# climate change and recreational fishing

PROJECT
2011/037

Australian Government
Department of Agriculture, Fisheries and Forestry

Australian Government
Fisheries Research and Development Corporation

# Climate Change and Recreational Fishing

Implications of Climate Change for Recreational Fishers and the Recreational Fishing Industry

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Australian Government
Department of Agriculture, Fisheries and Forestry

Australian Government
Fisheries Research and Development Corporation

# Project No: 2011/037

Published by Recfishing Research



ISBN number

Cover designed by Creative Avenue Rockhampton

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## ACKNOWLEDGEMENTS

Climate change was identified as a key issue in "Recreational fishing in Australia - 2011 and beyond: a national industry development strategy". This strategy was initiated by the Minister for Agriculture, Fisheries and Forestry and was developed by the Recreational Fishing Advisory Committee from 2008-11.

Under the strategy the Department of Agriculture, Fisheries and Forestry (DAFF) provided funding of $100k for a project to develop a climate change implications paper for recreational fishing. The Fisheries Research and Development Corporation (FRDC) was contracted to manage a number of projects under the national strategy, including this project.

As with the regional approach specified in DAFF's National Climate Change Action Plan for Fisheries and Aquaculture this work was done based on the 3 regions proposed in the Action Plan – South East (encompassing NSW, Vic, Tas and SA), Western (being southern WA) and Northern (being essentially tropical Australia). In the South East and Northern regions a workshop was held to assess the impacts of climate change on their region. The contribution of all those that contributed to the workshops is acknowledged as much of this report reflects the views expressed in those workshops.

As well as those that contributed to the workshop (see appendix 3) there were a number of people that provide expert input to the species that were selected and their contribution is acknowledged.

The follow are acknowledged for their review of species profiles:

Dr John Russell of the Queensland Department of Agriculture, Forestry and Fisheries for reviewing Mangrove Jack.
Gavin Begg and Darren Cameron who both reviewed Spotted Mackerel.
Andrew Tobin for reviewing Barred Javelin.

# 1. NON-TECHNICAL SUMMARY

Implications of climate change for recreational fishers and the recreational fishing industry

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## Objectives

The objectives of this project were:

1 Through case studies of vulnerable species in each of the three regions this project will explore and propose activities and strategies such as improved fisheries management measures which could be adopted to assist agencies, recreational fishers and the recreational fishing industry adapt and deal with climate change impacts

2 Explore climate change adaptation responses and move towards regional arrangements that foster a more flexible and responsive approach to recreational fisheries and fisher needs

3 Identify high priority mitigation opportunities so that the recreational sector can contribute to the global issue of reducing greenhouse gas emissions

## Non-technical Summary

**OUTCOMES ACHIEVED**

This report is the first national perspective of the implications of climate change on recreational fisheries and the recreational fishing industry providing a platform for further discussion of the ecological impact on species and evaluation of adaptation and mitigation options.

Highlight that with climate change will come increasing climate variability and stressors such as changing sea level it is recognised that everything we can do to ensure resilience of fish populations is essential.

Highlight of the need for monitoring to focus on data that can be used to better predict the future, especially in the areas of recruitment and recording species outside their normal range. These are areas where recreational fishers can play a role in data collection.

Recognition of the need for greater flexibility and responsiveness in fisheries management and to move to a whole of stock management approach as climate change alters the dynamics and distribution of fish stocks.

Recognition that understanding and mitigating the impacts of climate change on recreational fishing has some important human dimensions, such as understanding the choices fishers make in response to climate change and the flow-on effects of these choices.

Project team members from three regions examined the implications of climate change within those regions and then to use the findings to provide a national perspective. The regions were:

- Northern (tropical Australia)
- South East ( encompassing New South Wales, Victoria, South Australia, Tasmania)
- Western (southern Western Australia)

Workshops were held in the Northern and South East regions to address the project objectives with each workshop having a slightly different focus. The Northern region focused on social aspects of climate change while the South East region focused on the ecological aspects. In the Western region a series of interviews with key stakeholders and researchers were held and the information collated. Regional reports were then prepared based on the findings of the workshops and the species risk assessments. The regional reports have been incorporated into the final report.

Within each region a number of key species were selected and their vulnerability to climate change was assessed. Species considered important to recreational fisheries were selected using a similar methodology to that set out in Risk Assessment and Impacts of Climate Change for Key Marine Species in South Eastern Australia. Species selection also took into account other climate change projects that were also undertaking vulnerability assessments. While some species were considered to be recreationally important these were being assessed though other projects and were not included in this project.

The effects of climate change will act at the social, ecological and economic levels. At the social level this will translate into changes in fisher behaviour in response to changes at the ecological level. Adaptation is a measure of the extent to which change occurs at the social level.

In general individual recreational fishers have the greater capacity to adapt based on the flexibility in their decisions about fishing activities and these will be influenced by how much they value particular species. Fishing organisations are less flexible being constrained by their constituents and management is constrained by a lack of flexibility in legislation and regulations. Climate change will provide added pressure on fishing organisations and government to develop approaches and policies that provide a greater level of flexibility and responsiveness. This will be assisted if management and therefore monitoring places greater emphasis on collecting data that will assist in predicting the future. Data collection should focus on recruitment and species distribution as well as taking note of anomalies such as species outside their normal range, Recreational fishers can play a role in collecting such data.

With the onset of increasing climate variability fish populations will also fluctuate, especially in response to wet and dry periods, variable ocean currents and temperatures. Monitoring should ensure managers have excellent predictive knowledge on population fluctuations and changes in range. Decision rules for management changes will be needed so that management arrangements can implement agreed harvesting strategies and rapidly respond to these fluctuations.

Mitigation can play a role at both the social and ecological levels. Mitigation is a measure of changes to greenhouse gas emissions that are likely to reduce the impacts of climate change. There are no current measures of the contribution of recreational fishing to greenhouse emissions or of any changes to those levels. All members of the Australian community can play a role by altering behaviours to reduce energy use, for example, through solar power supplementing electricity grids, solar hot water systems, efficient lighting and insulation, reduced air conditioning, walking and biking rather than using cars and so on. Recreational fishers can be part of this general change in behaviours. Recreational fishers can also as a specific group think through their energy use in getting to their fishing grounds. Fishing closer to home, or using non-powered craft such as kayaks are simple strategies. Recreational fishers can also play a significant role in mitigation through a reduction in carbon emissions by moving to lower emission and more fuel efficient outboards.

At the more general level of the entire fishing industry and its linkages to the natural environment is the issue of estuary and wetland repair. Mangroves, salt marshes and seagrasses comprise less than 1% of the Australian landscape yet they sequester up to 39% of the carbon. Equally importantly, sequestration in these environments is essentially no risk. Compare this nil risk to other mitigation options proposed such as rangelands management or revegetation – in these terrestrial ecosystems risk remains high because of Australia's frequency of wild bushfires and droughts. From the recreational fishing industry perspective, any work to retain and repair fisheries habitat will also, as well as improving fishery productivity, have a carbon mitigation dividend.

The effect of climate change on fish species occurs at the ecological level and this will engender a response at the social level. The vulnerability of 14 key recreational species to climate change in the three regions was assessed with eight species assessed as resilient, four species assessed as uncertain and two species assessed as vulnerable. Each region provided a detailed assessment of the life histories of each species and their vulnerability at different stages of their life cycle. The south east region was able to build on prior research funded under the South East Adaptation Program and suggest adaptation and mitigation measures that could be taken for the key species in their region.

The work was confined to estuarine/marine species as there are detailed projections to 2030 on changing sea surface temperature beyond normal variability. The work of RedMap has already shown changing ranges for marine species. For freshwater fisheries much of the impact from climate change up until 2030 will be increasingly more variable rain events/ river flows. This is a recognised feature of freshwater fishing and recreational freshwater fishing already adapts to the variable stream flow/runoff conditions that characterise the Australian landscape.

| Northern region | South East region | Western region |
|---|---|---|
| Mangrove Jack *(Lutjanus argentimaculatus)* | Black Bream *(Acanthopagrus butcheri)* | West Australian Dhufish *(Glaucosoma herbaicum)* |
| Spotted Mackerel *(Scomberomorus munroi)* | King George Whiting (*Sillaginodes puntatus*) | Baldchin Groper *(Cheorodon rubescens)* |
| Red Emperor *(Lutjanus sebae)* | Mahi Mahi *(Coryphaena hippurus)* | King George Whiting *(Sillaginodes puntatus)* |
| Barred Javelin *(Pomadasys kaakan)* | Yellowtail Kingfish *(Seriola lalandi)* | Spanish Mackerel *(Scomberomerus commerson)* |
| Dusky Flathead *(Platycephalus fuscus)* | | Australian Salmon *(Arripis truttaceus)* |
| | | Roe's Abalone *(Haliotis roei)* |

| | |
|---|---|
| (green) | Considered to be resilient to climate change |
| (yellow) | Vulnerability to climate change uncertain |
| (orange) | Considered to be vulnerable to climate change |

Based on the assessments a number of recommendations are made:

1. Increased attention to Coastal Fisheries Habitat Protective Management or “No Habitat – No Fish"

With a more extreme and variable climate all possible steps should be taken to ensure resilient stocks. This especially involves protection, management and repair of fisheries habitat – our estuaries, seagrasses and wetlands, mangroves through to fresh wetlands. In many of our coastal systems much damage to habitat has occurred through other lands uses, roads, blocking of tidal flows, reclaiming, draining, flood-gating, ponded pastures and so on. Repair of estuary and wetland systems to ensure long term productive fisheries are therefore an imperative. Equally importantly, these ecosystems are the highest per hectare of all Australian ecosystems in their sequestering of carbon or “blue carbon” as it is known. Repairing estuaries and wetlands therefore delivers on both adaptation and mitigation objectives.

The first step in this endeavour is to maximise the opportunity for all species to successfully breed. Coastal and nearshore habitat of estuaries, mangroves, seagrasses, salt marshes, fresh to brackish wetlands and coral reefs all play crucial roles in the nursery phases of recreational species. Protective management to minimise damage to habitat, water quality, tidal and freshwater flows is essential. Where states do not already provide for protective management of habitat, this needs to be added to their fisheries regulations. The Queensland Fisheries legislation provides a good example of how best to afford protective management.

2. Australia-wide Program of Estuary and Wetland Repair – Repairing Coastal Productivity

Many of Australia's coastal ecosystems have been reduced in productivity through barrages, drains, causeways, bunds and floodgates that restrict or prohibit tidal flows and fish passage. Coastal ecosystems of estuaries and wetlands also sequester per hectare more carbon than any other ecosystem type. Drained fresh to brackish wetlands emit methane – adding to the greenhouse gas problem. Many of these now non-productive areas can be repaired to deliver multiple outcomes of fisheries productivity, improved water quality, enhanced biodiversity and coastal buffering against sea level rise. An Australia-wide program of repair is needed. The first steps towards this are now being funded through a partnership between FRDC and the Biodiversity fund. This one year project will demonstrate the opportunities for repair in two pilot areas – Burdekin floodplain, Qld; and Clarence floodplain, NSW and will develop a Repair Plan identifying high priority and achievable works Australia-wide. All state Recreational Fishing Bodies together with fisheries and conservation agencies are encouraged to recommend estuaries and wetlands that could be included within this Australia-wide Repair Plan.

3. Moving to "whole of stock management"

For many species such as Snapper along the Eastern Australian coast the changing sea surface temperatures and eddies will change the location of the populations. State based fisheries management of stocks will become increasingly sub-optimum. Increased cooperation between fisheries management agencies across State boundaries and across State–Commonwealth waters is essential. It is recommended that joint management arrangements of the total stock be developed as soon as feasible for the following species:

- Snapper
- Yellowtail Kingfish
- Mahi Mahi
- Dusky Flathead
- Spotted Mackerel

4. Continued investment in Monitoring

Recent experiences of "outliers" of various species and opportunistic take of these species are detailed in the SE regions report. RedMap provides a monitoring tool for all fishers to record fish beyond their characteristic range. Keeping track of fish changes in range over time provides early warning information that in time can be translated into better fisheries management. It is recommended that continued investment in RedMap occur through the DAFF extension components of its Clean Energy Future initiative. Monitoring should move to focus more on recruitment and the drivers of recruitment as in the "Crystal Bowl" project in Queensland predicting Barramundi stocks in the Fitzroy River.

5. Flexibility in Bag Limits and Catch Regulations

With increasingly variable climate and increasingly wet or dry periods, fish and prawn stocks will vary. In some years the increased abundance will allow for a loosening of bag limits. In other years, limits might need to be tightened. It is recommended that climate and its impact on abundance of recreational populations be incorporated within an approach towards more flexible and population responsive bag limits. Suggested species to pilot this approach are:

- King George Whiting
- Snapper
- Barramundi
- Black Bream

**Keywords**

Climate change
Recreational fishing
Adaptation
Mitigation
Vulnerability
Regional management

## 2. BACKGROUND

How this project was developed -

This project has been developed as a direct consequence of the Commonwealth government through DAFF and the Recreational Fishing Industry Development Strategy allocating $100K for a project for the development of a discussion paper on the implications of climate change for recreational fishers (RFAC 2011). The project has also been formulated specifically within the context of the DAFF coordinated *National climate change action plan for fisheries and aquaculture*. Implementing this Action Plan, as detailed on page 21, calls for both National Strategies and Regional Action/Adaptation. This project has been deliberately designed and was delivered to accord with this Implementation Plan viz - National Leadership and Strategies - Colin Creighton and Bill Sawynok as joint Principle Investigators, Regional Analysis and Action - South East - lead by Dallas D'Silva, Northern led by Steve Sutton and Western led by Ian Stagles.

Addressing FRDC strategic challenges -

Climate change adaptation is a major strategic challenge for FRDC and a R&D program in excess of $6M investment is underway. The outputs of this project, along with the outputs of the other projects in the initiative and other R&D findings will be collated into a Final Report on the initiative in 2013-14.

Climate change adaptation cross-cuts other FRDC strategic challenges - eg habitat, industry development and people development and this project has been designed to deliver within this broader context of fostering a long term sustainable fishing sector that gainfully exploits a bio-diverse and healthy suite of freshwater, estuarine and marine ecosystems.

Relationship to other projects -

This project has been designed and managed to dovetail into the FRDC - DCCEE climate change adaptation initiative with the specific outputs for recreational fishers, their activities, strategies and management arrangements to build upon and compliment other key projects within this FRDC - DCCEE initiative. Examples include the vulnerability assessments and the management opportunity analyses underway and the recreational fishing project using spearfishing data to explore changes in fish assemblages.

## 3. NEED

Climate change is manifesting in marine environments. Additional to climate variability there are documented shifts in ocean currents - temperature, behaviour and spatial impact. As the latest Marine Report Card has demonstrated [CSIRO & FRDC], biotic indications eg species changes in abundance and range suggest impacts are at a level greater than for terrestrial ecosystems and uses. Coupled with this is the common property nature of fisheries resources.

Management imperatives are already upon Government and all key sectors - conservation, commercial and recreational fishery management and aquaculture.

The first two challenges are to -
a) smartly adapt to biotic changes and variations in abundance
b) foster a more flexible and responsive approach to marine management.

Climate change is a social and political issue that carries with it a considerable degree of debate. Community understanding of the complexities of climate change and how Australia should respond is varied with multiple areas for confusion and misunderstanding. With this confusion as to the implications of climate change and options for adaptation and mitigation strategies, informed debate is extremely difficult. The recreational fishing sector is no different to the wider community.

Given the economic and social importance of recreational fishing in Australia, there is a national need and strong regional demand for strategies and adaptation activities and management systems that respond wisely to climate change.

The second two challenges are to:
c) ensure accurate information on climate change is available and is placed in context with other aspects such as habitat loss and water quality
d) foster knowledge and adaptation strategies from within the recreational fishing sector so that the sector can play its role in advocacy and public policy development.

## 4. OBJECTIVES

The objectives of the project were:

1 Through case studies of vulnerable species in each of the three regions this project will explore and propose activities and strategies such as improved fisheries management measures which could be adopted to assist agencies, recreational fishers and the recreational fishing industry adapt and deal with climate change impacts

2 Explore climate change adaptation responses and move towards regional arrangements that foster a more flexible and responsive approach to recreational fisheries and fisher needs

3 Identify high priority mitigation opportunities so that the recreational sector can contribute to the global issue of reducing greenhouse gas emissions

# 5. METHODS

Project members from three regions examined the implications of climate change within those regions and those findings were used to provide a national perspective. The regions were:

- Northern (tropical Australia)
- South East (New South Wales, Victoria, South Australia, Tasmania)
- Western (Western Australia)

Within those regions a number of key species were selected and their vulnerability to climate change was assessed. Species considered important to recreational fisheries were selected using a similar methodology to that set out in Risk Assessment and Impacts of Climate Change for Key Marine Species in South Eastern Australia (*Pecl et al 2010*). Species selection also took into account other climate change projects that were also undertaking vulnerability assessments. While some species were considered to be recreationally important these were being assessed though other projects and were not included in this project.

Workshops were held in the Northern and South East regions to address the project objectives with each workshop having a slightly different focus. The Northern region focused on social aspects of climate change while the South East region focused on the ecological aspects. In the Western region a series of interviews with key stakeholders and researchers were held and the information collated.

Regional reports were then prepared based on the findings of the workshops and the species risk assessments. The regional reports have been incorporated into the final report.

The Northern region provided a social-ecological systems model of recreational fishers and a recreational fisheries climate change adaption model that can be considered to have national application.

The South East region examined the issue of mitigation through examining the effect of reduced carbon emissions of outboard motors on the carbon footprint of recreational fishing and this can also be considered to have national application.

# 6. ADAPTATION

## NATIONAL PERSPECTIVE ON ADAPTION BY RECREATIONAL FISHERS

There was a reasonable level of consistency between the three regions in relation to their approaches to adaptation and these were combined into a national perspective.

The effects of climate change on recreational fishers and fisheries act at both the social and ecological level. At the social level this translates into changes in fisher behaviour in response to changes at the ecological level. Adaptation is a measure of the extent to which changes occur at the social level.

There were three levels of adaptation that were identified by the regions. These were:

- individual
- organisational
- management

In general terms it was considered that individuals have the greatest capacity to adapt as they have the greatest capacity to be flexible in their decisions about their fishing activities. This in turn can lead to the need for organisational and/or management response.

Organisations have less flexibility due to the need to represent their constituents, which generally makes organisations conservative, and are therefore likely to take longer to respond to climate change. Leaders, be they fishing celebrities or local leaders, are very influential in forming fishers opinions and there is a need to develop better informed leaders in relation to climate change.

Management has even less flexibility as it is constrained by legislation and regulation and the process for changing these is often cumbersome and lengthy. There is a need to develop a more flexible policy, legislative and regulatory framework. For example, stock assessments should focus on becoming predictive about the status of stocks to increase the time available for a management response.

## NATIONAL SUMMARY

The following is a national summary of the views of the three regions to adaptation.

Recreational fishers will:

- need to adapt to shifts in the range of species and fluctuations in populations of sepcies important to recreational fishers
- largely be influenced by how they value a particular species (eg eating qualities, catchability, fighting qualities, iconic status)
- have new fishing opportunities for species positively affected by climate change and reduced opportunities for those negatively affected

Organisations will need to:

- improve their knowledge of the likely impacts of climate change

- become more flexible in their engagement of recreational fishers and government
- improve leadership skills

Management will need to:

- develop more flexibility in management controls to be more responsive to fluctuations in fish stocks
- move towards a "whole of stock" approach
- focus information collection on data that can be used for early detection of climate change impacts on fish populations (eg recruitment, changes in distribution)
- improve engagement of land, habitat and coastal managers to ensure that fisher and fisheries needs are understood and accommodated
- focus on improvements to estuary and wetland habitats

Some opportunities identified were:

- pelagic species such as Yellowtail Kingfish, Skipjack Tuna, Striped Marlin, Cobia and Mahi Mahi are likely to extend their range further south due to a strengthening EAC
- involvement in data collection to extend the information base that can be used to assess the impacts of climate change
- development of predictive stock models to provide a greater lead time for management response
- development of future opinion leaders to help communicate climate change and recreational fishing information to recreational fishers
- involvement in habitat improvement projects especially in relation to estuaries and wetlands
- development of artificial reefs, fish stocking etc as an insurance policy against the effects of climate change

Each region provided a more detailed assessment of adaptation as it applied to their region.

## NORTHERN REGION ADAPTATION

The northern region provided an overview of recreational fishing social-ecological systems and climate change as well as a climate change adaptation model which is nationally applicable. The northern workshop then provided an assessment of exposure and sensitivity of recreational fishers to climate change.

