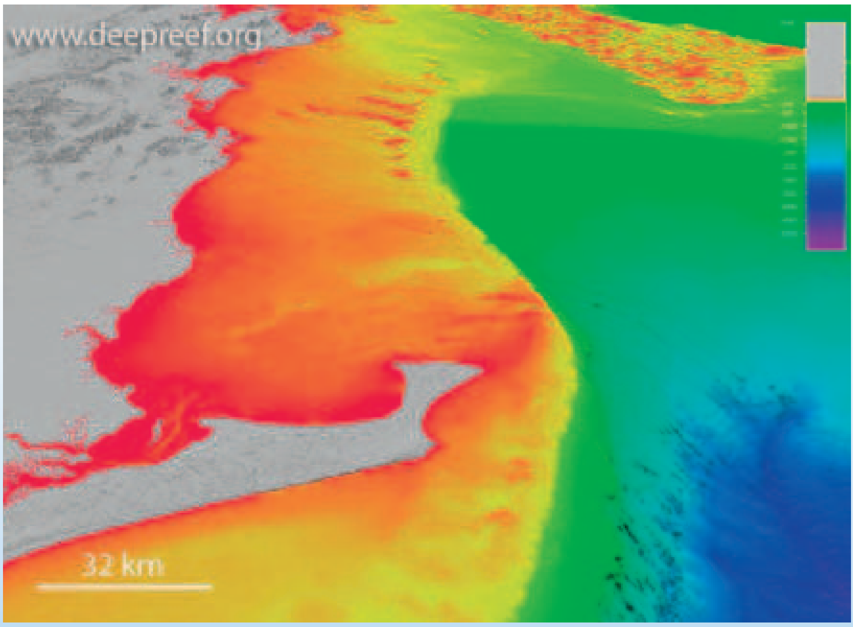
No information was found on the sensitivity of sea snakes to these predicted changes. In the 1950s, there were anecdotal reports that large numbers of sea snakes were observed to be washed up on Fraser Island beaches after cyclones and other severe weather events suggesting that, as surface breathers, they have both a high exposure and medium sensitivity to such storms. However, experts considered the sensitivity would be medium to low, depending on the species.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	L	L-M	L	M-H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of sea snakes.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
M	L	M-H	L

14. Habitat 10



Key facts

Habitat assessed: 'Habitat 10' comprises the area south and east of the Swains Reefs between depths of about 90 and 300 metres, in the southern Great Barrier Reef.

Knowledge of habitat: poor, with limited information on marine animals and plants of this area, but known to include breeding grounds for eastern king prawns.

Trawl fishery: includes deepwater areas in southern region of fishery, and potentially at risk from otter trawling in the Great Barrier Reef.

Habitat 10	Vulnerability
Higher sea surface temperature	L
Ocean acidification	H
Sea level rise	L
Changed rainfall patterns and nutrient inputs	L
Changed light spectra	L
Increased tropical storm intensity and flooding	L
Altered ocean circulation	H
Higher peak wind speeds	L

VULNERABILITY TO CLIMATE CHANGE

1. Habitat 10 may be subject to a high level of ecological vulnerability from altered ocean circulation and ocean acidification, which could result in changes to the species composition of the habitat as a result of changing recruitment processes and growth parameters. This vulnerability arises because, although little is known about the species composition and physical characteristics of this habitat, this vulnerability assessment is heavily influenced by the general assumption that deeper colder water habitats are generally slower growing, less productive and adapted to a more stable environment than their shallow water counterparts. However, the level of certainty is low because of information gaps.

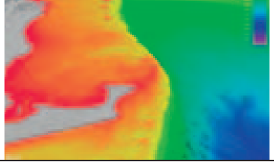
Background

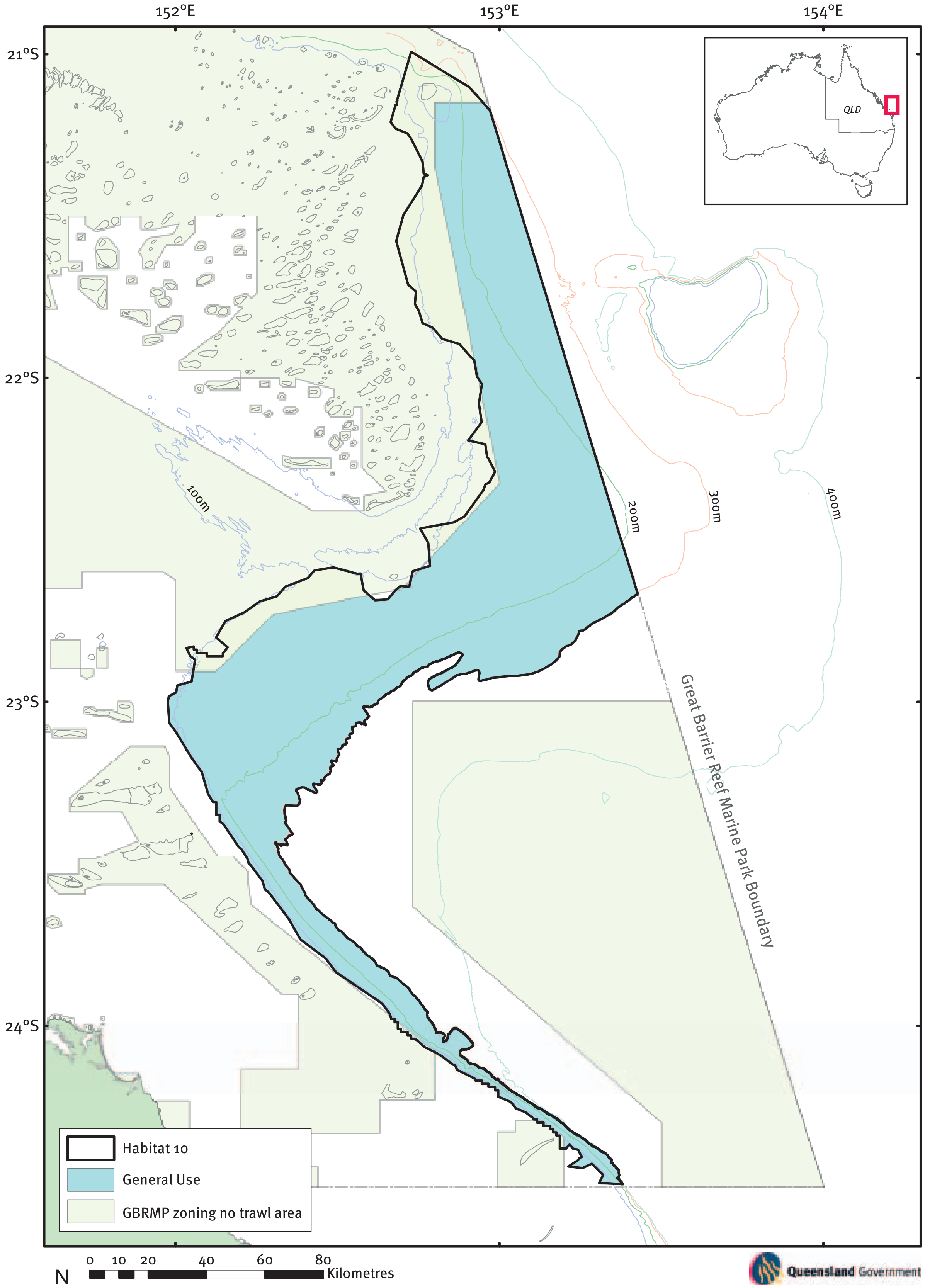
The area referred to in this report as 'Habitat 10' (after Pears et al. 2012) comprises the area south and east of the Swains Reefs between depths of about 90 and 300 metres, and includes deepwater areas fished by the ECOTF (Figure 7). Habitat 10 covers an area of 14,056 square kilometres. The area includes part of two bioregions defined for the Great Barrier Reef Marine Park, namely the 'X8 Southern Embayment' bioregion (within that depth range) and the southern part of the 'NU Terraces' bioregion. Little is known (and less has been published) about the marine animals and plants of this area. The area is known to be important for adult eastern king prawns, and includes breeding grounds for this species.

