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CLIMATE ADAPTATION FLAGSHIP

Development and Testing of a National Integrated Climate Change Adaptation Assessment Framework

Vincent Lyne (*Principal Investigator*), **Tim Skewes, Donna Hayes, David Brewer, Roger Scott, Rick Porter-Smith**

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Important disclaimer

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Non Technical Summary

This is the final report for the Department of Agriculture, Fisheries and Forestry (DAFF) funded FRDC (Fisheries Research and Development Corporation) Project 2009/055 conducted under the South Eastern Australia Program as Project 4.1. The framework and associated tools to implement an Adaptation Framework for fisheries and aquaculture impacts arising from climate change are presented, and example applications are provided for the South East Australia region. The framework and tools are applicable across other regions of Australia and further testing is recommended to refine and extend the tools developed here, as well as to provide a consistent national assessment of vulnerabilities and adaptation.

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

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

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

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

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

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

The key findings for the South East are reported under the two phases of the study: (1) The vulnerability assessment of bioregions and species to determine projections of future impacts from climate change - using the Business As Usual scenario as a baseline, and (2) The adaptation assessment framework based on scenarios of climate change to identify regional and sector specific adaptations and linkages.

1.1 Vulnerability Framework and Testing

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

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

1.2 Adaptation Planning and Testing

South East Australia was found to be a global “hotspot” for climate change undergoing a “regime shift” involving broadscale changes to environments upstream of the East Australia Current and associated ecosystems. Signs of change were noticed in mid-1990’s when the longspine urchin was making its way from New South Wales (NSW) across Bass Strait. The effects of the urchin on shellfish stocks off the east coast are now in part offset by a lucrative industry exploiting the urchin for its roe which is exported as a delicacy to South East Asia. Range changes to marine species were documented by Last et al (2010). Climate change trends here are much higher than the global average due to both temperature changes and changes to the East Australia Current system driven by southward shifting wind systems (Cai et al., 2005). Compounded with the climate change are decadal oscillations which led, during the hot summers of 1998-2000, to the collapse of a major aquaculture operator. Aquaculture now is a sophisticated industry that is attempting to outpace climate change through selective breeding, better management of rearing, feeding and pests, and long-term planning of infrastructure (Batteglene et al., 2011).

South East Australia is therefore facing significant challenges both in understanding the vulnerabilities and in identifying adaptation options and the changes that are required in current ‘Business As Usual’ practices to enable the adaptations to take place. Benefits may be possible for aquaculture for such species as oysters, mussels and other shellfish while also providing opportunities to establish new industries around invading migrants such as the longspine urchin. At the same time, there has been a decline in the recruitment of the lucrative rock lobster, and problems with the spread of an abalone virus.

Application of the adaptation component of the framework to the South East showed that shifting ecosystems will affect fisheries management based on existing spatial jurisdictional boundaries. At a regional scale, regional management policies and decisions are needed to cope with changes in productivity, trophic relationships and habitats. Regional adaptation will require management to develop and enforce regional policies and to inform more local and sector-specific management and adaptation. Regime shifts are dynamic in scale and intensity and poses serious challenges for stable management practices and industry operations, and the cascade of risk from regional to local scales, as well as the potential for local problems to spread to regional scale (such as the spread of diseases, pollution-related issues and socio-economic dependencies). While these aspects are considered in the adaptation framework, it was not possible to assess their utility as bioregional management (as practiced in Western Australia; see: http://www.fish.wa.gov.au/Sustainability-and-Environment/Sustainable-Fisheries/Pages/Sustainable-Fisheries-Management.aspx) was not implemented in the South East. However we did identify the key regional issues that need to be addressed as a matter of urgency given the scale of changes in the region.

The adaptation framework links regional policies, initiatives and assessments to local assessments and observations. However, when model assessments are uncertain, adaptation must increasingly rely upon local observations as these may provide the most accurate advance warning of change, and hence the best opportunity for adaptation. For example, the response of some operators implementing higher voluntary size limits and voluntary reef closures in the Victorian Abalone Fishery suggests that operators are responsive to changes in the stocks. Co-management arrangements where local decision choices are made by management working in tandem with operators is an adaptation approach that may work well for stocks that have strong spatial structuring in their response to fishing, and presumably to climate change.

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

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

Finally, the study recommends the urgent need to implement the adaptation framework in South East Australia to investigate adaptation strategies and to assess feasible options.

In summary, the framework and tools presented here offer a structured and relatively comprehensive treatment of the complexities of adapting to the impacts of climate change, and builds upon the advanced nature of fisheries assessment and management in Australia. The critical additional challenge posed by climate change impacts, in the form of a regime shift, is the need for regional assessment and management processes, which so far has primarily been the ambit of Commonwealth conservation agencies administered through the EPBC Act. Under the more severe forms of climate change scenarios, guidance at the regional level is required on ecosystem and fisheries management. Finally, the tools developed from this project will provide a sound basis for collaborative and co-management approaches for assessing climate change impacts on fisheries not only in the South East but also in the other regions around Australia and internationally.

2 Introduction

South East Australia is widely recognised as a global hotspot where temperature and associated oceanographic water properties are trending at higher rates than the global average (e.g. Ridgway, 2007). The El-Nemo South East Australia Program (*"Adaptation of fishing and aquaculture sectors and fisheries management to climate change in south eastern Australia"*) is a concerted program of research aimed at understanding the nature of changes in this region and options for adaptation planning to manage risks to fisheries and aquaculture.

This is the final report on the adaptation assessment framework for Project 4.1 (*"Development and Testing of a National Integrated Climate Change Adaptation Assessment Framework"*) of the South-Eastern Australia Program.

Adaptation is a multi-faceted process involving a complexity of decision makers and those who influence decision makers. Our view in developing this framework is primarily that of a performance, or evidence-based, approach driven in the first instance by components of the ecosystem that are vulnerable to climate change, and which may impact fisheries and aquaculture. Thus we present a two-part description of the framework: (1) Assessing the vulnerabilities, and (2) Assessing adaptation strategies and decision choices to address the vulnerabilities, but at the same time taking into consideration the conservation, socio-economic, and other human factors that will influence the decisions/actions.

Before detailing the conceptual basis for the framework and tools developed to implement the framework, we first outline the nature of changes we have seen, and expect to see, in the South East and challenges that are posed for adaptation planning in this rapidly evolving region.

3 Background to Climate Change in the South East

As an example of the nature of changes and adaptation that are likely to arise, we briefly review aspects of relevance to this project of the invasion of the longspine sea urchin across Bass Strait to Tasmania as an indicator of regime shift processes occurring in South East Australia.

Anecdotal information on changes in the South East first came to light in the early 1990's when underwater dive observations showed longspine sea urchins (*Centrostephanus rodgersii*) heading south across eastern Bass Strait (Peter Last 1994, *pers comm.* was amongst the first to notice this change). Since those observations were made, this sea urchin has invaded eastern Tasmania, but has also spawned an export industry that supplies fresh chilled roe as a delicacy to overseas and small domestic markets (see for example: http://www.themercury.com.au/article/2010/05/17/146585_lifestyle.html).

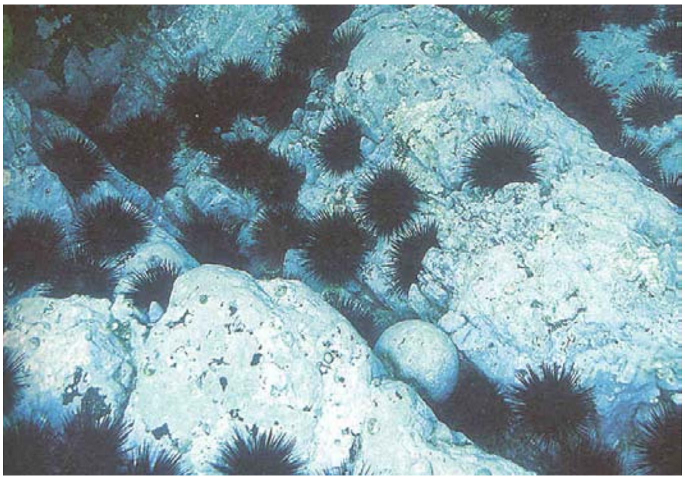


Figure 1 Image of *Centrostephanus rodgersii* **-** Black Spiny Sea Urchin from website at: http://www.woodbridge.tased.edu.au/mdc/Species%20Register/class_echinoidea.htm

While this invading species is a threat to lucrative existing shellfish industries - with flow-on impacts to other fisheries and the conservation sector - future concerns may revolve around management strategies similar to that for the existing commercial urchin fishery for *Heliocidaris erythrogramma* (DPIWE, 2005). Management measures for that fishery include limits on the size of the fishery, zone closures over critical periods and the introduction of Total Allowable Catch (TAC) principles to address latent effort and to maintain sustainable stocks. Impacts across other existing fisheries sectors such as predators species (southern rock lobster for example) will also need to be addressed.

A key questions raised by this invasion is to what extent adaptation planning could have helped ameliorate the considerable negative impacts of this species whilst taking advantage of the opportunity to establish a new industry. Likewise a key question is the future of this industry, and others, in the face of relentless progress in climate change which is predicted to extend the East Australia Current down the east coast of Tasmania (Cai *et al,* 2005).

In parallel to the evolving sea urchin invasion, research in the South East was spurred by long term observations at the Maria Island station which showed eastern Tasmanian waters warming at much higher rates than the global average (Lyne 2002, unpublished data – see Figure 2). Highest trends were observed during the autumn months corresponding to an increasing seasonal southward extension of the East Australia Current (also noted in Ridgway, 2007). Increasing anecdotal information of species and ecological changes led to a workshop in 2005 (Lyne *et al.,* 2005) where 30 scientists gathered to share information on their observations and analyses. Lyne *et al.* (2005) concluded that:

"... significant changes are underway in the Tasman Sea, with potentially widespread impacts on marine ecosystems and industries. Climate change models indicate that the Tasman Sea will continue to warm in the decades ahead. " These impacts will have flow-on implications for businesses, communities and economies that are dependent on the marine environment and its resources, such as the fisheries and aquaculture sector.

In an earlier related quantitative assessment of climate variability changes in the Southern Bluefin Tuna fishery, Lyne *et al.* (1999) concluded that changes were dependent on scale: *"Overall, the effect of environmental factors is scale-dependent; at scales involving regional variations in water masses, SOI-related effects are significant whilst at smaller scales, the structure of the water mass influences the consistency of catch rates."* Collectively, these studies point to changes in fisheries occurring at a number of scales from regional to local and evolving over decades into the future.

In a follow-up study of results presented at the 2005 workshop, Last et al. (2011) detailed changes seen in the fish fauna of temperate seas of south-eastern Australia. They concluded that: *"In more recent times, there have been major changes in the distribution patterns of Tasmanian fishes that correspond to dramatic warming observed in the local marine environment. "*, At a community scale, they also concluded that of the rare and unlisted species recorded, "*seven are Peronian species that are dominant members of a fish assemblage normally associated with barrens formed by the longspine sea urchin (Centrostephanus rodgersii)*". In other words the conclusion is that invasive species may lead to alterations in the community and by implication, trophic, dependencies at invaded sites.

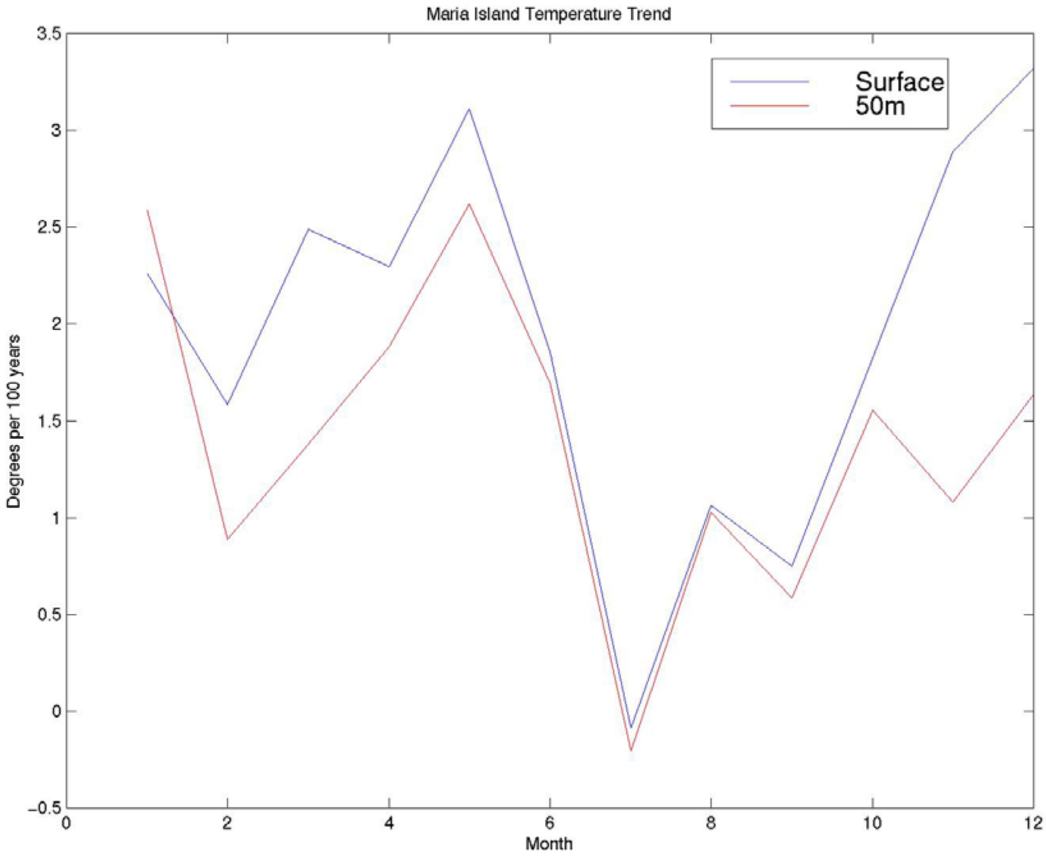


Figure 2 Long term temperature observations from Maria Island - an offshore monitoring station maintained by CSIRO (and recently by IMOS) since about 1940. This plot shows the

slope of the warming trend by month (thus, a trend parameter of zero is a constant level , i.e. no warming trend). With the exception of July, all months show warming trends of over 0.5 degrees per 100 years with a mean value of some 1.5 degrees per 100 years. Figure from Lyne 2002, unpublished.

These results reflect earlier conclusions reached at the south east climate workshop (Lyne *et al,* 2005): *"Changes in the distribution of a wide range of organisms have also been observed in recent decades in south-east Australia. While the biological records are often incomplete or discontinuous, the fact that changes in species distributions have been observed across a wide range of taxa (including fish, crustaceans, marine pests, algae and phytoplankton) suggests the ecosystem changes are linked to changes in the physical environment. Many of the changes are consistent with the hypothesis that the EAC extension is carrying more subtropical water (and subtropical species) poleward along the south-east coast of Australia. In addition to the long-term trend, a number of fisheries and ecosystem time-series show quasi-periodic cycles that appear to correlate with variations in physical variables in the atmosphere and ocean. Marine ecosystems, and the industries that depend on them, need to adapt to the combination of a long-term warming trend and multi-year cycles."*

Taking all of these studies into consideration, there is a clear implication that changes have occurred, and will continue to occur, at a regional ecological level as well as at local scales and at the species level. Interactions across fisheries may be linked via changes to environments of the type formed by, for example, sea urchin barrens, and by implications these changes may also reflect concerns at the conservation level. Such issues form the basis for the bioregional approach advocated in this project and these analyses can aid more focussed assessments of individual fisheries.

Key lessons from the longspine sea urchin invasion are summarised as follows:

1. Early anecdotal observations should have served as an early warning. Looking to the future we need processes in place for researchers and management to act on early warning information. The RedMap project (www.redmap.org) is one such current initiative that could be developed to serve this purpose; a number of information systems exist but these are not linked closely to management or research. A much more coordinated and integrated approach is required to recognise early changes and to link these through to assessments used by management.
2. Much later on (about a decade after initial observations) when information from long term monitoring stations and observations across a range of taxa showed scattered evidence of environmental and ecological changes, still no process existed to act on the information. Many of the changes were considered negatively, yet opportunities were clearly present. With time the negative impacts are likely to outweigh any early opportunities to take advantage of the situation and to potentially arrest, or control, more damaging future impacts.
3. The nature of change which was(is) occurring was not resolved well but some studies were indicating that changes were scale dependent with a strong seasonal signal associated with stronger extensions of the East Australia Current (EAC) into Tasmanian waters. Climate models are predicting that the EAC will indeed extend down the coast of Tasmania, which will result in a dramatic change in the environment and ecosystems off Tasmania.
4. The reactive response of the industry and management is not well documented or coordinated, and the evidence to date suggests that changes will continue for the next few decades at least. Thus there is a critical need for a concerted and coordinated response by researchers working alongside managers.

3.1 Project Outcomes and Outputs

The longspine sea urchin example points to the need for an integrated approach to adaptation that involves a genuinely integrated process of information monitoring feeding into research and management processes that can evaluate the evidence and risks, and act appropriately to treat those risks. These considerations form the basis of the key outcome of this project which is to develop an integrated, risk-based, adaptation framework that can be applied nationally and is to be tested in the South East.

The framework is presented and described in the next section (to be read in conjunction with accompanying Excel Workbooks (SEAP_bioregion_risk_V4_draft.xlsm and SEAP_species_risk_V4_draft.xlsm) together with procedures and examples for implementation which form the key outputs from this project - along with the description and guideline in applying the framework. This framework was tested and refined in the SEAP program but the tools should be applicable to other regions of Australia and with suitable modification (see later suggestions in report) to aquaculture.

While the framework is intended for application to the various regions around Australia, the specific outcomes of this project as applied within SEAP are:

1. Develop an integrated climate change adaptation assessment framework for fisheries and aquaculture, suitable for use regionally and at a national level.
2. Test and apply this framework in the south eastern region to evaluate adaptation response options for stakeholders (managers, fishers, aquaculturalists).

In this report we:

1. Outline the framework for the adaptation assessment process.
2. Describe the process used to derive the SEAP bioregions, including maps and region description.
3. Present the implementation templates for the vulnerability assessment.
4. Present worked example assessments for South East bioregions and species.
5. Present the framework and tools for adaptation planning and assess the use of the tools for example regions and species in the South East.

4 Adaptation Assessment Framework

The draft framework for the adaptation assessment previously presented as a milestone report (May 2009) is attached for reference with this report, and a summary of the key elements is presented in the Table below. For the purposes of this report, we focus on implementation tools of relevance primarily for Steps 3 to 6.

This framework has been developed to be applied to all marine regions and different priorities may apply in different applications of the framework. Thus, the tools presented in the following sections will need to be tailored to particular applications; experience in the application of the tools is essential to ensure that the assessments make best use of available information, models and expertise.

4.1 Summary of the Draft Framework

Activity	Description	Process
(1) Targets & Indicators	Operational definitions of adaptation targets (what is it that we are adapting to achieve)	Stakeholders and researchers articulate targets and indicators
(2) Information & Monitoring	Background information, model and monitoring of ecological components or services that are being impacted, to determine their state and dynamics	Researchers use indicators and work with stakeholder agencies in compiling available information, models and monitoring data
(3) Projecting climate exposures	Projecting trends of environmental and climate drivers (affecting ecological, socio-economic and managerial states) into the future	Stress variables are identified and climate modellers are consulted to produce relevant downscaled futures
(4) Projecting sensitivities and potential impacts	Projecting via models, the trajectories of ecological states into the future in response to trends in the climate drivers (3),	Potential impacts of stresses on key assets are evaluated for all plausible models
(5) Assessing vulnerability	Comparing future ecological states with desirable targets	For a given adaptation strategy, likelihood and severity of impacts are assessed across all models
(6) Evaluating adaptation strategies	Performance of adaptation strategies against sector, socio-economic and ecological outcomes are assessed. Process may be repeated to take account of key uncertainties.	Stakeholders and researchers conduct an integrated risk evaluation to assess performance of strategies against outcomes

5 Assessment Methods and Tools

5.1 Overall Approach

In this section we detail the methodology and tools for the vulnerability assessment and implications for adaptation. The approach entails defining the information and procedures to be used, the methods and tools for computing vulnerabilities and the outputs of the assessment process.

Following the discussion in the background, the approach we implemented assesses the cascade of climate change risks from regional scales (represented by bioregions – to be defined) which then provide context for risks acting on individual fisheries or aquaculture operations. Risks at the bioregion level provide context for overall risks from the ecological systems operating at regional scales, while the species-based risks are a combination of the ecological risks and risks to the species life history stages as illustrated in Figure 3.

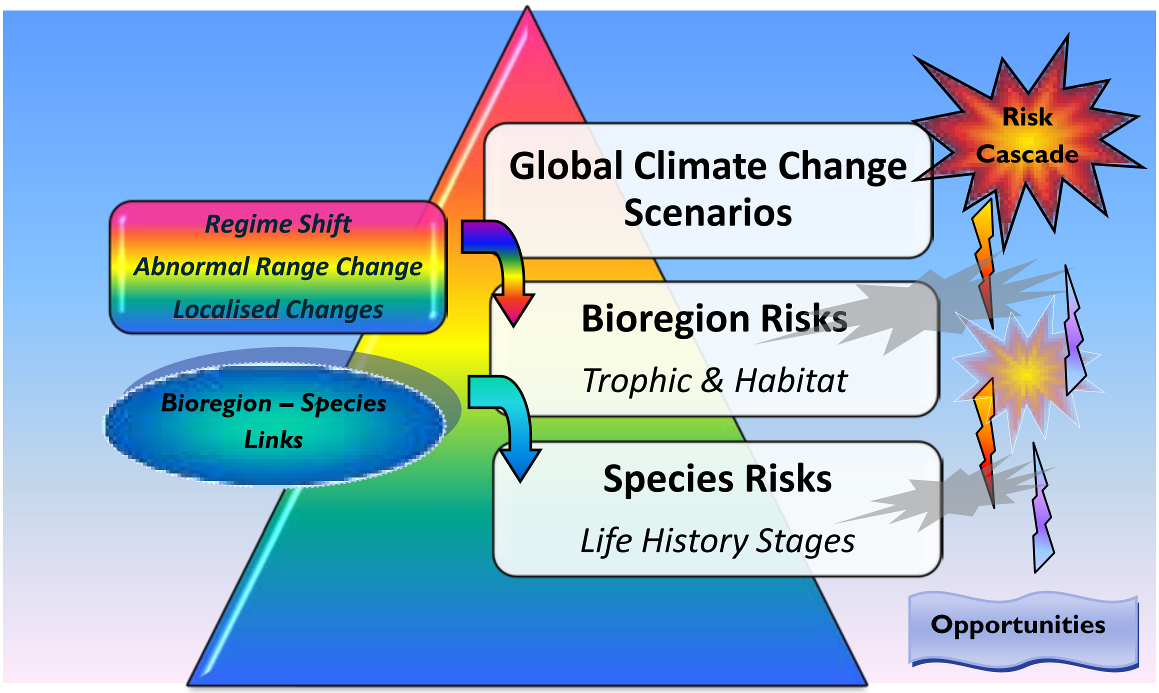


Figure 3 Illustration of the risk propagation framework showing the cascade of risk from global scales to bioregions to species. At left, a number of scenarios are possible for the Bioregion Risk ranging from a Regime Shift Scenario to Localised Changes. Links through a number of mechanisms provide context for Species Risks arising from the Bioregions. Opportunities may arise, for particular human and ecological groups, from changes in risks.

The selection of global climate change scenarios is the subject of other projects in the SEAP program so our focus here is primarily on the Bioregion Risk Scenarios and the tools to evaluate the flow-on of risks from the bioregions to species.

Thus, a three-step procedure is employed:

Step 1, Estimating the Bioregion Risk Scenario: Results from Global Climate Change modelling are coarse, but capable of providing at the broad regional level the scenarios that may affect bioregions. This information, together with reviews of the environmental and ecological changes (such as those presented in the previous section), will allow managers and researchers to assess the likelihood of the region being in one or more of the Bioregion Risk Scenarios in Figure 3. Note that due to the coarse scale of the model projections (generally at a grid scale of a half-degree or more in longitude/latitude) only the trend component is likely to be of value at the regional level. Details of these potential scenarios are the subject of one of the projects in the SEAP program.

Step 2, Estimating the Bioregion Risk: Bioregions as defined by IMCRA V4.0 (http://www.environment.gov.au/coasts/mbp/imcra/index.html) are used along with relevant depth zones updated as part of the Commonwealth Environmental Research Fund, Biodiversity Hub program (http://www.nerpmarine.edu.au/project/update-shelf-bioregionalisation). Two components of Bioregion Risk are evaluated: (1) Risks arising from potential climate change impacts to habitats, and (2) Risks arising from trophic dependencies - which are characterised here as flow-on impacts along the route from primary trophic components to secondary and then tertiary components. Thus, for example, impacts on primary prey components will affect predators in the next trophic level (secondary consumers). Overall Bioregion Risk is expressed as a combination of to habitats and trophic dependencies. Thus the output of this step is a potential overall impact trajectory for each bioregion.