### 1. Recreational Fishing Social-Ecological Systems and Climate Change

Recreational fisheries can be conceptualised as two interacting systems: a social system (people) and the ecological system (fisheries resources) (Figure 1). In recreational fisheries social-ecological systems, humans use and depend on ecological systems (fisheries resources) and receive a range of benefits from this use (food, recreation, connection with nature, jobs, income, etc.). However, human use of fish and their habitats affects the ecological system, possibly resulting in negative outcomes for the system (e.g. overfishing, habitat loss, etc). Because feedbacks and interdependencies exist between the social and ecological systems, the coupling of natural and social systems usually results in non-linear social-ecological dynamics that extend across multiple temporal and spatial scales that effect a range of outcomes and benefits (Hunt, Sutton, Arlinghaus, in press). Because of these complex interactions between human and ecological systems, efforts to predict, understand, and mitigate the effects of climate change on recreational fishers, the recreational fishing sector, and the fisheries resources that they depend on must include consideration of human factors as well as ecological factors.

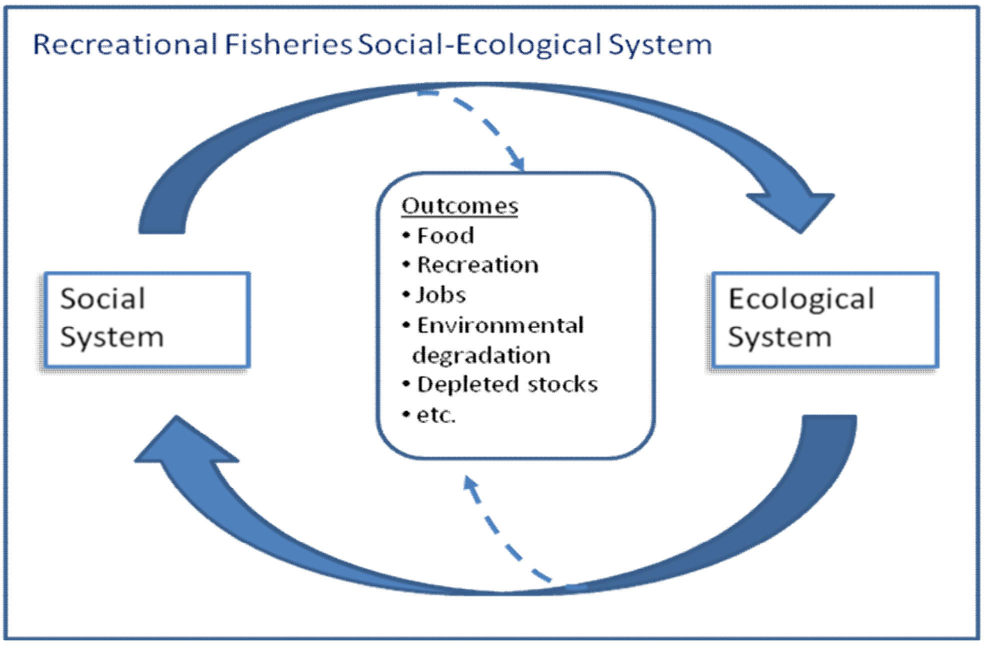


Figure 1. A social-ecological systems model of recreational fisheries

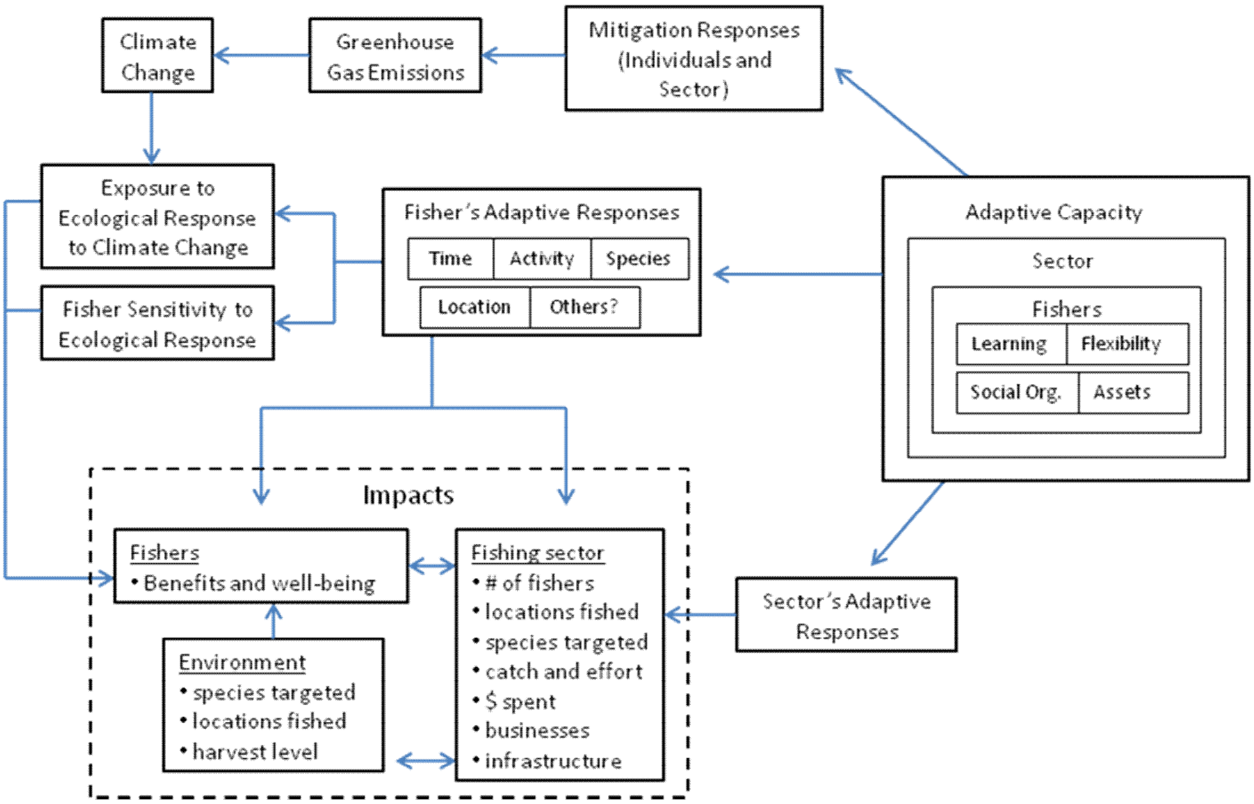


Figure 2. A climate change adaptation model for recreational fisheries

In the following sections, we briefly outline a model for predicting and understanding the potential impacts of climate change on the recreational fishing sector. This model has been derived by combining the literature on climate change vulnerability and adaptation with the literature on the substitution decision-making and behaviours that recreational fishers' undertake when faced with changes that impact the benefits they receive from fishing. Using this model, we demonstrate that many of the potential impacts on the recreational fishing sector will come not directly from ecological changes, but indirectly from recreational fishers' behavioural changes as they attempt to adapt to ecological change.

## 2. Recreational Fisheries Climate Change Adaptation Model

*2.1 Ecological Impacts of Climate Change*

The recreational fisheries climate change adaptation model is shown in Figure 2. Under this model, the impact that individual recreational fishers experience from climate change is a function of fishers' exposure to the ecological response to climate change and their sensitivity to that ecological response. The ecological response is defined as changes in the environment as a result of climate change (e.g., changes in species distribution or abundance). Although not shown in Figure 2, the ecological response to climate change is in turn a function of the exposure of the ecological system climate events and patterns that affect the system, but it also includes other changes in linked systems that might be induced by climate effects. In a practical sense, exposure is the extent to which a region, resource or community experiences changes in climate (IPCC 2007). It is characterised by the magnitude, frequency, duration and/or spatial extent of a weather event or pattern (Marshall et al. 2010). Ecological sensitivity is the degree to which a system is affected by, or responsive to, climate changes. The sensitivity of ecological systems to climate change is normally described in terms of physiological tolerances to change and/or variability in physical and chemical conditions (i.e. temperature, pH, etc.) (Marshall et al. 2010).

*2.2 Fishers' Exposure and Sensitivity to the Ecological Impacts of Climate Change*

Fishers' sensitivity to the ecological response to climate change represents the degree to which the benefits that an individual derives from recreational fishing would be affected by the ecological responses to climate change (assuming no adaptive behaviour by fishers). It is well established that recreational fishers receive a range of benefits from their participation in recreational fishing (e.g. being outdoors, catching fish, keeping fish for eating, spending time with family and friends, relaxing, etc.). It is also well established that fishers vary in terms of the benefits they desire and/or receive (Fedler and Ditton 1994). Consequently, a fisher's sensitivity to climate change will depend on what benefits are derived from fishing, the absolute and relative importance of those benefits, and the fishery use patterns of the individual (i.e. locations fished, species targeted, etc.).

*2.3 Individual Fishers' Adaptive Responses to the Ecological Impacts of Climate Change*

The preceding discussion of sensitivity and impacts assumes that fishers do not take any actions to try to adapt to changing environmental conditions. For most fishers, however, this is unlikely to be the case. It has been well established in the recreational fishing human dimensions and economics literature that fishers will undertake behavioural responses when faced with change of benefits. Through these behavioural responses, fishers will seek to modify the way in which they conduct their fishing activity in order to try to maintain the same level of benefits they currently get from fishing (Gentner and Sutton 2008). In other words, it is expected that fishers will change their individual behaviour in order to reduce their exposure and sensitivity to climate change. It is also expected that fishers will undertake similar behavioural responses if they perceive that taking advantages of "positive" ecological changes (e.g., increasing fish abundance) can increase the benefits they get from fishing. The recreational fisheries literature identifies four relevant types of adaptive responses that fishers might undertake in response to the ecological impacts of climate change: 1) changing the time at which they fish (time); 2) changing the species that are targeted or harvested (species); 3) changing the location where fishing occurs (location); and 4) replace fishing with another leisure activity that provides similar experiences and/or benefits of fishing (activity) (Gentner and Sutton 2008). To this can be added changing fishing technique, although for such as coral reef fishing off northern Australia, strong winds will simply preclude travelling to the reefs so that changing location to inshore becomes a more likely response.

A considerable amount of research has been aimed at understanding the extent to which recreational fishers undertake (or are able to undertake) these types of behavioural responses to maintain the benefits that they receive from fishing. The majority of that research has focused on species, activity, and location substitution (see Gentner and Sutton 2008 for a review). Briefly, that research has indicated that when fishers face changes in the quality of the fishing they experience, they will try to select alternatives that most closely resemble the originally experience they were seeking, thereby enabling them to maximize the benefits they get from fishing (Gentner and Sutton 2008). Furthermore, there is evidence to suggest that judgments about the acceptability of potential alternative fishing experiences must be made based on the perceptions of the fishers, not by the perceptions of outside observers such as managers or researchers (Vaske et al. 1983). For example, in a study of Salmon fishing in New Zealand, Shelby and Vaske (1991) found that few Salmon fishers were willing to substitute other nearby Salmon rivers for their preferred Salmon river. Reasons cited included the travel distance, costs associated with fishing there, and perceptions of lower fish populations and poorer fishing conditions. Similar results have been found when fishers have been asked about potential substitutes for their preferred species (e.g., offshore species such as billfish were not considered acceptable substitutes for shark fishing in the Gulf of Mexico (Fisher and Ditton 1994). These results suggest that some anglers associate fishing with certain species or locations, and consequently they may not perceive other species/locations as substitutes for their preferred species/location even though other species/locations may share apparently similar characteristics.

Research has also found that fishers' behavioural responses to changes are influenced by a range of demographic and fishing characteristic variables (Ditton and Sutton 2004). Demographic characteristics (e.g. age, income, gender, education level, etc.) can influence fishers' behavioural responses by influencing the constraints they experience on different types of fishing or different activities. Likewise, fishers who become highly committed to fishing or psychologically attached to certain locations or species are less able to replace the activity of fishing or their preferred species/location without loss of benefits (Sutton and Ditton 2005). For example in a survey of fishers in Queensland, only 35% of respondents who reported that fishing was their most important outdoor activity also reported having other activities that could be substituted for fishing. In comparison, 80% of fishers who rated fishing as their third most important activity said that other activities could be substituted for fishing (Sutton 2006) (In that study, 54% of fishers overall reported that other activities can be substituted for fishing). These demographic and psychological characteristics place constraints on the types of behavioural responses that individual fishers can/will undertake in response to the impacts of climate change, and suggest that the responses of individual fishers will be highly variable.

The recreational fisheries literature identifies the four behavioural substitution strategies discussed above (temporal, species, location, and activity) as common ways in which fishers can adapt their behaviour to changing environmental or management conditions. As previously noted, in the context of climate change, these behavioural response could be undertaken to reduce a fisher's exposure and/or sensitivity to climate change in an attempt to maintain the benefits derived from fishing, or they could be undertaken in order to take advantage of ecological changes that could result in an increase in benefits. Although these are likely to be behavioural responses most commonly undertaken by fishers, it is possible that fishers could respond to climate change impacts in other ways. Further research is needed to identify and understand other potential behavioural responses.

*2.4 Impacts Arising from Fishers' Behavioural Responses to Climate Change*

As a result of fishers changing their behaviour to reduce their exposure and sensitivity to climate change or take advantage of "positive" ecological outcomes, there are likely to be a range of impacts felt at the level of the fishing sector. For example, if fishers' response to the ecological impacts of climate change is to drop out of fishing and take up another leisure activity, the reduction in recreational fishing participation rate could have a number of flow on impacts such as reduced levels of public, financial, and political support for fisheries management, lower values placed on aquatic resources by the community such we are already observing with the destruction of fishing habitat and the construction of canal estates, and economic impacts on businesses and communities that support recreational fishing (Sutton et al. 2009). Likewise, if fishers switch target species or fishing locations, these redistributions of fishing effort could results in overharvesting for certain species or at some locations (Sutton and Ditton 2005). Large-scale redistribution of fishing effort to other areas could also have significant economic impact (positive and negative) on local communities that depend on recreational fishing activity. It is also possible that fishers' behavioural response to climate change can have a direct impact on their benefits and well-being. For example, if a recreational fisher drops out of fishing and replaces fishing with another activity, but is not able to get the same level of satisfaction and enjoyment from that activity, then that fishers' overall well being will be reduced. Conversely, the fishers' well-being could be increased if the fisher is able to increase the level of benefits achieved by switching to another activity.

There is not necessarily a strong direct relationship between impacts at the individual fisher level and impacts at the sector level. For example, if fishers undertake significant target shifting but are able to maintain the net benefits they get from fishing by doing so, then there will be no direct impact of climate change on the individual fishers (in terms of benefits received or overall well-being) but there is potentially a large impact at the sector level. Such adaptive behaviours could also have environmental impacts if target or location shifting results in overfishing of some species or at some locations. Such environmental impacts could then feed back to fishers, requiring them to undertake additional adaptive behaviours to reduce the impact of these environmental impacts on their fishing. The indirect impacts of climate change that result from fishers' adaptive responses are likely to be fishery specific, complex, and difficult to predict. A considerable amount of research and monitoring will be necessary to understand how fishers respond to the ecological impacts of climate change and how these adaptive responses impact individual fishers, the fishing sector, and the environment.

*2.5 Adaptive Capacity*

Ultimately, the impacts of climate change on recreational fishers will depend in part on how well the sector is able to respond and adapt to the impacts discussed in the previous section. Here, we use the term sector to refer to the individuals, businesses, informal institutions, and formal institutions (governments and management agencies) that have an interest or stake in recreational fisheries. Negative impacts of climate change will be minimised if the sector is able to adapt to and adequately manage the direct and indirect negative impacts of climate change at multiple levels (individuals, sector, environment) while taking advantage of positive ecological outcomes. At present, little is known about how the recreational fishing sector in Australia might respond to the direct and indirect impacts of climate change.

An important determinant of the recreational fishing sector's response to the direct and indirect impacts of climate change will be the sectors' capacity to adapt. Adaptive capacity refers to the conditions that enable people and communities to anticipate and respond to change, minimize and recover from the consequences of change, and take advantage of new opportunities (Adger and Vincent 2005; McClanahan and Cinner 2011). McClanahan and Cinner (2011) suggest that there are four components of adaptive capacity: 1) the flexibility of individuals and institutions to change their behaviour and respond to changes; 2) the availability of assets that provide resources to draw upon in times of change; 3) the ability of individuals, institutions, and communities to recognise change, attribute this change to their causal factors, and assess potential response strategies (i.e. the ability to learn); and 4) the ability of a community (or a sector) to organise and act collectively (i.e., social organisation). McClanahan and Cinner (2011) discuss in detail these dimensions of adaptive capacity and how they can be enhanced in the context of coastal resource-dependent communities in the western Indian Ocean. However, little is known about what adaptive capacity means and how it can be enhanced in the context of Australia's recreational fisheries. Important areas for future research in this area include understanding and defining flexibility, assets, learning, and social organisation in a recreational fishing context, determining the relative importance of these dimensions to the adaptive capacity of the recreational fishing sector, investigating whether other dimensions might exist for recreational fisheries, and understanding how important components of recreational fisheries adaptive capacity can be enhanced.

## 3. Workshopping the Climate Change Model with Recreational Fisheries Stakeholders

The climate change adaptation model presented in the previous sections had not previously been tested or applied within a recreational fisheries context. As noted in the previous sections, there are many gaps on our knowledge about how recreational fishers might adapt to climate change, what the impacts of climate change and recreational fishers' adaptation strategies might be, and how the climate change model might be used to investigate these issues. To begin the process of filling these knowledge gaps within the context of the adaptation model, a workshop was held with recreational fisheries stakeholders in Townsville on the 16$^{th}$ of May 2012, to discuss the implications of climate change for recreational fishers and the recreational fishing sector in northern Australia. In attendance were recreational fishers from Queensland and the Northern Territory, representatives of recreational fishing organisations, government fisheries and environmental managers, fisheries scientists, a tackle shop employee, a fishing charter operator, and a young leader in recreational fishing. The workshop firstly established recreational fishing as a social-ecological system vulnerable to the impacts of climate change; an approach which recognised that people within the system have the capacity to anticipate change and implement adaptation strategies to decrease vulnerability. The climate change adaptation model (Figure 2) was used as a guide for discussion throughout the workshop, as reflected in each sessions focus on a particular aspect of the model. The aims of the workshop were to: 1) identify potential impacts of climate change on recreational fisheries in northern Australia; 2) identify ways in which the recreational fishing sector could reduce its vulnerability to the impacts of climate change and remain socially and ecologically sustainable into the future, and 3) assess the value of the climate change adaptation model as a research tool for the recreational fishing sector.

*3.1 Northern Workshop Sessions 1: Exposure and Sensitivity of Recreational Fisheries to Climate Change*

*3.1.2 Sensitivity of Recreational Fishers to Ecological Changes*

There was general agreement in the workshop that recreational fishers would be sensitive to the range of potential ecological responses to climate change. It was noted that more detailed information of fish biology was necessary to expand our knowledge of these potential ecological changes and better assess the level of sensitivity within the recreational fishing sector. It was recognised that some ecological responses, such as range shift, would happen slowly and that recreational fishers were likely to adapt as these changes occurred. The discussion then focused on rapid episodic events, such as cyclones, unseasonal temperature shifts and changes in rainfall, which have a significant effect on fish habitat and biology. It was suggested that these events would increase in frequency and impact fishers to a greater degree than the 'slower' ecological responses to climate change. These events 'magnify' the types of ecological changes expected in relation to climate change, such as range shifts, movement patterns, and fish population sizes. It was the rapid ecological changes as a result of these events which were seen to trigger spontaneous adaptation reactions among fishers and subsequently drive change within the recreational fishing sector (e.g. the prevalence of Red Emperor in the Rockhampton area following Cyclone Yasi, and the impact of rapid temperature change on the billfish fishery in Bowling Green Bay).

The level of sensitivity of recreational fishing to ecological changes was seen to be related to the significance of the fishery (e.g. iconic species, location), the level of direct economic dependence on recreational fishers (e.g. charter operators), and the social characteristics of individual fishers (e.g. levels of specialisation, avidity, commitment, and attachment). It was suggested that whilst recreational fishers are sensitive to ecological responses to climate change, this sensitivity has probably not yet resulted in a reduction in the numbers of people involved in recreational fishing. Whilst the discussion tended to focus on the timescale for change, it was also recognised that the changes faced by recreational fishing as a result of climate change could be either direct or indirect, and positive or negative.

*3.2 Workshop Session 2: Adaptation and Impacts*

Given the exposure and sensitivity of recreational fishers to the ecological impacts of climate change, this session considered how recreational fishers adapt to these ecological changes and the potential impacts of these adaptation strategies on the recreational fishing sector.

*3.2.1 Fishers' Behavioural Responses to Change*

The discussion focused on the behavioural responses that recreational fishers are likely to undertake to reduce their sensitivity to the impacts of climate change.