Some species may use Habitat 10 for only part of their life cycle (e.g. eastern king prawns). However, as there is little information on which species are found in Habitat 10, this assessment has only considered the Habitat 10 area and not taken account of other habitats that may be used by a species.

Estimates of potential impact and vulnerability were initially assigned as high on a precautionary basis for all climate change variables because of the lack of information, however expert input through the workshop process was used to refine the assessment.

Little is known about the deepwater seabed habitats in area to the south and east of the Swains Reefs.





Bathymetry data derived from data provided by Rob Beaman, James Cook University. GDA - 1994.

Figure 7. Map showing Habitat 10 in the southern Great Barrier Reef Marine Park.

Exposure, sensitivity, potential impact and adaptive capacity of Habitat 10

HIGHER SEA SURFACE TEMPERATURE

Exposure, sensitivity and potential impact: All species and habitat elements found in Habitat 10 will be exposed to the predicted effects of changed sea surface temperatures. Changes to SST are predicted to be greater, however, than those to sea temperatures at greater depths (Waycott et al. 2007, Hobday et al. 2008) and hence populations occupying deeper habitats will be exposed to smaller changes in sea temperature.

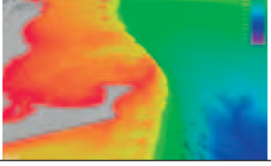
No information was found in the literature on the sensitivity of the species and habitat elements of Habitat 10 to the predicted changes in sea surface temperature.

Overall, participants at the expert workshop considered that the species and habitat elements of Habitat 10 would have a low level of exposure and sensitivity to the higher sea surface temperatures, because this is a deepwater area (generally greater than 100 metres).

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	H	L	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10. Participants at the expert workshop considered that the species and habitat elements of Habitat 10 would have a low adaptive capacity to higher sea surface temperatures on a precautionary basis given the limited knowledge base.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L



OCEAN ACIDIFICATION

Exposure, sensitivity and potential impact: All species and habitat elements found in Habitat 10 will be exposed to the effects of ocean acidification. As explained in the methods, exposure for all species is scored as high with a medium level of certainty to reflect the current uncertainty in the spatial variability of ocean acidification.

No information was found on the sensitivity of the elements of Habitat 10 to the predicted changes in ocean acidification.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	M	L	H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	H	L

SEA LEVEL RISE

Exposure, sensitivity and potential impact: All species and habitat elements found in Habitat 10 will be exposed to the predicted effects of sea level rise, however changes in sea level are expected to have minor effects on species living below 100 metres.

No information was found on the sensitivity of the elements of Habitat 10 to the predicted sea level rises. Participants at the expert workshop, however, considered that there was a high degree of certainty that the species and habitat elements of Habitat 10 had a low level of exposure and sensitivity to sea level rise.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	H	L	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10. Participants at the expert workshop considered that the species and habitat elements of Habitat 10 would have a low adaptive capacity to sea level rise on a precautionary basis given the limited knowledge base.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L

CHANGED RAINFALL PATTERNS AND NUTRIENT INPUTS

Exposure, sensitivity and potential impact: Species and habitat elements found in Habitat 10 are likely to have minimal exposure to the predicted effects of changes to rainfall and terrestrial inputs given the large distance of the habitat from shore.

No information was found on the sensitivity of the elements of Habitat 10 to the predicted changes in rainfall patterns and nutrient inputs. Participants at the expert workshop, however, considered that the species and habitat elements of Habitat 10 had a low level of exposure and sensitivity to these changes.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	M	L	H	L	M

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L

CHANGED LIGHT SPECTRA

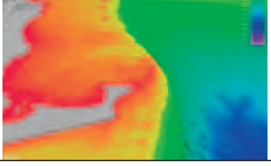
Exposure, sensitivity and potential impact: Species and habitat elements found in Habitat 10 will be exposed to the predicted changes in light spectra, however changes in light spectra are expected to have minor effects on species living below 100 metres.