Step 3, Estimating the Species Risk: Risks to species are assumed to comprise those for life history stages: (1) Eggs; (2) Larvae, (3) Juveniles, and (4) Adults, as well as risks arising from the habitat and trophic components relevant to each life history stage. Thus, for example, if a species' recruitment site is different to that of the adult stage, the risks for the relevant bioregions are used to qualify any climate change risk to that life history stage (in addition to direct physiological and other direct risks to that life history stage).

5.2 Key Assumptions and Considerations

While the spatial scale for analysis is the collection of bioregions in the Study region, existing information used for the example assessments are derived from gridded data produced by Global Circulation Models or regional climate simulations. These often have coarse resolution (0.5 degrees in latitude/longitude) compared to the width of bioregions (which can be very narrow, less than 1 km on the continental slope, for example). Under these circumstances, we assume - as a simple model of much more complicated sub-grid processes - that the overall trend in climate change variables is valid across smaller scales in the region under study. As shown by the example of Maria Island, discussed previously, enhanced seasonal excursions of the East Australia Current can lead to warming trends for some months and not for others; and in particular subregions of the Study region. Such influences, particularly seasonal ones, may affect spawning, recruitment and feeding cues with flow-on impacts to local and regional populations of species, communities and ecosystems. One option for dealing with such data limitations is the precautionary principle of assuming that exposures and sensitivities are rated at the maximum end of the potential rangse – this is the approach we advocate and use in this report. However where information is available on distributions of threats or drivers, we will weigh such precautionary assessments to estimate an overall impact.

For fisheries, a variety of spatial scales are also relevant. Each life stage may have different spatial occupancy and complications may arise from risks being assessed at various levels: for a local community resident in the bioregion, or across a number of bioregions; a subpopulation that may be adversely affected; or the population of the fishery represented by the adult range of the species. Considering all these factors, the spatial scope is taken in this Study to be defined as follows:

Fishery risk will primarily be assessed against impacts to populations in the bioregions of the study area which for the purposes of this exercise comprises the bioregions listed in Appendix A and illustrated by the maps in **Figure 4** ***and*** **Figure 5** ***(to be discussed later). Thus localised risks, even severe ones, will be scaled against overall risk to the fishery population contained in the bioregions of the Study. The ranking of risk will allow for potential severe localised impacts to individuals or schools in particular bioregions, but these will be subsumed within the overall risk to the fishery. In other words, there is no guarantee that "low risk" to the population will imply "low risk" to individuals or schools of fish, or subpopulations.***

Spatial scales were therefore considered separately for the different life history stages of each species, and their mapping to bioregions.

Trophic transfers were qualitatively assessed with respect to prey species, and for potential cascades of risks to higher trophic components. Thus, for a species at a particular trophic level, the impacts to prey species at the lower level was used to provide context for the overall risk.

Meta-population considerations (i.e., that the population will potentially contribute to overall species' health in the region) was considered when assigning impact.

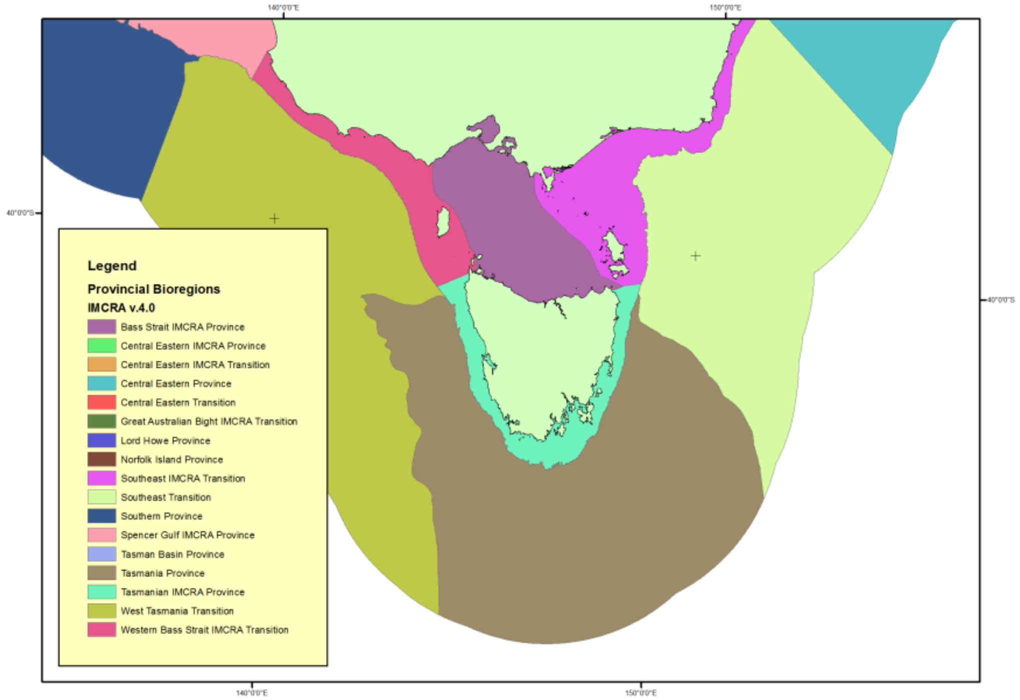


Figure 4 Provincial bioregions of the South East based on the IMCRA V4.0 characterisation (Commonwealth of Australia 2006). ***Note: the central Bass Strait province is included only for completeness and was not used in the impact assessments due to technical limitations with the bioregional data.***

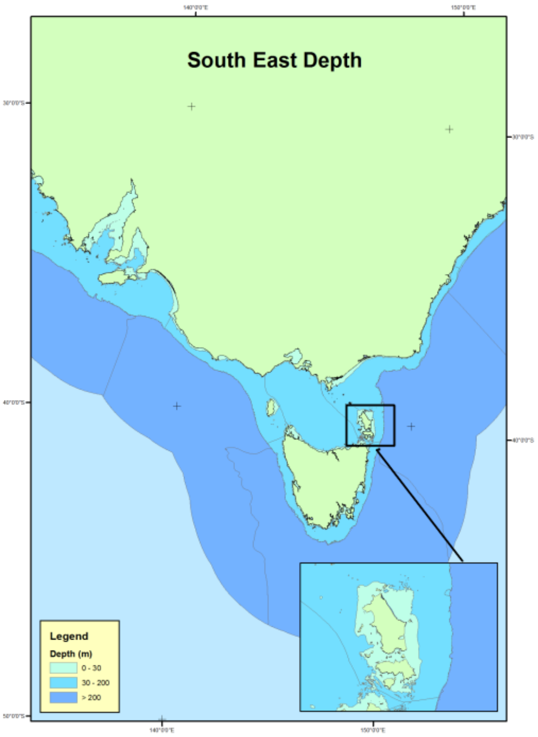


Figure 5 South East Bioregions developed from IMCRA v.4.0 and bathomes (0 - -30, -30 - -200, -200 to -2000m, shelf and slope and demersal). See Table 2 and Appendix A for definitions of bioregions.

Here again scales are set independently from climate change-related events in the bioregions, and those related to the fishery. Thus warming events in some bioregions could extend to interannual scales (Harris *et al.,* 1997) with impacts on fisheries (Harris *et al* 1998), or events could relate to a severe storm or hot weather spell. Likewise, fishery time scales range from short time scale interaction of various species, and their life stages, with components of the climate change events to times cales associated with flow-on impacts to fisheries from eggs and larvae being impacted by the events. In this latter case, effects on the population levels of fisheries may not be apparent until samples are taken or caught from adult populations, and back-dated recruitment estimates are made. Most difficult of all to quantify are accumulative impacts which may propagate through the food web before affecting a top predator. For the purposes of this study, we will assume that the relevant time scales are those associated with progression of impact events from the initial direct impact (on individuals or distributions of eggs/larvae) through to its ultimate impact on the population, including indirect impacts that arise from habitat impacts, accumulative impacts and trophic transfers.

Attribution

Apart from the case of obvious direct impacts, as for example, hot spells leading to deoxygenation affecting benthic species, questions will arise on how a number of other potential sources of risk may contribute to a measured impact. Confounding factors include those associated with the actual fishery operations affecting population levels of the fish species, pollution causing a range of health and potential mortality increases, particularly of coastal species. These additional stress factors may lower the threshold of resistance and resilience of the population to the added impacts from climate change. In our assessments we estimate the climate change risk independently before adding in additional risks that may arise from exogenous factors that are outside of the control of fisheries managers.

Risk criteria

For the purposes of this project, the primary risk criteria were assumed to be the risk to fishery population levels in the Study region (the South East – to be defined later). Other risks exist, such as mortality or sub-lethal effects due to individuals and schools subjected to extreme weather events. We did not address these risks and therefore no extrapolation of these assessments should be made beyond the ambit of the project's scope which deals only with potential impacts on population levels (for the species assessments). A further important limitation is that the study makes use of readily available information and expertise and therefore some estimates of risk are at best informed estimates, which may not be accurate or perhaps valid. Where uncertainty exists, we adopted the precautionary approach of increasing the risk towards what we consider the higher limit.

6 Risk analysis

In analysing the risks, we used a hybrid approach (Figure 6) that blended the risk assessment framework of the National Risk Assessment Guidelines (EMC, 2009) with the Exposure-Sensitivity-Adaptation capacity vulnerability framework used for climate change (IPCC, 2007). We used spatial maps of modelled projections of climate change variable to score the Exposure in Figure 6. We used the report by Pecl *et al* (2011) and expert opinion of researchers to score the species Sensitivities and to develop criteria for estimating the scale of impacts. In practice, these estimates will be agreed as outputs from planning workshops held with consultation with researchers, operators and managers. So, the estimates used in this report are not to be taken as being accurate or endorsed – they are assumed reasonable given the current state of knowledge and information, and are primarily for demonstration of the framework tools.

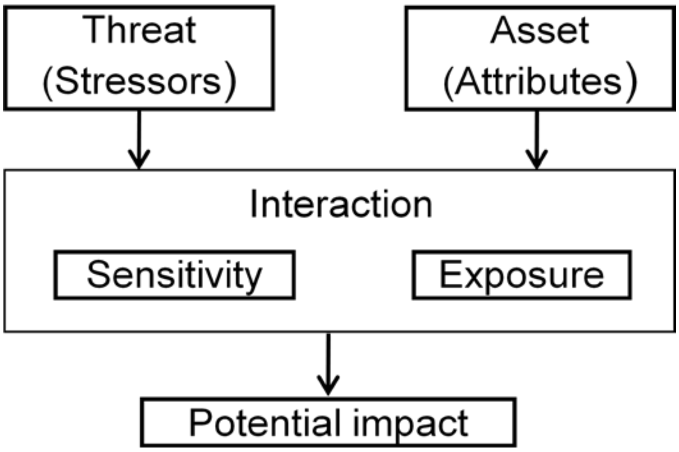


Figure 6. Exposure-Sensitivity-Adaptation risk assessment framework used in this study. Note, Sensitivity estimates implicitly consider the Adaptive Capacity (which is explicit in the IPCC approach).

6.1 Exposure

Exposure was scored as an index of the Quantum of Change (QC) relative to an extreme case scenario of impacts that might occur in 2100 for changes in each driver (i.e., the maximum scale of impact likely to correspond to the maximum change of the driver, relative to current baselines, experienced in the region in 2100). This QC was assumed to correspond to a maximum impact score, and earlier years are scaled relative to this extreme. So for example, a maximum expected temperature change expected in the region in 2100 is a rise of 4°C (relative to the period 1980-1999 - referred to as the 1990 baseline for convenience), and this may for argument sake correspond to a 50% decline in a species' population. Thus the QC in this case is a 50% population decline. If in 2050 a 2°C increase is experienced, we may estimate that this leads to half the QC change – i.e., a 25% decrease in population. Thus, for each climate change driver we estimate a QC scale against which the other years are assessed – a contrived example is shown in Figure 7.

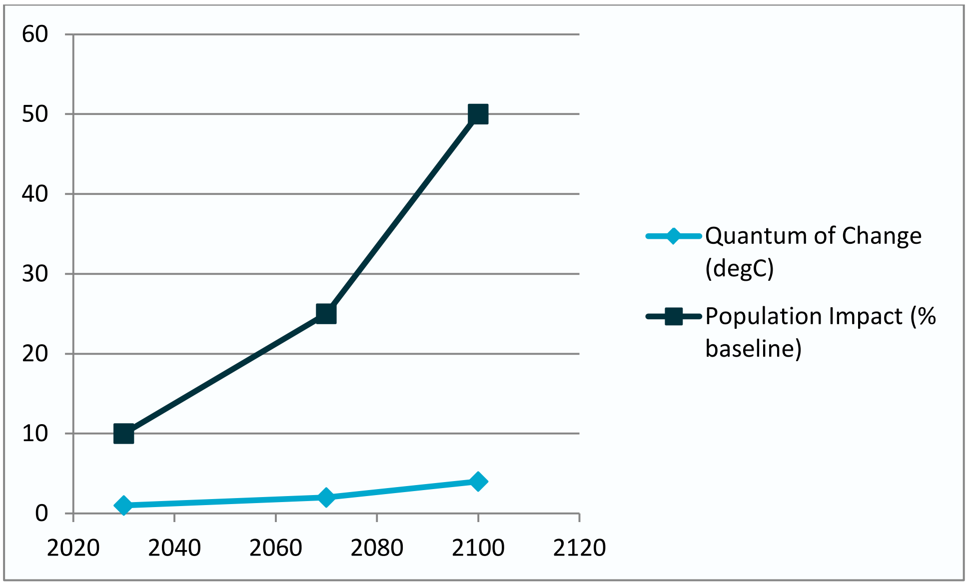


Figure 7 Example of the relationship between the Quantum of Change variable for temperature change in 2030, 2070, 2100 and the impact on population levels (impacts are % declines in population) of a hypothetical species.

The list of exposure variables considered for analysis included (as changes relative to the 1990 baseline):

1. Temperature as Sea Surface Temperature,
2. Rainfall,
3. Sea Level Rise,
4. Acidification,
5. Current patterns,
6. Wind Speed,
7. Storms,
8. Resource utilisation,
9. Land use (urban/industrial),
10. Pollution and contaminants.

Where possible we used published information to estimate the changes for 2030, 2070 and 2100 but for a number of these variables, we were unable to obtain appropriate information and either left them out or made educated guesses – these are described in the attached spreadsheets that accompany this report.

For Temperature, Rainfall and Wind Speed, we used projections from the Australian Climate Change website at: http://www.climatechangeinaustralia.gov.au/natsea34.php Projections from this site are shown below for the Low, Medium and High Emissions scenarios for 2030, 2050 and 2070. We used the best estimate provided by the 50th percentile projections and extrapolated, and interpolated, these to the years used in the analyses: 2030, 2070 and 2100.

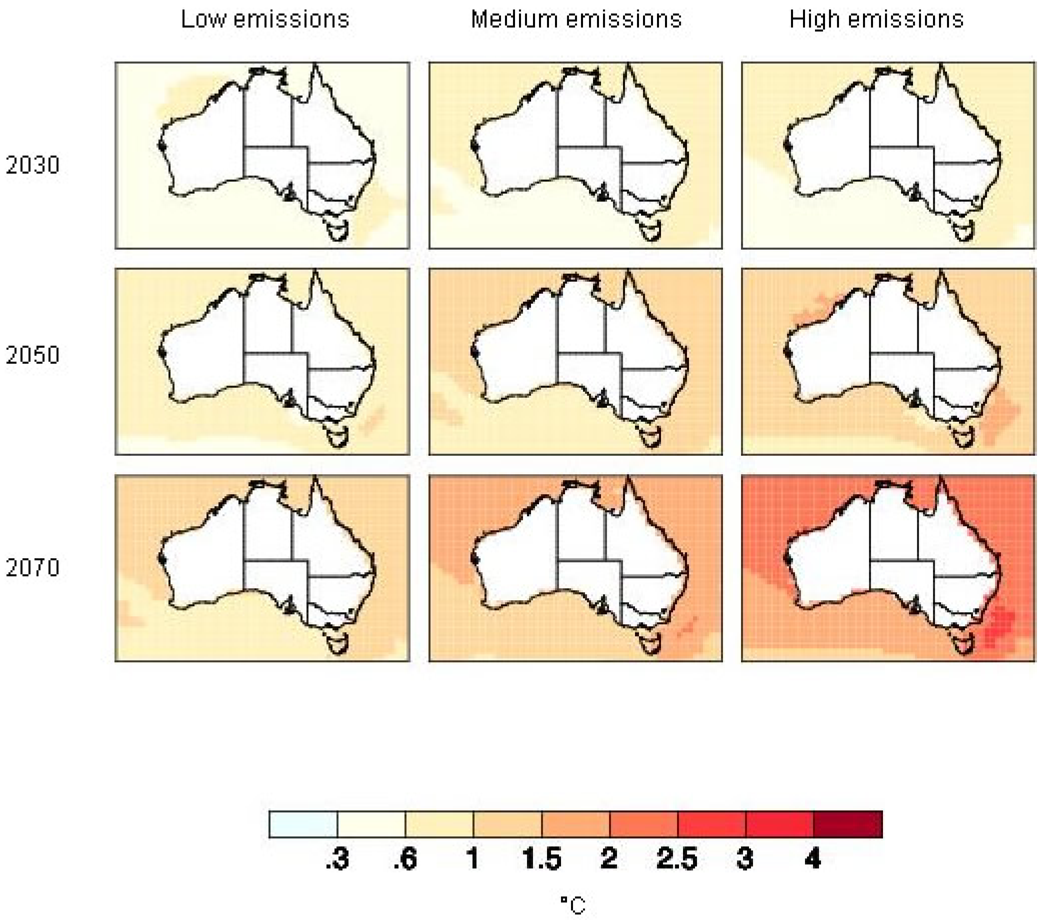


Figure 8 National Annual Sea surface temperature change 50th Percentile.

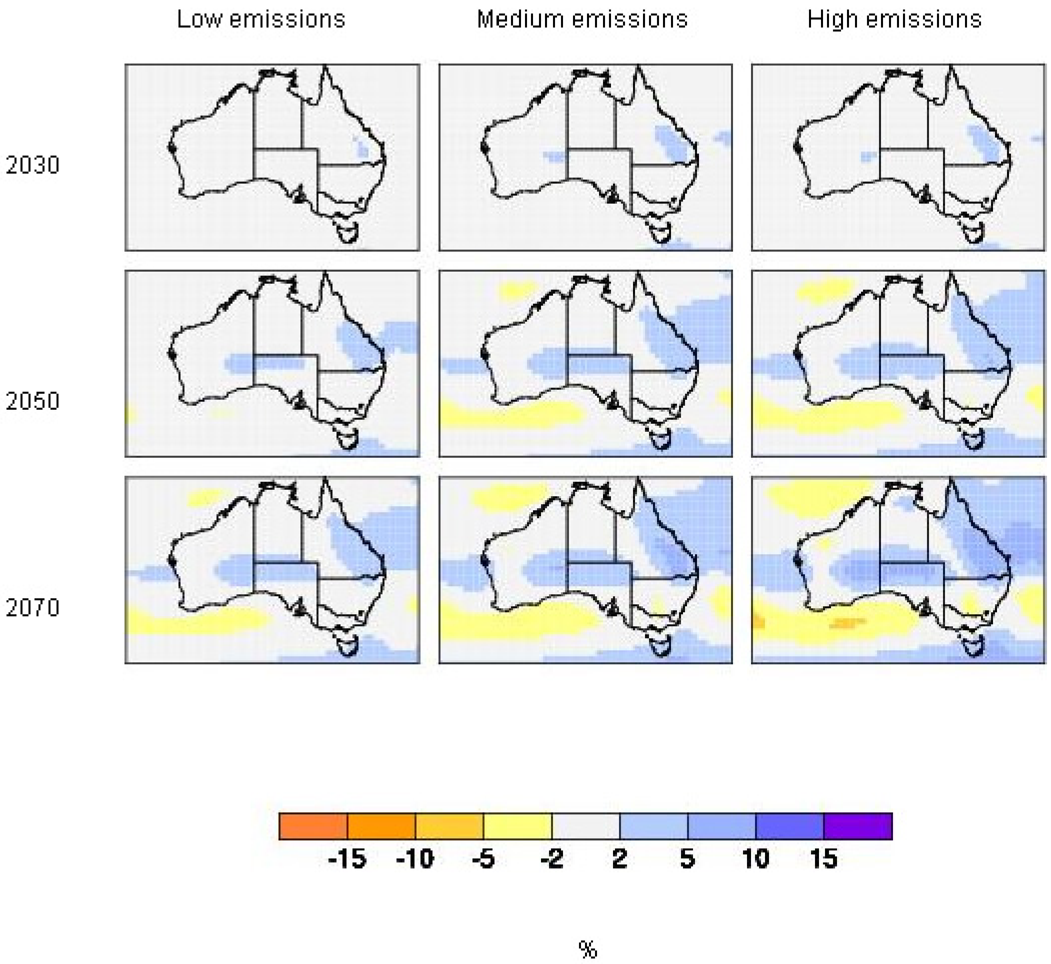


Figure 9 National Wind speed change 50th Percentile Annual.

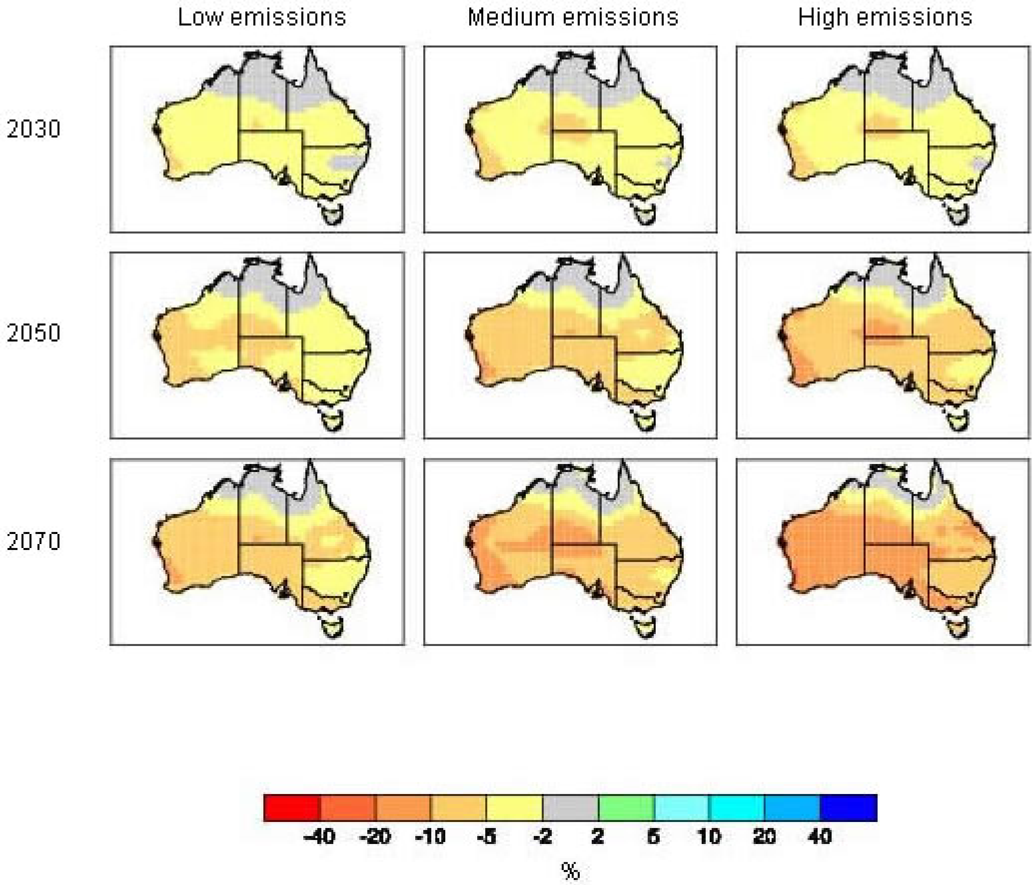


Figure 10 National Rainfall change 50th Percentile Annual.

We estimated other variables from internal workshops (CSIRO, Hobart. December 2011 and March 2012) of researchers with experience in climate change impacts on Australia's east coast fisheries and ecosystems. In practice, a participatory approach should be used to estimate the relevant variables from modelled projections, their changes and implication of these changes to exposures and potential impacts.

6.2 Sensitivity

Sensitivities were scored relative to the Quantum of Change for each of the Climate Change variables. For the Bioregion assessments, we used a database on Australia's fish fauna curated by the Australian Marine Biogeographic Information Network (AMBIN) group.

This database contains all fish taxa known to occur in the Australian EEZ. It was compiled from the species list from CAAB (Codes for Australian Aquatic Biota, http://www.cmar.csiro.au/caab) and attributed with a number of factors, including Trophic and Habitat (Substrate) affinities, which were used in the bioregion risk assessment. Habitat data for the whole of Australia at all depth levels does not exist, so by using the habitat affinities of fish we are in essence using the number of fish species that adhere to various habitats as a surrogate measure of the ecological relevance of that habitat. This is a key assumption, and of necessity it is an oversimplification of a complex set of relationships between species and habitat extents, and the relevance of habitats to ecological processes and fisheries population levels. However, the surrogate simplification is merely to highlight risks that may need more detailed assessments, or modelling, via tools such as the *Atlantis* modelling platform. And for simplicity, we also use impacts on the number of species that adhere to a particular habitat as a surrogate measure of impacts on that habitat in the bioregion being considered.