Although it was recognised that some fishers are more sensitive to change than others, it was agreed that fishers were generally adept at implementing more spontaneous adaptation measures to maintain the benefits they receive from fishing. As well as the four types of adaptive responses mentioned in the model (time, location, species and activity), the workshop identified a further five behavioural responses that could be engaged by recreational fishers to respond to changes and/or constraints on their fishing activity; gear change, perception change, illegal activity, catch and keep rates, and stocking and translocation (see Table 1).

Table 1. Recreational fishers' potential behavioural responses to climate change

| Behavioural Response | Characteristics |
|---|---|
| **Temporal substitution** | • Seasonal and frequency of fishing trips<br>• E.g. mild winter allows for Barramundi fishing throughout the year |
| **Location substitution** | • Place and depth substitution<br>• Constrained by different local fishing regulations – fear of being caught fishing illegally in a new location<br>• Perceptions of locations – good fishing, availability of iconic species, etc |
| **Species substitution** | • Perceptions of species – target species and substitute species<br>• Motivation for targeting specific species<br>• Creation of new iconic species |
| **Activity substitution** | • Reflection of commitment and attachment to fishing<br>• Reflection of ability to catch fish<br>• Amount of disposable income – tendency to decrease involvement in activities that cost money<br>• Reflected in lack of support for public meetings |
| **Gear change** | • Specialist gear has revolutionised the sector – lures, soft plastics<br>• Driven by tournaments<br>• Adapt fishing method – take advantage of change<br>• Striving for a better or more challenging fishing experience<br>• Increase skill and versatility – take advantage of change<br>• Social identity attached to gear/fishing technique<br>• Constrained by cost and current investment (costs vs. benefits) |
| **Changing perceptions** | • Species, gear, locations<br>• Facilitate other behavioural responses |
| **Illegal activity** | • Already a behavioural response to change<br>• Increasing number of intentional and unintentional breaches of regulations<br>• Difference between intentional and accidental poaching<br>• Complex rules and regulations may lead to accidental illegal activity<br>• Further management constraints may result in an increased in illegal activities<br>• Attempt to maintain benefits from fishing – e.g. consumption, trophy fish, etc |
| **Catch and keep rates** | • Value-adding to experience for some species<br>• Consumption could increase/decrease – related to perceptions of species<br>• Catch-and-release – post-release survival important<br>• Economic issues important – cost vs. benefit<br>• Convert recreational dollars into benefits for family (keep more fish to cover increasing costs of fishing/living)<br>•Frequency of fishing affects the number of fish kept |
| **Stocking and translocation** | • Legal or illegal<br>• Introduce pest species to maintain benefits<br>• Displacement of other species<br>• Introduction of diseases<br>• Impacts on habitat and ecology |

*Substitution Behaviours: Time, Location, Species and Activity*

Workshop participants agreed that fishers could substitute time, location, species and activity to adapt to changing conditions as a result of climate change. Fishers already adjust the time they fish (seasonal), the frequency of their fishing trips, and their fishing locations to reflect changing fishing conditions. For example, during a mild winter fishers target Barramundi throughout the year, and an increase in Barramundi in the Gladstone area has attracted many fishers from other areas who travel to Gladstone specifically to fish. Fishers will consider the costs of location substitution in relation to the benefits they gain from fishing in a new location. Whilst the associated costs for location substitution may be financial, they may also include the anxiety associated with fishing in new locations with a limited knowledge of local rules and regulations. It was also mentioned that location substitution should include the ability to adapt to a change in the depth at which the target species can be found. This was particularly relevant given the potential for extreme weather events to impact fish habitat and fish behaviour. Decisions involving species substitution were seen to be affected by fisher perceptions of different species and their motivation for targeting specific species. For example, the question was raised as to whether Mangrove Jack could be a good substitute species for Barramundi, and this prompted a discussion about fisher's diverse attachments to species and to gear (perceptions and motivations).

Workshop participants agreed that a majority of fishers have other recreational activities they could substitute for fishing. However, the diversity among recreational fishers in terms of commitment and attachment to fishing was recognised as having a significant effect on activity substitution. It was suggested that a person who fishes a few times a year most likely has substitute activities and will probably continue to fish at a similar frequency irrespective of changes due to climate change. However, a committed fisher most likely has few if any substitute activities and will subsequently be impacted by constraints on their fishing activity due to climate change. As one committed fisher at the workshop said, "if I go hiking, I go hiking to a place I can catch fish, if I go four wheel driving, I go four wheel driving to a place I can catch fish'. In this case, both hiking and four wheel driving are not substitute activities as the benefits directly associated with fishing would be lost. It was also suggested that activity substitution was a reflection of a fisher's ability to catch fish (i.e. fishers who were less successful at catching fish were more likely to have a substitute activity).

*Gear Change*

The development and marketing of specialist fishing gear was identified as fundamental to the direction of the recreational fishing sector. This has primarily been driven by fishing tournaments and has revolutionised the species targeted by recreational fishers (e.g. the uptake of lures and soft plastics). Significantly, gear change becomes an adaptation strategy that would allow fishers to target the same species in the same location but with different methods. Gear change is linked to the desire for a better fishing experience (i.e. it is an attempt to increase the satisfaction gained from fishing). Fishers may accumulate a mix of gear to increase their fishing results, and further develop their skill and versatility to take advantage of changed fishing conditions. It was suggested that recreational fishers who have invested heavily in fishing (e.g. boat, 4WD) are likely to change their gear in order to remain in fishing for as long as possible. However, gear change may be resisted by those fishers who identify strongly with the gear they already use (e.g. 'I am a fly fisher').

*Changing Perceptions*

As already suggested, adaptation in terms of species substitution, location substitution, and gear change can be affected by fishers' perceptions. It was noted that fishing tournaments and marketing strategies can shift perceptions about particular species and types of gear, potentially creating new iconic species (e.g. Bream). Similarly, fishers' perceptions of renowned locations for catching iconic species can also shift. For example, the recent association of Gladstone with Barramundi challenges the traditional perception that one must travel to Cape York and the Northern Territory to catch these fish. Changing perceptions was seen to facilitate other behavioural responses, such as species and location substitution, and gear change.

*Illegal Activity*

Illegal activity, either intentional or unintentional, was identified as another potential behavioural response to change, particularly in relation to complex rules, regulations and zoning. It was suggested that this complexity may lead to an increase in accidental/ unintentional illegal activity (e.g. fishing in the green zones). As a result, there are a number of people, mainly those who fish rarely, who are anxious about 'being caught' fishing illegally and this anxiety reduces the satisfaction they gain from fishing. However, some fishers make a deliberate decision to disregard the rules and to fish illegally. One participant suggested this was a real philosophical issue for some fishers – a difficult decision about how to maintain the benefits they receive from fishing within the constraints of a management regime – and that those fishers who deliberately break the law are actually working at the edge in order to maintain the benefits they receive from fishing (e.g. trophy fish, consumption). There was concern that ecological responses to climate change (e.g. decrease in fish populations), in conjunction with climate change related management responses, will further constrain fishing activity, and this may result in an increase in both intentional and unintentional illegal activities.

*Catch and Keep Rates*

Recreational fishers may adapt to change by increasing or decreasing the amount of fish they keep for consumption purposes. It was suggested that, as the cost of living increases (e.g. carbon tax) there may be a tendency among fishers to convert their recreational dollars into direct benefits for themselves and their families (i.e. they may decide to keep more fish to eat). This 'value-adding' may impact catch-and-release practices, facilitate changes in species perceptions (fish that are good to eat), and contribute to an increase in illegal activity. There was also some anecdotal evidence which suggested that the frequency of fishing impacts how many fish are kept (i.e. those who go fishing more frequently keep less fish than those who go fishing only occasionally).

*Stocking and Translocation*

Stocking and translocation of species (either legally or illegally) was also identified as a potential behavioural response to change. It was recognised that, whilst this may improve fishing in certain locations, it may also have longer term detrimental effects on recreational fishing and the ecology (e.g. introduction of pests and disease, destruction of habitat, etc.).

### *3.2.2 Impacts Arising from Fishers' Behavioural Response to Climate Change*

It was recognised that the behavioural responses described above would have impacts on the recreational fishing sector as a whole. Location substitution was deemed likely to impact both small communities that depend on a seasonal influx of recreational fishers to remain economically viable (e.g. Kurrimine) and 'new' locations which may be ill-equipped to cope with an increase in the numbers of fishers (e.g. Gladstone). Also, access to fishing gear may impact fishing location and subsequently increase pressure on specific fisheries (e.g. a decline in large boat sales in the Townsville region may increase pressure on inshore fisheries). Given that a majority of recreational fishers have substitute activities, this may impact their willingness to be involved in consultation and public meetings, as well as monitoring and research activities which contribute to the development of knowledge about specific fisheries. If recreational fishers leave the sector, this will impact the tackle trade and local tourism operators (e.g. charter operators, bait shops), fishing dependent communities, and scientific research (access to data/information from fishers). Finally, a potential increase in illegal activities, and the stocking and translocation of species has implications for management agencies.

### *3.3 Workshop Session 3: Adaptive Capacity*

The extent to which climate change will impact recreational fishing depends in part on how well the recreational fishing sector is able to respond and adapt to negative impacts and take advantage of new opportunities. This session focused on the capacity of the sector to adapt to change, guided by the four components of adaptive capacity mentioned earlier (capacity to learn, social organisation, assets and flexibility) (Table 2).

#### *Capacity to Learn About Change*

Workshop participants suggested that the general perception among recreational fishers of climate change risk does not reflect the reality of the situation, and the challenge for the sector is to close this gap between perception and reality to enhance adaptive capacity. This involves the capacity of the sector to provide meaningful information to fishers who can then incorporate this information as their own knowledge. Whilst there is a high capacity to learn among fishers, it is the extent to which fishers and other sections of the sector incorporate information about climate change as their own knowledge that may impact risk perception and adaptation to change. It was agreed that good communication is essential and that consensus among the scientific community about climate change would contribute to the learning process and enhance adaptive capacity. However, it was also pointed out that, given the uncertainty embedded within climate change science, the issue is about the capacity of fishers and the sector to also deal with uncertainty.

The capacity to learn was related to social organisation; the role of fishing media (TV, radio, magazines), fishing clubs, fishing events, and local identities and leaders in the learning process. In particular, the discussion focussed on the role of fishing clubs and the extent to which they either enhance or constrain learning and adaptation.

#### *Social Organisation*

Despite there being only 6% of fishers in fishing clubs and less than 10% who read a fishing magazine, it was agreed that fishers are generally highly organised, albeit in loose informal local groups; people who come and go and who talk regularly with each other. It was considered important to recognise how recreational fishers organise; i.e. when a current issue is considered pertinent recreational fishers will come together, connect and respond as a group, and when that issue is resolved the group will dissolve. As suggested by a fisheries manager in the workshop, ‘when you poke them you find out quickly that there is a recreational fishing sector’. These fluid networks can be catalysed when necessary to disseminate information and respond to regulation changes, etc.

Table 2. Dimensions of adaptive capacity for recreational fishers

| Adaptive Capacity Dimensions | Description |
|---|---|
| **Capacity to learn about change Knowledge/Learning/Acceptance** | • High capacity to learn among fishers<br>• Capacity to communicate information in a way that can be taken up and used<br>• Knowledge enhances the ability to adapt to change.<br>• Perception vs. reality of climate change – meaningful information is necessary for fishers to perceive climate change as a risk<br>• Broaden perceptions of iconic species, and the attractiveness of particular gear and fishing techniques<br>• Role of fishing clubs – enhance or constrain the ability to learn<br>• Loose informal networks of fishers<br>• Fishing events (e.g. Children's Fishing Classic, tournaments)<br>• Fishing media (TV, radio, magazines), social media and networking sites |
| **Social organisation** | • Fishing clubs (only 6% of fishers) – do they enhance or constrain adaptive capacity<br>• Fishers are highly organised in loose informal networks (includes key players/local leaders) with the capacity for higher levels of organisation when necessary (latent organisation)<br>• Leadership – recognized, respected, and informed (celebrity vs. local leaders)<br>• Foster future generation of leaders<br>• Effective representation important – need a respected, wellresourced peak body<br>• Effective consultation/engagement with management |
| **Assets** | • Funding needed for effective leadership and representation at various levels<br>• Knowledge assets – information about fish, fishers, and the environment<br>• Relevance to and acceptance within the broader community<br>• Access to resources and infrastructure<br>• Healthy resource<br>• People are our primary "assets" – need to find better and more effective ways to harness those assets. |
| **Flexibility** | • Many fishers are flexible and can adapt – related to attachment, specialization, identity, etc.<br>• Sector flexibility is slower (infrastructure, management, etc.)<br>• Development of trust between fishers/fishing community and government (sharing information)<br>• Involvement and engagement of fishers in decision-making will enhance trust and flexibility<br>• Fisheries management currently inflexible and proscriptive – how can this be improved?<br>• Flexible arrangements – need trust and engagement for these to be negotiated<br>• Willingness to experiment – find ways to harness the flexibility that does exist |

There are key players in these loose networks of recreational fishers and these people were identified as essential in terms of information transfer, lobbying activities and involvement in the management consultation process. There was a clearly stated need for respected, recognised and informed leaders to represent, support and advocate for the recreational fishing sector. However, given the nature of the sector, it was considered difficult to develop leadership roles and as such, there was an identified need to intentionally foster the development of a future generation of leaders. It was also recognised that there was no respected peak representative body with paid positions to support recreational fishers in Queensland. As a result, recreational fishers are not well represented in research and management consultation meetings, a situation which ferments dissent rather than develops good outcomes for the sector. It was also noted that individual recreational fishers are not paid for their role as recreational fishing representatives at these types of meetings.

*Assets*

It was suggested that limited financial resources constrain the development of effective leadership within the recreational fishing sector – financial assets are needed to fund a properly resourced network of representative bodies recognised by both recreational fishers and management agencies. Paid positions were identified as necessary given that unpaid volunteers generally have a narrow interest/agenda (e.g. fixing local boat ramps). The question was raised as to whether the funding for a representative body should be provided by the government or based on a 'user pays' system. Whilst recreational fishing is not income generating for individual fishers, it was recognised that 90,000 people were employed in the recreational fishing sector and that maybe there was a problem with the 'business model' that it was so difficult to develop leadership positions. It was suggested that the sector has an enormous capacity but does not know how to access that capacity (i.e. how can the sector use the assets (people) from tackle shops, charter fishers, tourism, etc.).

In relation to questions about the commitment of governments to the recreational fishing sector, it was suggested that broad community acceptance of recreational fishing would be an asset (i.e. if recreational fishing is relevant to the broader community then governments are likely to remain supportive of the sector). For example, broad community acceptance of recreational fishing as a legitimate activity may result in ongoing government support for the sector (e.g. ongoing investment in infrastructure) even though the government is under pressure to adapt to climate change. Therefore, the sector needs to identify building community acceptance, community demand, and community goodwill as fundamental to adaptive capacity. Fishing activities, such as tournaments, the Children's Fishing Classic (Townsville), fishing competitions and clubs become assets because they potentially foster community support.

A healthy resource was identified as an asset for the recreational fishing sector (e.g. if fishing is good then the satisfaction among fishers is also increased) as well as the knowledge that fishers have about that resource. It was also suggested that a healthy resource may enhance community acceptance of recreational fishing.

*Flexibility*

There was agreement among workshop participants that flexibility within the sector to respond to changes was inhibited by the current proscriptive management system imposed by the government. This resulted in a long lag time between when individual fishers adapt to change and when both the sector and management agencies respond (e.g. the development of infrastructure, regulation and policy changes, accommodation issues in 'new' fishing locations, etc). It was also noted that current regulatory constraints are not conducive to regional decision making which may impact the ability of the sector to adapt to climate change (i.e. regional management has the capacity to develop regional solutions which are necessary to respond to climate change). Examples were provided of alternative management models (e.g. management of mud crab fishery) which indicate an inherent degree of flexibility and also suggest the potential for experimentation to develop better management models for the future (e.g. regional management, adaptive management).

Trust was identified as fundamental to flexibility and the development of alternative management structures. This involved building mutual trust between government agencies, recreational fishers, and other stakeholders within the recreational fishing sector. It was suggested that trust could be developed through engagement rather than consultation (i.e. the involvement of recreational fishers in the decision making process), and the co-production of knowledge (i.e. research projects that involve both scientists and recreational fishers).

The flexibility of individual recreational fishers was seen to be influenced by attachment, identity and specialisation, and it was agreed that fishers would adapt differently depending on these factors.

### *3.4 Workshop Session 4: Future Directions*

This session focused on identifying research and adaptation priorities to enhance adaptive capacity and support a sustainable recreational fishing sector. The priorities that came from the discussion tended to reflect six broad categories; social organisation and benefits of fishing, leadership and representation, communication and education, trust, flexibility, and community support (Table 3).

#### *Social Organisation and Social Benefits*

Workshop participants agreed that a better understanding of how fishers and the sector are organised would contribute valuable information for the development of better leadership and representation, and more effective education and communication strategies. It was also considered important to understand the health and well-being benefits of recreational fishing.

#### *Leadership and Representation*

As suggested above, an understanding of how fishers and the sector are organised was identified as necessary to develop better leadership and representation. In particular, questions were raised about who are the opinion makers (celebrities vs. local leaders), and how do they currently engage with recreational fishers? An informed leadership was valued and as such, the education of future leaders was identified as a priority (especially in relation to climate change and climate change adaptation issues). In order to develop an informed leadership, create paid leadership positions, and increase the representation of recreational fishers, it was deemed important to involve recreational fishers as paid co-investigators on research projects. The development of a ‘business model’ for recreational fishing was also identified as a priority (i.e. to better harness assets to support leadership and representation).

Table 3. Priority areas for the recreational fishing sector for adapting to the impacts of climate change

| Priority | Description |
|---|---|
| **Social organisation and social benefits** | • Develop an understanding of how recreational fishers and the sector organise<br>• What are the health and well-being benefits of recreational fishing? |
| **Leadership and representation** | • Understand how fishers and the sector are organised so as to develop better leadership and representation<br>• Informed leadership – educate future leaders about climate change and climate change adaptation issues<br>• Involvement of recreational fishers as co-investigators on research projects – provide income for leadership and increase representation of recreational fishers, develop informed and respected leadership<br>• Who are the opinion makers, and how do they engage with recreational fishers?<br>• Develop a 'business model' for recreational fishing to better harness assets to support leadership and representation. |
| **Communication and education** | • Evaluate how recreational fishers currently access information<br>• How do we develop better coordination between the user of information and the source of information (relates to building trust)?<br>• Develop information for recreational fishers (climate change) |
| **Build trust** | • How do we build trust between fishers, managers, scientists, and other stakeholders?<br>• How do we engage recreational fishers in the management process (more than just monitoring/collecting data)?<br>• Develop joint projects between fishers and managers/scientists to encourage a mutual understanding of each other's skills and knowledge – encourage the co-development of knowledge<br>• Experiment with novel ways to increase trust, enhance communication, and improve cooperation |
| **Develop flexibility** | • Evaluate previous successful attempts at alternative management arrangements? What can we learn from these?<br>• Accumulative knowledge - on-going evaluation and experimentation<br>• What drives changes within the sector (iconic species, gear changes etc.)? Does this enhance flexibility? |
| **Build community support** | • Understand fishing participation - why are people leaving recreational fishing? What are the constraints that impact on participation? How are these issues compounded by climate change? What are the drivers of fishing participation?<br>• What does a decline in the number of recreational fishers mean in the context of climate change? Does this decrease a willingness to adapt to climate change?<br>• Recruitment into fishing – education and skill development for younger people, etc.<br>• How does the sector promote the benefits of fishing in the broader community?<br>• Create awareness in broader community of the role of fishers in environmental protection, scientific knowledge, climate change mitigation, etc. |

*Communication and Education*

Information, education and communication were identified as key elements for effective adaptation. Priorities included an evaluation of how recreational fishers currently access or receive information (e.g. traditional media, social media, internet, etc), an investigation into how best to encourage fishers to access available information (i.e. connect people who want information with the source of the information), and subsequently the development of a range of information specifically for recreational fishers (e.g. climate change information – what might happen, how it will affect them, what can the sector do about it).

*Build Trust*

Key questions were raised about how to build trust between fishers, managers, scientists, and other stakeholders within the sector, and how to engage recreational fishers in the management process. It was suggested that joint projects between fishers and managers/scientists would encourage a mutual understanding of each others' skills and knowledge and contribute to the co-development of knowledge. It was considered important to experiment with novel ways to increase trust, enhance communication, and improve cooperation between fishers, managers, scientists, and other stakeholders.