Participants at the expert workshop considered that there was a high degree of certainty that the species and habitat elements of Habitat 10 had a low level of exposure and sensitivity to predicted changes in light spectra given the depth at which they are found.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	H	L	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10. Participants at the expert workshop considered that the species and habitat elements of Habitat 10 would have a low adaptive capacity to changed light spectra on a precautionary basis given the limited knowledge base.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L



INCREASED TROPICAL STORM INTENSITY AND FLOODING

Exposure, sensitivity and potential impact: Species and habitat elements found in Habitat 10 are exposed to the direct and indirect impacts of such events, however physical disturbance from weather events decreases with depth, so effects are expected to be minor for species living below 100 metres.

Some species may be sensitive to changes in physical disturbance regimes caused by tropical storms, particularly those living at shallower depths and those that have a pelagic phase to their life history. Participants at the expert workshop, however, considered that overall there was a high degree of certainty that the species and habitat elements of Habitat 10 had a low level of exposure and sensitivity to the predicted increased in tropical storm intensity and flooding.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	H	L	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10. Participants at the expert workshop considered that the species and habitat elements of Habitat 10 would have a low adaptive capacity to increased tropical storm intensity and flooding on a precautionary basis given the limited knowledge base.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L

ALTERED OCEAN CIRCULATION

Exposure, sensitivity and potential impact: Species found in Habitat 10 will be highly exposed to any effects of changes to ocean circulation and currents.

Given the complex bathymetry of the area, it is likely that ocean circulation and current regimes are important drivers for species and habitat elements in the area, and therefore they would be expected to be sensitive to changes in ocean circulation and current patterns, however this would vary by species or type of habitat element.

Some species may be sensitive to changes in ocean currents, particularly those that have a pelagic phase to their life history. Changes to ocean circulation patterns may potentially alter (either positively or negatively) the distribution of larvae and the numbers that settle to preferred benthic habitats.

Participants at the expert workshop considered that the species and habitat elements of Habitat 10 had a high level of exposure and a medium level sensitivity to altered ocean circulation.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
H	M	M	L	H	L

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10. Participants at the expert workshop considered that the species and habitat elements of Habitat 10 would have a low adaptive capacity to altered ocean circulation on a precautionary basis given the limited knowledge base.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	H	L

HIGHER PEAK WIND SPEEDS

Exposure, sensitivity and potential impact: Species found in Habitat 10 will be exposed to any effects of changes to wind patterns. However, direct effects from changes in wind are expected to be minor for species living below 100 metres.

Some species may be sensitive to these changes indirectly through the effects of wind on ocean currents (see above).

Participants at the expert workshop considered that there was a high degree of certainty that the species and habitat elements of Habitat 10 had a low level of exposure and sensitivity to higher peak wind speeds.

Exposure		Sensitivity		Potential impact	
Level	Certainty	Level	Certainty	Level	Certainty
L	H	L	H	L	H

Adaptive capacity and vulnerability: No information was found in the literature on the adaptive capacity of Habitat 10. Participants at the expert workshop considered that the species and habitat elements of Habitat 10 would have a low adaptive capacity to higher peak wind speeds on a precautionary basis given the limited knowledge base.

Adaptive capacity		Vulnerability	
Level	Certainty	Level	Certainty
L	L	L	L

15. Discussion

Discussion

This report provides the first attempt to synthesise information and conduct a preliminary assessment of ecological vulnerability for selected components of the Queensland East Coast Otter Trawl Fishery (ECOTF). This report will be considered by managers, industry and scientists in the ongoing adaptation planning work for the fishery, which aims to identify options for reducing the negative impacts of climate change. It is noted that climate change is just one of a number of pressures affecting the fishery, and this wider context is being considered, particularly through Queensland's current review of management arrangements for the fishery and industry development work.

The ECOTF, like other fisheries, has always experienced climate-related variability. The report has reviewed how changes to the marine environment as a result of climate change may affect the target species that support the fishery and other selected ecological components that interact with the fishery. In future, the frequency and magnitude of climate variability and the level of uncertainty will increase. The report has identified which species are likely to be most strongly affected by projected changes in climate and which climate change variables are likely to make these species vulnerable (Table 1). Saucer scallops, some species of sea snakes, red-spot king prawns, Balmain bugs and Habitat 10 had the most high vulnerability scores of the species assessed. The climate change variables likely to have the greatest influence on ecological components of the fishery were ocean acidification, altered ocean circulation and increased tropical storm intensity and flooding.

This report, in turn, will be valuable for considering what features of the industry may be affected by climate change, for example, shifts in species distribution could affect availability of seafood product with flow on effects to local industries. Importantly, biophysical and socioeconomic drivers will be considered as part of the adaptation planning for the fishery.

Points for consideration when evaluating the findings of this preliminary assessment include:

- Not all the impacts are negative. The current descriptions of impact have attempted to account for any positive effects (such as the anticipated benefits to banana prawns from increased flooding) by reducing sensitivity scores.
- Changes may occur in the abundance of prawns (or other species) for reasons unrelated to climate change (or fishing), such as has been seen in the Gulf of Carpentaria (Blaber et al. 2010).
- Effects may be synergistic or antagonistic making predictions of cumulative impacts difficult (e.g. Nowicki et al. 2012).
- There are a number of studies reported here on the observed or predicted effects of climate change on similar species or groups from temperate zones but, as noted by Munday et al. (2008), such predictions may be inappropriate for tropical species.
- Overall effects on species or habitats will depend on interactions between climate shifts and other pressures.
- It is generally not possible to accurately predict all of the important changes related to climate that may affect a particular fishery. Consequently, well directed data collection, monitoring and adaptive management are important to increase ability of fishers and managers to respond appropriately (Plagányi et al. 2011).

- Climate change science is a rapidly expanding area. As new information becomes available, some of the predictions in this report may need to be revised in any future ecological vulnerability assessments.
- The species and habitat that have been already assessed as being at high risk from trawling from the earlier Ecological Risk Assessment process are likely to have an inherently greater sensitivity to the effects of climate change, and may also have a lower adaptive capacity. This potentiality has been explicitly considered during the expert workshop phase of the current assessment process.
- The geographic scope of the earlier ecological risk assessment reported by Pears and co-workers (Pears et al. 2012) differs from the current report as it was limited to the Great Barrier Reef. At the time the current document was prepared, results from an associated ecological risk assessment for the remainder of the fishery were not available, and are therefore not considered here. It is noted, however, that the second ecological risk assessment may identify additional ecological components at potential risk from the fishery, which may require further consideration in future climate change vulnerability assessments.