For the Trophic component of risk we remapped the AMBIN attributes into 3 categories:

1. Trophic, 1° consumers
2. Trophic, 2° consumers
3. Trophic, 3° consumers

We assumed that risks cascaded down the trophic chain. For example, a second degree predator would experience the risks to its prey in the primary consumer category and any other trophic risk arising from within the secondary consumers (that it might prey upon). In addition, positive changes might arise from negative changes to its predators at a higher level but we have to encode such links within the tools we have so far developed. Such feedback links would require much more trophic expertise and time to encode and are not included as part of the current assessments.

Table 1 Remapping of the AMBIN trophic attributes into primary, secondary and tertiary categories. Each AMBIN attribute was distributed across the new categories (and scaled to sum to 1.0)

	SEAP Categories		
AMBIN Categories	**1° consumers**	**2° consumers**	**3° consumers**
Detritivore	1		
Herbivore	1		
Invertebrate carnivore		0.8	0.2
Invertebrate carnivore/piscivore		0.2	0.8
Mammalivore			1
Omnivore	0.3	0.7	
Parasite			1
Phytoplanktivore	1		
Piscivore		0.2	0.8
Zooplanktivore		0.8	0.2

The habitat units that we used from the AMBIN database comprised:

1. Habitat, Reef
2. Habitat, Estuarine
3. Habitat, Flotsam
4. Habitat, Hard
5. Habitat, Macroalgae
6. Habitat, Macrobenthos
7. Habitat, Rocky
8. Habitat, Seagrass
9. Habitat, Soft

Sensitivities of these units to the Quantum of Change were estimated through an internal expert judgement process, as detailed in the accompanying spreadsheets. The number of species in each category is shown in the spreadsheets using the database as it existed in 2009. Since then, updates have been made to the database, which should increase the accuracy and number of species. Species numbers were low for the bioregions to the west of Tasmania, particularly western Tasmania so this area will require attention in future.

For the species risk assessment we split the fishery population into life history stages that had the potential to interact with climate change drivers in unique ways. Fishery life history stages included, Eggs, Larvae, Juveniles and Adults. Additional factors representing indirect impact pathways from the bioregion risk included, Trophic interactions and Key Habitats. For each fishery component, descriptions were required to assess sensitivities. These included:

- Pre-impact status and future trajectories (including exploitation levels, neighbouring fisheries, and Illegal Unregulated Unreported (IUU) catch);
- Supporting habitats;
- Trophic position (what does it eat that may be impacted, and what eats it);
- Drivers/threats (what are the drivers, other than climate change, that impact on the fishery component);
- Spatial extent (latitude, longitude and depth) and temporal dynamics (range, max, min, seasonality);
- Outputs (what are the outputs from the fishery component);
- Value statements;
- Data available (dataset, location, name), and uncertainty/information gaps.

Sensitivities here will reflect an established relationship between the biological/physiological responses of a fishery component to a physical aspect of the stressor, and as such is generally consistent across stressor ranges. However, the sensitivity will vary in terms of the reaction response curve (often non-linear), and variation in the composition of the fishery component. The QC approach was used here as well, and criteria for potential impacts are listed below (note positive sensitivities are the mirror image of the negative ones).

Sensitivity criteria	Life Stage Effect
None	Zero effect - high certainty based on studies and estimated stressor levels
Low (up to -0.3)	Zero effect most likely but uncertainty due to lack of studies and/or estimated stressor levels
Moderate (-0.3 to -0.7)	Potential for some adverse ephemeral effects at the scale of individuals or "small" groups based on studies and estimated stressor levels
High (-0.7 to -1.0)	A number of plausible scenarios of adverse effects at the scale of subpopulations based on studies and estimated stressor levels

A similar mapping was used for the bioregion sensitivity criteria with appropriate modification of “small” referring to the biomass and the number of species likely to be impacted.

6.3 Potential impact

The potential impact was estimated as the product of Sensitivity and Exposure. This produces a Potential Impact score for each bioregion, or species attribute-climate stressor interaction. These scores were placed in a matrix and the cumulative impact was summed across the row for each component, while the score across the columns was the added impact for each stressor component. Overall impacts were then expressed as the average of cumulative impact risk for all considered stressors on all fishery components. Risk matrices for individual fisheries are shown in the accompanying spreadsheets. Weightings for the risk were computed for the bioregions from the total number of species in the South East bioregions. For the life history stages, a number of options are available for weighting the impact scores, such as for example, the total area of bioregion in which each of the different life history stages are found (the mapping of species to bioregion is included in the species risk assessment spreadsheet, but we did not proceed to use the bioregion area as a potential weighting factor, although this is possible as an update to the current analyses).

7 Development of South East SEAP Bioregions

Bioregions for the southeast were developed with IMCRA v.4.0 (Commonwealth of Australia 2006), which is a combination of the Interim Marine and Coastal Regionalisation of Australia IMCRA v3.3 (Interim Marine and Coastal Regionalisation for Australia Technical Group 1998), which is a marine regionalisation of shelf/inshore waters, and the 2005 National Marine Bioregionalisation (Department of the Environment and Heritage 2005) for off-shelf waters. These bioregions were further divided using the bathomic structure (see Table 1 and Lyne *et al.* 2009) to obtain the bioregions used in this report.

The shapefiles (SE_bioregion2000.shp) for the SE bioregions were developed with ESRI ArcMap 10. For the analyses reported here we used the "SEAP 4.1 Bioregion" bioregion units. The depth zonation structure (bathomes) is illustrated in Figure 11.

Table 2 South East Bioregions derived from IMCRA v.4.0 and 30m, 200m and 2000m bathymetry.

	IMCRA v.4.0	**Province Name**	**SEAP 4.1 Bioregion**	**Depth Structure**
NERITIC	36	Tasmania Neritic Province	Tasmania Coastal	0 - 30
			Tasmania Shelf Epipelagic	0 – 200
			Tasmania Shelf Demersal	Near Bottom
	38	Central Eastern Neritic Province	Central Eastern Coastal	0 - 30
			Central Eastern Shelf Epipelagic	0- 200
			Central Eastern Demersal	Near Bottom
	37	South East Neritic Transition	South East Coastal	0 - 30
			South East Shelf Epipelagic	0 - 200
			South East Shelf Demersal	Near bottom
	35	Bass strait Neritic Province	Bass Strait Coastal	0 - 30
			Bass Strait Shelf Epipelagic	0 - 200
			Bass Straight Shelf Demersal	Near Bottom
	34	Western Bass Strait Neritic Transition	Western Bass Strait Coastal	0 – 30
			Western Bass Strait Shelf Epipelagic	0 - 200
			Western Bass Strait Shelf Demersal	Near Bottom
	33	Spencer Gulf Neritic Province	Spencer Gulf Coastal	0 – 30
			Spencer Gulf Shelf Epipelagic	0 - 200
			Spencer Gulf Shelf Demersal	Near Bottom

OCEANIC	8	Southern Province	Southern Ocean Epipelagic	0 - 200
			Southern Ocean Interior	200 -2000
			Southern Ocean Slope Demersal	Near Bottom
	37	West Tasmania Transition	West Tasmania Ocean Epipelagic	0 - 200
			West Tasmania Ocean Interior	200 -2000
			West Tasmania Slope Demersal	Near Bottom
	11	South East Transition	South East Ocean Epipelagic	0 - 200
			South East Ocean Interior	200 -2000
			South East Slope Demersal	Near Bottom
	12	Central Eastern Province	Central Eastern Epipelagic	0 - 200
			Central Eastern Ocean Interior	200 -2000
			Central Eastern Ocean Demersal	Near Bottom
	10	Tasmania Province	Tasmania Ocean Epipelagic	0 - 200
			Tasmania Ocean Interior	200 -2000
			Tasmania Slope Demersal	Near bottom

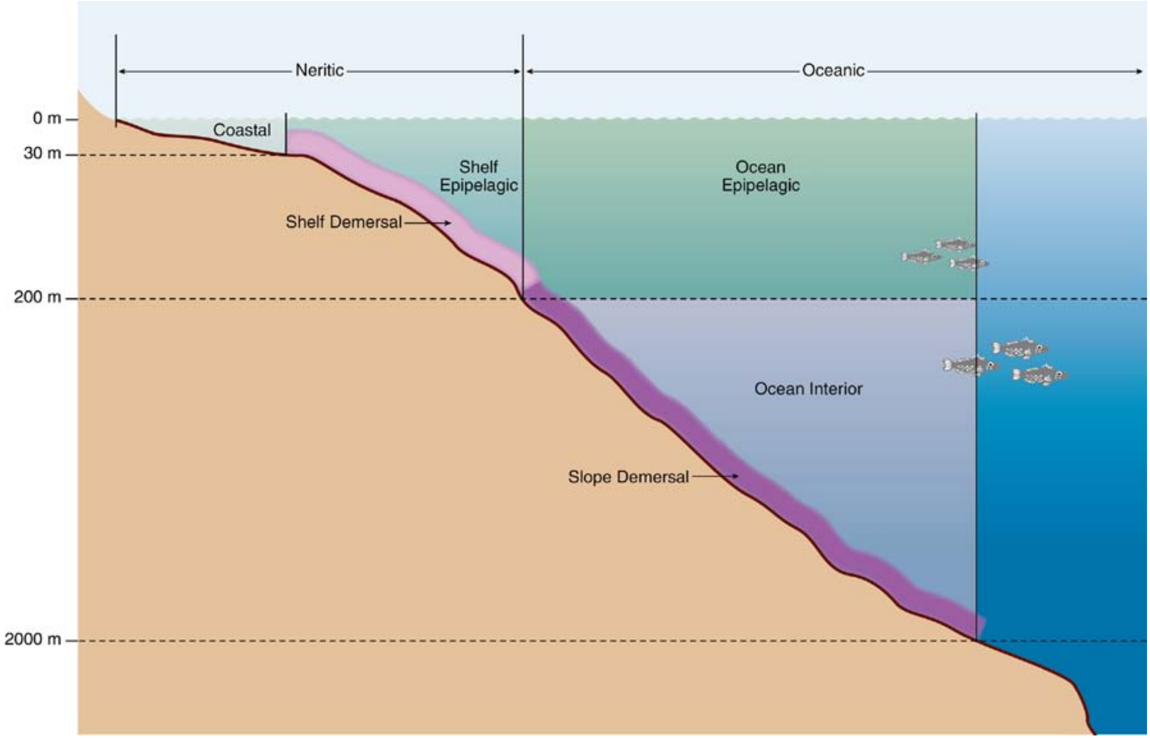


Figure 11 Schematic of the bathomes illustrating the SEAP bioregion names for the coastal, shelf and slope zones (not to scale).

The depth structures used are illustrated in Figure 12 and described in a Table in Appendix A .

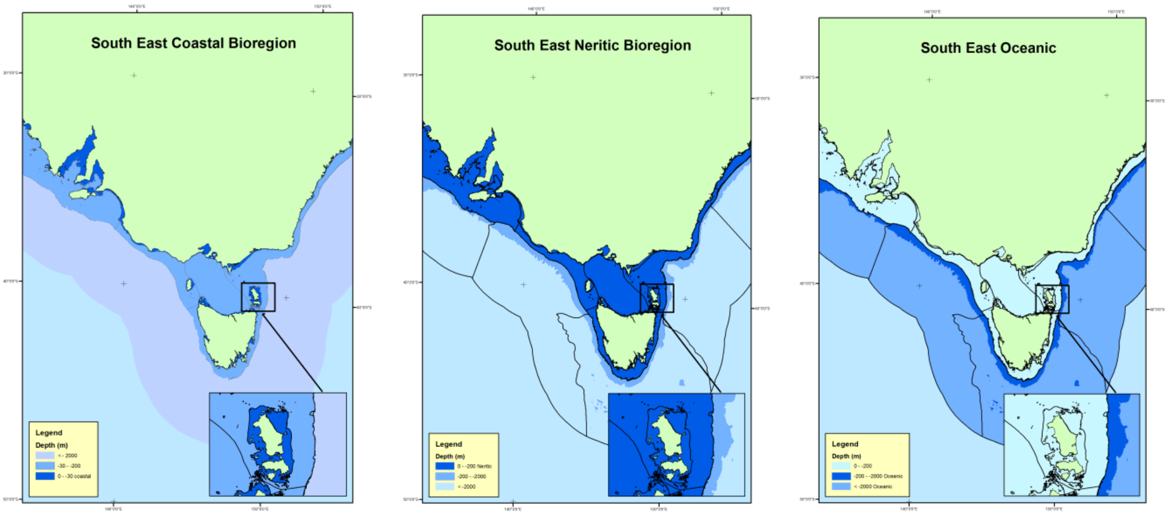


Figure 12 Depth structuring showing the Coastal region (0 - -30m) (far left plot), the Neritic region (0 - -200m) (central plot) - this region is further divided into Shelf Epipelagic and Shelf Demersal), and the Oceanic region (-200 to -2000m) (far right plot) - this region is further divided into Ocean Epipelagic, Ocean Interior and Slope Demersal.

8 Case Studies and Discussion

Two spreadsheet examples accompany this report:

(1) A bioregion assessment example that assessed potential impacts to the Habitat and Trophic components of the bioregions to various climate change stressors as well as exogenous stressors discussed in the Exposure section of this report, and

(2) A species example using Snapper (*Pagrus auratus)* based on descriptions and assessments provided in the Pecl *et al* (2011) report. We refer the reader to this report for details on the species. A key reason for choosing this example species is to explore both negative and positive changes, as this species currently does not reside in Tasmanian waters and there may be potential for its migration in future years. This aspect illustrates the utility and scope for applying the bioregional approach to investigate dynamic aspects of species from changes to their environmental envelope.

8.1 Bioregion Example

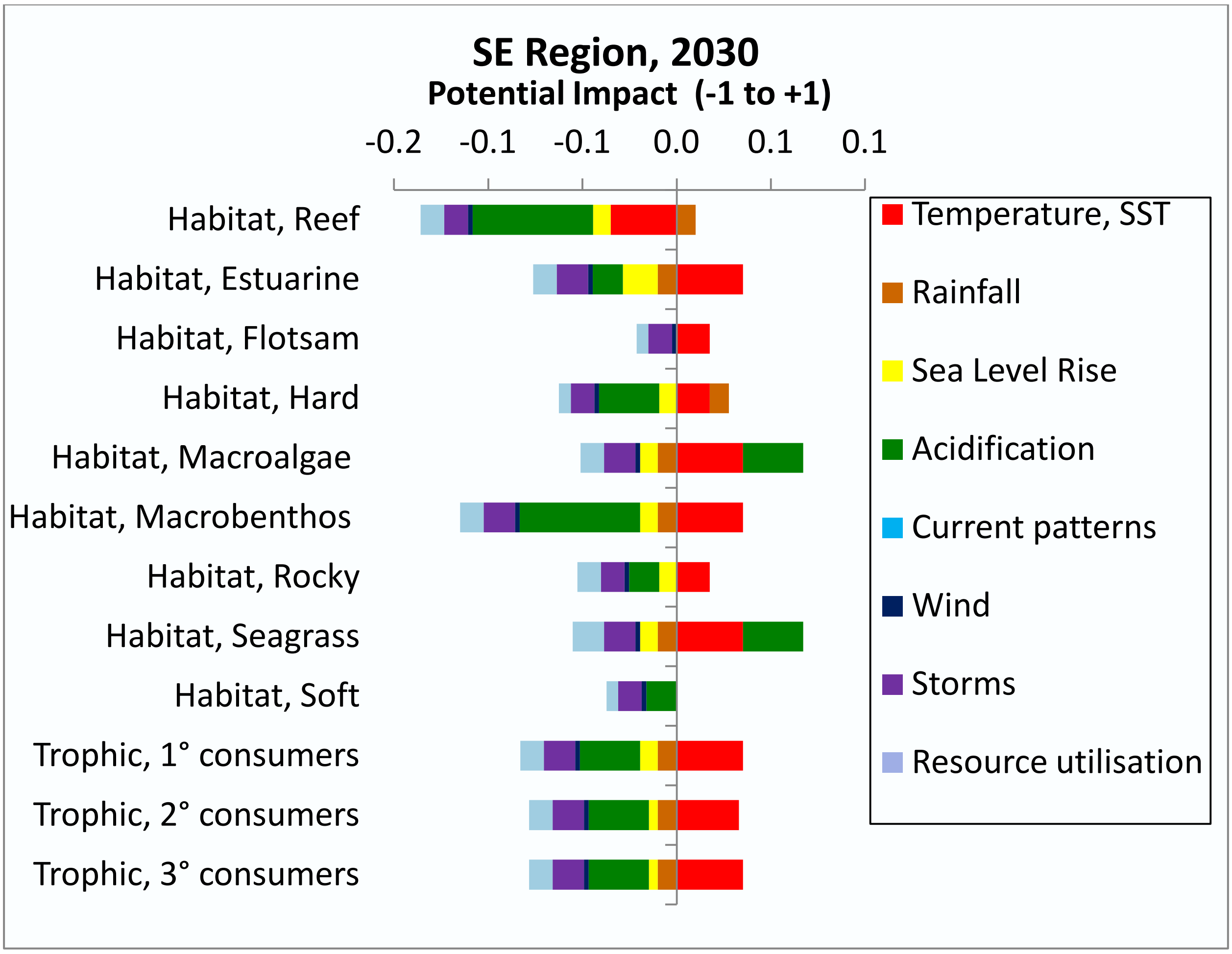
Potential impact and weighted impact scores are plotted in the following figures for each of the years: 2030, 2070 and 2100 (for full details, please refer to the accompanying spreadsheets) along with a spatial summary.

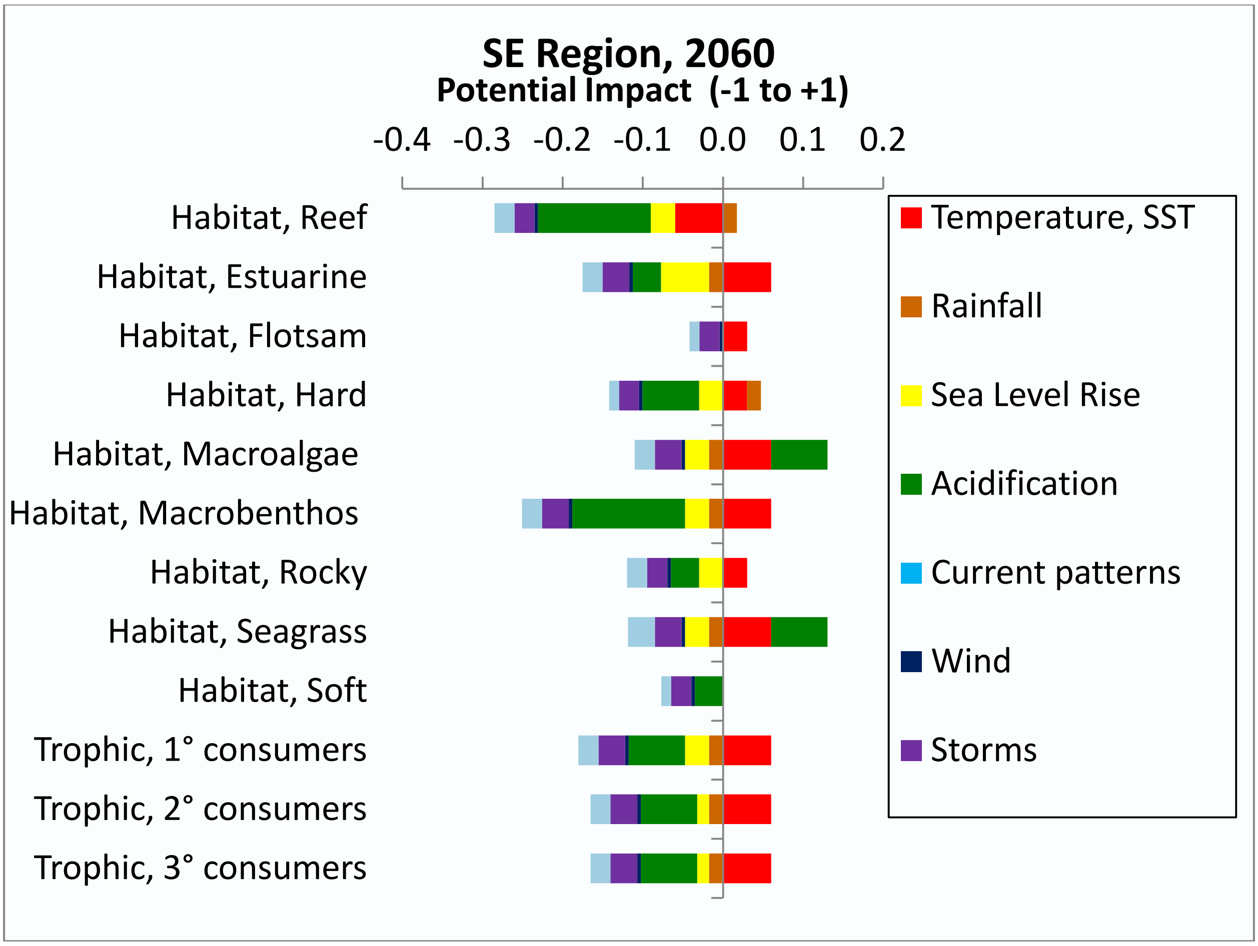
Some salient features to note in the plots are:

1. Both positive and negative impacts are evident for a few "stressors" and most of the attributes (positive impacts primarily for Temperature and Acidification),
2. Weighted impacts are largest for the "Reef" habitat and the Secondary Consumers due to their larger numbers (of fish species) in the bioregions (at least as captured in the database as of 2009),
3. Impacts increase progressively from 2030 through to 2100,
4. Acidification is flagged as a critical stressor throughout this period, but particularly so for Secondary Consumers in the latter years,
5. Positive impacts are noted for Macroalgae and Seagrass (although their weighted values are small) with key contributions from Temperature and Acidification,
6. On a weighted basis, the largest positive impacts occur in the Reef and Hard habitats (key contributions from Temperature and Rainfall), and Secondary Consumers (key contribution from Temperature),
7. Overall, negative impacts outweigh the positive ones.

This preliminary assessment provides pointers to those attributes of bioregions and components of drivers that require further analyses in order to formulate targeted adaptation strategies.

Figure 15 shows the weighted impact map for the three years and the bathomes, using different colour scales for each bathome. Figure 16 shows the weighted impacts, with the same colour scale for all plots. Primary impacts are noted for the bioregion units in the north east epipelagic and west Tasmanian Transition of the Study region.