*Develop Flexibility*

In order to develop flexibility it was considered important to evaluate previous attempts at alternative management arrangements. The knowledge gained from this process could facilitate further experimentation with management structures, with a particular focus on regional management arrangements. It was also considered important to understand what drives changes within the sector (e.g. iconic species, gear changes, etc.), and how does this enhance flexibility?

*Build community Support*

It was deemed important to develop an understanding of recreational fishing participation (e.g. what are the drivers and/or constraints that impact fishing participation, and why people are leaving recreational fishing?), and whether this participation rate will be compounded by the effects of climate change? Also, in the context of climate change, what are the implications for the sector of a decline in the number of recreational fishers? Other priorities focused on the need to promote recreational fishing in the broader community in order to improve recruitment (e.g. benefits of fishing) and build community support (e.g. environmental protection and climate change mitigation measures).

## SOUTH EAST REGION ADAPTION

The south east region provided general principles on responding to climate change and in relation to species assessed provided recommended fisher adaptation and mitigation to fish stock changes to 2030. These recommendations are contained in the assessments of each species.

**Recreational fisheries management and climate change**

- Recreational fishers are generally opportunistic and it is likely they will adapt and adjust their behaviour in line with future changes in species distribution and abundance.
- Recreational fishing behaviour will largely be influenced by how much the sector values a particular fish species (eg eating qualities, catchability, fighting qualities).
- The role of fisheries management is evolving with respect to climate change. Management needs to be flexible and capable of facilitating adaptation by the sectors.

- Fisheries legislation needs to be responsive and provide flexible tools to revise management controls such as bag and size limits.
- Management strategies need to ensure fishing does not exacerbate the impact of climate change on fish stocks.
- Overfished or depleted stocks will be less resilient and more vulnerable to the effects of climate change and it is important we continue to manage under the ethos of fish for the future.
- Conversely, pelagic species (Yellowtail Kingfish, Skipjack Tuna, Striped Marlin, Cobia, Mahi Mahi) that are likely to extend further south due to the strengthening EAC will provide new fishing opportunities for the recreational and charter fishing sectors that also need to be monitored and managed.

**Adaptation principles for recreational fishers and fishery/policy managers**

Recreational fishers:

- Modify and adjust fishing practices, techniques and species targeted (e.g- opportunism) as range extensions occur.
- Work with fishery managers to review recreational catch limits and other management controls to ensure sustainable fisheries management.
- Be a ‘citizen scientist’ and share the considerable fishing knowledge by reporting unusual catches and sightings to fishery managers using tools such the Range Extension Database Map (Redmap) www.redmap.org.au.
- Participate in angler diary programs to provide structured fishery dependent information to allow cost effective and participative monitoring.
- Develop future opinion leaders in the sector to help communicate climate change and recreational fishing information to the sector.

Fishery managers:

- Ensure legislation and policy is flexible, adaptive and capable of responding to emerging issues.
- Collect information on key species using cost effective monitoring programs to allow early detection of climate change impacts on fish populations.
- Review recreational catch limits and other management controls to ensure sustainable fisheries management.
- Disseminate to the recreational fishing community and implement engagement strategies such as forums, workshops and seminars to share information and build awareness.
- Work with relevant land, habitat and water managers to ensure fisher and fishery needs are understood and accommodated.
- Assist relevant land and coastal managers to improve fisher access in areas that are currently barriers to adaptation (e.g. new opportunities being realised) due to inadequate infrastructure.

## SOUTH WEST REGION ADAPTION

### Management adaptation responses

- There are research gaps with most species during the larval and nursery / juvenile phases, the most critical part of their respective life cycles. It is at this point that the species in this study are most vulnerable to change or mortality. This period of life cycles needs to be better understood if fisheries mangers are to be able to make informed decisions within a reasonable time frame to overcome these, as yet, not clearly understood impacts.
- In order for fisheries managers to make appropriate adjustments to specific significant fish stock population variations resulting from climate change prompt accurate ongoing catch information will be required for both the recreational and commercial sectors.
- Following the "heat wave event" in Western Australia in 2010/11 when many fish, including juveniles, died in shallow bays from Dongara to Lancelin as a result of hypoxia and abnormally high water temperatures. One manageable contributing factor to the hypoxic conditions was the high accumulation of excessive amounts of decomposing wrack along the shoreline of these bays, which added significantly to rapid de-oxygenation. Subsequently some areas of seagrass have disappeared resulting in loss of high value habitat, reduced $CO_2$ sequestration and detrimental increased sand movement. This excess wrack must be carefully managed in order to limit these shallow water mortalities and environmental degradation.
- Restocking of some of the species identified in this paper is viable to varying degrees with current practises. Given the success of recent restocking work with black Bream in Western Australia (Gardner *et al* 2010) is would be timely to commence further research into the hatchery and subsequent restocking viability of key species.
- Provision of more FADs would provide alternative recreational fishing opportunities for pelagic species.
- Provision of artificial reefs would provide increased productivity in addition to increased recreational fishing opportunities.
- Protection of identified nursery areas under threat from both human activities and climate change impacts.
- Species which spend part of their life cycle in estuarine environments would have improved recruitment if water quality and flows in river systems, that feed into the estuaries, where improved.
- Wherever possible clearly identified breeding aggregations of key recreational species should be protected to maintain optimum breeding biomass.
- Encourage a whole of government approach to holistically manage aquatic eco-systems so that all species can be adequately managed and protected throughout their range.
- Pursue improved management of closed (to the sea) systems is required under Department of Fisheries scientific direction rather than leaving the decision to open a sand bar to third parties with unknown impacts on the estuarine spawning movements of oceanic species.
- Encourage a whole of government approach to resolving aquatic environmental issues rather than having one department locking up perfectly good sustainably fished areas of the ocean while estuary nursery areas are being killed off by neglect.

## 7. MITIGATION

### NATIONAL PERSPECTIVE ON MITIGATION BY RECREATIONAL FISHERS

Mitigation can play a role at both the social and ecological levels. Mitigation of climate change is about reducing greenhouse gas emissions and recreational fisher can play a part in reducing those emissions. However, there is no current measure of the contribution of recreational fishing to greenhouse gas emissions so that no assessment can be made of the level of emissions, or of any changes to those levels based on actions by recreational fishers.

There were a number of areas identified by the regions where emissions could be reduced or contributions could be made to carbon capture. These were:

- reduction of carbon emissions from outboard motors
- reducing fuel usage
- production of fishing tackle and associated products
- improvement to fish habitat

Some opportunities identified were:

- a reduction in carbon emissions by encouraging a shift from two to four stoke outboards or moving to lower emission engines
- a reduction in carbon emissions by reduction in travelling and fuel use
- program of Australia wide restoration and repair of estuaries and wetlands

Recreational fishers can play a role in reducing carbon emissions by choosing outboard motors that have low carbon emissions. This assumes their destinations remain the same distance or less from their home port. Travelling further afield because of climate change impacts on fish stocks may negate any savings, but would still result in less aggregate impacts than if they were travelling further afield with less fuel efficient motors.

Improvements to fish habitat can have a two fold effect in taking up carbon from the atmosphere and improve fish stocks and greater attention needs to be paid to this area. Nursery areas were identified as requiring special attention.

*Increased attention to Coastal Fisheries Habitat Protective Management – or "No Habitat – No Fish"*

With a more extreme and variable climate all possible steps should be taken to ensure resilient stocks. The first step in this endeavour is to maximise the opportunity for all species to successfully breed. Coastal and near shore habitat of estuaries, mangroves, seagrasses, salt marshes, fresh to brackish wetlands and coral reefs all play crucial roles in the nursery phases of recreational species. Protective management to minimise damage to habitat, water quality, tidal and freshwater flows is essential. Where states do not already provide for protective management of habitat, this needs to be added to their fisheries regulations. The Queensland Fisheries legislation provides a good example of how best to afford protective management.

*Australia-wide Program of Estuary and Wetland Repair – Repairing Coastal Productivity*

Many of Australia's coastal ecosystems have been reduced in productivity through barrages, drains, causeways, bunds and floodgates that restrict or prohibit tidal flows and fish passage. Coastal ecosystems of estuaries and wetlands also sequester per hectare more carbon than any other ecosystems. Drained fresh to brackish wetlands emit methane – adding to the greenhouse gas problem. Many of these now non-productive areas can be repaired to deliver multiple outcomes of fisheries productivity, improved water quality, enhanced biodiversity and coastal buffering against sea level rise. An Australia-wide program of repair is needed. The first steps towards this are now being funded through a partnership between FRDC and the Biodiversity fund (2012/036 "Revitalising estuaries and wetlands for carbon sequestration, biodiversity, fisheries and the community"). This one year project will demonstrate the opportunities for repair in two pilot areas – Burdekin floodplain, Qld; and Clarence floodplain, NSW and will develop a Repair Plan identifying high priority and achievable works Australia-wide. All state Recreational Fishing Bodies together with fisheries and conservation agencies are encouraged to recommend estuaries and wetlands that could be included within this Australia-wide Repair Plan.

## REDUCING CARBON EMISSIONS

The reduction of carbon emissions was addressed by the south east region.

Objective

- Examine the effect of reduced carbon emissions of outboard motors on the carbon footprint of recreational fishing.

Data for this summary was sourced from Department of Environment and Water Resources, 2007.

*3.1 What are the outboard emissions of interest?*

Two and four stoke engines used for outboards and personal watercraft emit volatile organic compounds (VOCs referred to also as hydrocarbons (HC) from unburnt and partially burnt fuel and oxides of nitrogen (NOx), which contribute to ozone (photochemical smog) formation in summer. They also emit particles, carbon monoxide (CO) and a range of water and air toxics such as benzene.

*3.2 Emission comparisons by motor type*

There are five types of spark-ignition engines used in outboard engines and personal watercraft:

- two stroke with carburettor (2c)
- two stroke with pre-chamber fuel injection (2i)
- two stroke with direct fuel injection (2di)
- four stroke with carburettor (4c)
- four stroke with fuel injection (4i)

Two stroke carburettor engines used for boats emit proportionally more VOCs and other air pollutants than the comparatively more expensive, but more fuel efficient direct injection two stroke and four stroke engines. This is due to their inability to completely separate the inlet gases from the exhaust gases, resulting in up to 30% of the fuel being left unburnt, plus the need to add oil to the fuel to lubricate the engine. Within each engine type there is a considerable variation in emissions.

For VOCs (HC) and NOx traditional two stroke carburettor engines 2c produce 104 to 681 g/kw/hr compared to the other engines (2i, 2di, 4c, 4i) which are below 30 g/kw/hr.

For CO emissions the variation within each engine type makes it difficult recommend a best performer. Two stroke carburettor engines 2c produce between 156 to 630 g/kw/hr, 2i engines between 124 to 282 g/kw/hr, 4c between 144 to 469 g/kw/hr and 4i between 78 to 336 g/kw/hr.

*3.3 The Australian Market*

Australia does not manufacture outboard motors and in 2005 98% of all outboards in Australia came from the six major outboard manufactures. These were Yamaha (Japan), Mercury/ Mariner (USA), BRP (USA, brand names - Evinrude E-TEC, Johnson and Seadoo), Honda (Japan), Suzuki (Japan) and Tohatsu (Japan). In 2005, two stroke carburettor engines represented 63 per cent of the 47,937 outboard engines sold in Australia. No two stroke carburettor engine sold in Australia meets any current United States or Europe standards. Australia is still well behind other developed countries in its uptake of low emission outboard engines**.**

*3.4 Overseas Regulations*

The USA regulates the combined emissions of VOCs and NOx and reports carbon monoxide (CO) emissions. They have the same limits for two and four stroke outboard petrol engines. The USA introduced exhaust emission limits for marine outboard engines in 1998 and these became progressively stricter up to 2006. California's standards, introduced in 2001, encourage early adoption of stricter emissions standards through a consumer star labelling program.

The Europeans separately regulate VOCs, NOx and CO emissions and have separate limits for two and four stroke petrol engines.

In total 98% of four stroke and 98% of fuel-injected two stroke engines are likely to comply with at least one exhaust emission limit (in USA and Europe).

*3.5 Reducing outboard emission opportunities*

Australia has two obvious opportunities to reduce its outboard emissions:

1. Continue moving toward purchasing low emission motors
2. Better define and support low emission engines within engine classes (e.g. low VOCs, NOx and CO emissions).

These opportunities may be met voluntarily or through regulation. A voluntary labelling scheme developed by the Outboard Engine Distributors Association already exists. It aims to provide information to the consumer that is readily-accessible and easily understood and therefore can assist in helping the consumer make better informed choices. Similar to the USA and Europe, Australia could also introduce Minimum Performance Standards regulated by government.

Another consideration for reducing outboard emissions is to encourage fishers to travel shorter distances. This may be achieved by:

- Creating new fishing opportunities,
- Creating more fishing access points

*3.6 What impact could be made by reducing outboard emissions?*

It is unclear how recreational fishers fit in terms of their overall outboard carbon emissions. It is also unclear what moving from the current level of emissions to the best case scenario would mean for overall emission reductions. There is a need to get some information about the current and improved emission scenario's.

*3.7 Other major sources of emissions*

While outboard motors produce carbons, there are a number of other activities that recreational fishers require for their sport. These include:

- Car travel and towing
- Production of fishing equipment
- Collection, processing and storage of bait (commercial fishing industry)

It is unknown precisely what these activities contribute to carbon emissions, but it would be worthwhile considering mitigation measures in these areas as well as focusing on outboard engines.

# 8. CLIMATE CHANGE EFFECTS ON FISH SPECIES IMPORTANT TO RECREATIONAL FISHERS

## NATIONAL OVERVIEW

The effects of climate change on fish species occurs at the ecological level and this will engender a response at the social level.

Species selected were of importance to recreational fishers, were considered at risk due to climate change and were not being assessed as part of other climate change projects. This resulted in popular recreational species such as Snapper and Barramundi not being included in the risk assessment.

Species that were selected are shown in Table 4 along with their vulnerability to climate change as assessed by each region. Each region provided a detailed assessment of the life histories of each species and their vulnerability at different stages of their life cycle. The south east region included adaptation and mitigation measures that could be taken in relation to each of the species in their region.

Table 4. Species assessed by each region on their vulnerability to climate change

| Northern region | South east region | South west region |
|---|---|---|
| Mangrove Jack<br>*(Lutjanus argentimaculatus)* | Black Bream<br>*(Acanthopagrus butcheri)* | West Australian Dhufish<br>*(Glaucosoma herbaicum)* |
| Spotted Mackerel<br>*(Scomberomorus munroi)* | King George Whiting<br>(*Sillaginodes puntatus*) | Baldchin Groper<br>*(Cheorodon rubescens)* |
| Red Emperor<br>*(Lutjanus sebae)* | Mahi Mahi<br>*(Coryphaena hippurus)* | King George Whiting<br>*(Sillaginodes puntatus)* |
| Barred Javelin<br>*(Pomadasys kaakan)* | Yellowtail Kingfish<br>*(Seriola lalandi)* | Spanish Mackerel<br>*(Scomberomerus commerson)* |
| Dusky Flathead<br>*(Platycephalus fuscus)* | | Australian Salmon<br>*(Arripis truttaceus)* |
| | | Roe's Abalone<br>*(Haliotis roei)* |

| | |
|---|---|
| (green) | Considered to be resilient to climate change |
| (yellow) | Vulnerability to climate change uncertain |
| (orange) | Considered to be vulnerable to climate change |

Climate change is predicted to result in population shifts for a number of species so a move to a "whole of stock management" approach needs to be developed.

For many species such as Snapper along the Eastern Australian coast the changing sea surface temperatures and eddies will change the locations of the populations. State based fisheries management of stocks will increasingly become sub-optimum. Increased cooperation between fisheries management agencies across State boundaries and across State - Commonwealth waters is to be promoted. It is recommended that joint management arrangements of the total stock be developed as soon as feasible for the following species:

- Spotted Mackerel
- Dusky Flathead
- King George Whiting
- Mahi Mahi
- Yellowtail Kingfish
- Spanish Mackerel

## 9. NORTHERN REGION SPECIES ASSESSMENT

*3.1.1 Northern Workshop Session 1: Profiling Key Recreational Fisheries Species*

The current state of knowledge of the fishery and life history characteristics of five example recreational fishery species in northern Australia were presented in this session of the workshop. These species were used as examples to assess the potential ecological responses to a changing climate [exposure] that might impact recreational fisheries. The session then focused on the sensitivity of recreational fishers to the ecological impacts of climate change. The five species considered were Dusky Flathead (*Platycephalus fuscus*), Barred Javelin (*Pomadasys kaakan*), Red Emperor (*Lutjanus sebae*), Mangrove Jack (*Lutjanus argentimaculatus*) and Spotted Mackerel (*Scomberomorus munroi*). These species were selected as they are primarily targeted by recreational fishers and are representative of species that exhibit a wide range of life history characteristics and utilise a wide range of habitats. The species profiles reviewed current knowledge of the fisheries and life history characteristics of the species and use this information to infer potential their vulnerability and resilience to climate change. These species summaries highlighted the generally poor understanding of the impacts of climatic change on the biology of these species. We highlight that our ability to predict specific responses to climate change are diminished because of uncertainty in climate predictions and our limited understanding of the environmental impacts on the biology of fish species. However, inferring from the general characteristics of these species we identified a range of potential ecological responses to climate change. These responses included the potential for permanent and seasonal range shifts, changes in location of spawning, changes in timing of spawning, changes in movement pattern and potential for greater temporal variation in population sizes.

### Mangrove Jack, *Lutjanus argentimaculatus* (Forsskål, 1775)

**Authors: Richard J. Saunders and David Welch**

The Mangrove Jack, *Lutjanus argentimaculatus*, is a member of the family Lutjanidae (the tropical Snappers). The species has a wide distribution in the Indo-West Pacific from East Africa, the Red Sea and east to Samoa. It has also invaded the eastern Mediterranean via the Suez Canal. The species occurs throughout the northern half of Australia from the northern half of Western Australia throughout the Northern Territory and Queensland into central New South Wales, and sometimes as far south as Sydney. Juveniles and sub-adults are found in nearshore reefs and islands, coastal estuaries and freshwater streams. Adults tend to migrate further offshore to reefs and occur to depths of at least 180 m. The Mangrove Jack is a particularly significant species for recreational fishers throughout its Australian distribution particularly in nearshore environments.

## 1. The fisheries

- Mangrove Jack are not a major target species for commercial fisheries in Australia but are captured as by-product species in reef line and trap fisheries and Barramundi net fisheries
- They are a significant target species for recreational fisheries throughout their northern Australian range particularly in riverine and coastal areas.

*Western Australia*
Mangrove Jack are not a major component of any commercial fisheries in Western Australia with a total of 8 t landed across the state's commercial fisheries in 2010 (Department of Fisheries, 2011). Traps are used to capture this species off the northern coast. There are no estimates of recreational harvest for Western Australia.
*Northern Territory*
Mangrove Jack is not a significant part of any commercial fisheries in the Northern Territory. They are targeted by some recreational fishers and are of course a by-product species of recreational fishers targeting Barramundi. A small number are taken in the Aquarium Fishing/Display fishery: 281 individuals in 2010 (Northern Territory Government, 2011). There are no estimates of the recreational harvest for the Northern Territory.

*Queensland*
Mangrove Jack is captured as by-product species in the Queensland Coral Reef Fin Fish Fishery. No data on numbers or catch weight is published for this fishery however it is likely to be insignificant (DEEDI, 2011a). The species is also landed as part of the East Coast Inshore Fin Fish Fishery (ECIFF) which has both net and line sectors but is < 1% of the total catch by weight (Simpfendorfer et al., 2007). Catch in the ECIFF has been 2, 7, 12 and 5 t for the 2006/07 – 2009/10 financial years respectively (DEEDI, 2011b). Estimates of recreational harvest by number in Queensland are 117,000, 107,000 and 77,000 for the years 1999, 2002 and 2005 respectively with similar numbers recorded as released (McInnes, 2008). There may be an underreporting of the total harvest in the commercial log book scheme as this species is often reported in generic categories such as mixed reef fish. This species is also caught incidentally in fish trawls in the Gulf of Carpentaria.

## 2. Life history

***Life cycle, age and growth***
The life history of the Mangrove Jack (Figure 3) has been well investigated, particularly in Queensland (see Russell et al. 2003). This research confirmed that Mangrove Jack has a complex life history with juveniles and sub-adults occurring in inshore coastal and estuarine systems, and freshwater environments, with mature adults found further offshore (Russell et al., 2003; Russell & McDougall, 2005). Mangrove jack are a long lived species. In freshwater and estuarine environments age estimates ranged in age from 0 to 11 years and in offshore environments from 2 to 39 years (Russell et al., 2003).