Ocean acidification is one of the changes likely to have a major effect on the ecology of the areas covered by this assessment within the next 20 to 50 years. The chemical reactions that produce this acidification are well understood and there is a high level of certainty for the predicted change. There is much less certainty, however, about the likely spatial variability in this change and whether species in deeper or shallower waters or in different types of habitats may experience greater or lesser amounts of ocean acidification. Such spatial variability may well be important in determining the level of exposure of the species considered here. Assessments of vulnerability may therefore change as knowledge of this spatial variability accrues.

Ocean acidification and increasing temperatures are some of the key concerns for habitat-forming corals on the Great Barrier Reef (Pratchett et al. 2011). Ocean acidification was also the greatest concern in our assessment, however increasing temperatures were only fifth among eight variables for importance in our assessment. This may reflect the dependence of the ECOTF on species that are largely not directly associated with coral reefs. Many of the species assessed here are instead dependent on more inshore habitats, and are therefore more affected by terrestrial inputs and coastal processes.

The adaptation potential of pelagic species is regarded as high because of significant opportunity for large-scale movements (Poloczanska et al. 2009). The adaptation potential of species with pelagic larvae could therefore be considered to be similarly high. It does not follow, however, that the adaption potential of entirely benthic species must be low as there are other ways to adapt than to move.

For example, sharks and rays were regarded by the expert group that assessed their vulnerability (Chin et al. 2010) to have inherently low adaptive capacity because of the longevity and slow generation times that this means so that adaptation through genetic evolution was not considered likely within the 100 year time frame used for the assessment. When compared to sharks and rays, most of the species in this assessment are short-lived species and would be expected to have inherently greater adaptive capacities than the sharks and rays. Shorter generation times are expected to aid genetic adaptation to rapid climate change, which depends also on factors such as the amount of adaptive genetic variation present, effective population sizes, and connectivity between populations that can aid in the spread of tolerant genotypes (Pankhurst and Munday 2011). This inherent adaptive capacity was noted for saucer scallops by participants at the expert workshop but has not been explicitly included in the scoring of other species. As a consequence, the adaptive capacity of other species may have been underestimated.

Another aspect that has not been considered in this assessment is the potential influence of climate change on population structuring and genetic diversity. It is acknowledged that the shifts in distribution that may occur for some species and the potential loss of some sub-populations may lead to changes in the relative frequency of haplotypes. Our current knowledge of the genetic diversity within the species considered here is, however, insufficient to allow for the explicit inclusion of this variable in the assessment.

This assessment has examined the vulnerabilities of individual species, or small groups of similar species, as a method of determining the ecological vulnerability of the ECOTF to climate change. An alternative approach is to use ecosystem models to assess the impacts of climate change on marine communities as investigated by Brown et al. (2010). In their study, it was predicted that climate change would increase primary production in the marine environment by up to 20 per cent off northern Queensland and up to 30 per cent or more off southern Queensland by 2050. The results of this increase in primary productivity varied among functional groups but, overall, over 50 years, total fishery landings and the value of landings were generally predicted to increase due to this increasing primary productivity. Biomass of functional groups of conservation interest, including sharks, also generally increased, but the biomass of marine mammals (not considered here) declined due to seagrass declines. Reliable primary productivity predictions were found to be a necessary part of predicting ecosystem and fishery responses to climate change, but knowledge of ecological interactions was considered to be required to predict outcomes for particular species because interactions affect the magnitude and direction of biomass changes. Limitations to the study of Brown and co-workers include the coarse spatial resolution of the circulation model used and uncertainties as to how changes in primary production would influence the abundance of higher level consumers because of gaps in knowledge about diet, life history and reproduction for species such as sharks.

These predicted increases in fisheries production are apparently contrary to the generalised global summary of Perry (2011) who concluded that, although there would be little overall change in the global maximum potential fisheries catch (±1 per cent), current models predict decreases of 40 per cent in the tropics. The changes are predicted to be spatially variable, however, and the catch potential in 2055 (relative to 2005) for marine fisheries in Queensland waters has been predicted to increase by about 16-30 per cent under a scenario of increasing CO_2 emission (Cheung et al. 2010).

Furthermore, Jennings and Brander (2010) have suggested that knowledge of the processes that determine the size–structure of marine communities can be used to predict the effects of climate change on marine communities and the consequences for fisheries.

A different approach again has been proposed by Johnson and Welch (2010) who employ the same exposure/sensitivity/adaptive capacity method for determining vulnerability as used here and score a very similar set of variables for assessing the exposure factor. They demonstrate the method for three fisheries, including the ECOTF, but score sensitivity and adaptive capacity for a different set of variables than used here and across the fishery as a whole, rather than on a species-by-species basis. In their approach, combined scores for each factor (exposure, sensitivity and adaptive capacity) are simple arithmetic averages of the scores for each variable. Their approach is a comparative one and is intended to identify priorities for action among a set of fisheries.

Differences in the predicted effects of climate change from different approaches are quite likely. As pointed out by Pörtner and Peck (2010) the implications of climate change for marine fish populations result from phenomena at four interlinked levels of biological organisation: changes at the level of the organism, individual-level behavioural changes, population-level changes and ecosystem-level changes. Different approaches may focus on, or give different weight to, the changes expected at the different levels in this hierarchy.