SE Region, 2030
Potential Impact (-1 to +1)
-0.2
-0.1
-0.1
0.0
0.1
0.1
Habitat, Reef
Habitat, Estuarine
Habitat, Flotsam
Habitat, Hard
Habitat, Macroalgae
Habitat, Macrobenthos
Habitat, Rocky
Habitat, Seagrass
Habitat, Soft
Trophic, 1° consumers
Trophic, 2° consumers
Trophic, 3° consumers
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms
Resource utilisation


SE Region, 2060
Potential Impact (-1 to +1)
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
Habitat, Reef
Habitat, Estuarine
Habitat, Flotsam
Habitat, Hard
Habitat, Macroalgae
Habitat, Macrobenthos
Habitat, Rocky
Habitat, Seagrass
Habitat, Soft
Trophic, 1° consumers
Trophic, 2° consumers
Trophic, 3° consumers
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms

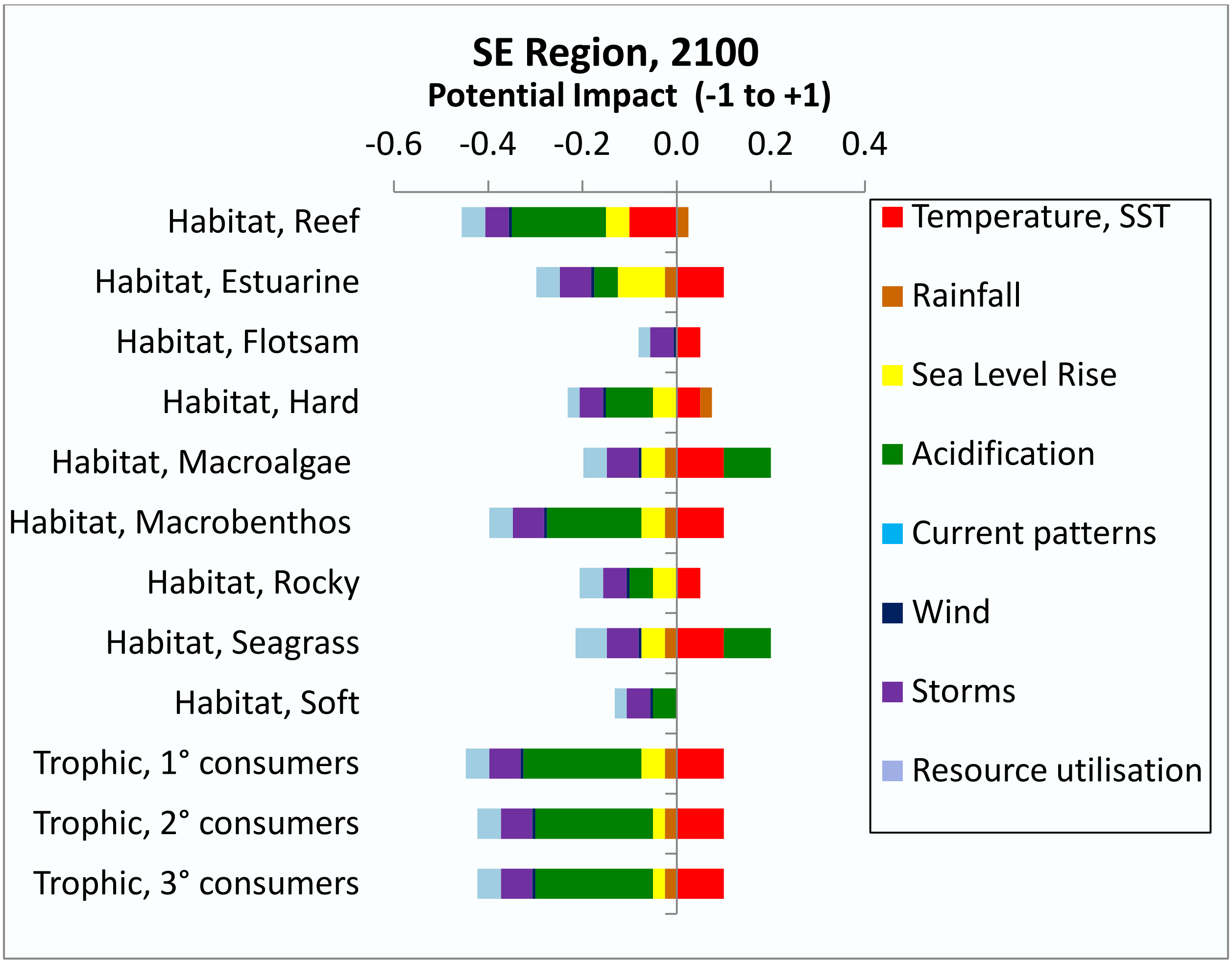
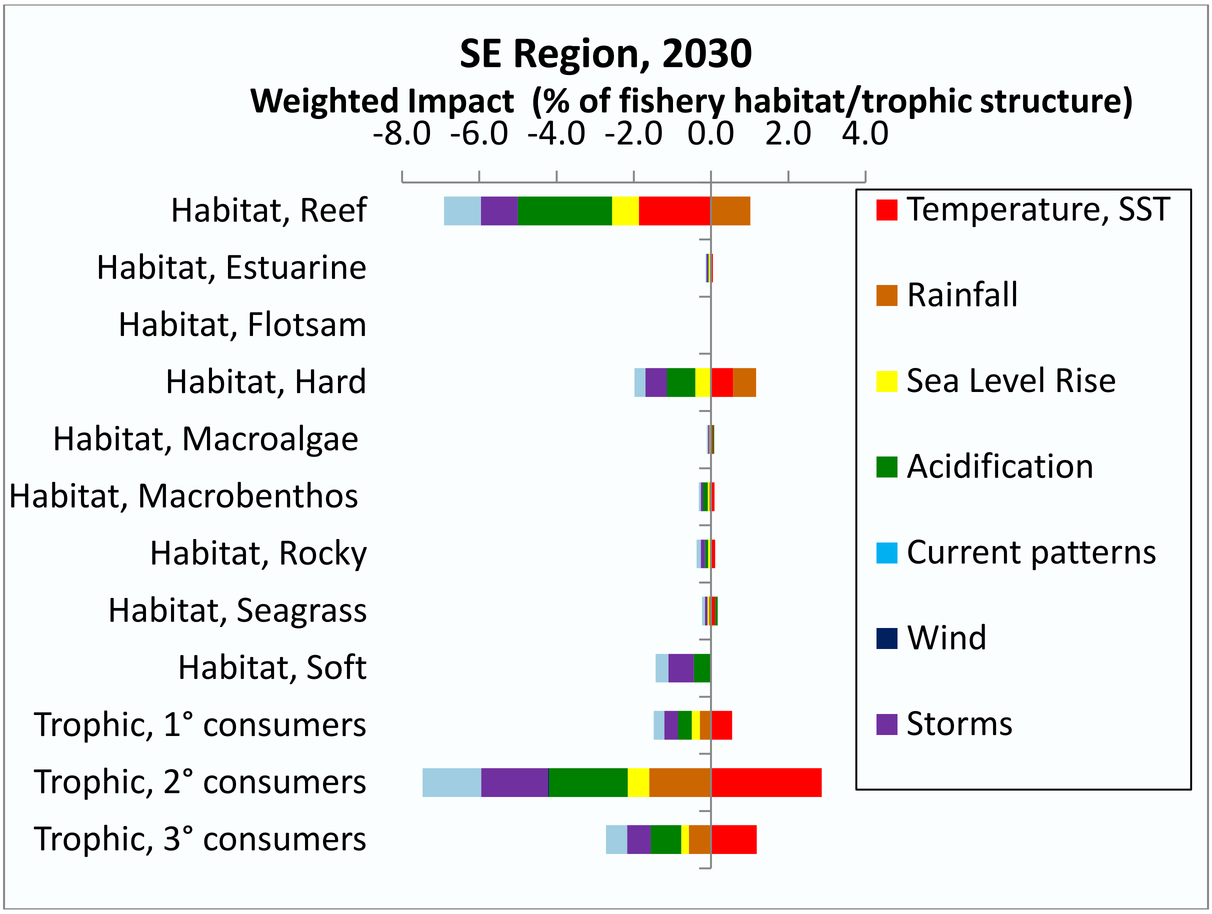
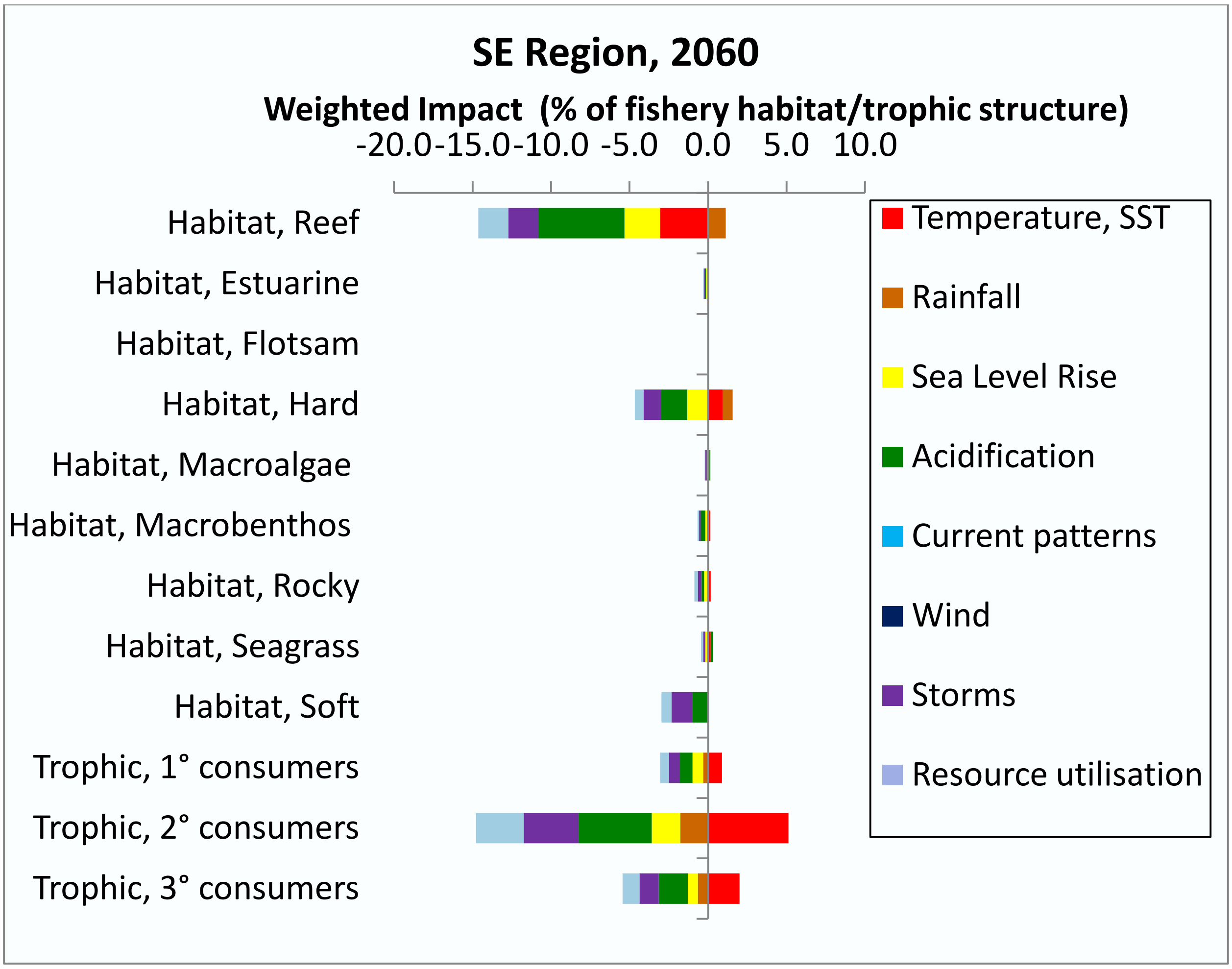


Figure 13 Three plots in sequence showing Potential Impacts across the South East bioregions for 2030, 2060 and 2100 respectively. In each plot, positive impacts (bar to the right of 0.0) and negative ones (barplot to the left of 0.0) are shown for each of habitat and trophic components. Each barplot shows the component contribution of the different stressors shown in the keyto the right.


SE Region, 2030
Weighted Impact (% of fishery habitat/trophic structure)
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
Habitat, Reef
Habitat, Estuarine
Habitat, Flotsam
Habitat, Hard
Habitat, Macroalgae
Habitat, Macrobenthos
Habitat, Rocky
Habitat, Seagrass
Habitat, Soft
Trophic, 1° consumers
Trophic, 2° consumers
Trophic, 3° consumers
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms


SE Region, 2060
Weighted Impact (% of fishery habitat/trophic structure)
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
Habitat, Reef
Habitat, Estuarine
Habitat, Flotsam
Habitat, Hard
Habitat, Macroalgae
Habitat, Macrobenthos
Habitat, Rocky
Habitat, Seagrass
Habitat, Soft
Trophic, 1° consumers
Trophic, 2° consumers
Trophic, 3° consumers
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms
Resource utilisation

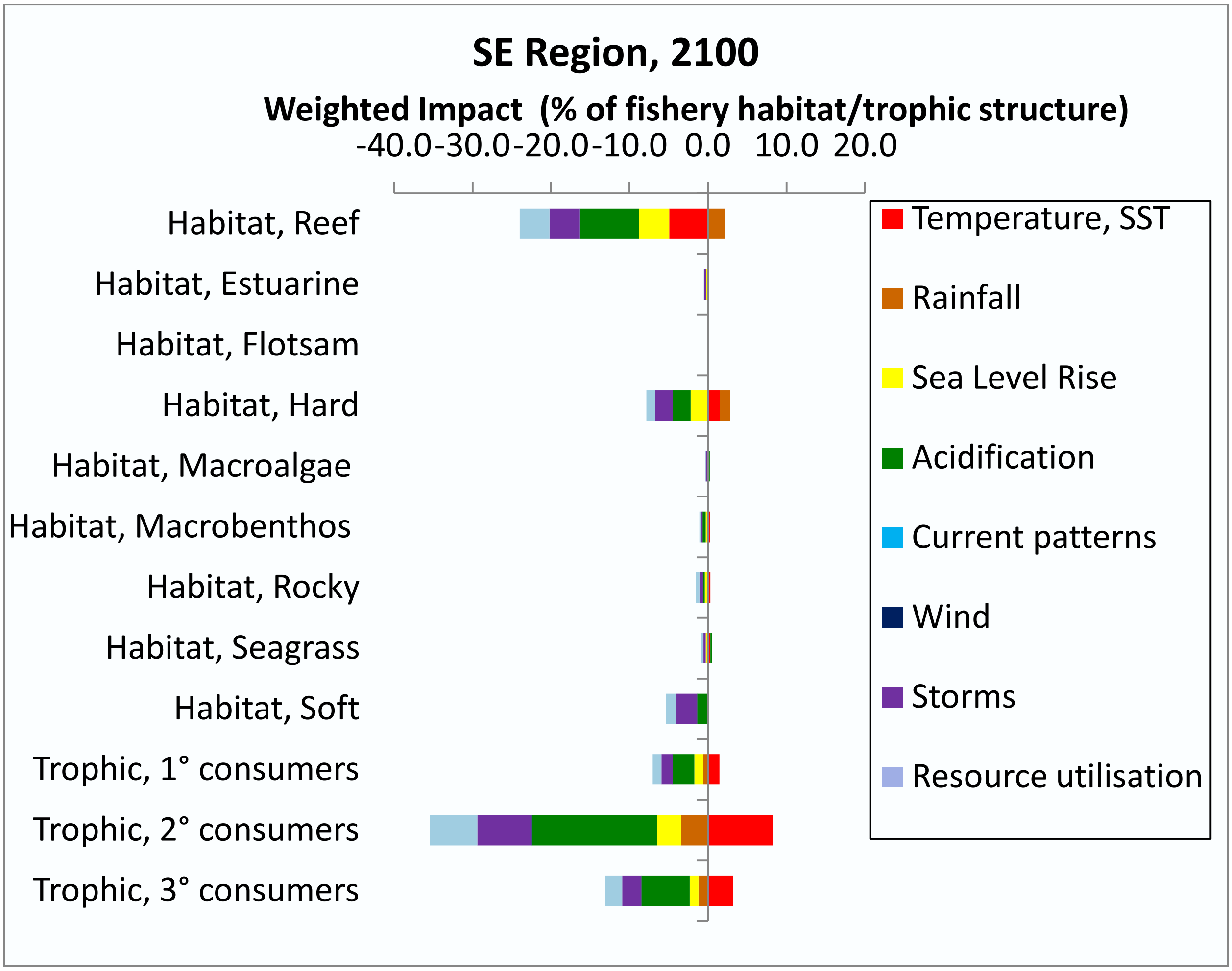


Figure 14 Three plots in sequence showing the Weighted Potential Impacts across the South East bioregions for 2030, 2060 and 2100 respectively. Impacts for each bioregion are weighted by the number of species for each of the habitat and trophic categories shown. In each plot, positive impacts (bar to the right of 0.0) and negative ones (bar to the left of 0.0) are shown for each of habitat and trophic components. Each bar shows the component contribution of the different stressors shown in the key to the right.

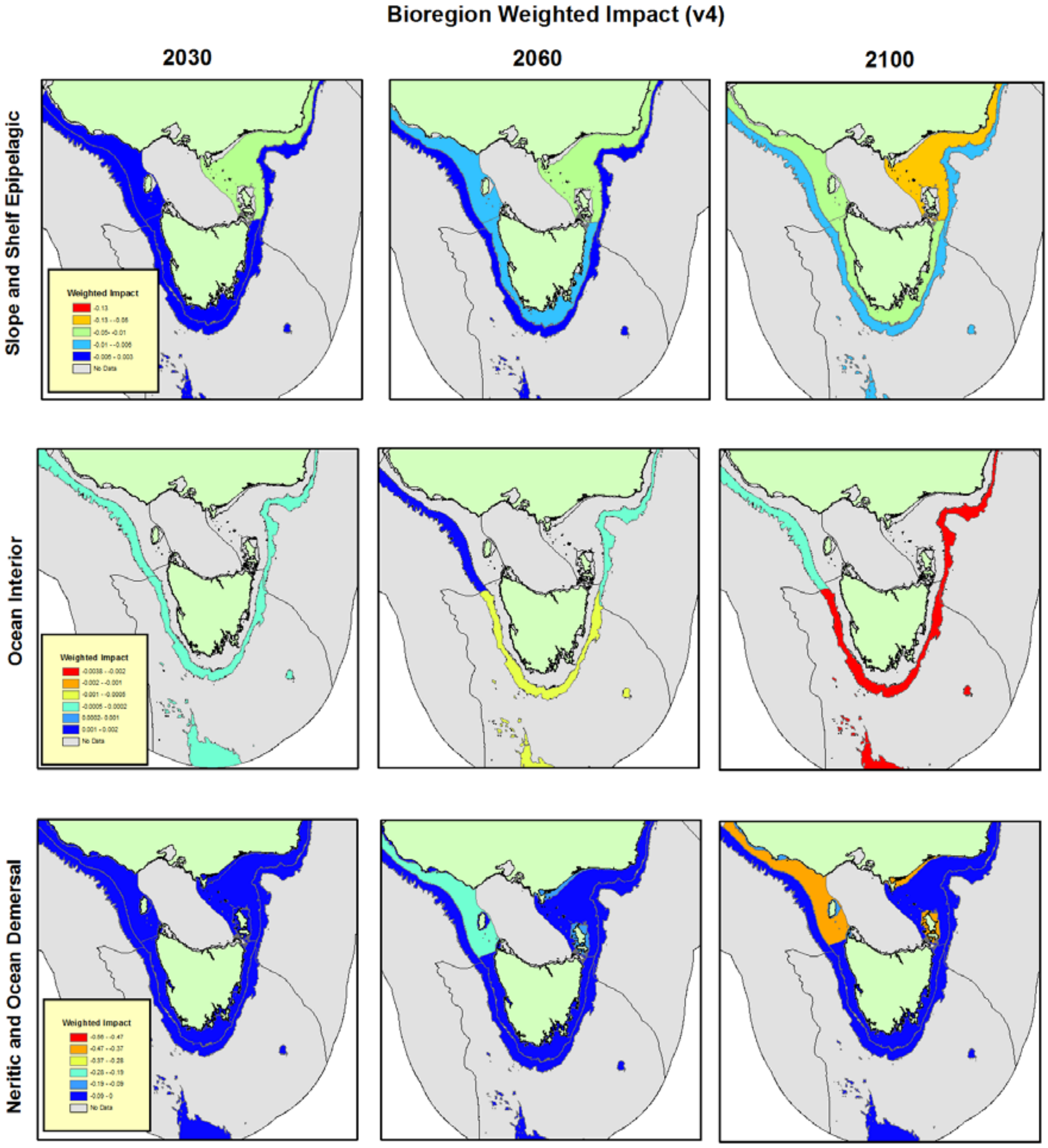


Figure 15 Map showing the computed weighted bioregion impact scores for 2030, 2060 and 2100 (columns) for the different bathomes (rows). Note that central Bass Strait was not included in the analyses, so its score should be ignored.

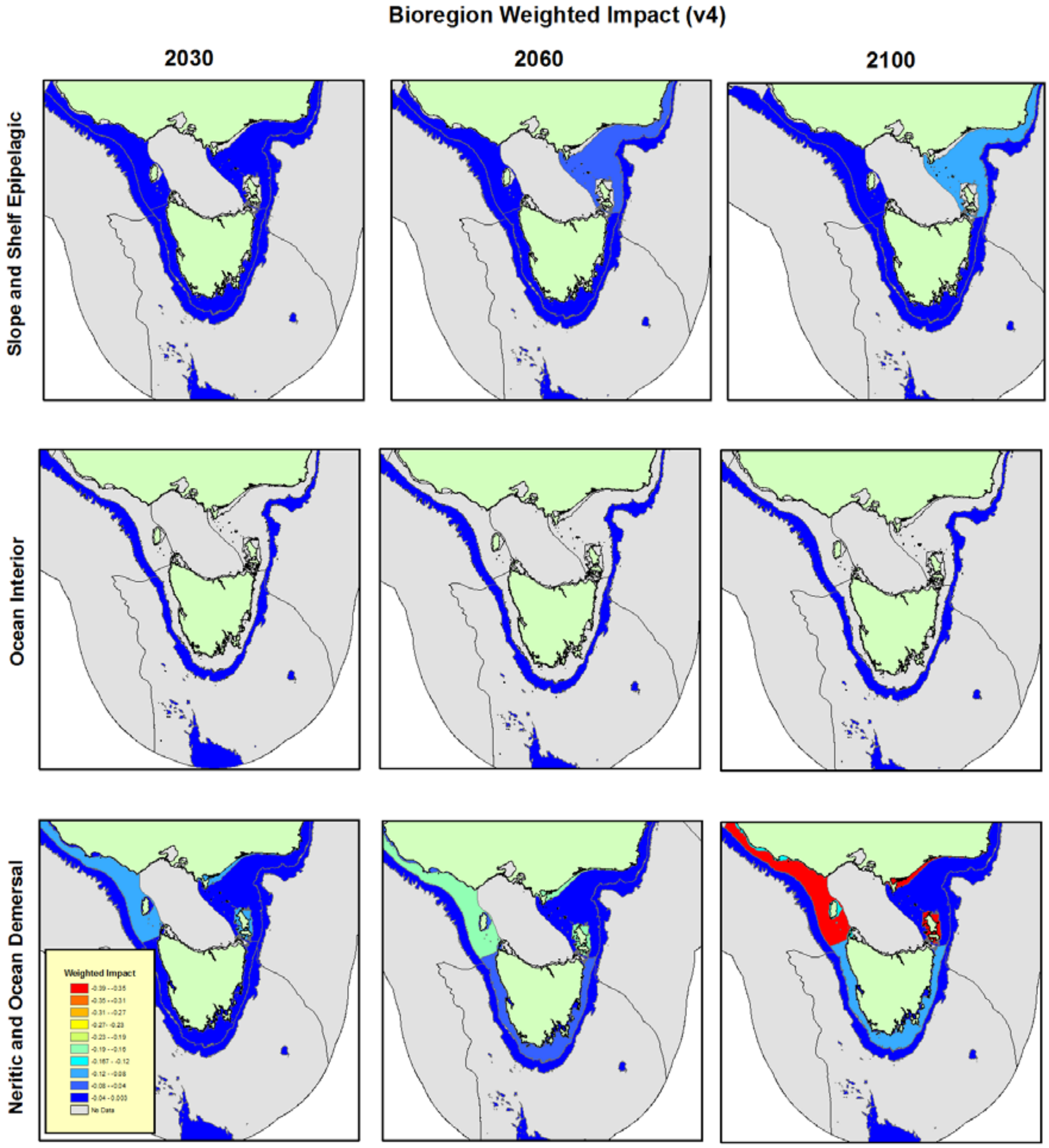


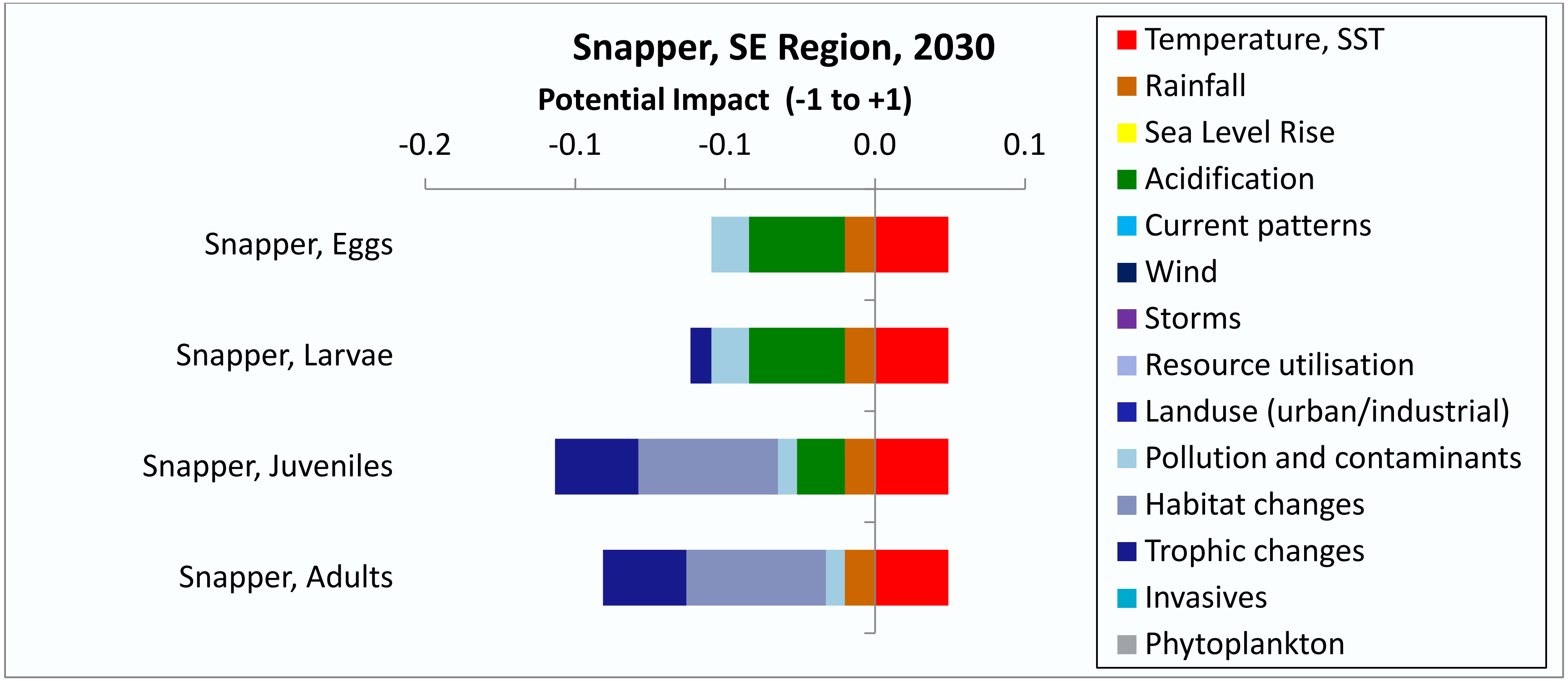
Figure 16 Map showing the computed weighted bioregion impact scores for 2030, 2060 and 2100 (columns) for the different bathomes (rows), using the same colour scale for all plots. Note that central Bass Strait was not included in the analyses so its score should be ignored.