The species is gonochoristic, with mature fish primarily found in offshore environments. Males mature at a smaller size than females with a length at 50% maturity of 47 cm Fork Length (FL) and 53 cm FL for females and both males and females can be 10 years old or more (Russell et al., 2003). Gonad development occurs between October and March with a peak in gonadosomatic index occurring in December suggesting a Spring-Summer spawning season in northern Queensland (Russell & McDougall, 2008). However, there is evidence in lower latitudes that the species spawns throughout the year (Anderson & Allen, 2001). Mangrove Jack also form spawning aggregations in some parts of the world (eg. Palau: Johannes, 1978). In Australian waters spawning sites and behaviour are not well known although based on the distribution of mature fish it is assumed that spawning occurs offshore.

They are highly fecund broadcast spawners and larvae become free swimming by the time they reach 12 mm Total Length (TL) (Doi et al., 1998; Russell and McDougall, 2008). Recruitment of juveniles to inshore riverine environments occurs at 20-30 mm from February (Russell et al. 2003). Mangrove Jack leave the estuarine and inshore environments between approximately 325 and 430 mm Caudal Fork Length (CFL) at ages between three and eleven years (Russell et al. 2003).

Age and growth of Mangrove Jack has been extensively described by Russell et al. (2003). This study encompassed the distribution of the species within Australia but the data is best for the Queensland East coast. Some evidence for higher somatic growth rate of juveniles when able to utilise freshwater systems was identified. Furthermore, growth did vary between regions with faster growth evident in fish from northern New South Wales and southern Queensland than further north. Growth parameters (von Bertalanffy) are provide in Table 5 for the Queensland East Coast.

Table 5. Von Bertalanffy growth parameters for Queensland east coast adapted from Russell et al. (2003). Population genetic studies across northern Australia indicate a high level of gene flow and that they are likely to belong to the same genetic stock (Ovenden & Street 2003).

| **Location** | **Sex** | **$L_\infty$ (mm)** | **K** | **$t_o$ (years)** |
|---|---|---|---|---|
| North of Cooktown | ♀ | 632.7 | 0.164 | 1.77 |
| | ♂ | 616.2 | | |
| Ingham to Cooktown | ♀ | 673.7 | 0.136 | 1.051 |
| | ♂ | 644.2 | | 2.364 |
| Queensland East Coast | ♀ | 681.2 | 0.126 | 2.893 |
| combined | ♂ | 650.6 | | 1.761 |

***Distribution, habitat and environmental preferences***

Mangrove Jack occur throughout the Indo-West Pacific from Australia to southern Japan, west to East Africa and the Red Sea (Allen 1985). In Australia, it is widespread ranging from central New South Wales on the east coast to Geraldton on the west coast (Figure 4). It is, however, most common in the northern parts of its Australian range. The species utilises a wide range of habitats throughout its life cycle. It is commonly associated with reef environments in shallow near-shore waters to depths of at least 180 m (Kailola et al. 1993).

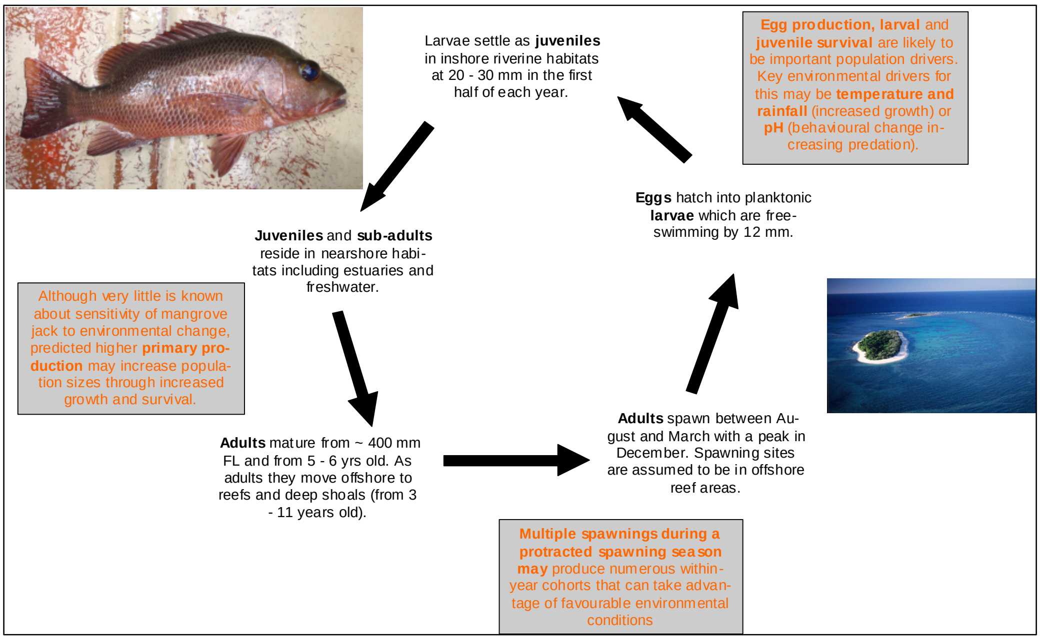


Figure 3. Generalised life cycle of the Mangrove Jack, *L. argentimaculatus*, and the stages of potential environmental driver impacts.

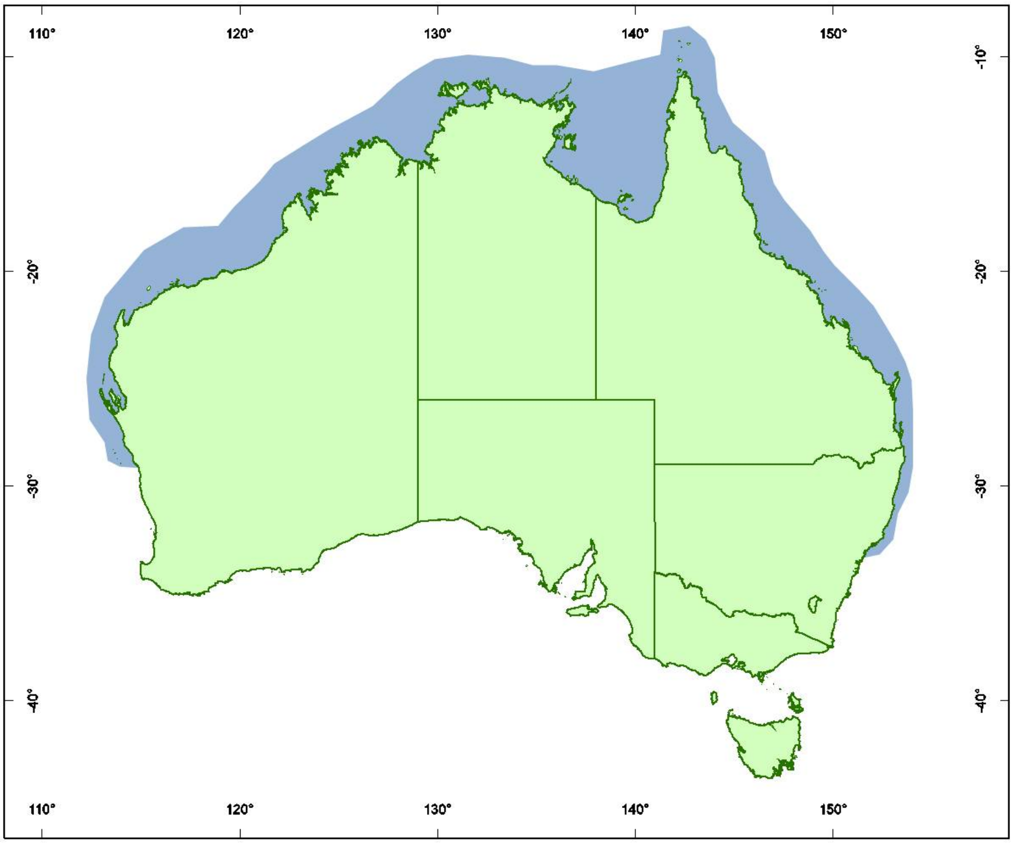


Figure 4. The Australian distribution of Mangrove Jack. This represents their usual occurrence and sometimes they can be found outside this range.

***Predators and prey***
Mangrove jack are carnivorous. As juveniles in creeks Mangrove Jack take fish (Robertson & Duke, 1990) but crabs, particularly *Sesarma* sp., are also a significant component of the juvenile and sub-adult diet (Sheaves & Molony, 2000). As adults' Mangrove Jack diet is poorly documented however as a large reef predator is likely to comprise largely of a variety of fish species.

***Recruitment***
Young of the year Mangrove Jack recruit seasonally to estuaries and rivers in the first half of each year (Russell et al. 2003). Significant inter-annual recruitment variation occurs and this can occur at a large spatial scale. For example, recruitment in 2000 was generally poor for Mangrove Jack in several large river systems in far north Queensland across a large geographical range (Russell et al. 2000). The reasons for such inter annual variations are unknown.

## 3. Current impacts of climate change

Currently, there are no documented impacts of climate change available. A study in the US on the Gray Snapper, *Lutjanus griseus*, found that population sizes had increased over a 30 year period and was correlated with increasing water temperatures in estuaries. This was suspected to be because of increasingly higher winter water temperature minimums due to changes in the North Atlantic Oscillation. They postulated that the lower winter temperatures provide favourable over-wintering conditions for juvenile fish thereby enhancing recruitment (Tolan and Fisher, 2009).

## 4. Sensitivity to change

- The sensitivity of Mangrove Jack to environmental change is unknown.

There are no documented studies on the sensitivity of Mangrove Jack to changes in environmental variables.

One study using an ecosystem modelling approach found that over the next 50 years under plausible climate change scenarios (IPCC A2 emission scenario), primary production across northern Australia will increase. This was due to increases in nutrients and also temperature. They predicted that this would result in increases in fisheries catches by 10 % in NW Western Australia and up to 60 % in parts of the east coast region (Brown et al., 2009). The results of this study suggest that Mangrove Jack catches under future climate change is likely to increase, however, these predictions are not species-specific and so it is impossible to say what the future impact on Mangrove Jack would be.

## 5. Resilience to change

- Mangrove Jack are likely to be resilient to localised environmental change

Mangrove Jack occupy many different habitat types across a wide range of latitudes and therefore appear resilient to a range of environmental conditions. Furthermore, they are reported to be a single genetic stock across the entire northern Australian range (Ovenden and Street, 2003) meaning they are more resilient to localised changes.

## 6. Other

**Ecosystem level interactions**

Climate change is predicted to have potentially profound effects on estuarine and coastal environments through a variety of physical, biological and ecological mechanisms (Sheaves et al., 2007). The complexities of the interaction of changes and their subsequent impacts on individual species makes sensible and accurate predictions challenging.

**Additional (multiple) stressors**

Mangrove Jack represent a significant target species for recreational fisheries across all of northern Australia and increasing human populations are likely to increase this targeting. Mangrove Jack rely on estuarine habitats for their juvenile and sub-adult life history stages and as such are likely to be affected by any changes in coastal habitat caused by a changing climate. Anthropogenic influences that effect estuarine environments (eg. water quality) are likely to affect Mangrove Jack populations however no data are available to determine the key variables of influence nor the extent or direction of their potential impact. Gehrke et al (2011) concluded that fisheries in estuarine areas will become increasingly vulnerable to climate change, particularly temperature increases, where catchments have been modified by riparian clearing, agriculture, forestry or mining.

**Critical data gaps and level of uncertainty (in particular, sensitivity to environmental variation: pH, temp, rainfall/river flow, extreme events)**

Estimates of recreational harvest are very poorly known for Mangrove Jack despite being a major recreational fisheries target species. Better estimation should be a key future research priority. The sensitivity of Mangrove Jack to environmental influences, particularly those relevant to estuarine habitats, should be investigated. Key variables of interest include temperature, rainfall, sea level rise, acidification and extreme events (Sheaves et al., 2007).

## Spotted Mackerel, *Scomberomorus munroi* Collette & Russo, 1980

## Authors: Richard J. Saunders and David J. Welch

The Spotted Mackerel, *Scomberomorus munroi*, is a member of the family Scombridae (the Tunas and Mackerels). The species is distributed in the northern half of Australia, from the Abrolhos Islands in Western Australia (WA) to central New South Wales (NSW), and southern Papua New Guinea. The Spotted Mackerel is particularly significant to both recreational and commercial fishers in the Queensland East Coast Inshore Fin Fish Fishery (ECIFFF).

## 7. The fisheries

- Catches in Western Australia, Northern Territory and the Gulf of Carpentaria are poorly known but are likely to be relatively low.
- The majority of the catch is in the Qld ECIFFF but significant commercial and recreational catch is also made in NSW.
- Commercial catch in the Qld ECIFFF is regulated by a total allowable catch quota however, recreational catch in this fishery is not known.

*Western Australia and Northern Territory*
Commercial catches of Spotted Mackerel are negligible in Western Australia and are reported under "other mackerel" at 0.9 t in 2010 (WA Government 2011). There is no reported commercial catch of Spotted Mackerel in the Northern Territory however it is most likely taken and mixed in with other mackerel. In both Northern Territory and Western Australia most Spotted Mackerel landings are likely to be from the recreational fishing sector.

*Queensland*
In the Queensland Gulf of Carpentaria Inshore Fin Fish Fishery the commercial catch of Spotted Mackerel is low. In 2007, the only year for which data are able to be reported due to confidentiality reasons (less than 5 vessels), only 4 t was landed (DEEDI 2011a). The commercial catch in the Queensland Gulf of Carpentaria Line Fishery is not known but is unlikely to be high as the total commercial catch of all mackerel was 185 t in 2009 and was almost entirely comprised of Spanish Mackerel (*Scomberomorus commerson*) with only 0.2 t of by-product species (DEEDI 2011b). The recreational catch in the Gulf of Carpentaria is not known. Spotted Mackerel are landed in the Torres Strait Finfish Fishery but are reported under by-product species which is a minor component of the total catch (Marton et al. 2010).

The Queensland ECIFFF is a multi-species fishery comprising of charter, commercial, Indigenous and recreational fishing sectors. It is Queensland's largest and most diverse fishery. Fishing methods used are hook and lines (all sectors) and nets (commercial). Until 2002/03, commercial ring netting of Spotted Mackerel was legal and commercial catch was considerably larger than current levels (Figure 5). As of 2003/04, commercial landing of Spotted Mackerel in the ECIFFF has been restricted to a total allowable catch of 140 t and the combined catch for all sectors is recommended not to exceed 296 t (DEEDI 2011b). Commercial landings were 100 t in 2009-10 and have been highly variable over the past four years (average annual catch: 65 t). Charter landings were 11 t in 2009/10 (DEEDI 2011b). The most recent estimate of recreational harvest from the statewide RFISH diary surveys was 148 t in 2005 (DEEDI 2008). Begg *et al*. (2005) re-analysed all RFISH data in a standardised manner, and obtained estimates of total annual recreational catch from Queensland of between 52 t and 265 t (mean of 175 t).

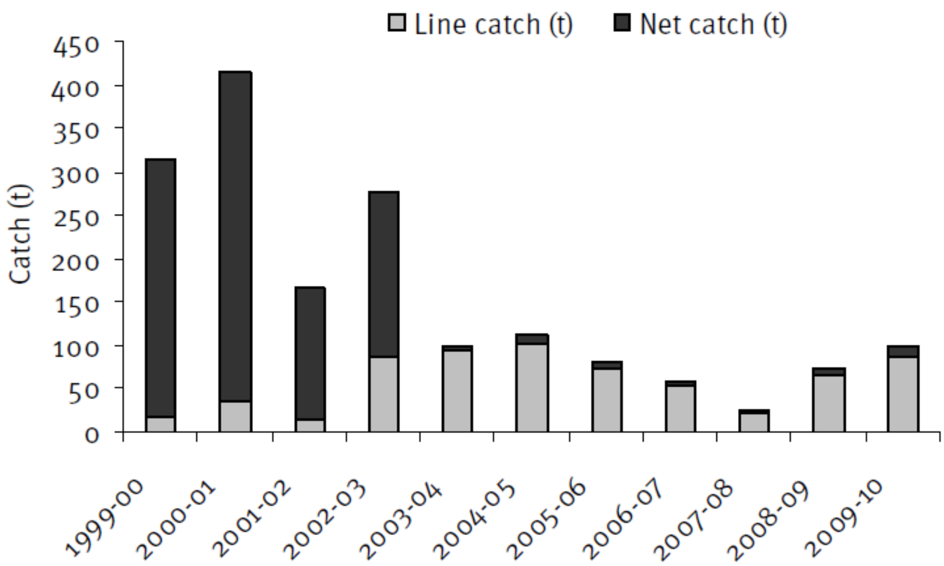


Figure 5. Commercial catch (t) of Spotted Mackerel caught by line and net in the ECIFFF, reported in logbooks 1999-00 to 2009-10. The substantial net catch prior to 2003-04 was the result of ring netting, which was banned from 2003-04 (Figure extracted from DEEDI 2011b).

Monitoring of Spotted Mackerel catches on the east coast since 2008 indicate that the commercial sector tend to take more fish in smaller size classes relative to the recreational sector. Very few fish over 95 cm TL are taken in either sector. The age structure taken by each sector is very similar and the majority of the catch by both sectors are comprised of 1- and 2-year old fish with fish older than 5 yrs being rare. The oldest fish sampled during monitoring was an 8-year old male (http://www.dpi.qld.gov.au/28_21410.htm, accessed 12/04/2012).

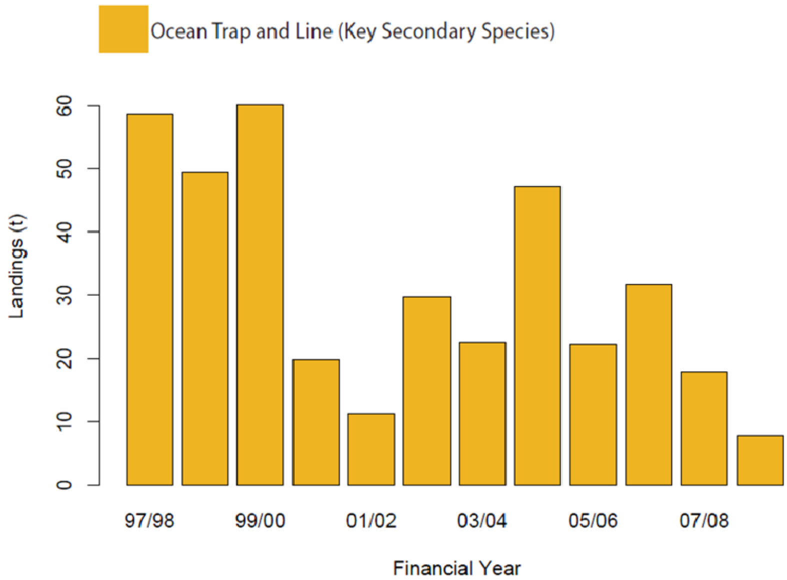


Figure 6. Reported landings of Spotted Mackerel by NSW commercial fisheries from 1997/98. Fisheries which contribute less than 2.5% of the landing are excluded (Figure extracted from Rowling et al. 2010).

*New South Wales*

Spotted Mackerel are landed commercially in the ocean trap and line fisheries in New South Wales as a key secondary species. The annual commercial catch ranges from less than 10 t to nearly 60 t (Figure 6). The species is also landed in the NSW recreational fishery and is thought to be between 10 t and 100 t (Rowling et al. 2010).

## 8. Life history

***Life cycle, age and growth***

A comprehensive understanding of Spotted Mackerel ecology and life history has been documented for the Australian east coast (Begg and Hopper, 1997; Begg et al., 1997; Begg, 1998; Begg et al., 1998; Begg and Sellin, 1998) (Figure 7). Spotted Mackerel are dioecious (ie. separate sexes). Males attain sexual maturity between 401-450 mm FL and females between 451 to 500 mm FL and spawning occurs in northern Queensland waters from August to October (Begg, 1998). There is evidence that spawning is restricted to the waters between Townsville and Mackay (Jenkins et al. 1985). Aggregations of Spotted Mackerel seasonally occur mid-year north of Townsville, but these are not considered to be aggregations associated with any spawning (Cameron and Begg, pers. comm.). A tagging study has provided some evidence for a seasonal migration of Spotted Mackerel in that recaptures occurred to the north of the release sites (Rockhampton and Hervey Bay) in August and September but to the south of these locations during the Austral summer (Begg et al., 1997). Movements into NSW are therefore seasonal and restricted to the Austral summer and autumn months. Movements north of Cairns and in the Northern Territory and Western Australian waters are unknown. Known movements support a genetic study which identified that Spotted Mackerel form a single stock on the east coast of Australia and that this stock was genetically different from that in the Northern Territory (Cameron & Begg 2002). No information is available on Western Australian stocks or where the boundary between the Queensland east coast stock and the Northern Territory stock occurs.