16. References

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Appendix 1: Summary tables of the assessments for main target species and potentially at risk ecological components

L = Low; M = Medium; H = High

Eastern king prawns	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	Certainty	Level	Certainty	Level	Certainty	Level	Certainty	Level	Certainty
Higher sea surface temperature	H-inshore L-offshore	H	M	H	H-inshore L-offshore	H	H	M	M-inshore L-offshore	M
Ocean acidification	H	M	L	M	M	M	H	M	L	
Sea level rise	M	H	M-inshore L-offshore	L	M-inshore L-offshore	L	H	M	L	L
Changed rainfall patterns and nutrient inputs	H-inshore L-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M	H	M	M-inshore L-offshore	M
Changed light spectra	M	M	L	M	L	M	H	M	L	M
Increased tropical storm intensity and flooding	H-inshore M-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M	H	M	M-inshore L-offshore	M
Altered ocean circulation	H	H	M	H	H	H	M	M	H	M
Higher peak wind speeds	M	M	L	M	L	M	H	M	L	M

Tiger prawns	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	Certainty	Level	Certainty	Level	Certainty	Level	Certainty	Level	Certainty
Higher sea surface temperature	H-inshore M-offshore	M	M	M	H-inshore M-offshore	M	H	M	M-inshore L-offshore	M
Ocean acidification	H	M	M	L	H	L	M	M	H	L
Sea level rise	H-inshoreL-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M	H	M	M-inshore L-offshore	M
Changed rainfall patterns and nutrient inputs	H-inshore M-offshore	H	M-inshore M-offshore	M	H-inshore M-offshore	M	H	M	M-inshore L-offshore	M
Changed light spectra	M	M	L	M	L	M	H	M	L	M
Increased tropical storm intensity and flooding	H-inshore M-offshore	H	H-inshore L-offshore	M	H-inshore L-offshore	M	H	M	M-inshore L-offshore	M
Altered ocean circulation	M	H	L	M	L	M	H	M	L	M
Higher peak wind speeds	M	H	L	M	L	M	H	M	L	M

Saucer scallops	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**
Higher sea surface temperature	H	H	H	H	H	H	M	L	H	L
Ocean acidification	H	M	H	M	H	M	L	M	H	M
Sea level rise	L	H	L	M	L	M	H	H	L	M
Changed rainfall patterns and nutrient inputs	M	M	H	M	H	M	L	L	H	L
Changed light spectra	L	H	L	M	L	M	L	L	L	L
Increased tropical storm intensity and flooding	M	H	H	L	H	L	M	L	H	L
Altered ocean circulation	H	H	M	M	H	M	M	L	H	L
Higher peak wind speeds	M	H	L	L	L	L	M	L	L	L

Banana prawns	**Exposure**		**Sensitivity**		**Potential Impact**		**Adaptive Capacity**		**Vulnerability**	
	Level	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**
Higher sea surface temperature	H	H	M	M	H	M	H	M	M	M
Ocean acidification	H	M	L	M	M	M	H	M	L	M
Sea level rise	H	H	M	L	H	L	M	M	H	L
Changed rainfall patterns and nutrient inputs	H	H	L	H	M	H	M	M	M	M
Changed light spectra	M	M	L	M	L	M	M	M	L	M
Increased tropical storm intensity and flooding	H	H	L	H	M	H	H	M	L	M
Altered ocean circulation	L	H	L	H	L	H	H	M	L	M
Higher peak wind speeds	H	H	L	M	L	M	H	M	L	M

Endeavour prawns	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**
Higher sea surface temperature	H-inshore M-offshore	M	M	M	H-inshore M-offshore	M	H	M	M-inshore L-offshore	M
Ocean acidification	H	M	M	L	H	L	M	M	H	L
Sea level rise	H-inshore L-offshore	H	M-inshore L-offshore	M	H-inshore L-offshore	M	H	M	M-inshore L-offshore	M
Changed rainfall patterns and nutrient inputs	H-inshore M-offshore	H	M-inshore M-offshore	M	H-inshore M-offshore	M	H	M	M-inshore L-offshore	M
Changed light spectra	M	M	L	M	L	M	H	M	L	M
Increased tropical storm intensity and flooding	H-inshore M-offshore	H	H-inshore L-offshore	M	H-inshore L-offshore	M	H	M	M-inshore L-offshore	M
Altered ocean circulation	M	H	L	M	L	M	H	M	L	M
Higher peak wind speeds	M	H	L	M	L	M	H	M	L	M

Red-spot and blue-legged king prawns	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**
Higher sea surface temperature	H-RSK M-BLK	M	M	M	H-RSK M-BLK	M	H	M	M-RSK L-BLK	M
Ocean acidification	H	M	M	L	H	L	M	M	H	L
Sea level rise	M	M	M	M	M	M	M-RSK H-BLK	M	M-RSK L-BLK	M
Changed rainfall patterns and nutrient inputs	L	H	L	M	L	M	H	M	L	M
Changed light spectra	M	M	L	M	L	M	H	M	L	M
Increased tropical storm intensity and flooding	H	H	H	M	H	M	M-RSK H-BLK	M	H-RSK M-BLK	M
Altered ocean circulation	L	M	L	M	L	M	M	M	L	M
Higher peak wind speeds	M	H	M	M	M	M	H	M	L	M

Moreton Bay bugs	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**
Higher sea surface temperature	H	H	L	M	M	M	H	M	L	M
Ocean acidification	H	M	M	L	H	L	M	L	H	L
Sea level rise	M	H	L	M	L	M	H	M	L	M
Changed rainfall patterns and nutrient inputs	H	H	L	M	M	M	H	M	L	M
Changed light spectra	M	M	L	M	L	M	M	L	L	L
Increased tropical storm intensity and flooding	M	M	M	M	M	M	M	L	M	L
Altered ocean circulation	H	H	M	H	H	H	H	M	M	M
Higher peak wind speeds	H	H	L	L	M	L	H	L	L	L

Balmain bugs	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**
Higher sea surface temperature	M-Smooth bug L-other species	M	M	L	M-Smooth bug L-other species	L	M	L	M-Smooth bug L-other species	L
Ocean acidification	H	M	M	L	H	L	M	L	H	L
Sea level rise	L	H	L	M	L	M	M	L	L	L
Changed rainfall patterns and nutrient inputs	L	H	L	M	L	M	L	L	L	L
Changed light spectra	M-larvae L-adult	M	L	M	L	M	L	L	L	L
Increased tropical storm intensity and flooding	L	M	L	M	L	M	M	L	L	L
Altered ocean circulation	H	H	M	H	H	H	L	L	H	L
Higher peak wind speeds	M	M	L	L	L	L	M	L	L	L