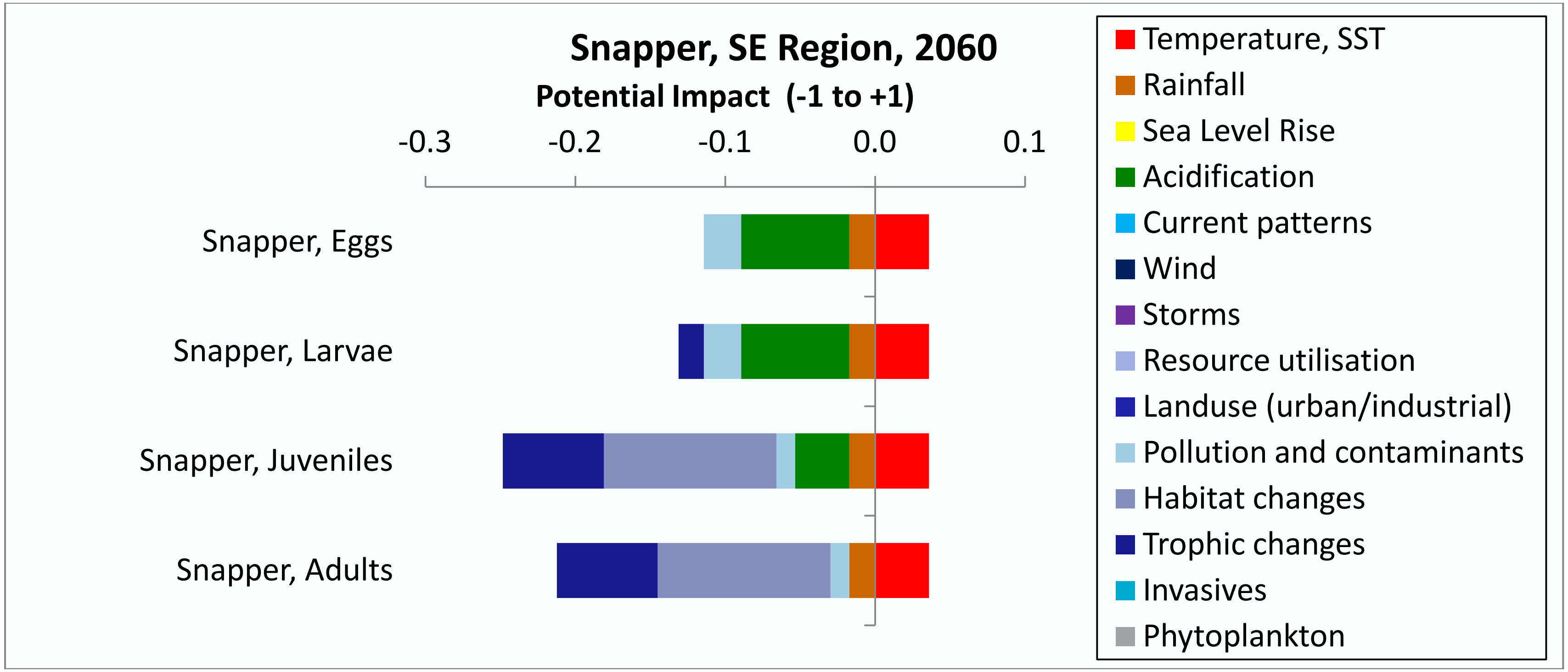
8.2 Species Example

For the species example, the attached spreadsheet shows a worked application for Snapper. As in the previous example, Potential Impact and Weighted Impact scores are plotted for each of the years to show the impact from stressors on the life history stages. Note that the Trophic and Habitat context risks are taken into account in these scores by mapping the distribution of the different life history stages to each of the bioregions analysed in the previous section. This analysis takes advantage of a range of existing information, models and expert assessments so the approach is ideally suited to a participatory style of engagement with researchers, operators and managers. In addition, this approach allows risks at the bioregion (spatial) scale to be incorporated into life history impact assessments.

Some key features of the results to note are:

1. While some positive impacts (from Temperature) are noted for the early years, by 2100 the negative impacts dominate,
2. Acidification is a key negative stressor for Eggs and Larvae,
3. Habitat changes is a key negative stressor for Juveniles and Adults, and links back to impacts at the bioregional level – compared to more direct impacts for Eggs and Juveniles,
4. The patterns in Potential Impact and Weighted Impact are similar because of issues with the weighting factor (see section on Sensitivities). In a future update we intend to explore use of the bioregional attributes and areas to provide more meaningful weighting (the weighting scheme used was to assume all life history stages were of equal importance),
5. Juveniles and Adults are projected to be more impacted than Eggs and Larvae – although this may change with the change in weighting, but there is a clear bioregional influence on the former life history stages.


Snapper, SE Region, 2030
Potential Impact (-1 to +1)
-0.2
-0.1
-0.1
0.0
0.1
Snapper, Eggs
Snapper, Larvae
Snapper, Juveniles
Snapper, Adults
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms
Resource utilisation
Landuse (urban/industrial)
Pollution and contaminants
Habitat changes
Trophic changes
Invasives
Phytoplankton


Snapper, SE Region, 2060
Potential Impact (-1 to +1)
-0.3
-0.2
-0.1
0.0
0.1
Snapper, Eggs
Snapper, Larvae
Snapper, Juveniles
Snapper, Adults
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms
Resource utilisation
Landuse (urban/industrial)
Pollution and contaminants
Habitat changes
Trophic changes
Invasives
Phytoplankton

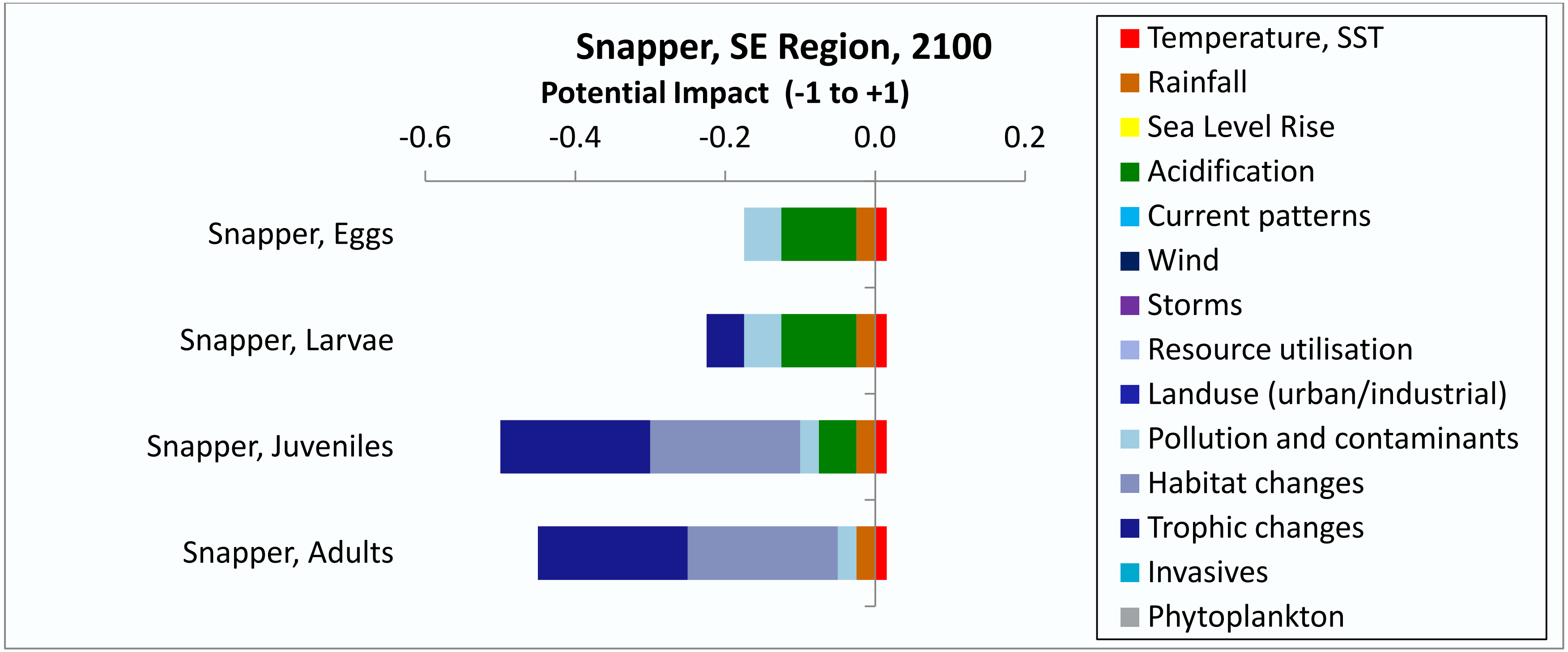
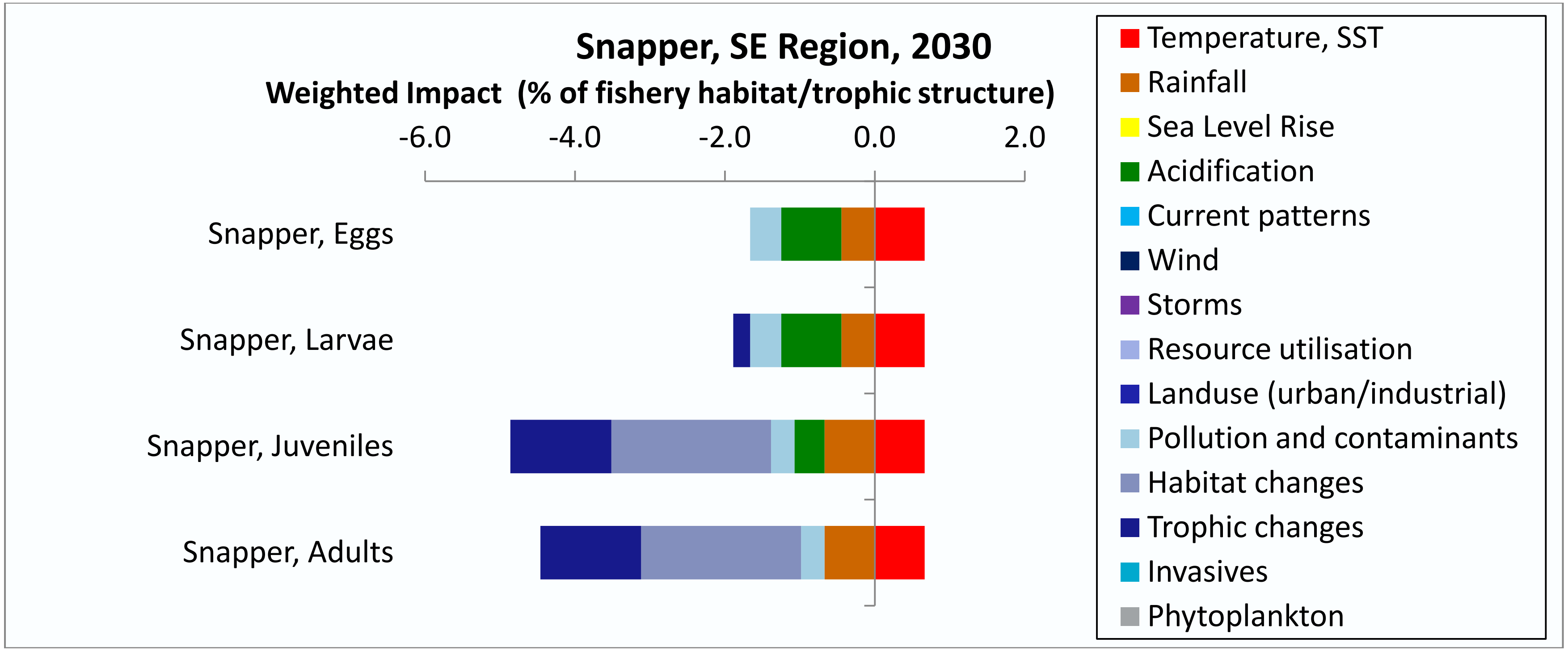
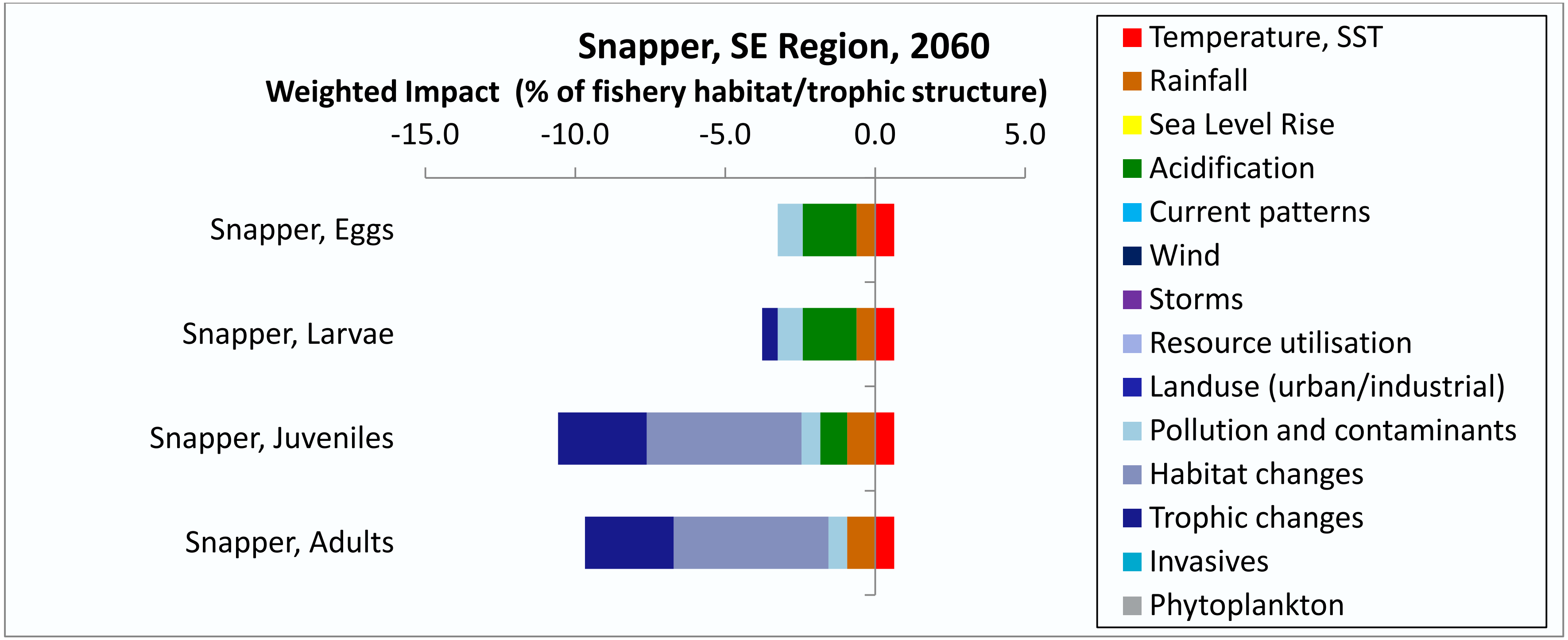


Figure 17 Potential impact for Snapper life history stages. Description of the plots is as for Figure 13.


Snapper, SE Region, 2030
Weighted Impact (% of fishery habitat/trophic structure)
-6.0
-4.0
-2.0
0.0
2.0
Snapper, Eggs
Snapper, Larvae
Snapper, Juveniles
Snapper, Adults
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms
Resource utilisation
Landuse (urban/industrial)
Pollution and contaminants
Habitat changes
Trophic changes
Invasives
Phytoplankton


Snapper, SE Region, 2060
Weighted Impact (% of fishery habitat/trophic structure)
-15.0
-10.0
-5.0
0.0
5.0
Snapper, Eggs
Snapper, Larvae
Snapper, Juveniles
Snapper, Adults
Temperature, SST
Rainfall
Sea Level Rise
Acidification
Current patterns
Wind
Storms
Resource utilisation
Landuse (urban/industrial)
Pollution and contaminants
Habitat changes
Trophic changes
Invasives
Phytoplankton

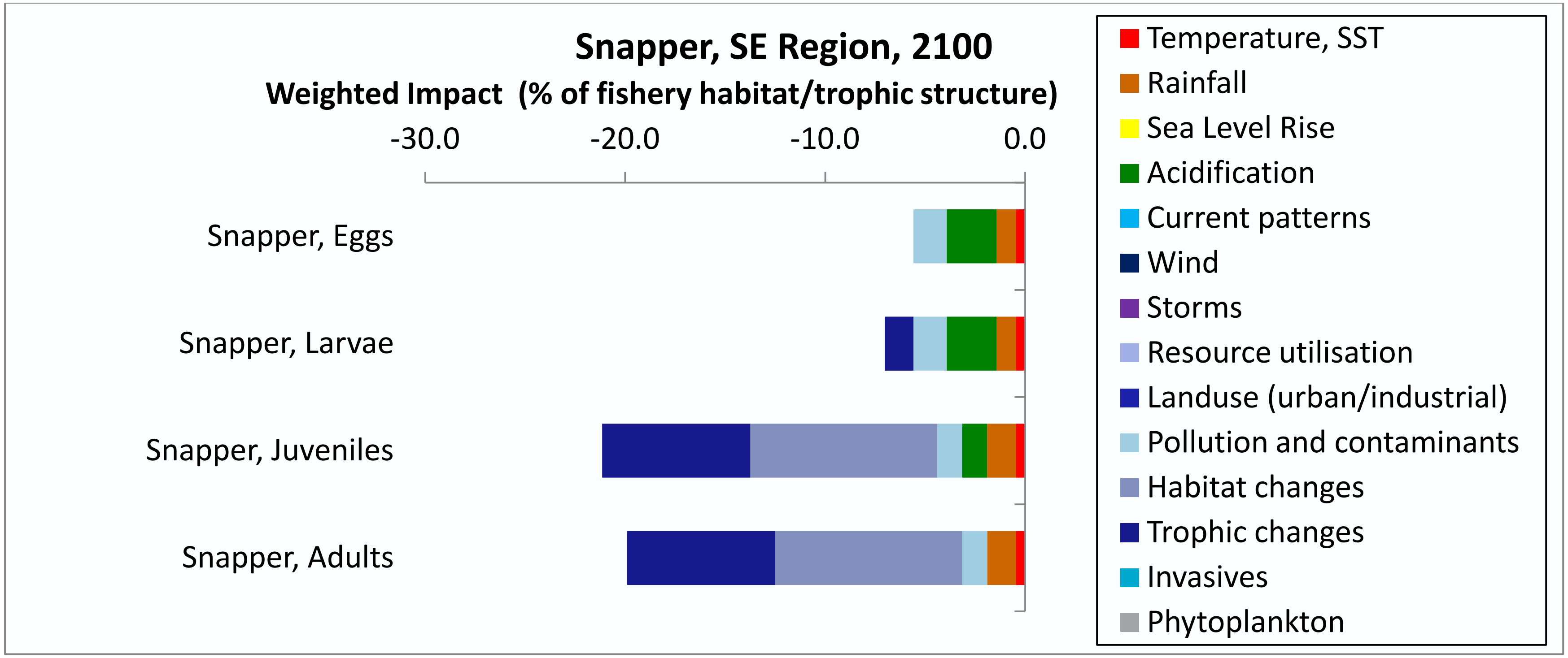


Figure 18 Weighted potential impact for Snapper life history stages. Description of the plots is as for Figure 14.

The weighted impact map for 2030, 2060 and 2100 (Figure 19) shows a similar pattern to that for the bioregion with main impacts along the north eastern coastal and shelf bioregions and in eastern Bass Strait. The projected weighted impacts are illustrated in Figure 20 to Figure 22.

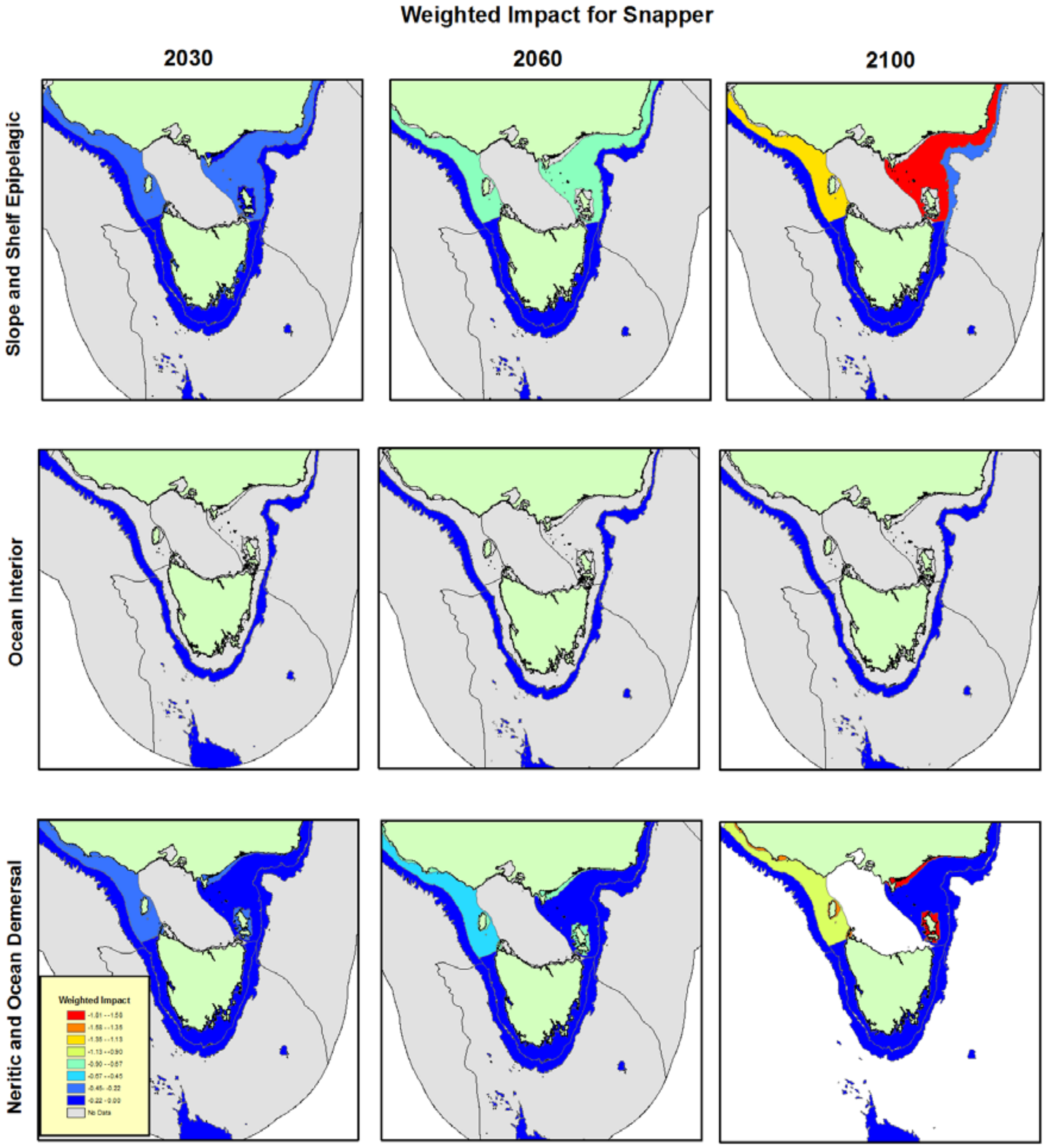


Figure 19 Map showing the computed weighted species impact scores for 2030, 2060 and 2100 for the different bathomes. Note that central Bass Strait was not included in the analyses so its score should be ignored.