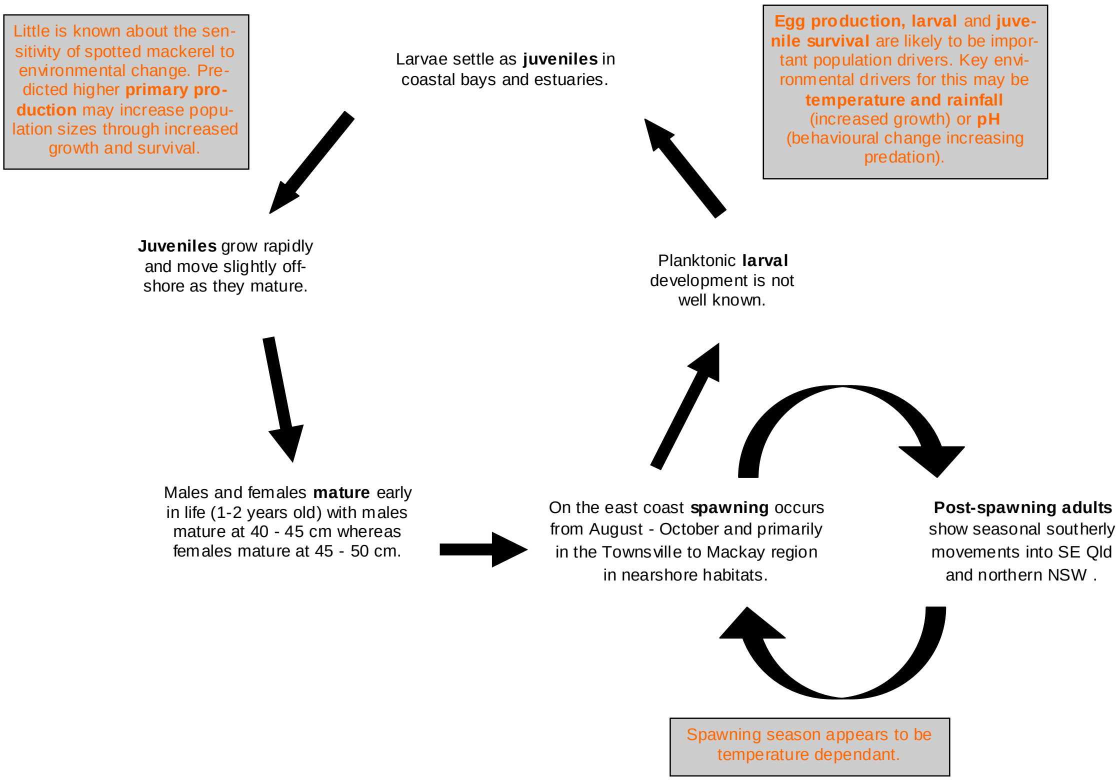


Figure 7. Generalised life cycle of the Spotted Mackerel, *S.munroi*, and the stages of potential environmental driver impacts. Life cycle is based on published research for the east coast stock (Begg and Hopper, 1997; Begg et al., 1997; Begg, 1998; Begg et al., 1998; Begg and Sellin, 1998).

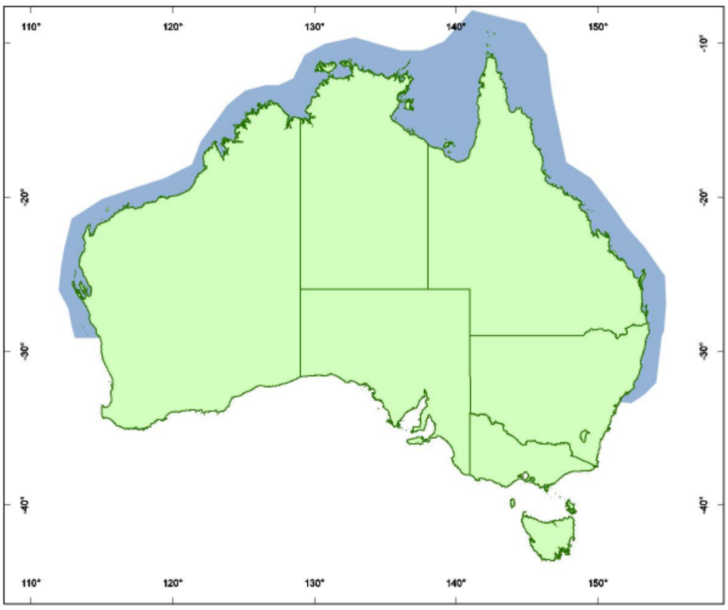

Figure 8. Australian distribution of Spotted Mackerel.

Growth of Spotted Mackerel has been studied by Begg and Sellin (1998) for Queensland and NSW. In that study Von Bertalanffy growth parameters differ between the sexes but regional differences were minor with respective parameters in the range of: $L_\infty$ = 727 to 729 mm FL, K = 0.272 to 0.339 and $t_o$ = -4.00 to –2.53 for males and $L_\infty$ = 823 to 866 mm FL, K = 0.41 to 0.52 $t_o$ = -1.96 to -1.36. Longevity of Spotted Mackerel is at least 8 years and they are known to attain 104 cm and 10 kg in weight (Allen, 2009).

***Distribution, habitat and environmental preferences***

Research encompassing otolith microchemistry, genetic diversity, tagging and reproductive biology as well as seasonal variation in commercial harvesting strongly support the hypothesis that Spotted Mackerel form a single east coast stock with an annual large scale movement along the Queensland east coast to northern New South Wales. This includes Queensland and New South Wales feeding grounds in summer and a return migration in winter to northern spawning grounds (Begg and Hopper 1997, Begg et al 1997; Begg et al 1998; Begg 1998; Cameron & Begg 2002).

***Predators and prey***

Spotted Mackerel feed primarily on fish, particularly Clupeids and Engraulids. The diet is also supplemented with invertebrates such as prawns and squid (Begg & Hopper, 1997).

***Recruitment***

There is no information on egg and larval development of Spotted Mackerel. They are known to have a pelagic larval phase and it is believed that larvae and juveniles move into coastal embayments and estuaries. This suggests that survival of annual cohorts are likely to be influenced not only by local environmental conditions, such as water temperature, salinity, pH, rainfall and river flow, but also by land-based influences on estuarine and nearshore conditions. Fishery independent measures of recruitment are unavailable across regions, however, inter-annual variation in landings of Spotted Mackerel suggest some recruitment variation.

## 9. Current impacts of climate change

There are no reported impacts of climate change on Spotted Mackerel.

## 10. Sensitivity to change

- The known east coast spawning area is spatially and temporally restricted, i.e. north Qld from August to October
- Potential southerly extension of the species range and annual migratory pattern with increasing temperatures

As drivers for spawning are unknown, there is the potential for climate change to impact on Spotted Mackerel spawning patterns and distribution. Thermal tolerances are not understood however the species migrations appears to be correlated with water temperatures. The presence of reproductively active fish in waters of north Queensland is associated with a period of lower temperatures and annual southward migrations are correlated with warming waters during the Austral summer and autumn. The East Australia Current has been shown to have increased in strength and has extended further southward over the past 60 years (Ridgeway and Hill, 2009) and this may have influenced the annual southerly migrations of Spotted Mackerel into New South Wales during this time but this has not been documented anywhere. If, as is predicted, this trend continues, Spotted Mackerel may become a far more important species in New South Wales, especially since larger Spotted Mackerel are more typical in New South Wales, with the possibility of increasingly southwards migrations and/or an increasing presence through a range shift.

The early life history stages of most organisms are generally more sensitive to environmental conditions. Although not documented for Spotted Mackerel, based on evidence for other similar *Scomberomorus* species (see McPherson, 1978, 1981; Williams & O'Brien, 1998; Halliday et al, 2001), they may settle as juveniles in inshore and estuarine nursery areas. This makes early survival and growth potentially influenced by local rainfall and river flows as has been documented for other species with inshore early life history stages (eg. Halliday et al, 2008, 2011).

## 11. Resilience to change

- Spotted Mackerel have a broad distribution across northern Australia and are highly mobile.

Spotted Mackerel have a broad distribution range covering the entire northern Australian coastline. Although at least two stocks are apparent across this range, the spatial scale of stock division is vast. For example, the east coast population of Spotted Mackerel, at least to Cairns in the north, has been shown to represent a single stock (Begg et al., 1997; Begg et al., 1998; Begg and Sellin, 1998). This broad distribution, and the fact they are a highly mobile pelagic species, suggests they are resilient to changes in the environment. Further, Spotted Mackerel have been shown to have variable growth rates, as well as size and age at maturity and sex change depending on location and possibly population densities indicating they are an adaptable species to varying environmental and population conditions. They have a broad diet with two of their major prey families (Clupeids and Engraulids) some of the most prolific baitfish species throughout northern Australia.

## 12. Other

### Ecosystem level interactions

Spotted mackerel rely on schooling baitfish as prey species and the effects of climate change on baitfish species remains very poorly understood. Should it prove baitfish are markedly affected by climate change this will affect the resilience of many species, including Spotted Mackerel.

### Additional (multiple) stressors

Spotted Mackerel are a popular target species on the Australian east coast, particularly for recreational fishers, which will inevitably increase with increasing human populations. The commercial fishery was historically heavily fished, however management changes that introduced a total allowable commercial catch (TACC) and restricted commercial fishing gear to hook and line has reduced annual catch from a peak of 410 t in 2000-01 to the average annual catch over the past four years of 65 t (DEEDI, 2011b). The level of recreational catch is poorly understood.

Given the likelihood of juvenile preference for nearshore waters the survival of annual cohorts may be more prone to being affected by land-based influences on estuarine and nearshore conditions, such as changes in water quality.

**Critical data gaps and level of uncertainty (in particular, sensitivity to environmental variation: pH, temp, rainfall/river flow, extreme events)**
Better estimates of recreational harvest levels for both Queensland and New South Wales need to be determined given their importance to this sector and the high level of uncertainty in current estimates. Future assessments should use data from each jurisdiction (Qld, NSW) since the east coast is assumed to represent a single stock.

The sensitivity of Spotted Mackerel early life history and adult stages to increases in temperature and rainfall should be investigated since the spawning areas appear to be linked to certain times and places (north Qld waters during August-October), and the fishery sector allocation implications of a southerly shift in their range. The effect of rainfall/river flows on early life history survival and subsequent recruitment to the fishery should be investigated via recruitment indices and commercial catch data. Last but not least, at a more ecosystem level the implications of climate change on bait fish require better understanding and will have implications for many species.

## Red Emperor, *Lutjanus sebae* (Cuvier, 1828)


### Authors: Richard J. Saunders and David Welch


The Red Emperor, *Lutjanus sebae*, is a member of the family Lutjanidae. The species has a wide distribution from east Africa to the western Pacific. It occurs in the northern half of Australia from mid Western Australia, across the Northern Territory and down the Queensland coast, primarily in reef habitats. The Red Emperor is a significant species for both recreational and commercial fishers throughout its Australian distribution.

## 13. The fisheries

- Commercial catches are taken in Western Australia, Northern Territory and Queensland.
- The majority of the Australian catch is by commercial and recreational fishers in the Queensland Coral Reef Fin Fish Fishery and in north-western Western Australia.
- Recreational catch of Red Emperor is poorly understood in all northern Australian fishery jurisdictions.

*Western Australia*
Red Emperor is an important commercial and recreational species in Western Australia (Department of Fisheries, 2011). The species is taken as part of the Gascoyne Demersal Scale Fishery, the Pilbara Demersal Scalefish Fisheries and the North Coast Demersal Fishery with each fishery comprising recreational, commercial and charter fishing operations. In the Gascoyne Demersal Fishery Red Emperor are a non-target species and catches have ranged over the past 10 years from 9.8 t (2009/10) to 24.4 t (2000/01). In the North Coast Demersal Fishery catches are more significant, with Red Emperor being the second most important species by weight within this fishery. Total catch taken in both the Pilbara and Kimberley regions in 2010 was 308 t (Department of Fisheries, 2011).

The recreational catch was estimated for the area between Onslow and Broome in 2002 (Newman et al., 2004). In boat ramp surveys *Lutjanus sebae* ranked in the top ten fish kept in only one of the seven districts considered with an estimated 355 fish kept in the Point Samson district. By weight, however, the species was more significant with catches in top ten by weight in four of the seven districts; Dampier at 2,956 kg, Karratha at 190 kg, Point Samson at 1,309 kg and Port Hedland with 937 kg. The species did not feature in the catch of shore based fishers in the region (Newman et al., 2004). In 2010 the charter catch of Red Emperor in Western Australia was 12.7 t. Stocks in Western Australia are considered to be sustainably fished at current levels of effort (Department of Fisheries, 2011).

*Northern Territory*
Red Emperor are a major part of the by-product catch in the Northern Territory Demersal fishery which mainly targets Goldband Snapper (*Pristipomoides* spp.), Saddletail Snapper (*Lutjanus malabaricus*) and Crimson Snapper (*L. erythropterus*) using drop lines and traps. Total commercial catch in this fishery was 208 t in 2010, down from 505 t in 2009. Red emperor contributed 3.5% (7.3 t) of the total catch in 2010. Red Emperor is also taken as part of the Timor Reef Fishery which uses baited traps and vertical lines (NT Government, 2011). The only recreational estimate of Red Emperor catch was in 2002 by Henry and Lyle (2003) who estimated that 9.5 t were kept. Catches of Red Emperor in the Northern Territory recreational and Fishing Tour Operator sectors is currently considered to be negligible.

*Queensland*
Red Emperor is captured as part of the Queensland east coast Coral Reef Fin Fish Fishery. The fishery is managed with spatial and temporal closures, size limits and gear restrictions. In 2003/04, a commercial catch quota was introduced for Coral Trout, Redthroat Emperor and "Other Species". Red Emperor catch is included in the "Other Species" with the quota set at 956 t (DEEDI, 2011) and their minimum legal size limit was increased from 45 cm TL to 55 cm TL. Commercial catch of Red Emperor was estimated to be 104 t in the year prior to the introduction of quota (2003/04). In 2004/05 catch was 26 t and has steadily increased each year since and was estimated to be 60 t in 2009-10 (DEEDI, 2011).

The best estimates for the recreational catch in Queensland are from the DEEDI RFISH diary programs. The RFISH surveys estimate the retained catch of Red Emperor in 2002 was 88,000 fish and in 2005 there were 52,000 retained. If we assume an average weight of 4.45 kg for retained Red Emperor (as in Henry and Lyle, 2003), this equates to approximately 392 t in 2002 and 231 t in 2005. The reduction in catch over these survey periods corresponds with the timing of the increase in the MLS to 55 cm TL introduced during 2003.

The stock status is considered "uncertain" as there is limited understanding of the recreational catch and age structure of the population (DEEDI 2011).

## 14. Life history

***Life cycle, age and growth***
A series of recent publications on life history of Red Emperor based primarily in Western Australia have improved the understanding of the species considerably (Figure 9). Red Emperor are gonochoristic but there is considerable growth difference between the sexes with males generally attaining a larger size than females (Newman & Dunk, 2002). Growth has been studied in both north-western Western Australia and Queensland and growth parameters are published (Table 6). Red Emperor are capable of reaching sizes of approximately 100 cm (Allen, 1985) and can attain weights up to at least 15 kg however their growth rates are relatively slow (Table 6) and their asymptotic length is reached between 10 and 15 years of age, although growth can continue throughout their life (Newman and Dunk, 2002). The species is relatively long lived with the oldest reported specimen from the Great

Barrier Reef being 32 years, one specimen from New Caledonia was 35 years and the oldest reported was from deep water off north-west Western Australia at 40 years (Loubens, 1980; Newman et al. 2010). The age-at-maturity for both sexes has been estimated to be approximately 8 years (Newman et al., 2001).

From a Western Australian study estimates of natural mortality for Red Emperor are low (0.104 – 0.122 $year^{-1}$) (Newman and Dunk, 2002). Red Emperor are therefore considered to have a low production potential, being long-lived, relatively slow growing, low natural mortality, and large size and age at maturity, making them vulnerable to over-exploitation (Newman and Dunk, 2002).

Table 6. Von Bertalanffy growth parameters for Qld and WA Red Emperor.

| Location | Sex | $L_\infty$ | K | $t_o$ | Reference |
|---|---|---|---|---|---|
| Kimberley (WA) | ♀ | 482.62 | 0.27 | 0.07 | Newman & Dunk 2002 |
| | ♂ | 627.79 | 0.15 | -0.60 | |
| Qld | ♀ & ♂ combined | 792.1 | 0.14 | -0.92 | Newman et al. 2000 |

Multiple stocks of Red Emperor have been found to occur along the west coast (Stephenson et al. 2001) and it is likely that multiple stocks are present across northern Australia. However, a lack of genetic difference within or between the east and west coast of Australia suggests the widespread dispersal of Red Emperor larvae resulting in high levels of gene flow (van Herwerden et al 2009), since adults exhibit little movement (Stephenson et al. 2001).

On the GBR Red Emperor have an extended spawning season of approximately 7 months duration during the Austral spring-summer period (McPherson et al, 1992) while in the Northern Territory females are reported to spawn year round with males only spawning at limited times (Kailola et al, 1993). They are known to be broadcast spawners with a pelagic larval phase (Allen, 1985).

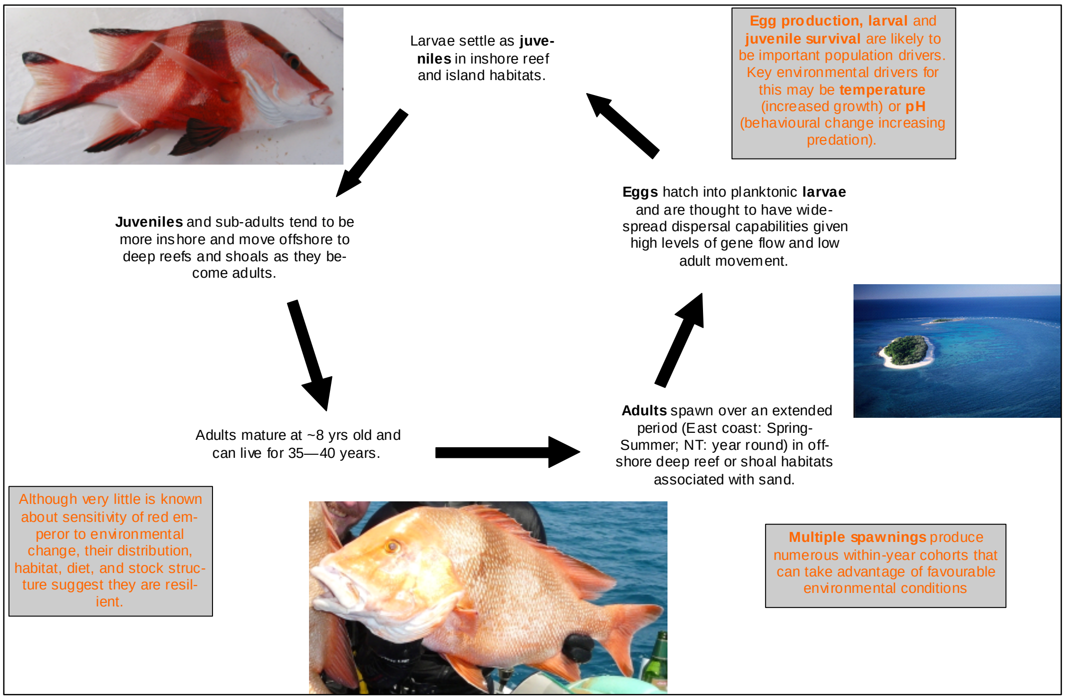


Figure 9. Generalised life cycle of the Red Emperor, *L. sebae*, and the stages of potential environmental driver impacts. Images: Michael de Rooy, GBRMPA, Fishing & Fisheries Research Centre (JCU).