Sea snakes	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**	**Level**	**Certainty**
Higher sea surface temperature	H	H	L	L	M	L	H	L	L	L
Ocean acidification	H	M	L-M	L	M-H	L	M	L	M-H	L
Sea level rise	L	H	L-M	L	L	L	M	L	L	L
Changed rainfall patterns and nutrient inputs	M	L	L	L	L	L	M	L	L	L
Changed light spectra	M	L	L	L	L	L	M	L	L	L
Increased tropical storm intensity and flooding	H	L	L-M	L	M-H	L	M	L	M-H	L
Altered ocean circulation	M	L	L-M	L	L-M	L	M	L	L-M	L
Higher peak wind speeds	H	L	L-M	L	M-H	L	M	L	M-H	L

Habitat 10	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
	Level	Certainty	Level	Certainty	Level	Certainty	Level	Certainty	Level	Certainty
Higher sea surface temperature	L	H	L	H	L	H	L	L	L	L
Ocean acidification	H	M	M	L	H	L	L	L	H	L
Sea level rise	L	H	L	H	L	H	L	L	L	L
Changed rainfall patterns and nutrient inputs	L	M	L	H	L	M	L	L	L	L
Changed light spectra	L	H	L	H	L	H	L	L	L	L
Increased tropical storm intensity and flooding	L	H	L	H	L	H	L	L	L	L
Altered ocean circulation	H	M	M	L	H	L	L	L	H	L
Higher peak wind speeds	L	H	L	H	L	H	L	L	L	L

Appendix 2: Expert workshop report: climate change vulnerability and adaptation options for the East Coast Otter Trawl Fishery, 28-29th July 2011, Brisbane

Report prepared by Rachel Pears, Great Barrier Reef Marine Park Authority, August 2011
Email: rachel.pears@gbrmpa.gov.au

EXECUTIVE SUMMARY

Managers, scientists and the commercial fishing industry are working on a collaborative project to consider climate change vulnerability and adaptation options for the East Coast Otter Trawl Fishery (ECOTF). The project will investigate how current trends in climate may impact on fishery resources in the future, and ways to effectively manage those impacts. Project partners are the Department of Agriculture, Fisheries and Forestry (DAFF, formerly the Department of Employment, Economic Development and Innovation), the Great Barrier Reef Marine Park Authority, Queensland Climate Change Centre of Excellence, and the Queensland Seafood Industry Association.

As part of this project, a two day expert workshop was held in Brisbane on 28 and 29 July 2011. The workshop was facilitated by Neil Cliffe from DAFF, and participants were invited for their expertise in the Queensland trawl fishery, marine ecosystems and climate change science.

The workshop process was designed to draw on the varied knowledge and experience of participants to better understand the likely impacts of climate change on key species and habitat in the ECOTF and on the fishery as a whole. There was also an opportunity to consider potential responses.

A draft vulnerability assessment report was provided to participants and workshop exercises stepped participants through the results with the aim of building on this preliminary assessment through the inclusion of their expert advice. Workshop outputs have identified which species are likely to be most strongly affected by projected changes in climate, and which climate change variables are likely to make these species vulnerable.

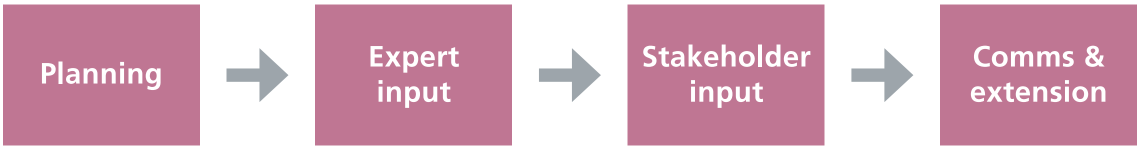
A tool called the Climate Risk Management Matrix was used at the workshop. This tool was trialled and selected at an earlier project workshop (in March 2011). The matrix tool is an effective approach for stakeholder and expert engagement in climate change adaptation planning for primary industries. The current project is the first case study applying this tool in an Australian fishery. Participants at the July workshop provided input to a Climate Risk Management Matrix for the trawl fishery.

The workshop process enabled industry members and other experts to feed their knowledge and experience into the project. The next stages of the project will seek wider input into the project, and there will be a greater focus on socioeconomic implications and adaptation options for the industry.

OVERVIEW OF EXPERT WORKSHOP

A two day expert workshop was held in Brisbane on 28 and 29 July 2011 to progress the Vulnerability and Adaptation Options Project for the East Coast Otter Trawl Fishery. The project is being undertaken collaboratively by Great Barrier Reef Marine Park Authority (GBRMPA), DAFF (particularly Fisheries Queensland and Agri-Science Queensland), the Queensland Seafood Industry Association (QSIA) and the Queensland Climate Change Centre of Excellence (QCCCoE).

The key stages of the project are illustrated in the figure below. The July workshop was part of the Expert Input stage scheduled from April to September 2011. A desktop vulnerability assessment review has also been prepared, and input from the expert workshop is assisting to refine outputs and build understanding of climate change implications for the fishery.



The July 2011 workshop agenda is provided in Appendix A and list of participants is given in Appendix B. The workshop was facilitated by Neil Cliffe from DAFF with support from staff from other partner organisations. Workshop participants were invited based on their engagement in the trawl fishery, fisheries knowledge and/or related scientific/ecological/climate change expertise. At the workshop participants provided expert input into improving the understanding of climate change impacts on the species, habitat and productivity of the ECOTF. The combined experience of the workshop participants is summarised in Appendix C.

The workshop objectives were to:

- Revisit the purpose of the larger project and what we are trying to achieve at this workshop and at subsequent stakeholder workshops with project outputs/products.
- Review and refine the vulnerability assessment for the ECOTF.
- Define regions and species groups to address in the risk matrix analysis.
- Define, prioritise and record organisational elements to populate risk matrix.
- Populate sections of the risk matrix, focusing on a range of aspects (including biophysical).
- Record adaptations in matrix coincidentally if they are raised.
- Outline plan for future regional stakeholder workshops including further input to matrices.

The workshop process was designed to draw on the varied knowledge and experience of participants to better understand the impacts of climate change on key species and habitat in the ECOTF and on the fishery as a whole. There was also an opportunity to consider potential responses.

This report provides a brief summary of the workshop process, outputs, main issues raised during the workshop and the outcomes achieved. The detailed workshop outputs and the scoring agreed at the workshop are contained within the Appendices to this report.