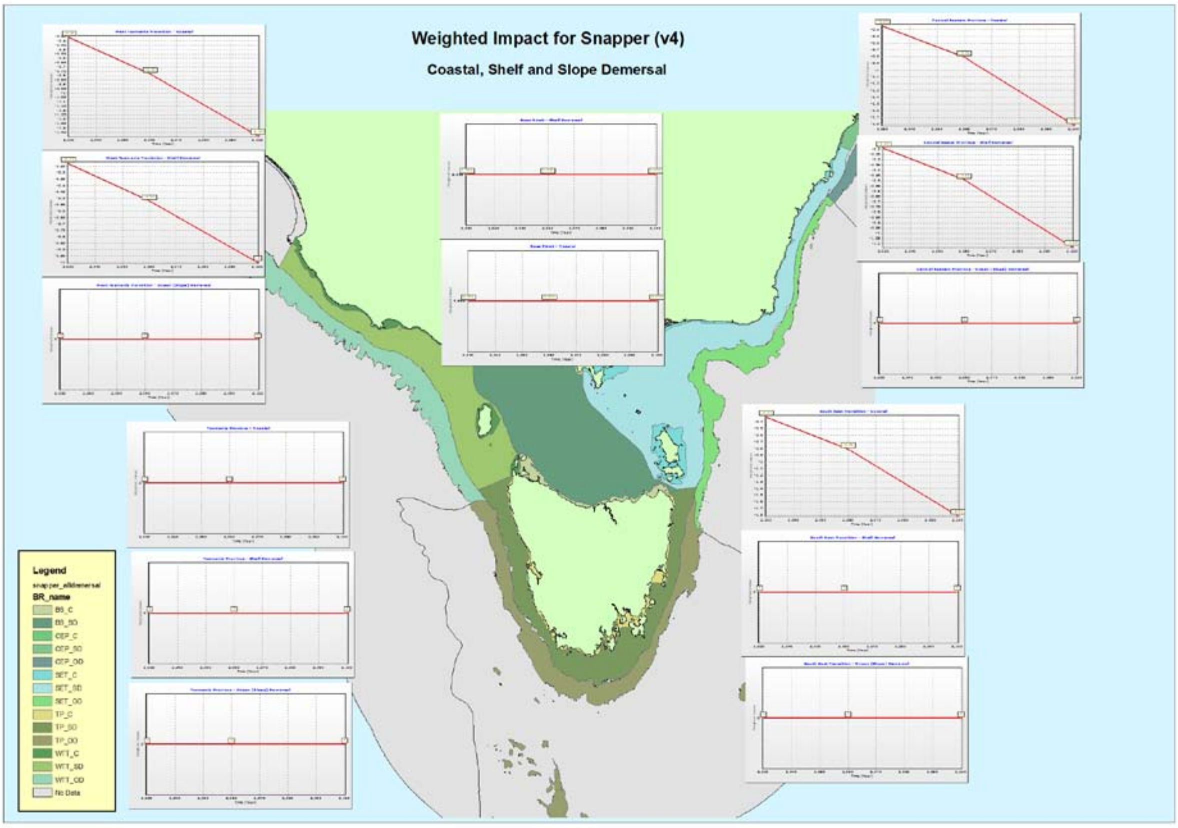


Figure 20 Spatial-temporal illustration of the weighted impacts for Snapper for the demersal bathomes. Note there are no data for Bass Strait bioregion – hence the zero impact line.

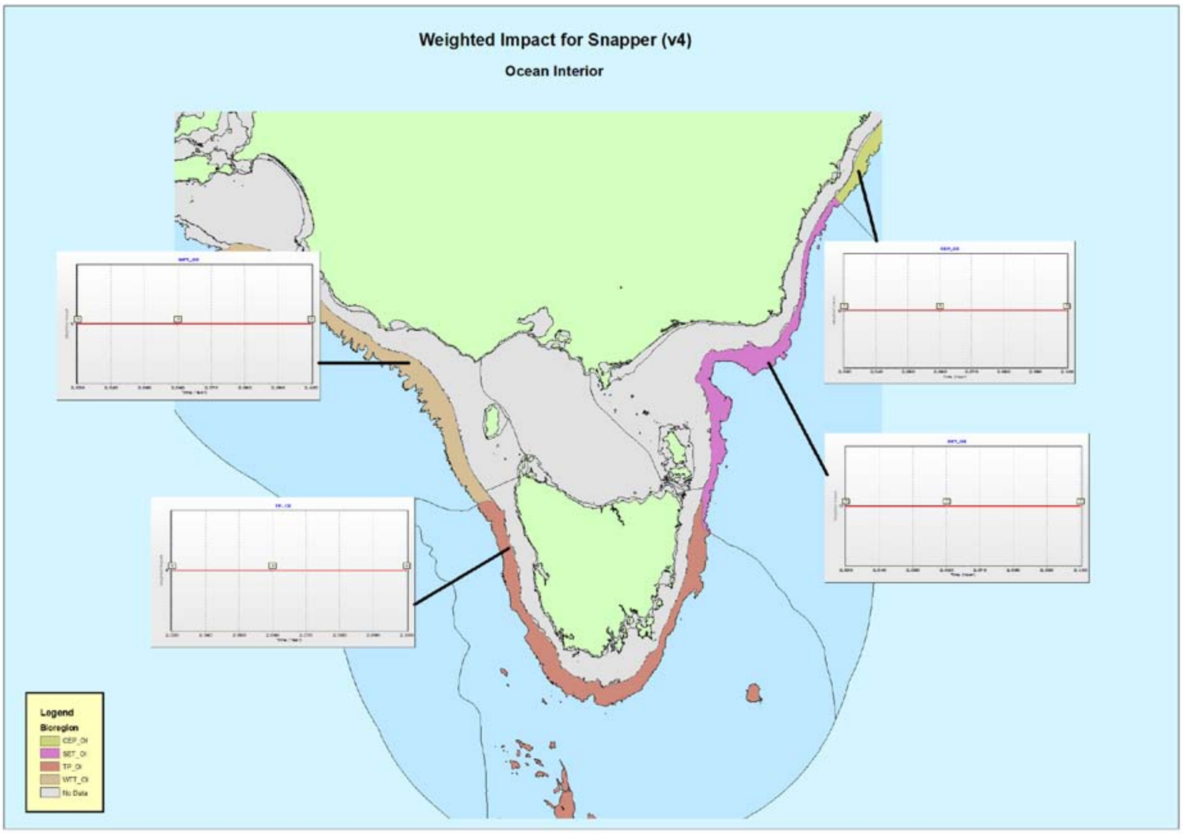


Figure 21 Spatial-temporal illustration of the weighted impacts for Snapper for the Ocean Interior bathomes. Note there are no data for Bass Strait bioregion – hence the zero impact line.

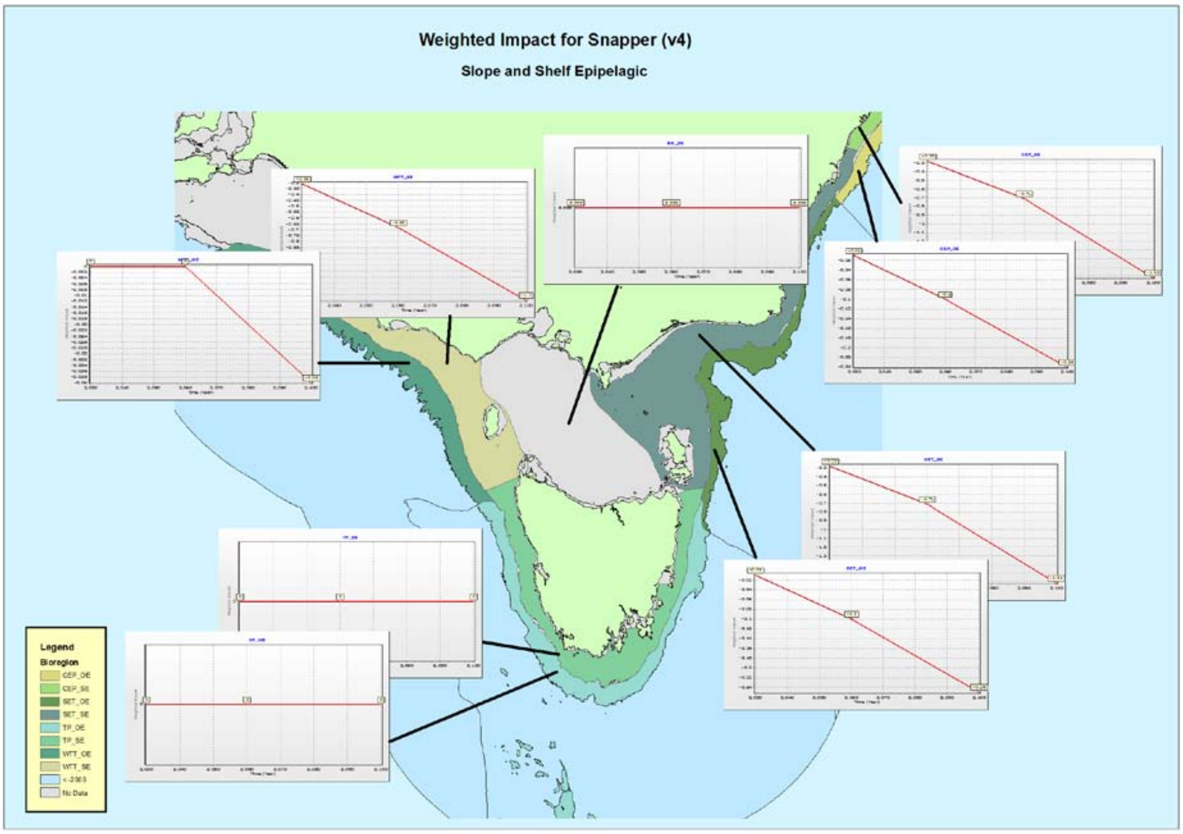


Figure 22 Spatial-temporal illustration of the weighted impacts for Snapper for the Slope and Shelf Epipelagic bathomes. Note there are no data for Bass Strait bioregion – hence the zero impact line.

9 Adaptation Planning and Assessment

In this section we extend the toolset developed for impact assessments to construct adaptation options to assess the effects of alternative decision choices on projected impacts - schematically illustrated in Figure 23. Projected trajectories of impacts on bioregions and species are used as input into an adaptation planning and assessment process from which decisions and actions feed back to changes in projected impacts. This iterative feedback process is used until overall goals in relation to adaptation pathways and targets (Step 1 of the overall framework) are satisfied.

The framework is appropriate for both regional and ecosystem based adaptation, and a species or fishery-by-fishery based adaptation. Both approaches are accommodated by selecting relevant targets and decisions/actions related to the projected impacts. The framework is sufficiently generic to apply to other taxa that rely upon habitat and trophic components at a bioregional level, and a set of life history stages at the species level. In application to aquaculture, the same framework is appropriate but in this instance, "bioregions" would refer to distinct operations associated with the various stages of rearing the species, and species life history stages would include the usual set (eggs, larvae, juveniles, adults) as well as possibly subsets of adult life stages associated with growth stages and operations; for example, clearing parasites by towing cages to freshwater sites, or preparing mature fish for marketing. The same framework is applicable, but with targets and decision matrices suited to the operations and species.

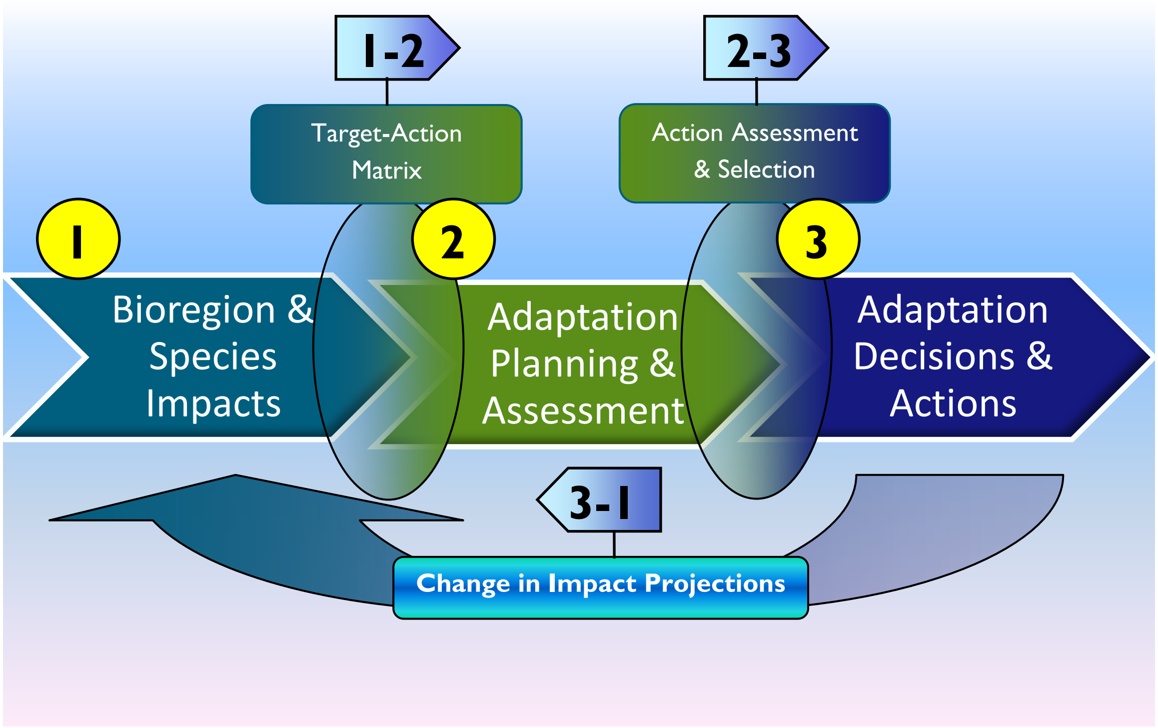


Figure 23 Schematic illustration of overall adaptation and decision making process: (1) Bioregion and species impact trajectories are input into (2) Adaptation planning and

assessment, leading to (3) selected Adaptation decisions and actions. Assessments and tools used to progress from one stage to the next comprise: (1-2) A Target-Action Matrix; (2-3) procedures to assess and select actions, and (3-1) feedback of actions to changes in Impact Projections.

The impact assessment framework and associated tools were based on those used to assess sustainable livelihoods (Skewes et al., 2011), while the adaptation assessment framework in Figure 23 is based on work in progress in CSIRO in the Climate Adaptation Flagship. Discussions were held with interested researchers, operators and managers in adapting and implementing these tools to fisheries and aquaculture. In the following sections, we describe elements of the framework in turn and present guidelines for implementing them to fisheries and aquaculture.

The framework presented is a dynamic process for adapting to climate change. In contrast, Victoria has developed a climate change strategy for its fisheries and aquaculture for 2008-2018 which deals with the processes that have to be implemented and/or managed to ensure adaptation does occur (Figure 24). As such, the frameworks are complementary in the sense that ours focuses, for the purposes of this project, on the adaptation that needs to take place, whereas the Victorian strategy is about the management processes, structures and information sharing – the "enabling" aspects of adaptation - that are required to ensure adaptation does occur. While this is part of the framework that we will elaborate on in later sections, a clear understanding is first required of the impact risks and the adaptation that needs to take place. Much of the Victorian strategy builds on the advanced nature of fisheries and aquaculture management in Australia, so for the purposes of this project we will focus our attention on the adaptation needs and dynamics, but acknowledge that the enabling aspects of adaptation are a key aspect of ensuring that the intended adaptation does take place (as intended), and that the risks are shared and opportunities realised.

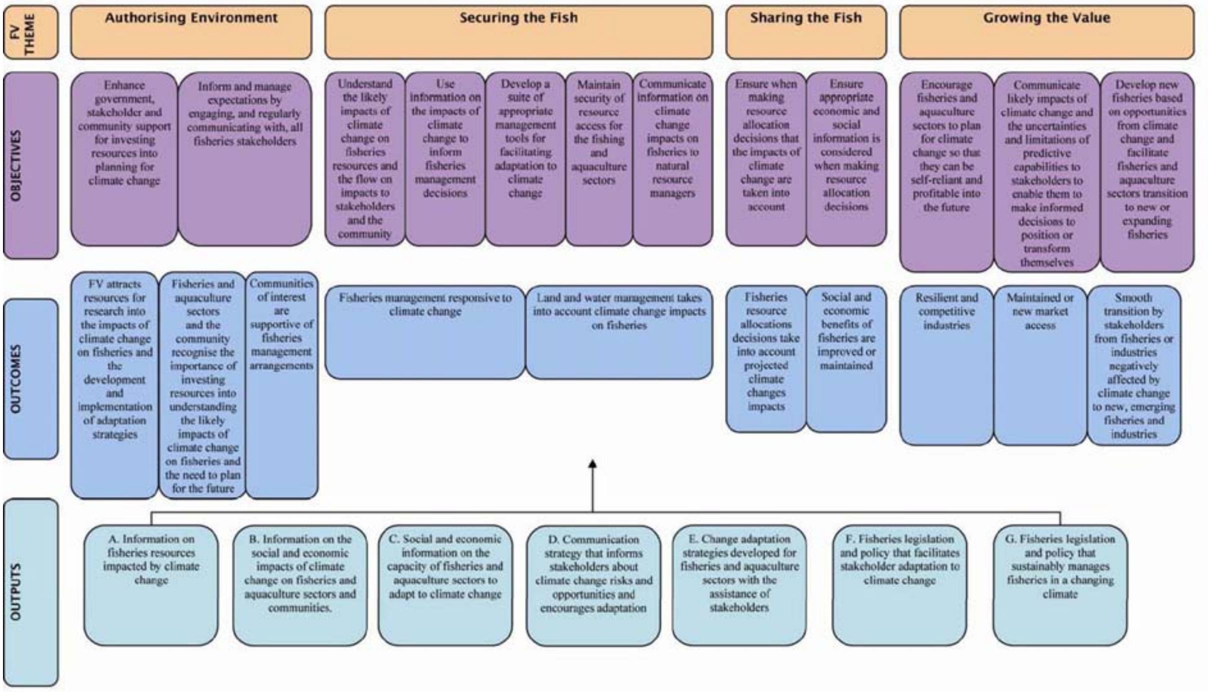


Figure 24 Victoria's strategy for fisheries and aquaculture 2008-2018. Image source: http://www.dpi.vic.gov.au/__data/assets/image/0015/102417/vcc_img9_big.jpg

9.1 Bioregion and Species Impacts

Previously we presented the methods, and example results, for assessing the impacts of climate change on bioregions; and the context this provides for the species-based assessments. The outputs from these assessments are projected impacts, from the 1990 baseline, for 2030, 2070 and 2100. For simplicity we assumed that impact trajectories are linear between these years (but they need not be if more accurate models are available to project the impacts). The impact trajectories are inputs that managers and other decision makers (operators, government, communities, investors, insurers) will use in making decisions that lead to actions which directly, or indirectly, will have an effect on the impact trajectory. Key features of the trajectories are the times when thresholds (to be discussed in the next section) may be reached.

Indirect effects may arise from associated impacts resulting from the bioregion and species impacts. These result in additional impact-related projected trajectories of interest to a number of stakeholders who will make decisions and may instigate actions based on those trajectories. However unlike the "scientific" bioregion and species impact trajectories, the projection of these related trajectories relies upon models, and mental models, of the stakeholders – we leave this to be discussed later but for now note that these stakeholder models must be articulated in a form suitable for firstly relating associated impacts (of interest to the stakeholder) to the bioregion/species impacts, and secondly must enable projections to be made of the associated impacts. To demonstrate the application of the approach, we will review, in the sections to follow, documented assessment and management strategies that outline targets, and intended targets, related to impacts that may occur at the bioregion and/or species level.

9.2 Associated Impacts and Measures

In this section we review a select set of management related documents to identify the key measures which are used by managers, operators and other stakeholders. When these measures are used in conjunction with triggers and thresholds, they define targets and indicators that can be used to prompt re-assessments that may in turn lead to changes in decisions and actions. This approach (Figure 25) is implemented in most Australian fisheries and is a form of adaptive management.

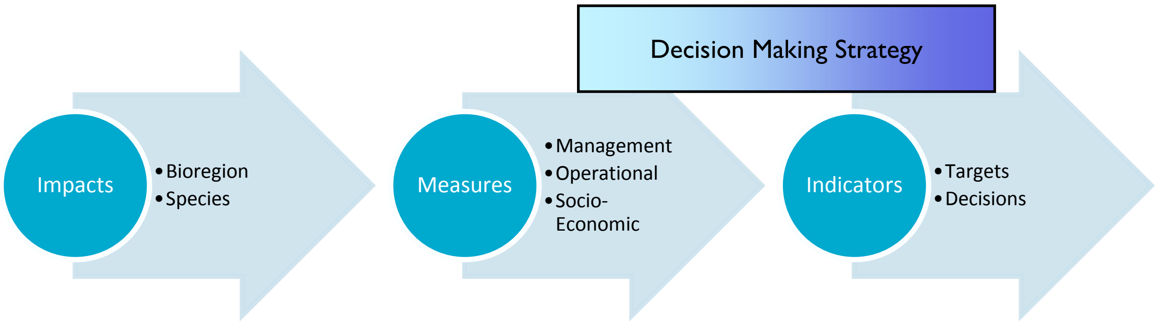


Figure 25 Illustration of decision process from Impacts to Measures which in conjunction with triggers and thresholds are used as Indicators that may lead to changes in Decisions. Selection and definition of Indicators is guided by Decision Making Strategy (precautionary, maximise sustainable economic yield,…).

The basic principles of adaptive management apply equally to climate change impacts and fisheries related ones, so the focus of attention here is on the relative forms of impacts (and responses required) from fishing versus those that are likely to arise from climate change. Table 3 summarises the relative comparison.

Table 3 Comparison of impacts and responses as they exist in current fisheries to changes that may be required to deal with climate change.

Fisheries Processes	Climate Change Processes
Regulated catches: Amount, locations, sizes, species, gear, season.	Threats and opportunities from a variety of interacting scales: Phenology changes (change in seasonal cycles), interannual, regime shift, change in extreme events, long-term shifts.
Bycatch and flow-on impacts are monitored and assessed as part of EPBC Act (see next section).	Complex flow-on impacts and interactions at regional and local scales. Requires close collaboration across the States for each fishery, and between fisheries as part of ecosystem changes.
Assessment models and management procedures are adapted to deal with stock declines, stock recovery, serial depletion, local subpopulation impacts and disease outbreaks.	Regime shifts, large scale changes and extreme events may impose rapid shifts and impacts on stocks as well as potential for spread of invasives and diseases. Impacts on species with pelagic life history stages may be more difficult to assess and manage. Assessment models need to be upscaled, while retaining local assessment capabilities, and incorporate abilities to forecast future climate change variables affecting ecosystems and species – this will require greater collaboration and skill development amongst environment modellers and fisheries researchers.
Working management and co-management arrangements with operators in place for specific fisheries and locations.	Wider-scale and more responsive management/co-management and monitoring may be required to deal with climate change impacts.
Catch, effort and monitoring information managed within dedicated information management systems that are regularly updated, and are an integral part of the stock assessment process.	Information, expertise and modelling capabilities are widely dispersed (nationally and globally). The potential to develop ecosystem and stock assessment models, which are responsive to climate change, at regional and national scales exists (e.g., *Altantis*).

In what follows, we focus attention on differences (and less so on similarities) between impacts, associated impacts and measures that are fisheries-rather than related to climate change, or may be synergistic with climate change. The intent here is to understand how current adaptation arrangements and processes (the Business-As-Usual scenario) may need to change/adapt in order to respond to the threats and opportunities which may be brought about by climate change. Thus our treatment of the current fisheries management arrangements is not comprehensive, but illustrates the adaptation required.

9.2.1 Management Measures

Under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), ecologically sustainable management of fisheries requires assessment of (DEWR 2007):

1) Stock status and
2) impacts on other parts of the ecosystem; The act also requires management to use a precautionary approach that allows for the inherent uncertainty in marine systems and monitoring information.

The first two requirements relate to impacts, while the third is a conditional requirement that a precautionary approach is required to deal with uncertainties and the capability of management to track the impacts. In essence, this requirement is part of the adaptive capability (of management) and those of researchers charged with assessing the state of the stock and ecosystem. We will return to these points later but note for now that the requirements are a mix of those related to impacts and management capability.

The intent behind these requirements is (DEWR 2007): "*…not only for long-term species and ecosystem viability but also to underpin economic sustainability*". Thus implicit ecological and economic sustainability needs are meant to be catered for under the EPBC Act, these are further defined under the two Principles of the Act:

PRINCIPLE 1: *A fishery must be conducted in a manner that does not lead to over-fishing, or for those stocks that are over-fished, the fishery must be conducted such that there is a high degree of probability the stock(s) will recover.*

PRINCIPLE 2: *Fishing operations should be managed to minimise their impact on the structure, productivity, function and biological diversity of the ecosystem.*

Under each of these Principles, a number of Objectives that define Measures and Targets by which the performance of the fishery is to be judged. We explore each of these using the notation PxOy where "x" is the Principle number (1 or 2) and "y" is the Objective number relating to that Principle.

Principle 1 – Objective 1 (P1O1)

P1O1: The Objective here is "*The fishery shall be conducted at catch levels that maintain ecologically viable stock levels at an agreed point or range, with acceptable levels of probability.*"

Under this Objective, the Measure is the **Stock Level** (with associated probability levels), which is maintained, by controlling Catch Levels, at an Agreed Point or Range, with Acceptable Levels of Probability. The contextual matters associated with the Stock Level relate to Targets/Indicators, the information and assessment capabilities that define the state of the Stock, and nature of the decisions and actions. In following the flow of the framework, we discuss these elements sequentially in subsequent sections.

Principle 1 – Objective 2 (P1O2)

P1O2: The Objective here is: "*Where the fished stock(s) are below a defined reference point, the fishery will be managed to promote recovery to ecologically viable stock levels within nominated timeframes.*"

The key Measure here is still the **Stock Level,** but now a time frame is imposed for the recovery of the stock up to an "ecologically viable" level.