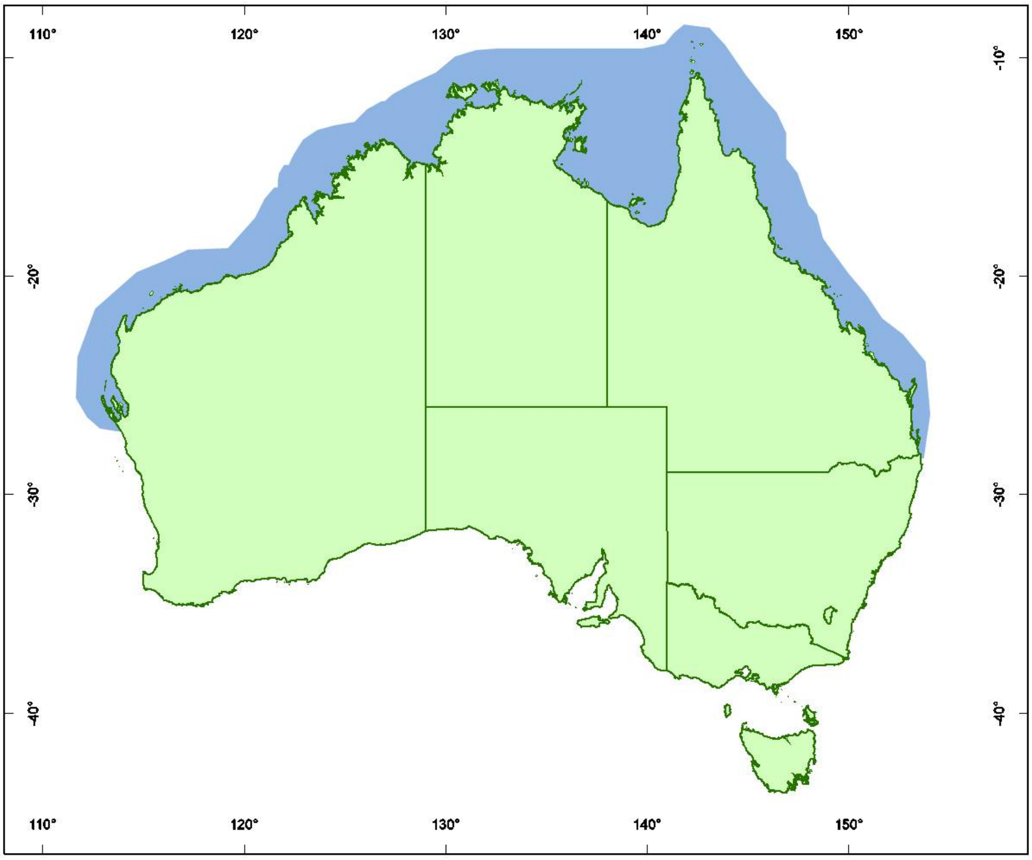


Figure 10. The Australian distribution of Red Emperor.

***Distribution, habitat and environmental preferences***

Red Emperor occur throughout the Indo-West Pacific from Australia to southern Japan, west to East Africa and the Red Sea (Allen 2009). In Australia it occurs from northern NSW around the northern Coast to as far south as Cape Naturaliste in south-west WA (Figure 10) (Newman et al. 2010). It is, however, most common in the northern parts of its Australian range. It is most commonly associated with reef environments in shallow near-shore waters to depths of at least 180 m (Kailola et al. 1993). On the GBR juveniles and sub-adults were frequently observed in nearshore habitats. Cross-shelf differences were also observed in their relative abundance with significantly more Red Emperor present on inshore reefs, mid-shelf reefs, and inter-reefal shoals compared with outer-shelf reefs. They were also more likely to be found in depths greater than 15 m (Newman and Williams, 1996). They are commonly associated with habitats that have both sandy and hard substrate types.

***Predators and prey***

A study in the Gulf of Carpentaria during 1990 found that the most common prey item by weight found in stomach content samples of Red Emperor were teleosts (73.0 %). The next most common by weight was crustaceans (14.1 %; not including Penaeidae and Stomatopoda) (Salini et al, 1994). Other than the above prey types, Red Emperor will eat a variety of prey types with Annelids, Cephalopods, Penaeids, Stomatopods, and Mollusc found in stomach content samples. However, the size of the Red Emperor sampled during this study (n = 113) did not exceed 387 mm SL and it is possible that diet will change as fish get larger. Predators of Red Emperor are likely to be those of higher order (eg. sharks) and/or much larger predators.

***Recruitment***
There is no published information on the recruitment dynamics of Red Emperor however it is likely that larval survival will be variable form year to year due to inter-annual variation in favourable environmental and biological conditions, although this may be tempered by protracted spawning seasons.

## 15. Current impacts of climate change

There are no known current impacts of climate change on Red Emperor.

## 16. Sensitivity to change

- Very little is known of the sensitivities of Red Emperor to environmental factors.

Juveniles appear to favour nearshore environments (though not exclusively) and may therefore be more influenced by land-based and anthropogenic impacts. However, very little is known of the sensitivities of Red Emperor to environmental factors. In other tropical lutjanid species spawning seasonality has been linked to temperature and for nearshore spawners, to rainfall also (Freitas *et al.*, 2011). However, these authors acknowledged that there was latitudinal and species-specific variation in apparent spawning patterns making generalisations about environmental spawning cues for lutjanids difficult to make. The cues for Red Emperor may be varied and have wide ranges since they have a protracted spawning season.

## 17. Resilience to change

- The attributes of Red Emperor suggest it is resilient to differences in environmental conditions.

Red Emperor are found over a wide latitudinal and temperature range and their distribution extends across the continental shelf from shallow inshore waters to deep offshore waters. They appear to prefer reef/shoal habitat associated with sand but this is variable, and their diet appears to be varied. Across northern Australia they are reported to be a single genetic stock comprising multiple separate adult stocks. They are also known to be hardy in aquariums. All of these attributes suggest that Red Emperor are a resilient species to differences in environmental conditions and therefore change.

## 18. Other

**Ecosystem level interactions**
Juvenile Red Emperor are reported to be frequently found in association with Sea Urchins (Allen, 1985), however the significance of this is unknown.

**Additional (multiple) stressors**
Although current levels of fishing effort for Red Emperor is considered to be sustainable in WA and the NT, in Qld it is considered uncertain due to a lack of information. Recreational catch is prominent on Qld in particular and is likely to increase in the future with increasing human populations. Further, Red Emperor have life history characteristics that make them

relatively vulnerable to over-exploitation. The discard rate for Red Emperor on the GBR is known to be high given the large MLS limit, however despite often being caught from deep water post-release survival is estimated to be high (Brown et al, 2008).

**Critical data gaps and level of uncertainty (in particular, sensitivity to environmental variation: pH, temp, rainfall/river flow, extreme events)**
Better estimates of recreational harvest of Red Emperor are required to better assess stock status in all jurisdictions of northern Australia. Critical gaps that need to be investigated is the sensitivity of Red Emperor to environmental variation including pH and temperature, particularly for early life history stages.

## Barred Javelin, *Pomadasys kaakan* (Cuvier, 1830)

### Authors: Richard J. Saunders, Natasha Szczecinski and David J. Welch

The Barred Javelin, *Pomadasys kaakan*, is a member of the family Haemulidae (Grunters). The species occurs throughout the Indo-Pacific from the Red Sea and the east coast of Africa to south-east Asia and northern Australia (Froesy & Pauly 2012).

## 19. The fisheries

- Commercial catches of Barred Javelin are generally reported as "Grunter". This is a complex containing at least three species.
- The Barred Javelin is an important by-product species in commercial fisheries targeting Barramundi
- The species is an important recreational fishery species, particularly in north Queensland

*Western Australia*
25 t of Grunter (*Pomadasys* spp.) were landed across all of WA's commercial fisheries in 2009/10 financial year (Department of Fisheries 2011). Although this complex includes *P. kaakan*, *P. argenteus* and *P. maculatus* the latter is likely to be a minor component given their small size

*P. kaakan* has been identified as one of the top 20 species landed by recreational fishers in the Pilbara and West Kimberley but the size of the catch in the region has not been estimated. Some fine scale regional data is available on catch in north-west WA (Newman et al. 2009).

*Northern Territory*
Grunters are taken as by-product in commercial Barramundi fisheries in the NT. However, less than 2 t of Grunter have been reported each year for 2008, 2009 and 2010 (NT Government 2011). No data on the importance of *P. kaakan* in recreational fisheries in the NT is available however most of the NT recreational catch comes from the Gulf of Carpentaria (Thor Saunders, pers. comm.).

*Queensland*
In Qld, commercial fishers land Grunter in the Gulf of Carpentaria Inshore Fin Fish Fishery (GOCIFFF) and the East Coast Inshore Fin Fish Fishery (ECIFFF). Average catch in the GOCIFFF over the past seven years was 27 t (to 2009) (DEEDI 2011a). In the ECIFFF average catch was

28 t over the past four financial years (to 2009/10) (DEEDI 2011b). The annual catch by charter operators in the ECIFFF has ranged from 401 kg to 2,288 kg since 2004. The status of the species in Queensland is listed as uncertain due to poor knowledge of the recreational harvest.

The species has been noted as one that is a common target species by recreational fishers (Greiner & Patterson 2007; Hart & Perna, 2008). The tourist recreational catch of *P. kaakan* in the Gulf of Carpentaria was estimated to be between 100 and 118 tonnes over the period March – September 2006. Further, at a local scale, the Karumba recreational tourist fishery (from May to August inclusive) catch of *P. kaakan* was 13.5 t, representing 30% of the total catch in that fishery (Hart & Perna, 2008).

Recent research work in the Lucinda region of the north Queensland east coast indicates that recreational fishers catch fish predominantly between 280 and 360 mm TL whereas commercial fishermen catch a more even spread of sizes with significantly more fish over 600 mm than recreational fishers (Szczecinski, unpublished data). Furthermore, the recreational catch of Grunter was highly skewed toward females with a ratio of 15:1. In the commercial sector however, this ratio was only 2:1 (Szczecinski, unpublished data).

## 20. Life history

***Life cycle, age and growth***

The life history of *P. kaakan* is poorly understood as very limited research has been done (figure 11). However, on the Qld east coast the reproductive period off Townsville is reported to occur between September and November (Bade, 1989). Further south on the Qld east coast, a more extensive reproductive period, from September to March, has been reported (Russell 1988). Recent research in the Lucinda region in far north Queensland also indicates an extremely protracted spawning season with actively spawning fish collected from August to June, although fish were not collected during January, April, May and December (Szczecinski, unpublished data). The species is thought to mature by its third year (Garrett, 1996). In the Lucinda region, over 50% of fish (males and females) are mature by 200-239 mm TL (Szczecinski, unpublished data). Histological sections of mature ovaries indicate the species is most likely a multiple batch spawner (Bade, 1989). Frosey & Pauly (2012) note that spawners form shoals near river mouths during the winter, but the statement is unreferenced.

Age and growth of *P. kaakan* were described for the Queensland east coast by Garrett (1996). Von Bertalanffy growth parameters reported were $L_\infty$ = 579 mm FL, K= 0.35 and $t_0$= -0.66. More recent information on growth has been determined for the species in the Lucinda area (near Hinchinbrook Island, far north Queensland) and this data differed from that of Garrett (1996) with Von Bertalanffy parameters $L_\infty$ = 746 mm FL, K= 0.18 and $t_0$= -0.79 (Szczecinski, unpublished data). The oldest fish reported was 14 years (Garrett 1996), estimated from increments in whole otoliths. *P. kaakan* is reported to reach 800 mm (Froesy & Pauly 2012) but in Bade (1989) the largest fish reported was 530mm TL, and 610mm FL in Garrett (1996).

***Distribution, habitat and environmental preferences***

*P. kaakan* occurs throughout the Indo-Pacific from the Red Sea, east coast of Africa, south-east Asia and northern Australia (see Figure 12) (Froesy & Pauly 2012). It lives inshore primarily in estuarine and shallow coastal waters (Bade 1989; Smith & Heemstra 1986).

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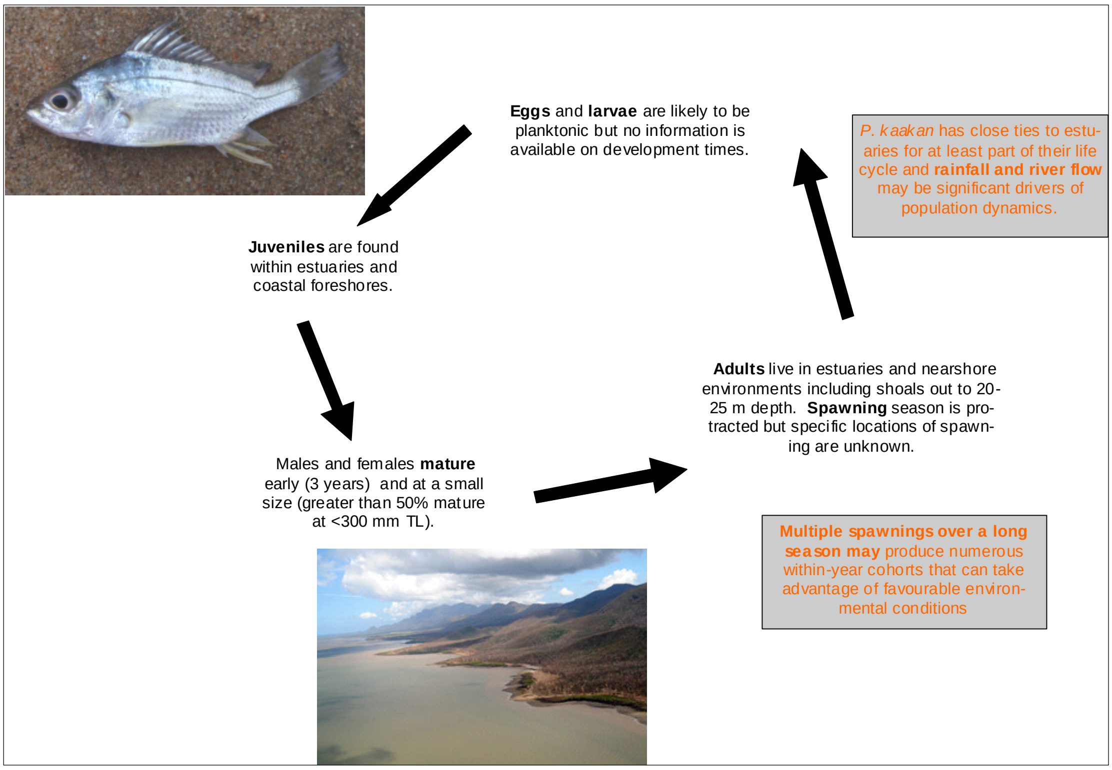


Figure 11. Generalised life cycle of the Barred Javelin, *P. kaakan*, and the stages of potential environmental driver impacts.

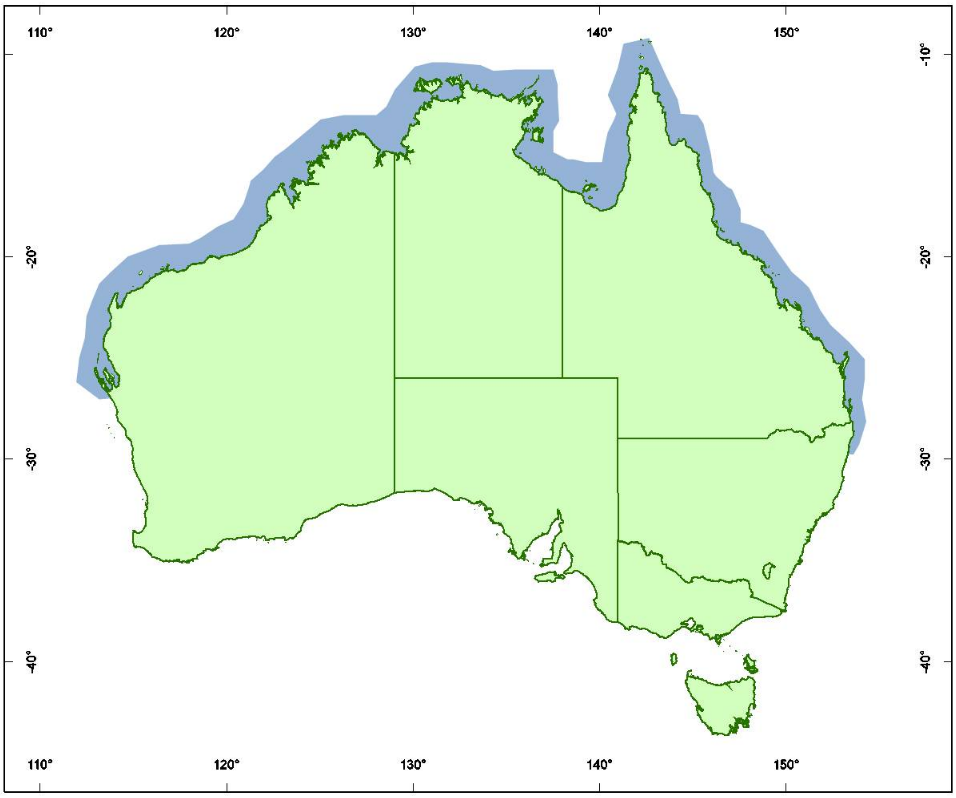


Figure 12. The Australian distribution of Barred Javelin.

***Predators and prey***

The diet of *P. kaakan* around Townsville on Australia's east coast was described in Bade (1989). Principal prey items identified from stomach contents were polychaetes, crustaceans and fishes (Bade 1989). In that study, the most common prey item for larger fish (over 150mm) were decapods, while polychaetes were the most common prey item for specimens under 150mm.

***Recruitment***

There are no known measures of recruitment of grunter species in Australia and no population age structure information is available.

## 21. Current impacts of climate change

There are no known current impacts of climate change on grunter species in Australia.

## 22. Sensitivity to change

- Sensitivity of Barred Javelin to environmental change is unknown.

The sensitivity of Barred Javelin to changes in environmental conditions is not known. However, they occupy nearshore and estuarine habitats and environments that are subject to large fluctuations in variables such as salinity, temperature and nutrient levels. As such, they are likely to be resilient to changes. It is also possible that rainfall and river flows are significant drivers of population recruitment and growth rates given this has been found to occur in several other nearshore/estuarine species (Halliday et al., 2008; Meynecke et al., 2006; Robins et al., 2006; Staunton-Smith et al., 2004).

## 23. Resilience to change

- Barred Javelin are likely to be resilient to changes in the environment..

Barred Javelin are distributed widely across northern Australia occupying many different tropical regions in environments known to vary widely (see above). They are therefore likely to be resilient to changes in the environment. They also have habitat to the south of their current range that they could occupy with increasing marine temperatures

## 24. Other

**Ecosystem level interactions**

As with many other similar species the ecosystem level interactions of Barred Javelin under climate change are very difficult to predict given uncertainty in exposure and sensitivity as well as predation and competition.

**Additional (multiple) stressors**

Fishing impacts are probably low at current levels in most regions of tropical Australia, however there remains a high level of uncertainty in the level of recreational harvest and the sustainability of this catch, particularly in the GoC and where recreational catches may be excessive (Hart and Perna, 2008). The stock structure of *P. kaakan* is unknown and will determine their sensitivity to localised depletions under fishing pressure or other impacts. Finally, Barred Javelin occupy estuaries and nearshore environments throughout their life cycle and are therefore exposed to land-based impacts such as water quality, agricultural and mining run-off, etc.

**Critical data gaps and level of uncertainty (in particular, sensitivity to environmental variation: pH, temp, rainfall/river flow, extreme events)**
Recreational harvest levels is a key concern (Greiner & Patterson, 2007; Hart & Perna, 2008) and uncertainty for Barred Javelin in northern Australia and better estimates are needed for future more robust assessments of populations. Better understanding of the sensitivity of the Barred Javelin (and the Silver Javelin, *P. argenteus*) to environmental variables such as temperature, salinity, pH and rainfall/river flow is needed to make more robust predictions about the potential impacts of climate change on these species.

### Dusky Flathead, *Platycephalus fuscus* Cuvier, 1829

### Authors: Richard J. Saunders and David J. Welch

The Dusky Flathead, *Platycephalus fuscus*, is a member of the family Platycephalidae (the Flathead) of the order Scorpaeniformes. The species is restricted to the east-coast of Australia from eastern Victoria to north Queensland and is a very important recreational species in NSW and Qld

## 25. The fisheries

- Commercial catch is taken in inshore net fisheries in Qld and NSW.
- Recreational catch is much larger than the commercial catch.

*Queensland*
The Dusky Flathead is landed by commercial fishers in the East Coast Inshore Fin Fish Fishery (ECIFFF) and comprises <1 % of the total species composition by weight (Simpfendorfer et al., 2007). In 2009-10 there was 57 t of Flathead reported in the commercial sector and the annual average over the past four years is 66 t. In the tropics Dusky Flathead form the bulk of Flathead catches. Given the size limits in place for this species the fishery harvests predominantly females. Catches and catch rates have been stable and the species is currently considered to be sustainably fished (DEEDI, 2011a). RFISH diary surveys done to assess recreational catch in Queensland for the years 1997, 1999, 2002, and 2005 record catch of Flathead ranging from 133 t in 1999 to 70 t in 2005 (McInnes, 2008). A large proportion of this catch is likely to be Dusky Flathead but the species composition is unknown. The species has minimum and maximum size limit and bag limits are in place for the recreational sector.