In brief, the process for the expert workshop was:

- Find out who is in the room and share our knowledge and experience around the ECOTF…
- Present information on marine climate change projections…
- Present a draft Ecological Vulnerability Assessment of species within the fishery...
- Review the assessment with expert knowledge and input from participants…
- Use the risk matrix tool to identify climate change impacts on specific elements of the fishery…
- Collate impacts by region and groups of species…
- Discuss future steps to build on this work in the regions…

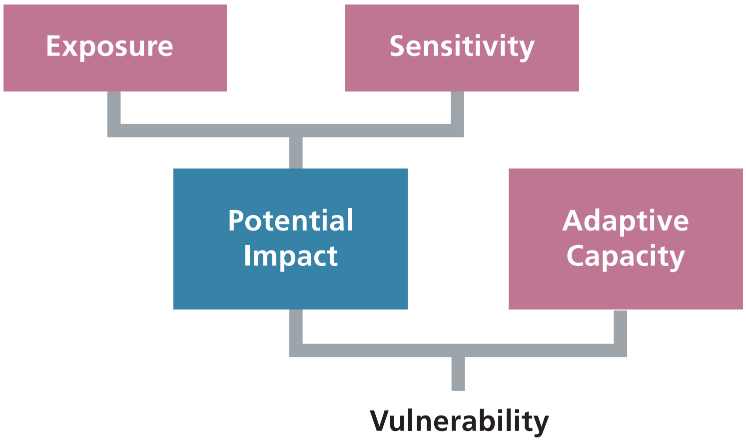
The climate change variables selected for consideration and the reasons for their choice are outlined in the following table.

Variable	Rationale for use
Higher sea surface temperature	Changes to sea temperatures will have direct effects on all marine organisms and especially those unable to regulate their body temperature.
Ocean acidification	Changes to water acidity will have direct effects on many marine organisms and especially those that produce calcareous shells.
Sea level rise	Changes to sea levels will have indirect effects on many marine organisms through changes to the distribution and area of habitats.
Changed rainfall patterns and nutrient inputs	Changes to the level, frequency and quality of terrestrial inputs will have direct and indirect effects on many inshore marine organisms and especially those with an estuarine life history stage.
Changed light spectra	Changes to the light spectra may have direct effects on some marine organisms or indirect effects through its effect on photosynthetic organisms.
Increased tropical storm intensity and flooding	Changes to the frequency, timing or severity of storms or other causes of physical disturbance will have direct or indirect effects on many marine organisms.
Climate variability driven by El Niño-Southern Oscillation (ENSO) events	Changes to the frequency or intensity of ENSO events could have indirect effects on many marine organisms.
Altered ocean circulation	Changes to ocean currents could have direct effects on many marine organisms and especially those with planktonic phases to their life cycles.
Higher peak wind speeds	Changes to wind patterns could have indirect effects on some marine organisms through its effect on ocean currents and waves and as a source of physical disturbance.

Reviewing the draft vulnerability assessment

After the initial introductory remarks and presentations participants were divided into groups to consider in detail the information contained in a draft vulnerability assessment report provided to participants. The lead author of the report was A Morison. Group exercises stepped participants through the results with the aim of building on this preliminary assessment through the inclusion of their expert advice. Participants worked in these groups to review and where necessary revise the vulnerability assessment scores (Appendices D and E), and then used this information to develop summary statements (Appendix F) in accordance with the instructions in Appendix G.

The approach adopted for the vulnerability assessment is illustrated below and follows the exposure/sensitivity/adaptive capacity framework widely used in climate change vulnerability assessments. Participants considered the level and certainty for each variable. A scoring guide and instructions on developing summary statements were provided to participants.



The figure above shows the relationship between exposure and sensitivity to potential climate change impact and influence of adaptive capacity in determining vulnerability.

Workshop outputs have identified which species are likely to be most strongly affected by projected changes in climate, and which climate change variables are likely to make these species vulnerable.

Issues arising from the vulnerability assessment included the need to give greater consideration to any potential positive opportunities (at least in the short term) for species or habitats as part of the vulnerability assessment. Some participants suggested ways to revise the vulnerability assessment framework and these will be considered in finalising the vulnerability assessment report and other project outputs. Some issues were also raised about terminology and will be further considered in finalising the report and other project outputs.

The summary statements (as written by participants) are captured in Appendix F of this workshop report (intended audience = workshop participants). The project team then propose to develop statements covering any gaps and also to consider how to cover the low vulnerabilities. Then we will edit statements for consistency/simplify if necessary and incorporate into the vulnerability assessment report and future communications (intended audience = broad).

Populating the risk matrix

An earlier project workshop (in March 2011) trialled and supported the use by the project of a tool known as the Climate Risk Management Matrix (Cobon et al. 2009). This matrix tool is an effective approach for stakeholder and expert engagement in climate change adaptation planning for primary industries. The current project is the first case study applying this tool in an Australian fishery. Participants at the July workshop provided input to a Climate Risk Management Matrix for the trawl fishery.

Participants developed a set of matrix headings capturing key organisational elements for the fishery (Appendices H and I).

For the matrix exercises, the fishery region X species groupings considered were:

- North of 16 degrees S: tiger/endeavour/blue-legged/red-spot/Moreton Bay bugs
- Central between 16 and 22 degrees S: red-spot/tiger/banana/endeavour/scallops/Moreton Bay bugs/blue-legged
- South of 22 degrees S: eastern king prawn/scallops/Moreton Bay bugs/banana/tiger/Balmain bugs

Participants then worked in groups to populate matrices for the fishery (Appendix J).

Workshop outcomes

The key outcomes from the expert workshop were:

- A refined Ecological Vulnerability Assessment to Climate Change for key species and ecological components in the ECOTF.
- Matrices which identify climate change impacts on specific elements of the ECOTF.
- An understanding of how this information will feed into future adaptation planning activities later in the project.
- Greater understanding of climate change considerations for the ECOTF relevant to each participant's situation.

Evaluation of the workshop

A workshop evaluation form was completed by many of the participants and the overall feedback was positive (details are provided in Appendix K). The mix of participants at the workshop was considered to provide the right expertise and knowledge for the work undertaken.