Principle 2 – Objective 1 (P2O1)

P2O1: The Objective here is: "*The fishery is conducted in a manner that does not threaten bycatch species.*"

There is little guidance from the objective alone as to what is(are) the key measure(s). However reading further on elaborations of the Objective, information on "composition and abundance of bycatch" needs to be collected, or else an "indicator group of bycatch species" is monitored. Decisions and actions relate to bycatch avoiding of capture and mortality. Discussion of vulnerability of bycatch also highlights two risks: "*vulnerability to fishing technology (e.g. its catchability), or its vulnerability in terms of ecological impact (eg loss of predators or prey).*" Taking these into consideration, information needs to be maintained on the bycatch species caught (species, number and/or weight/size).

Principle 2 – Objective 2 (P2O2)

P2O2: The Objective here is: "*The fishery is conducted in a manner that avoids mortality of, or injuries to, endangered, threatened or protected species and avoids or minimises impacts on threatened ecological communities.*"

Here again the Objective provides little guidance on measures but the guidelines require that "*Reliable information is collected on the interaction with endangered, threatened or protected species and threatened ecological communities.*" , and that assessments are conducted of the impact of the fishery on endangered, threatened or protected (ETP) species. Data from Objective P2O1 would seem relevant also to this Objective, but modelling is required to assess impacts on the status of ETP species.

Principle 2 – Objective 3 (P2O3)

P2O3: The Objective here is: "*The fishery is conducted in a manner that minimises the impact of fishing operations on the ecosystem generally.*"

Further details on "ecosystem" are provided in the contextual descriptions, which refer to impacts on three categories as detailed below:

1. Impacts on ecological communities
- *Benthic communities*
- *Ecologically related, associated or dependent species*
- *Water column communities*

2. Impacts on food chains
- *Structure*
- *Productivity/flows*

3. Impacts on the physical environment
- *Physical habitat*
- *Water quality*

No specific measures are provided for assessing the above impacts.

To summarise the above deliberations, we compare and contrast, in Table 4, the approach advocated in the EPBC Act with the approach for assessing impacts in the Adaptation Framework advocated in this project. Objectives under the EPBC Act are of necessity a mix of guidelines to protect the fishery, the associated bycatch and ecosystem components, as well as guidelines that need to be followed if the fishery (or associated bycatch/ecosystem) is threatened. Thus, there are measures and suggested decisions/actions for the fishery to adapt to adverse impacts, or imminent adverse impacts. In the Adaptation Framework, a structured approach is advocated with an integrated assessment of ecosystem impacts (via the Bioregional Assessment) that in turn, provides context for the species/fishery specific impacts. While the EPBC objectives may contain elements of the assessment and management needed to ensure conservation and sustainability (of ecosystem components and the fishery), the Adaptation Framework provides an integrated way of achieving these outcomes. In subsequent sections, we explore the capability of operators and managers to implement the EPBC objectives and implications for adaptation to climate change impacts.

In the next section, we examine indirect impacts related to the dependence of operators and communities on fishing. Further elements not examined here, but capable of being included in the Framework, are performance measures related to management itself – required in order to assess managers capability to deal with changes in the fishery and ecosystems, and control of operational processes affecting impacts to the fishery. For simplicity in demonstrating the Framework and tools, we restrict attention here to socio-economic impacts on operators and their dependents, we assume for simplicity that management performance is directly related to impacts on the fishery stock and associated bycatch. As discussed previously, the Victorian strategy 2008-2018 does address many of the capability/enabling aspects of adaptation and we defer to that framework for the implementation aspects of the adaptations required.

Table 4 **Summary of implications of *EPBC Act* objectives in relation to fisheries impacts and the Adaptation Framework approach (developed in this project) for dealing with related impacts to climate change.**

Objective	Measure	Context	Comment on Framework Application
P1O1	Stock Level Change/Decline	Probabilities required for application of Precautionary Approach	Aligns with Species Impact assessment approach in Framework but Framework also takes account of Bioregion (and hence to some extent, Ecosystem) context. Consideration of Probabilities will come into play in determining Targets/Indicators and timing of Decisions/Actions.
P1O2	Stock Level Recovery	Rate of recovery required within an agreed Time Frame	Suggested approach here has implications for a possible adaptation response to rebuild stocks (if that is the decision taken) impacted by climate.
P2O1	Bycatch Composition/Abundance	Information and assessments conducted to determine vulnerabilities of bycatch species and/or bycatch indicator group	Framework attempts to account for ecosystem-related impacts through the context provided by the Bioregion Impact assessment. Bycatch related impacts align with the Trophic Impacts assessed as part of the Bioregion Impact assessment. Potential feedback of bycatch impact to Bioregion Impact.
P2O2	Bycatch Injury/Mortality	To assess effectiveness of avoidance, and bycatch minimisation strategies, on bycatch injury and mortality rates	This objective is relevant as a monitoring activity to assess recovery of bycatch. As such it is related to an Adaptation strategy to deal with impacts. We will discuss this in a later section on Adaptation Actions
P2O3	Ecosystem Component Status (Communities, Species, Habitat, Structure, Productivity, Water Quality)	To assess impact of fishery on ecosystem generally	It is difficult to see how this objective will be implemented in practice given the complexities of potential impacts to the extensive list of ecosystem components. The Framework Bioregion Impact approach advocated here provides an alternative simpler and pragmatic method of dealing with ecosystem related impacts. Furthermore, these ecosystem impacts provide context for the Species related impacts.

9.2.2 Operation Dependent Measures

Core aspects of adaptation are the adaptive response of operators in targeting the species, and the flow-on impacts to associated outcomes such as incomes, operational viability and community livelihoods. For the purposes of demonstrating the approach we compiled a list of such measures by examining the assessment reports and Ministerial announcements on: the Abalone fisheries of NSW (DEWR 2011), Victoria (DEWR 2010) and Tasmania (Tarbath and Gardner, 2010) and the Rock Lobster fisheries of Victoria (DPI 2009) and Tasmania (Gardner et al. 2011). The intent in examining a number of States was to first examine the range of measures being used, as well as to identify those measures which are inter-dependent – and hence may require some form of regional agreement and coordination for best-practice adaptation. We also examined the ABARE Fishery Status Report (Woodhams et al., 2011) for relevant measures. Measures alone are not sufficient in themselves to dictate adaptation choices. Attributes such as confidence levels and how those measures are to be used in assessments, or whether they align with existing models (scientific, cognitive models possibly in the case of some operators/communities, and policy-relevant models for management) will influence decision choices. Thus the context and use of measures is important in the decision making process - which we elaborate upon in subsequent sections, but touch upon here in relation to the Rock Lobster and Abalone case studies.

Key facets of the two species in relation to possible climate change impacts are:

1. **Rock Lobster:**
    a. Spawning and recruitment may not necessarily be local, so juveniles and adults in one area may be the result of downstream supply from other areas. For example, regional declines have occurred throughout Tasmania despite apparent good egg production (Gardner et al. 2011). The suspicion is that recruitment may depend on egg production in other States;
    b. Traps used to capture the species also capture a variety of other species, and some losses may occur from octopus and seal attacks. Thus part of the ecosystem dependence/interaction relates to capture methods;
    c. Victoria conducted a risk assessment of its stocks and concluded that the highest risk was from climate change: "*Climatic factors such as wind, ocean currents/upwellings and larval dispersal are thought to play a role. In the future, climate change may impact on some or all of these factors and has been identified as a key risk for this fishery.*" A significant risk is the stock-recruit relationship and its use in projecting future stock levels both regionally and locally.
2. **Abalone:**
    a. In Tasmania, declines in catch and increases in size imply that fishing mortality is high and that stock levels are low.
    b. Catch efficiencies may be increasing to a point where there is "*a rise in reported catch rates without an associated increase in abalone abundance, or alternatively, it can lead to catch rates appearing to be stable while the stock abundance is, in fact, declining.";* The disconnect between catch rates and stock levels has led management to rely upon divers' perceptions of stock levels.
    c. Rapid local depletions suggest the need for targeted spatial management strategies.

Thus uncertainties in relation to Rock Lobster are from the stock-recruitment relationship and potential flow-on recruitment to downstream sites from upstream sources of eggs/larvae. In the case of Abalone, considerable uncertainties exist on the cause of rapid depletions, and management now relies heavily on field observations to control local catches. This is a long-standing problem (e.g. McShane 1995), which is being managed by local catch quotas and size limits that take account of spatial differences in growth and mortality. It is appropriate to briefly mention the nature of adaptation in relation to uncertainty – we will return to this issue in a later section for more detailed treatment. This is an issue that has been extensively researched in the control system literature and is part of the so-called State-Space estimation process that involves a system model and an observation model (see for example: http://en.wikipedia.org/wiki/State_space_%28controls%29). In brief, under conditions where one has a good understanding of the system (e.g. stock-recruit relationship), the predictions of the model are relied upon heavily resulting in model parameter estimates that are relatively "smooth" and less reliant upon abrupt changes in observations. In contrast, in situations where the model does not provide a reliable forecast, the estimate of the state (recruits in our case) is based on a smoothed trend over the past observations. The reliance by managers on diver observations (rather than stock-recruit models) is line with the sort of response that control system theory would suggest takes place in this instance, but the advantage of the State-Space approach is that the estimation is conditioned upon errors or uncertainties in both the model and the observations. In effect, the prediction from the model and the data trend are weighted, based on their predictive capabilities, to provide the estimate of the system state (see for example tutorials on the "Kalman Filter").

So to summarise (and somewhat pre-empting discussion in a later section), the key point here is that the nature of adaptation must be attuned to the degree of confidence we have in our models and observations. In general where difference confidences are placed on the model and the observations, the algorithm uses a weighted estimate based on the fit between the predicted state and that estimated from the observations. Thus, until uncertainties in the stock-recruit relationship are resolved (perhaps through field-based experiments and testing of models), or some other reliable model of recruit prediction is developed, more reliance must be placed on field-based measures. In the latter case, adaptation is reactive and the reaction time must ideally be at least as quick as, or quicker than, the changes taking place. A more pro-active and less precautionary adaptation response is only possible once reliable projections are developed.

Turning now to the other measures, Gardner et al. 2011 provide a summary list of performance measures for the Rock Lobster fishery which, with some modification, can be applied to many others. These are grouped under major categories as follows:

Commercial fishery catch and effort

- Total commercial catch (total and by area)
- Total commercial effort (total and by area)
- CPUE total, all shots and day shots only
- Catch per vessel per day
- Well mortalities, octopus mortalities and personal use
- Active days per vessel
- Catch and catch rate trends in key blocks
- Mean weight of lobster (by area)
- Legal size discards (total and by area)
- Harvest rate (by area)

Recreational fishery catch and effort

- Total recreational catch (total and by area)
- Total recreational effort (total and by area)
- Success rate of recreational fishing by area and gear
- Recreational participation and licensing trends
- Seasonality of recreational catch
- Size composition of catch/area/method
- Weight of recreational caught lobsters /area/method
- Fisher satisfaction
- Attitudes to management arrangements

Recruitment and Sustainability

- Spawning biomass (by area)
- Estimated recruitment (by area)

- Undersize abundance (by area)
- Puerulus settlement

Ecosystem

- Discarded by catch
- Retained by product
- Protected species interaction data
- Biomass of large lobsters (>140 mm CL) by region

Economics

Commercial

- Market capitalisation of quota units
- Economic yield
- Gross value of product
- Commercial price
- Revenue per vessel per day
- Trends in quota ownership data
- Number of active commercial vessels
- Number of vessels taking 100%, 50%, 20% of the catch
- Trends in use of regional ports (home base and unloading)

Recreational

- Recreational fishing satisfaction

These measures, and management of Australian fisheries based on these measures, demonstrates a degree of sophistication, and points to existing adaptation capability and capacity within these fisheries that may be sufficient to deal with declines in stock levels and recruitment changes. However, inspection of the assessment reports for both Rock Lobster and Abalone point to some key uncertainties notably:

- Reliability of historical stock-recruit relationship and its spatial variation
- Need to more fully document and model disease threats such as the Abalone Viral Ganglioneuritis (AVG) outbreak
- Potential interdependencies between spawning/recruitment in one region and downstream supply of juveniles to another region

The response of some operators implementing higher voluntary size limits and voluntary reef closures in the Victorian Abalone Fishery suggests that operators are much more responsive to changes in stocks than management. So, an important attribute of measures is how rapidly a change is measured after it has occurred, and how rapidly that measure is translated into decisions designed to control, or take advantage of, the changes. Co-management arrangements where local decision choices are made by management working in tandem with operators is an adaptation approach that may work well for stocks that have strong spatial structuring in their response to fishing. Here again, the relative prediction capabilities of regional assessment models versus those based on local observations/models can be used to manage and adapt to differences in responses at local sites.

9.2.3 Measures and Values

Voluntary decisions and actions also point to the existence of assessment "models" being used by operators in guiding their activities. These models may be formal or heuristic (for a discussion of cognitive decision making see Kahneman's 2011 excellent exposition on fast and slow thinking) and in process may involve similar feedback links that reinforce or change the existing cognitive models used for decision making. Here again, the behaviour of the operators will be determined by their confidence in the models/assessments being made by management versus their observations and cognitive models gained from experience/history, or from experiences/readings elsewhere that they think may also apply to their circumstances. Adaptation in such situations should adjust towards the "best" approach for projecting the state of the stock. However, different groups will place different "values" on the same outcome (Figure 26). For example, higher catch rates may be seen as a success by operators, but conservationist may take an opposite view in terms of conservations outcomes. It is the translation of "measures" into "values" and the use of those values in assessment models by different groups, to guide decisions and actions, that are at the heart of "adaptation". In that sense, adaptation is a multi-faceted process where groups act upon outcomes with differing, and perhaps conflicting, views and valuations so that the net result on stock levels, incomes, conservation status, and other measures, involves a highly dynamic interaction between decision makers within the industry, or those who are able to influence decision makers.

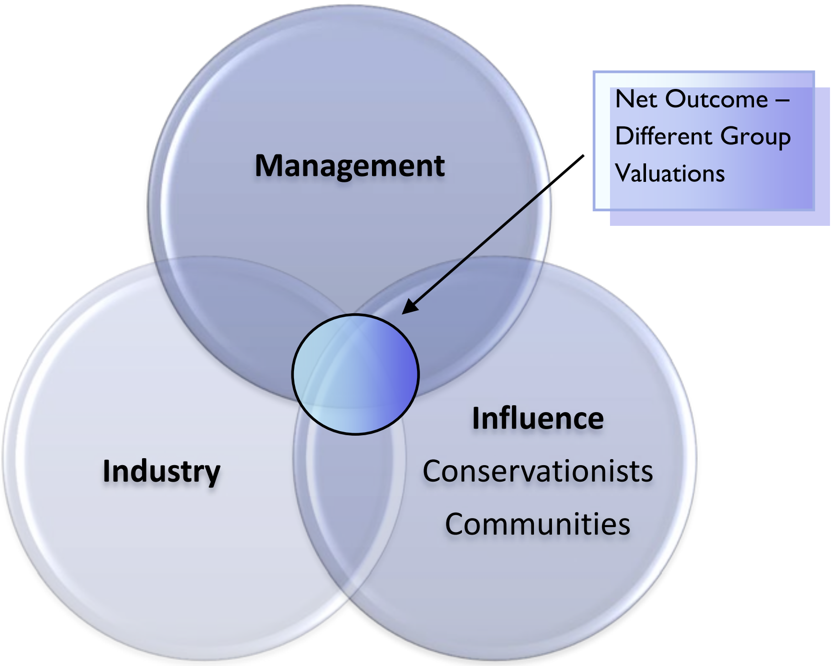


Figure 26 Illustration of the groups involved in decision making, and the differing valuations of measures used by the decision makers that then produces a net outcome (represented by a set of measures).

Likewise, in the context of species with pelagic life history phases, good outcomes in one region may not necessarily translate to good outcomes in a downstream region that is receiving recruits or reliant upon migration from that region. In a competitive industry, disease outbreaks in one region may not cause as much concern as it would if the disease were to spread from that region to others.

9.3 Target-Action Matrix

Referring to Table 6, the Target-Action Matrix (TAM) is the core element of the adaptation planning framework proposed here. It takes input from the measures and in conjunction with triggers and thresholds, selects the decisions most likely to be made by the various groups of decision makers. The columns of the matrix represent Targets/Indicators that are relevant to the performance of the commercial fishery and those that may be imposed by the EPBC Act (see previous discussion). Other conservation-related Human Targets, Social, Economic and Other (such as political, cultural for instance) are listed as rows. Decisions are presumed to be driven by Performance Targets with Human Targets acting as context for the choices, and priorities, of Decisions/Actions contained in each cell of the matrix. Each cell in the matrix therefore has a prioritised list of Decisions/Actions for each relevant group of decision makers. A key element of any participatory, or co-management, planning process is agreement on populating the matrix which involves agreeing upon a Strategy for the Adaptation Outcome and a set of criteria (based on the Strategy) for prioritising the decisions/actions in each cell of TAM.

The process that is currently used to make decisions is referred to as the Business As Usual (BAU) approach and it provides the datum against which other strategies are assessed. In the adaptation framework, alternative approaches to selecting and making decisions in the TAM are explored to select those (the Adaptation Pathways) that may yield more favourable outcomes expressed as a prioritised set of targets and indicators which must be agreed to as the outcome of the overall Adaptation Process (the key outcome of the BAU process must also be agreed to – be it Maximum Sustainable Yield or a more precautionary stock level in the case of uncertainties in stock dynamics, or alternatively as an observation-based adaptive strategy in the case of high uncertainty).

In defining the intended outcomes of adaptation, a Strategy for Adaptation, should be developed that guides how decisions from the TAM will be selected in order to achieve desired Targets and Indicators. However in situations of high uncertainty where there is a lack of models capable of projecting future impacts, the outcomes of adaptation may well not be a Target or Indicator (or a set thereof), but rather the "Strategy" itself - as a process that defines how decisions/actions will be selected from the TAM in order to deal with the uncertainties. The outcomes in this instance will be notional as the process is meant to implement the best possible set of decisions/actions in order to deal with the uncertainties; but hard limits may be placed in situations where for instance the state of the stock is nearing extinction levels (this can be captured as one of the Performance Targets in a column which may over-ride all other row-based Human Targets).

The Strategy chosen for adaptation should depend on the nature of the Bioregional and Species Impacts that are projected to occur. Amongst a range of scenarios that are possible for these Impacts, the ones that contrast sharply with current fisheries-related impacts may require novel forms of adaptation that have not been implemented thus far. Some of these scenarios are:

1. **The Regime Shift Scenario:** Here, a regime shift in ocean circulation brings about dramatic changes in water properties and wholesale ecological shifts. This will trigger a number of Performance Targets across fisheries with implications for those species that are under threat and unable to respond by shifting, coping or adapting to their new environment – particularly so in the case of endemics at the extreme range of their habitat. Species shifts will displace existing fisheries and possibly create new ones requiring changes in management rules, regulations and controls, and requiring adaptation by operators in targeting the invading species, or chasing the disappearing ones. In addition there may be changes to growth rates, recruitment success, disease prevalence as well as invasives. This scenario is not as far-fetched as it may seem as in view of the predictions by Cai et al.

(2005) of dramatic shifts in the East Australian current and the conclusions by Last et al. (2010) that: "*…there have been major changes in the distribution patterns of Tasmanian fishes that correspond to dramatic warming observed in the local marine environment.*" Other anecdotal observations from fishers are listed by Pecl et al. (2009) and earlier warnings were sounded by Lyne et al. (2003) and Lyne et al. (2005). These are all indicators of dramatic changes off eastern Australia, and that the Regime Shift Scenario is underway. There is clear need for coordination across NSW, Victoria, Tasmania and the Commonwealth to develop an agreed Strategy at the regional level and for fisheries anticipated to change. Following our framework, regional coordination and guidance are necessary to provide context for local and fishery-specific adaptations. The purpose of the collaborative regional Strategy is to formulate policies and management arrangements to deal with:

   a. Exploring options for a regional coordinating group of State fisheries managers (and Commonwealth as necessary) to oversee implementation of adaptation decisions and actions that transgress State/Commonwealth jurisdictions
   b. Inter and intra-State shifts in ecosystems along with their associated fisheries
   c. Formulating agreed policies in relation to displaced fisheries and "new" fisheries
   d. Providing a central pool of fisheries researchers, integrated information and monitoring data to assist the formulation of consistent assessments, regional policies and coordinated management
   e. Monitoring the regional environment so as to provide "early warning" of changes - as regime shifts typically involve enhanced variability in the environment causing dramatic shifts in species distributions and populations

2. **Abnormal Range Change Scenario:** Warming and changes in phenology lead to shifts in species physiological responses (growth, fecundity, cues), productivity and eventually changes in population and subpopulation levels. Distributional changes may exceed nominal ranges causing unusual sightings and catches of species. In some sense, this is a milder form of the Regime Shift Scenario and it may not require the establishment of regional coordination. More collaborative arrangements between State agencies affected by the changes may suffice but with similar aims as a regional body. Invasives and disease prevalence may also be altered under this scenario.

3. **Localised Change Scenario:** Here, the phenology changes and perhaps disturbances caused by altered extreme events lead to localised changes that may affect life history stages. Assessment models and management controls must be sensitive to impacts caused by these changes. The characterisation of mortality, growth and recruitment success may need recalibration to account for the changes. The Strategy in this case may be one of increasing the precautionary aspects in assessments and management to reduce the risks to the stock. Co-management arrangements to deal with spatial depletion and spatially variable stock-recruit relationships are well suited to deal with this Scenario.

To capture the connection between regional and State/local adaptation, a Target-Action Matrix (Table 5) should be constructed for adaptation at a regional scale appropriate to the Climate Change Scenario (one of those discussed above). Bioregions are used as the basis for this TAM and the Performance Targets comprise those for the Trophic Impact and Habitat Impact projections. In contrast to the Fishery TAM (Table 6), the target statistics used here are based on bioregions (for Performance Targets) and the collection of operators or communities relevant for the bioregion(s) (for Human Targets). Thus, the statistics here may be aggregated across a number of fisheries and local communities, and much of the statistics should be derivable from the TAMs constructed for individual fisheries. Likewise, managers involved in constructing the regional TAM will comprise those whose fisheries are involved in the region as well as those authorities with an oversight of more regional/national matters (AFMA, DEWHA, DAFF,…).

In principle the EPBC Act and its implementation should be capable of dealing with ecosystem-related issues. However the Act deals primarily with the impacts of fisheries on ecosystems, whereas climate change is more about the impact of ecosystem changes on fisheries. Given that formal procedures are in place to administer the EPBC Act, one option to deal with climate change impacts is to augment the Principles under the Act to cover the anticipated impacts, and the adaptation needs (regional coordination, collaboration, regional information collection and assessment, bioregional management planning, ..). Other less formal arrangements may be needed in the interim until the regional needs are clearly identified. Under a Regime Shift scenario, BAU fisheries practices and simple extensions thereof may not be sufficient to deal with issues likely to arise. Some operators have expressed to us that they don't think management practices need to change so this issue needs to be resolved early on. Some States are progressing well in developing their climate change strategies but the issue of cross-State and cross-fishery coordination and management will present significant challenges without an agreed administrative mechanism and regional adaptation framework.

Table 5 Illustration of the regional Target-Action Matrix structure. Using Climate Change Scenarios, and a Regional Adaptation Strategy, each column of the matrix contains a Target related to the performance of bioregions (for example: habitat extent and quality, trophic compositions, productivity) and each row contains a Human Target, relevant to the operators and communities associated with the bioregions, in one of the categories: Social, Economic, Conservation and Other (for example under Economic: Gross Value of Product, or Return per Vessel per day per area,…) – see list in previous section.

		Bioregion Performance Targets *(for each Climate Change Scenario)*
Human Targets	Social Targets	Each Cell of the Matrix contains a Prioritised set of Decisions/Actions that may be taken when the particular combination of Bioregion Target (column) and Human Target (row) are met. Decisions by relevant group (identified in each cell) will made to: • Do nothing or ignore the problem • Business As Usual • Reduce exposure/sensitivity to threat • Actions to avoid the threat • Increase Adaptive Capability and/or Capacity • Cope with the threat • Policies and actions to distribute risk • Reduce other compounding threats • Actions to reduce uncertainty • Take advantage of an opportunity • Coordinate information monitoring & sharing • Integrating risk assessments • ….
	Economic Targets	
	Conservation Targets	
	Other Targets	

Depending on the groups involved, each cell of the TAM may contain a number of prioritised lists relevant for each group. This is to capture the differing valuations the different groups will place on a given Performance Target. In cases where these decisions are in conflict with the overall Adaptation Strategy, part of the adaptation process is to undertake activities to realign those decision choices that go against the Strategy – we will return to this in the next section on Action Assessment and Selection. Thus, the role of the management group (which should be represented in each cell of the matrix) is to ensure that priorities and decision choices are aligned with the Adaptation Strategy while attempting to accommodate concerns expressed through the Human Targets.