Where to next

Workshop outputs will be considered by managers, industry and scientists in the ongoing adaptation planning work for the fishery. As the project progresses there will be opportunities for wider stakeholder involvement in the project, and a greater focus on socioeconomic implications and adaptation options for the industry. In particular, the intention is that outcomes from this workshop will be used as a key input into several future workshops to be held regionally later in 2011-2012. The purpose of these workshops will be to extend this information, which is focused on resources and productivity, to industry and other stakeholders and then obtain their input into the development of:

1. a broader understanding of the associated social and economic risks or opportunities, and
2. options to assist the ECOTF adapt to these identified risks or opportunities.

This project is the first phase of adaptation planning for the trawl fishery, and is due for completion in 2012. The project has received funding under the Great Barrier Reef Climate Change Action Plan 2007-2012, and from the Queensland Department of Employment, Economic Development and Innovation (now DAFF) and the Queensland Climate Change Centre of Excellence.

List of Appendices

Appendices A and B are provided below. The other appendices to the workshop report (available on request) provided the detailed expert workshop outputs but are not included here:

A. Workshop agenda

B. List of participants

C. Combined experience of group

D. Group outputs from vulnerability assessment exercise

E. Revised summary of vulnerability assessment scores

F. Summary statements regarding climate change vulnerability

G. Instructions given to participants for developing summary statements

H. Output from group discussion to identify ECOTF Matrix Organisational Elements

I. Prioritised Key ECOTF Matrix Organisational Elements identified for matrix discussion

J. Group outputs from Climate Risk Management Matrix

K. Workshop evaluation and feedback

L. Questions requiring follow up

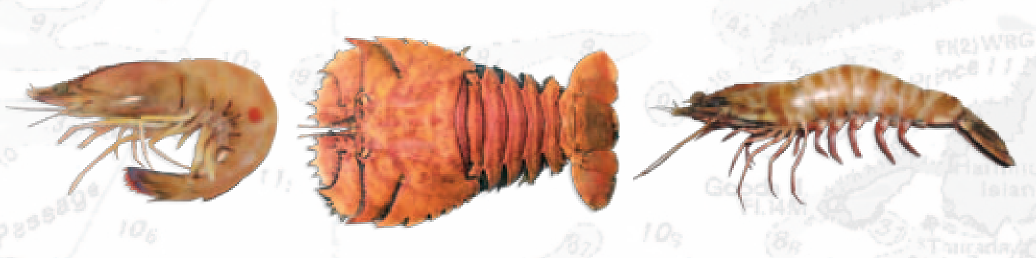
APPENDIX A TO WORKSHOP REPORT: WORKSHOP AGENDA

Agenda – Day 1	
Time	Activity
9.00 – 9.15	**Convene for tea/coffee**
9.15 – 9.40	Welcome/Introductions/Roadmap
9.40 – 9.55	ECOTF Project outline – Rachel Pears
9.55 – 10.20	Marine Climate Change Projections – Vanessa Hernaman
10.20 – 10.30	Ocean Acidification – Vanessa Hernaman
10.30 – 10.45	Questions and Discussion
10.45 – 11.15	**Smoko**
11.15 – 11.40	ECOTF Vulnerability Assessment Report – Sandy Morrison
11.40 – 12.00	Discussion/Clarification of vulnerability assessment
12.00 – 12.45	Small group discussion to review vulnerability assessment
12.45 – 1.20	**Lunch**
1.20 – 2.30	Group work continued to finalise review of vulnerability assessment
2.30 – 2.50	Define regional scope of the impact assessment and grouping of species - Eddie Jebreen
2.50 – 3.20	Discussion to define key fishery elements – Neil Cliffe
3.20 – 3.50	**Smoko**
3.50 – 4.50	Group work to populate risk matrix
4.50 – 5.00	Reflection on the day…
5.00	Day 1 close…

Agenda – Day 2	
Time	Activity
8.30 – 8.40	**Convene for tea/coffee**
8.40 – 9.00	Reflect on yesterday… Are we achieving our stated purpose…?
9.00 – 9.15	Speed presentation – Northern Fisheries Project and Climate Change Impacts on Barramundi Productivity Project – Julie Robins
9.15 – 10.30	Group work to continue to populate risk matrix…
10.30 – 11.00	**Smoko**
11.00 – 11.30	Compare and contrast matrices from other groups…
11.30 – 12.00	Plenary discussion to review progress on matrices…
12.00 – 12.30	Continue to populate matrices
12.30 – 1.15	**Lunch**
1.15 – 1.30	Speed presentation on Atlantis modelling – Vanessa Hernaman
1.30 – 2.30	Finalise input to matrices
2.30 – 3.00	Check review of matrices
3.00 – 3.20	Where to from here? (Collation of material and regional workshops)
3.20 – 3.30	Workshop evaluation
3.30 – 4.00	**Smoko, Thanks and Goodbyes!!**
4.00	Workshop close

APPENDIX B TO WORKSHOP REPORT: LIST OF PARTICIPANTS

Name	Organisation
Neil Cliffe (main facilitator)	DAFF
David Cobon (facilitator)	QCCCoE/DERM
Grant Stone (facilitator)	QCCCoE/DERM
Vanessa Hernaman (facilitator)	QCCCoE/DERM
Eddie Jebreen	Fisheries Queensland, DAFF
John Kung	Fisheries Queensland, DAFF
Anthony Roelofs	Fisheries Queensland, DAFF
Brad Zeller	Fisheries Queensland, DAFF
Richard Taylor	Trawl Industry
Steve Murphy	Trawl Industry
Geoff Tilton	Trawl Industry
Nick Schultz	Trawl Industry
Clive Turnbull	Northern Fisheries Centre, DAFF
Rob Coles	Northern Fisheries Centre, DAFF
Tony Courtney	Agri-Science Queensland, DAFF
Michael O'Neill	Agri-Science Queensland, DAFF
Ryan Donnelly	Pro-vision Reef
Chloe Schauble	GBRMPA
Rachel Pears	GBRMPA
Sandy Morison	Consultant
Eric Perez	QSIA
Sian Breen	WWF
John Beumer	DAFF
Julie Robins	DAFF



This vulnerability assessment report is available at www.gbrmpa.gov.au