Table 6 Illustration of the fishery Target-Action Matrix structure. Under guidance from an Adaptation Strategy, each column of the matrix contains a Target related to the performance of the fishery (for example, stock not to decline below 20% virgin biomass, CPUE to be above a minimum target,…) and each row contains a Human Target in one of the categories: Social, Economic, Conservation and Other (for example under Economic: Gross Value of Product, or Return per Vessel per day,…) – see list in previous section.

<table>
<tr><th colspan="3">Fishery/Ecosystem Performance Targets</th></tr>
<tr><td rowspan="4">Human Targets</td><td>Social Targets</td><td rowspan="4">Each Cell of the Matrix contains a Prioritised set of Decisions/Actions that may be taken when the particular combination of Fishery/Ecosystem Target (column) and Human Target (row) are met. Decisions by relevant group (identified in each cell) will made to:
• Do nothing or ignore the problem
• Business As Usual
• Reduce exposure/sensitivity to threat
• Actions to avoid the threat
• Increase Adaptive Capability and/or Capacity
• Cope with the threat
• Risk sharing
• Reduce other compounding threats
• Actions to reduce uncertainty
• Take advantage of an opportunity
•
• ….</td></tr>
<tr><td>Economic Targets</td></tr>
<tr><td>Conservation Targets</td></tr>
<tr><td>Other Targets</td></tr>
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2-3

Action Assessment
& Selection

9.4 Action Assessment and Selection

For any given situation where a Performance Target is met or about to be met, a range of decision choices are possible leading to differences in future projections of the Measures that are consistent within the ambit of the Adaptation Strategy. Decision choices at an early stage may foreclose future decisions, or alternatively offer greater scope for future adaptations. The costs and benefits of alternative decision choices and projections are entangled in differing group valuations (of the same outcome measure) as well as inherent uncertainties in projecting future outcomes against the backdrop of uncertainties in assessment models, monitoring information, future aspirations, climate change trajectories and the time and space scales (and other dimensions of decision choices) over which costs and benefits are valued and tallied. In the generic case, social and institutional dynamics must be considered in determining which decision choice set is most likely to be selected and how it will be implemented (for example, as extremes, under a dictatorial regime there is a restricted choice set and a regimented implementation, whereas a truly participatory planning approach could be mired in endless negotiations to get unanimous agreement before any decisions are made).

There are no simple solutions to this dilemma which in our overall framework is identified as Step 1: ***getting written agreement on the scope of the adaptation including agreed targets and indicators***. As a way around this problem, and as discussed before, the intended outcome may not be to achieve a definitive target or indicator, but to get coordination and integration, across the relevant groups in implementing an ***Agreed Strategy*** that will define, through agreed criteria, how decisions will be prioritised and implemented – and not necessarily proceeding to evaluate future projections and cost-benefits of alternative projections. Either approach (full blown cost-benefit analysis or Strategy-based decision choice selection) is accommodated within the framework but of necessity the cost-benefit approach is more comprehensive but may not be as robust to uncertainties without comprehensive evaluation of all potential uncertainties and their implications.

The Adaptation Framework as it stands allows decisions to be forced from the Fishery Performance perspective (column targets over-ride row targets) or else by the Human Targets, or perhaps by some weighted combination of the two. For the purposes of a fishery application we will assume that the Fishery Performance Targets take precedence and that the purpose of participatory planning, or co-management, is to obtain agreement on how the context provided by the Human Targets will influence alternative decision choices/strategies that are consistent with the desired fishery performance based adaptation outcome.

As further complication is climate change impacts at the bioregional level (as discussed previously) which may impact on fishery performance across fisheries and/or State jurisdictions. In such cases, the affected groups need to undertake a collaborative regional adaptation assessment to determine decisions/actions or Strategies that need to be implemented at the relevant regional level and specifically focussed on impacts at habitats and trophic aspects (as per our suggested impact assessment approach). These assessments will then provide part of the context (the Strategy) for the more State-based or local adaptation assessments as illustrated in Figure 27.

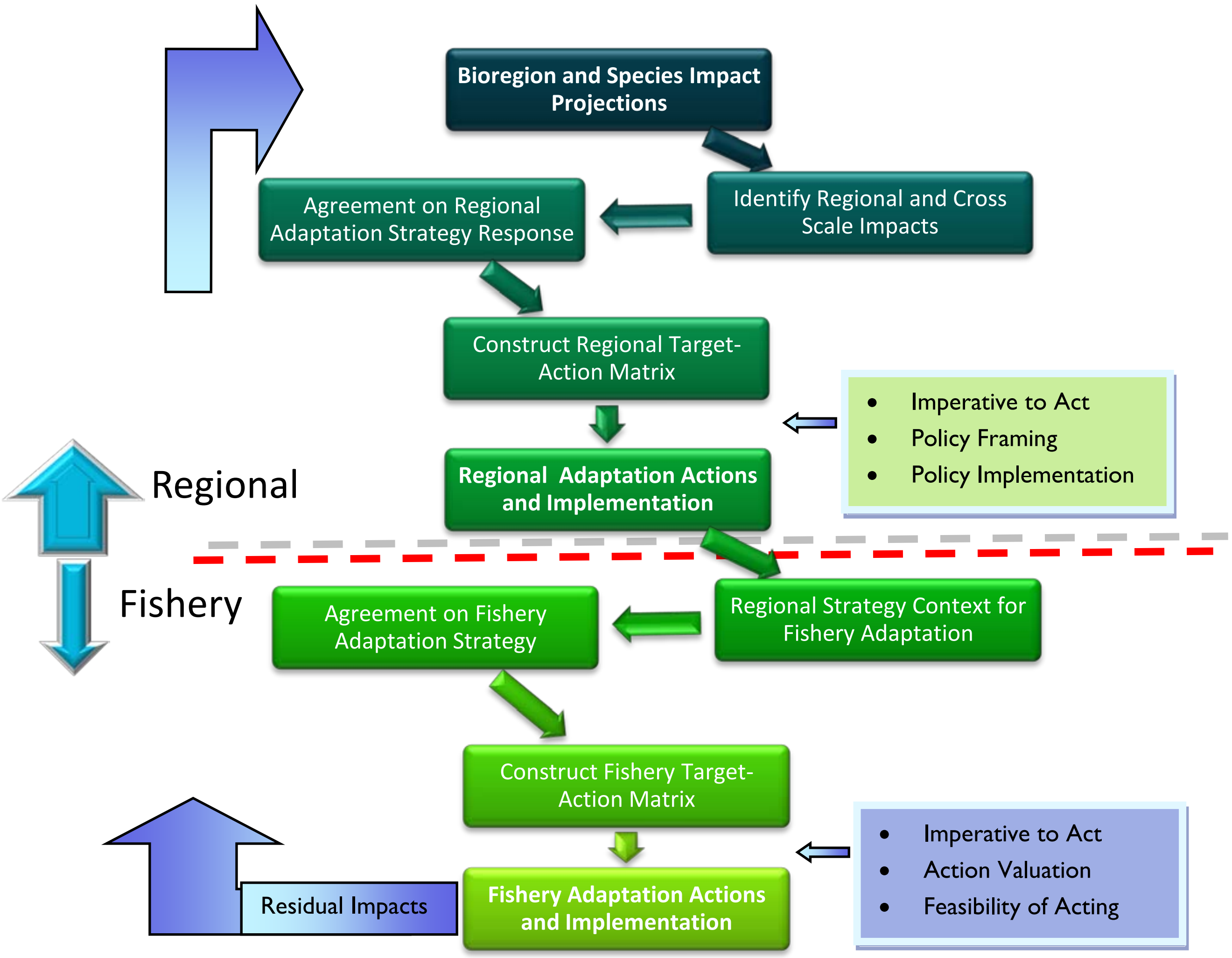


Figure 27 Flow chart for implementing hierarchical adaptation decisions/actions where climate change impacts cross regional and local scales; thereby requiring coordination and actions at regional scales that provide context for local adaptation. Residual impacts, from iterative application of the approach, are fed back to refine adaptation strategies and pathways.

In cases where cost-benefit calculations are deemed to be desired for the fishery, these should be calculated as departures of existing cost-benefits from the Business As Usual case. In cases where quantitative assessments are not feasible or desired, qualitative assessments may be possible using the following criteria:

1. Imperative to Act
   a. This will involve joint consideration of the urgency to act in the face of the Bioregion/Fishery Target being reached and the context provided by the Human Target. For example, unless starvation or livelihoods are at risk, a fishery at risk of collapse would require urgent action to instigate recovery actions. On the other hand, an island community with a burgeoning population and declining fish stocks will be driven by their livelihood needs.

2. Valuation of Adaptation Action
    a. In the absence of quantitative data a qualitative relative ranking of costs and benefits from 10 to 0 (or high, medium, low, zero) could be used to characterise differences from BAU.
3. Feasibility of Acting
    a. As examples, this may depend on resources to enforce compliance, assessment skills/knowledge, monitoring information, operational costs for compliance, or infrastructure resources required for effective management.

For the regional managers, their actions are primarily in policy formulation and evaluation so the criteria set comprises:

1. Imperative to Act
    a. The imperatives here are much the same as those for the fishery case but concerns here will be a more regional nature driven by issues that are common across a number of fisheries, or conflicts across jurisdictions, and typically involving valued fisheries.
2. Policy Feasibility
    a. Managers, with assistance from fisheries modellers and assessors, assess the merits and costs of alternative decisions and actions, and likely consequences on impact trajectories.
3. Policy Implementation
    a. Policies are enforced through changes or additions to rules, regulations and alterations to existing fisheries management structures and processes. The management group may also call upon fisheries to carry out assessments required to deal with issues under consideration.

One example of regional coordination to adaptation is the collaborative research between Victoria and Tasmania on assessing spatial management options in the Rock Lobster fishery, including translocation of stock from deep to shallow water, and from slow to fast growing areas. The framework presented here can be used to identify and assess such collaborative arrangements and their effect on more local scale adaptations.

10 Summary

In summarising the key messages of this project, the framework for vulnerability assessment, and that for adaptation, are linked through two mechanisms:

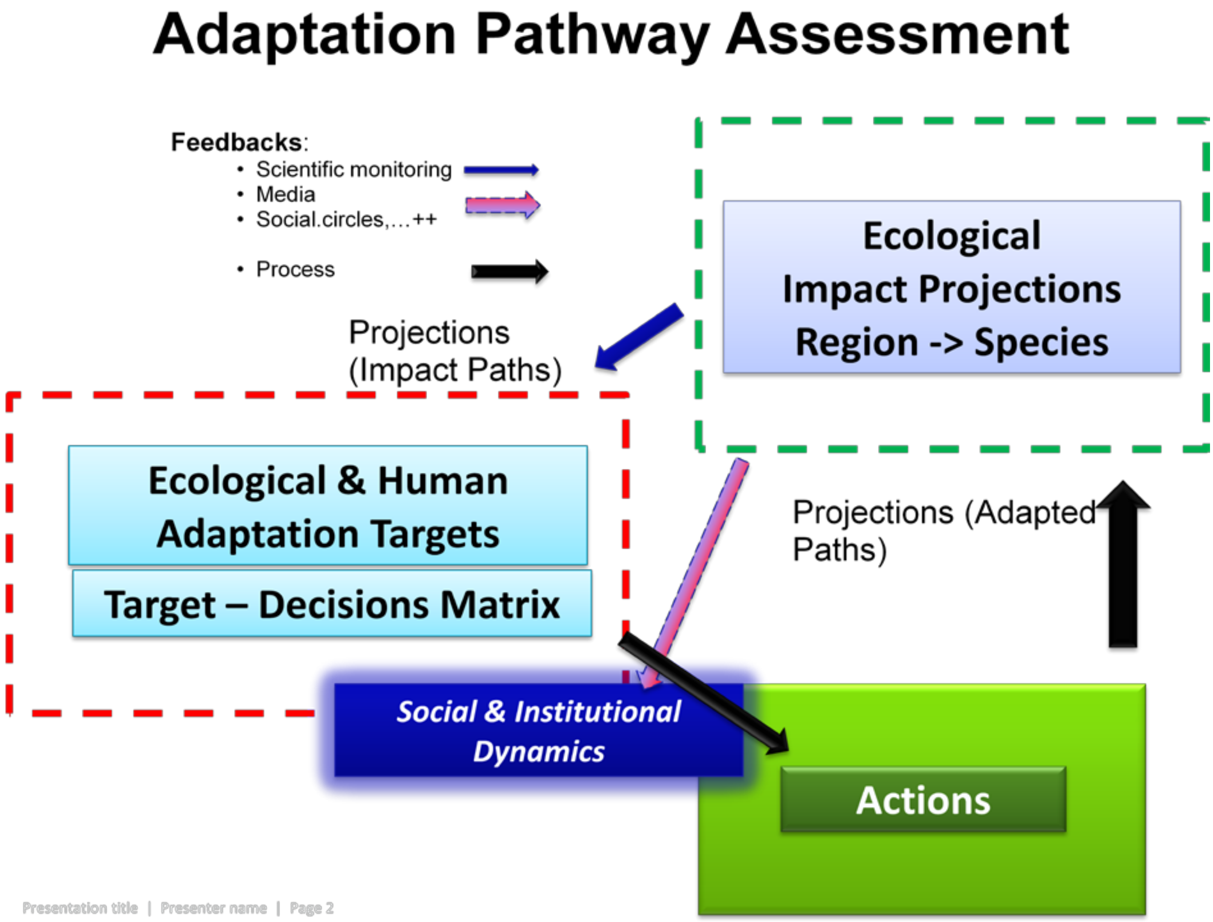
1. A hierarchical approach that links regional impacts and adaptation to provide context for the fisheries and local impacts and adaptation;
2. Recognising that adaptation strategies, decisions and implementations are conditioned upon the nature of the impacts and uncertainties surrounding decision making, but ultimately must be driven by agreed targets and indicators, or alternatively agreed "strategies", for the intended adaptation outcome.

In applying the framework to the South East we identified an urgent need for adaptation management given the scale and intensity at which climate related changes are taking place. Warnings on potential changes were identified as early as 1994 and further reinforced by other studies in 2003 and later. To date, no suitable framework was available that could deal with the many facets not only of climate change but the adaptation process and cross-scale issues. The framework and tools presented here offer a structured and relatively comprehensive treatment of the complexities of adapting to climate change impacts, and builds upon the advanced nature of fisheries assessment and management in Australia.

The critical additional challenge posed by climate change impacts is the need for regional assessment and management processes, which so far has primarily been the ambit of Commonwealth conservation agencies, to be tightly linked into providing guidance on fisheries management. Within a Regime Shift situation, the pace of management reform must adapt at least as quickly as those whose livelihoods are being affected by changes to the fisheries. We make a number of suggestions in the report as to how this may be facilitated by taking advantage of existing administrative and collaborative management arrangements.

Finally, the tools developed from this project will provide a sound basis for collaborative and co-management approaches to assessing climate change impacts on fisheries not only in the South East but also in the other regions around Australia and internationally.

For reference, Figure 28 and Figure 29 summarise schematically the components of the generic adaptation approach that we have used for this project. The framework is an evolving approach which is also being used to assess sustainable livelihoods in developing countries (Skewes et al. 2011). It represents a structured approach to dealing with the complexities of impact risks from climate change and adaptation responses that are required to assess and manage those risks. Figure 28 shows the broad components and linkages between the vulnerability assessments; adaptation planning, decision making and actions feeding back to alter vulnerabilities. The core aspect of the adaptation component is the Target-Action matrix which in situations of high uncertainty may be simplified to focus on Strategies. Further details of the components are provided in Figure 29.



Adaptation Pathway Assessment

Feedbacks:
- Scientific monitoring
- Media
- Social.circles,…++
- Process

Projections (Impact Paths)

Ecological Impact Projections Region -> Species

Ecological & Human Adaptation Targets

Target – Decisions Matrix

Projections (Adapted Paths)

Social & Institutional Dynamics

Actions

Presentation title | Presenter name | Page 2

Figure 28 Illustration of the broad components of the Adaptation Planning and Assessment approach showing projections of ecological impacts (top right box) linking into the Target Decision Matrix assessment (central left box). Social and Institutional dynamics affects the choice of Decisions and Actions which are then implemented to alter the projected impact pathways.

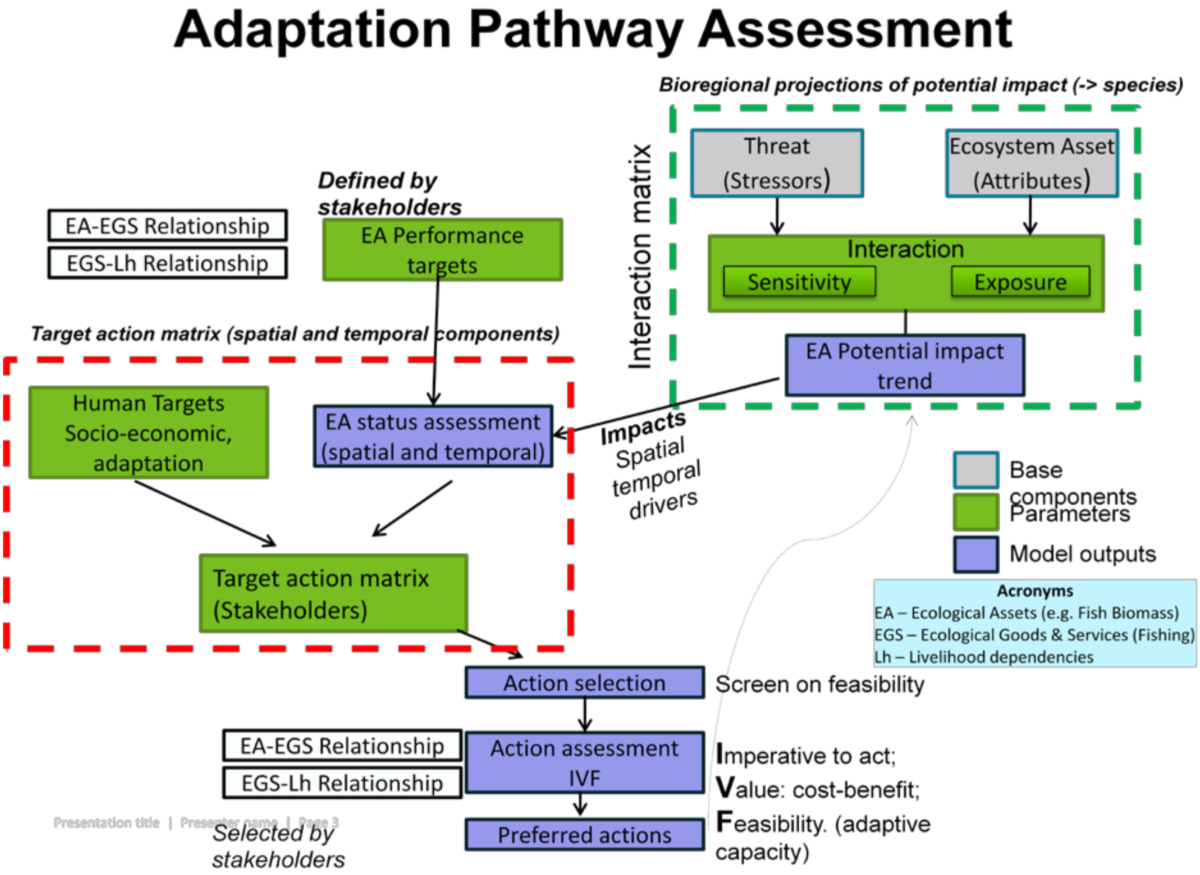


Figure 29 Schematic summarising details of the proposed adaptation processes for fisheries and aquaculture.

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Appendix A Bioregion Descriptions

REGION (IMCRA v.4.0)	GRID_CODE	NAME	SB_CODE	SEAP Bioregion (SB)	Bathome (m)	Area (km^2)	Water Type
8	1	Southern Province	1	SP_Ocean Interior	200 -2000	66937	Warm Temperate waters
8	2	Southern Province	2	SP_Ocean Epipelagic	0 - 200	66937	Warm Temperate waters
8	4	Southern Province	3	SP_Slope Demersal	near bottom	66937	Warm Temperate waters
9	1	West Tasmania Transition	4	WTT_Ocean Interior	200 -2000	301980	Transition
9	2	West Tasmania Transition	5	WTT_Ocean Epipelagic	0 - 200	301980	Transition
9	4	West Tasmania Transition	6	WTT_Slope Demersal	near bottom	301980	Transition
10	1	Tasmania Province	7	TP_Ocean Interior	200 -2000	125	Cold temperate waters
10	2	Tasmania Province	8	TP_Slope Epipelagic	0 - 200	125	Cold temperate waters
10	4	Tasmania Province	9	TP_Slope Demersal	near bottom	125	Cold temperate waters
12	1	Central Eastern Province	10	CEP_Ocean Interior	200 -2000	262794	Warm Temperate waters
12	2	Central Eastern Province	11	CEP_Ocean epipelagic	0 - 200	262794	Warm Temperate waters
12	4	Central Eastern Province	12	CEP_Slope Demersal	near bottom	262794	Warm Temperate waters
33	5	Spencer Gulf Neritic Province	13	SGNP_Shelf Demersal	near bottom	102370	Warm Temperate waters

33	2	Spencer Gulf Neritic Province	14	SGNP_Shelf Epipelagic	0 - 200	102370	Warm Temperate waters
33	3	Spencer Gulf Neritic Province	15	SGNP_Coastal	0 - 30	29312	Warm Temperate waters
34	5	Western Bass Strait Neritic Transition	16	WBSNT_Shelf Demersal	near bottom	33850	Transition
34	2	Western Bass Strait Neritic Transition	17	WBSNT_Shelf Epipelagic	0 - 200	33850	Transition
34	3	Western Bass Strait Neritic Transition	18	WBSNT_Coastal	0 - 30	3994	Transition
35	2	Bass Strait Neritic Province	19	BSNP_Shelf Epipelagic	0 - 200	59674	Cold temperate waters
35	3	Bass Strait Neritic Province	20	BSNP_Coastal	0 - 30	6438	Cold temperate waters
35	5	Bass Strait Neritic Province	21	BSNP_Shelf Demersal	near bottom	59674	Cold temperate waters
36	5	Tasmanian Neritic Province	22	TNP_Shelf Demersal	near bottom	28445	Cold temperate waters
36	2	Tasmanian Neritic Province	23	TNP_Shelf Epipelagic	0 - 200	28445	Cold temperate waters
36	3	Tasmanian Neritic Province	24	TNP_Coastal	0 - 30	4603	Cold temperate waters
37	1	Southeast Neritic Transition	25	SNT_Shelf Epipelagic	0 - 200	51225	Transition
37	5	Southeast Neritic Transition	26	SNT_Shelf Demersal	near Bottom	51225	Transition
37	3	Southeast Neritic Transition	27	SNT_Coastal	0 - 30	8599	Transition
38	1	Central Eastern Neritic Province	28	CENP_Shelf Epipelagic	0 - 200	14859	Warm Temperate waters
38	5	Central Eastern Neritic Province	29	CENP_Shelf Demersal	near Bottom	14859	Warm Temperate waters
38	3	Central Eastern Neritic Province	30	CENP_Coastal	0 - 30	1905	Warm Temperate waters

Glossary

Risk Analysis Terms

Adaptive capacity: The potential or capability of a species (as a population), or potentially impacted entity, to avoid or adjust its exposure and/or sensitivity to an actual or expected stressor, or to cope with the consequences.

Driver: An environmental forcing or human pressure that has the potential to impact the state of the natural environment including its biological components.

Exposure: Degree to which an entity of interest (e.g. fisheries population, ecosystem asset) is exposed to the driver/stressor under consideration. This can be related to the intensity of the stressor, and/or the spatial overlap of the stressor and the asset.

Impact: Change in the state of an entity caused by the exposure of the asset to a driver/stressor and its sensitivity to the stressor. This is the potential impact before accounting for adaptive responses from the entity. In the context of risk assessments, the result or effect of an event that materializes the risk.

Sensitivity: Degree to which an entity is affected by, or responsive to, a driver/stressor (note that sensitivity includes both problematic and beneficial responsiveness). This will often reflect, for example, an established relationship between the biological/physiological responses of an ecosystem component to a physical aspect of the stressor, and as such is generally consistent across stressor ranges. However, the sensitivity will vary in terms of the reaction response curve (often non-linear), and variation in the composition of the ecosystem entity.

Stressor: Any physical, chemical, or biological agent or process arising from a driver, which can induce an environmental or biological response.

Bioregion Terms

Coastal: The marine zone from high tide mark to out to 30m water depth.

Ocean Interior: Consists of Mesopelagic and Bathypelagic with depth range from 200m to 2000m water depth.

Neritic: Region from the low time mark to the edge of the Shelf (200m depth)

Shelf Epipelagic: Consists of the depth range 0 m to 200m. This bioregion does not overlap the coastal region.

Slope Epipelagic: In this report Epipelagic is the surface layer of water on the slope (Oceanic region) from 0 – 200m.

Shelf Demersal: This region is the benthos and includes the water column near the benthos on the shelf. The depth ranges from 30m water depth out to 200m water depth.

Slope Demersal: This region is the benthos and includes the water column near the benthos on the shelf. The depth ranges from 200m water depth down to 2000m water depth.

CONTACT US
t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION
Division/Unit Name
Vincent Lyne
t +61 3 62 325 333
e Vincent.lyne@csiro.au
w www.csiro.au/cmar