*New South Wales*
Commercial landings of Dusky Flathead are restricted to the Estuary General Fishery in NSW (Rowling et al. 2010) and are higher than the Qld commercial sector. Commercial catches in NSW since 1997/98 have generally been in the range of approximately 120 - 230 t. Commercial catches are mainly comprised of female fish (Gray et al, 2002). The catch in this fishery has varied between ~120 – 180 t in recent years after a large drop following a buy-out of many commercial fishers during 2000 (Figure 13). Historically, commercial catch of Dusky Flathead since 1952/53 has generally remained between 150 and 250 t per annum (Rowling et al. 2010).

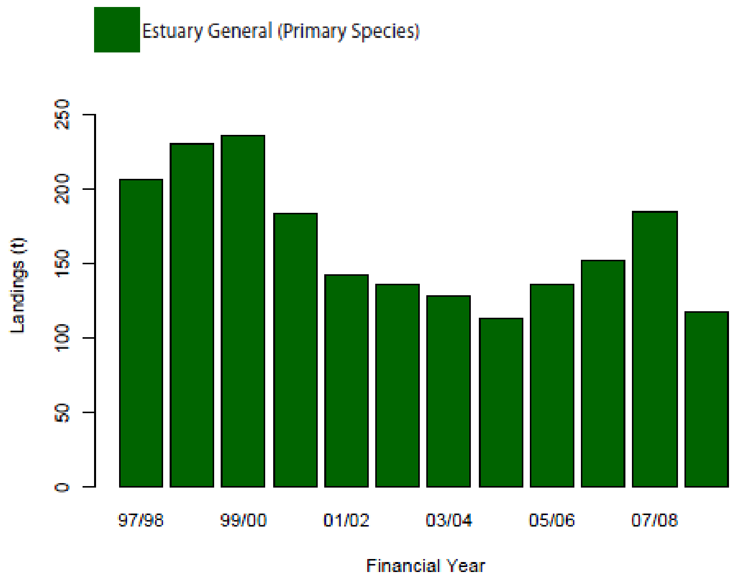


Figure 13. Commercial catch of Dusky Flathead in NSW commercial fisheries from 1997/1998 to 2008/09 (figure extracted from Rowling et al. 2010).

The commercial catch of Dusky Flathead in NSW is dwarfed by the recreational catch which is thought to lie between 570 and 830 t (Rowling et al. 2011). Henry & Lyle (2003) report flathead to be the second most prominent group taken by recreational fishers in Australia, however, no analysis of flathead catch by species was done. Dusky flathead are assessed as fully fished in NSW waters. They have a minimum size limit only but a restriction of one fish > 70 cm TL, with a recreational bag limit of 10 (Rowling et al. 2011).

## 26. Life history

***Life cycle, age and growth***

Dusky flathead are the largest flathead species attaining 1.2 m TL and 15 kg (Gomon et al. 2008). Growth has been well described by Gray & Barnes (2008) for NSW but several studies across the range of species have also considered age and growth (e.g. Dredge 1976; West 1993; Gray et al. 2002). Gray & Barnes (2008) reported sexually dimorphic growth for Dusky Flathead. The von Bertalanffy growth parameters for females were: $L_\infty$ = 127.59 mm, K= 0.084, $t_o$= -2.39 and for males: $L_\infty$ = 43.21 mm, K= 0.714, $t_o$= -0.67 (Gray & Barnes 2008). There is some evidence that Dusky Flathead from Victoria attain sexual maturity at a smaller size than those from southern Queensland (*see* Kailola et al. 1993).

Spawning occurs in northern Queensland from September to March (Dredge 1976), in Moreton Bay from November to February, and January to March in NSW and Victoria (Kailola et al. 1993). These are all periods associated with an increase in day length and water temperature (Dredge 1976). The species is likely to be a multiple batch spawner and has high fecundity producing between 294,000 and 3,948,000 pelagic eggs (Gray & Barnes 2008). The larvae are pelagic and are described in Neira et al. (1998).

There has been some speculation that Dusky Flathead are protandrous hermaphrodites (Dredge 1976, Kailola et al. 1993) but this was based on observations of sized based sex ratios and no histological or physiological studies have found evidence for this. It is now considered more likely that the species exhibits dimorphic growth between the sexes resulting in exclusively large females and a very high proportion of males in the smaller size classes (Gray & Barnes 2008).

This species was successfully reared under laboratory conditions for a pilot program of stock enhancement in south-east Queensland (Butcher et al. 2000; 2003). Eggs were developed successfully at 23°C, and as 12 mm hatchlings they were transferred to 24–26.5°C ponds prior to being released at 35–50 mm (Butcher et al. 2000; 2003). The life cycle of Dusky Flathead is presented in Figure 14 with comments on potential influences of environmental variables on the different life history stages.

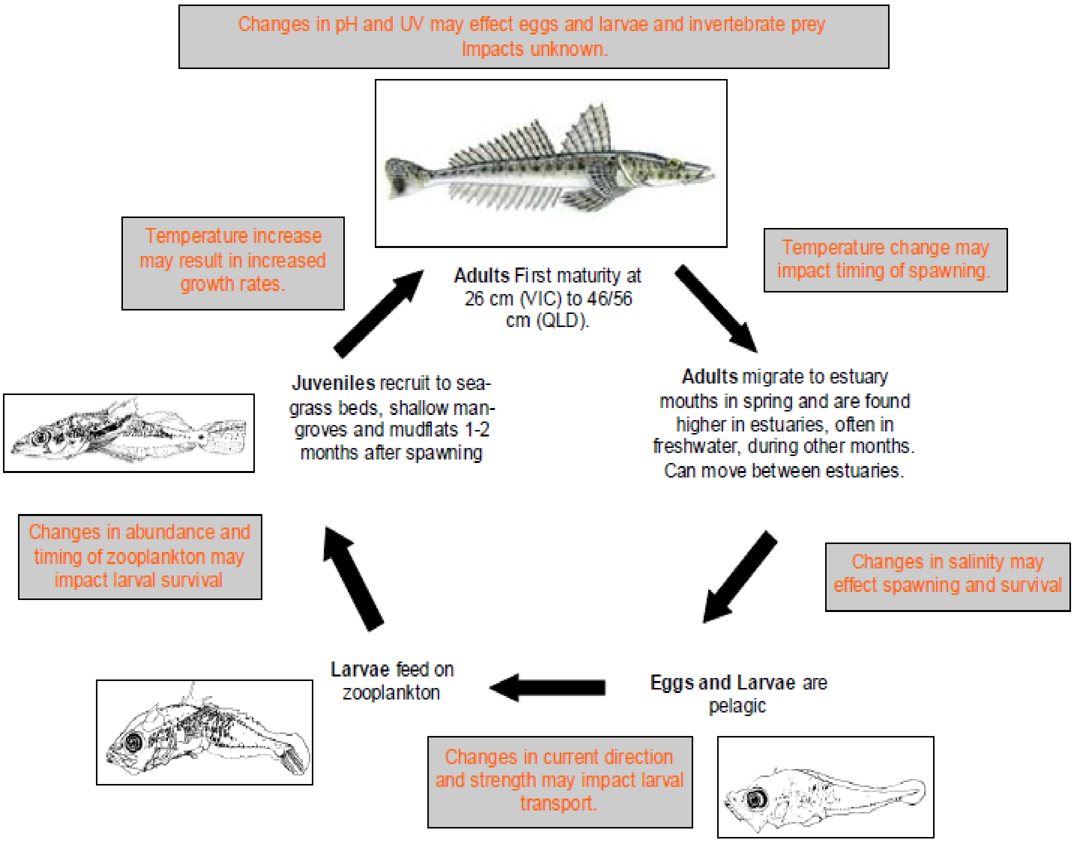


**Figure 14. Generalised life cycle of the Dusky Flathead, *P. fuscus*, and the stages of potential environmental driver impacts (Source: Hutchinson, 2011).**

### *Distribution, habitat and environmental preferences*

The species is restricted to the east-coast of Australia from eastern Victoria to north Queensland. Dusky flathead occur in inshore coastal and estuarine environments usually associated with soft substrates, including mud, sand and seagrass. Movement studies show that Dusky Flathead are capable of moving long distances within an estuary (> 30km) and moving between estuaries (West 1993; Hindell 2008).

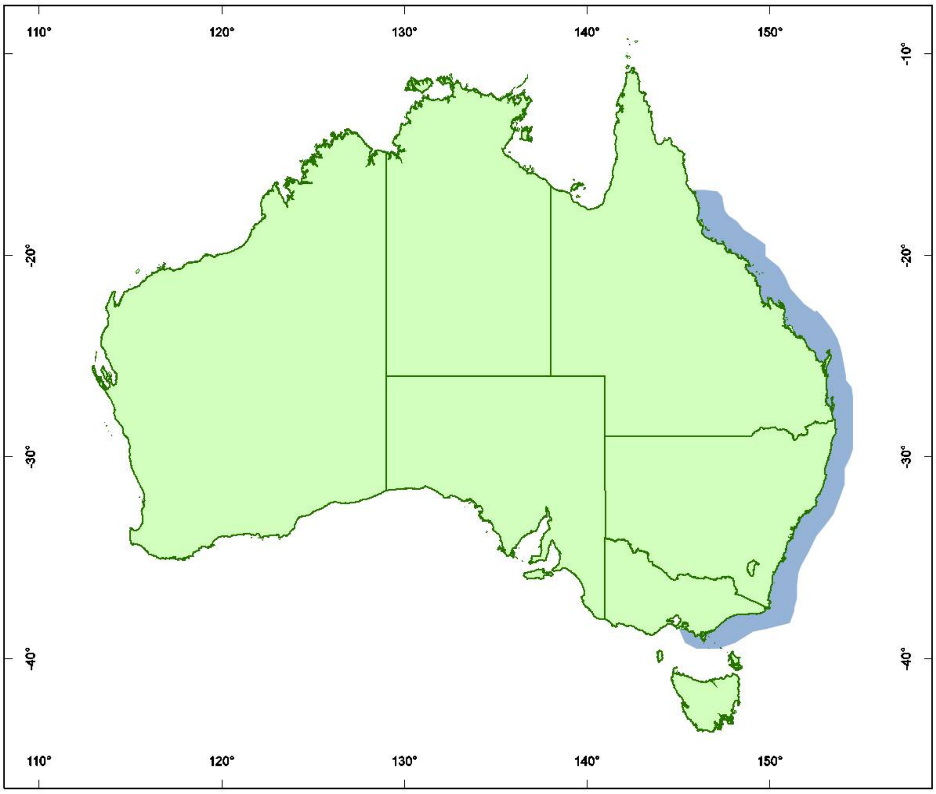


Figure 15. Distribution of Dusky Flathead.

***Predators and prey***

Flathead have been recorded in the diet of dolphins (Parra & Jedensjö 2009) and Elasmobranches (Walker 1989; Braccini et al. 2005; Treloar et al. 2007). As larvae they are likely to be taken by a wide range of Teleosts. Dusky flatheads are primarily ambush predators (Dredge 1976; Kailola et al. 1993). The diet includes include Fish, Crustaceans, Molluscs and Polychaetes (Dredge 1976).

***Recruitment***

Recruitment processes of Dusky Flathead are not well understood. Larvae have been captured between September and May in estuaries and coastal waters of New South Wales (Gray and Miskiewicz 2000) and juveniles recruit to bays 1–2 months after spawning (Hindell 2008). Age structures of Dusky Flathead collected from commercial catch samples from four different estuaries of NSW collected over 2-3 years suggested that inter-annual recruitment can be highly variable (Gray et al., 2002).

## 27. Current impacts of climate change

There are no known current impacts of climate change on Dusky Flathead.

## 28. Sensitivity to change

- Rainfall has a positive correlation with Dusky Flathead catch and catch per unit effort
- Life history strong association with seagrasses suggests that if climate change influences seagrass extent then the population of Dusky Flathead will also be affected.
- Very little else is known of the sensitivity of Dusky Flathead to environmental variation

From a study in the Logan River, Queensland, the total catch of estuarine species in fisheries catch was been shown to be linked to the amount of freshwater runoff, particularly for Flathead species (Loneragan and Bunn, 1999). A more recent study in different regions of the Queensland east coast found a significant positive correlation between annual coastal rainfall, the Southern Oscillation Index (SOI) and fisheries catch and CPUE of Flathead (Meynecke et al., 2006).

## 29. Resilience to change

- Dusky Flathead are likely to he resilient to environmental change.

The latitudinal range of Dusky Flathead along almost the entire east covers a wide range in water temperatures and suggests a wide thermal tolerance for Dusky Flathead. It is not known, however, whether the east coast is comprised of a single stock or separate stocks. A study of Dusky Flathead commercial catches from four estuaries from different regions of NSW indicated differences in age, size and sex structures of the catch along with differences in mean-size-at-age suggesting the possibility of separate stocks (Gray et al, 2002). The fewer the number of stocks the more resilient Dusky Flathead are likely to be to changes in environmental conditions. Dusky flathead are considered to be generalist predators with a range of prey species making them resilient to changes in the availability of prey species.

## 30. Other

**Ecosystem level interactions**
Ecosystem scale interactions are not well understood as with all species. Changes in the community structure of plankton have already been documented to have occurred in response to climate change. Jordan (1998) linked strong year class strength of Southern Sand Flathead with peaks in the abundance of plankton. It is therefore likely that changes in the plankton will influence flathead populations.

**Additional (multiple) stressors**
Fishing effort for Dusky Flathead is high in both NSW and Qld, particularly by the recreational sector. Although stock status in each state is considered to be ‘sustainably fished’, estimates of total mortality are considered to be high suggesting stocks may be subject to over-exploitation (Gray et al., 2002). Habitat impacts of climate change may affect all Flathead species since they are benthic preferring soft substrates. Being an inshore and estuarine species Dusky Flathead will also be exposed to land-based impacts such as changes in water quality and salinity, and they are known to absorb a wide range of pollutants (Mondon et al., 2001).

**Critical data gaps and level of uncertainty (in particular, sensitivity to environmental variation: pH, temp, rainfall/river flow, extreme events)**
One of the major information gaps for Dusky Flathead is knowledge of the sensitivity of each life history stage to changes in particular environmental variables such as temperature, salinity, pH, rainfall and extreme events. The larval and juvenile stages are potentially the most sensitive. Currently recreational harvest of Dusky Flathead is high and will only increase as human populations increase. Better estimates of recreational harvest levels are required to better manage the potential for cumulative impacts resulting in over-exploitation.

# 10. SOUTH EAST REGION SPECIES ASSESSMENT

## SPECIES AND AREA IN PROJECT SCOPE

The project identified recreational species in South-east Australia that meet the following criteria:

i) The vulnerability of species was assessed using the findings of the report titled 'Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia' (Pecl et. al. 2011).
ii) The importance of recreational species was confirmed through review of previous angler surveys, creel survey data, etc.
iii) The data richness of species life history information was assessed by reviewing the scientific literature to ensure sufficient knowledge of habitat and likely response to environmental change can be postulated.

With these criteria King George Whiting *Sillaginodes punctatus*, Black Bream *Acanthopagrus butcheri,* Mahi Mahi *Coryphaena hippurus* and Yellowtail Kingfish *Seriola lalandi* were selected. Although Yellowtail Kingfish and Mahi Mahi data was more limited than for the other two species, there was sufficient information to 'tell the story' for these species and they cover the 'adaptation spectrum' (i.e. – both risks and opportunities).

While Abalone, Rock Lobster and Snapper are important and meet all of the criteria, the existing SEAP project and potential duplication of effort ruled them out.

Each species was reviewed as a whole and at times separately across southern NSW, Victoria, Tasmania (in particular eastern Tas) and Eastern South Australia.

## DETERMINING FISHER, RESEARCHER AND MANAGEMENT INTERPRETATION OF THE PREDICTED CLIMATE CHANGE SCENARIO

A two day workshop was held on 1-2 March 2012 at Queenscliff Victoria with South East Australia's recreational fishing sector, management and research experts. The aim of the workshop was to present the latest science for select species in conjunction with understanding adaptation as previously described in this report.

The workshop was attended by key recreational fishing representatives from across the South East, as well as fishery managers and scientists.

## CASE STUDY OF BLACK BREAM TO 2030

**Species:**

Black Bream (*Acanthopagrus butcheri*)

**Distribution**

Black Bream are found from southern New South Wales to Shark Bay in Western Australia (Figure 16). They have a wide salinity tolerance, from seawater to freshwater, with the life cycle of Black Bream usually completed within a specific estuary (Walker and Neira 2001; Norriss et al. 2002). Movement patterns of Black Bream within rivers and estuaries and out of estuaries into nearshore environments have been studied throughout the range of the species using both traditional and acoustic tagging methods. Several studies suggest that there is only occasional movement of Black Bream between bays and inlets and that their distribution within an estuary varies seasonally with salinity, water temperature and food availability (Hassell et al. 2008).

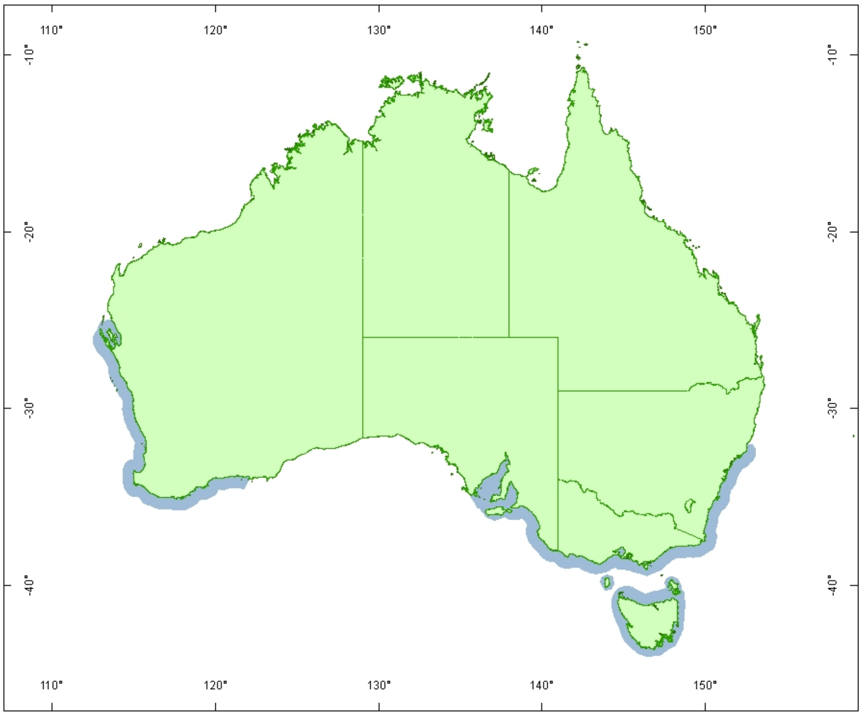


Figure 16. Map detailing the distribution of Black Bream (Pecl et al, 2011).

**Biology**

Black Bream live at least 29 years (Morison et al. 1998) and possibly up to 37 years (DPI 2008) with adults reaching 60 cm (4 kg) (Figure 17) (Cadwaller 1983). Age at maturity varies widely, with spawning occurring first at ages of 1-4 years, and 50% maturity from ~130-250 mm in Victoria and WA (Coutin et al. 1996; Norriss et al. 2002). The species generally spawns upstream in sheltered areas of estuaries near the interface between fresh and brackish water. In the Gippsland Lakes the relationship between environmental flows, salinity stratification and successful Black Bream larval survival has been demonstrated (Jenkins, 2010). It was determined that 71% of the recruitment variability could be explained by flow and stratification alone.

Black Bream eggs are planktonic and as a function of their buoyancy are mostly found in waters where the salinity is between 15 and 20; at 17 they float in the upper 45 cm of the water column (Butcher 1945). Eggs generally hatch two days after fertilisation (Haddy and Pankhurst 2000) at a diameter of ~1.7 mm (Neira et al. 1998). Eggs are thought to be restricted to natal estuaries (Newton 1996). Larvae in Hopkins River Estuary, VIC have been found exclusively in pelagic habitats, mainly in upper and middle parts of the estuary (Willis et al. 1999). The larvae remain in the water column for about one month before settling into shallow macrophyte and seagrass beds when they are 10 to 18 mm in length (Ramm 1986; Neira 1998; Willis et al. 1999; Walker and Neira 2001).

In East Tasmania, newly settled juveniles of ~15mm have been found over rocky areas in the Little Swanport estuary (Morton et al. 2005). Growth of adults is dependent on season and age, with the fastest growth in summer during the first 6-8 years, with low temperatures and increased rainfall in winter slowing growth (Sarre and Potter 2000). Growth is fastest during the first year, with slightly lower growth in 2nd and 3rd years (Butcher 1945).

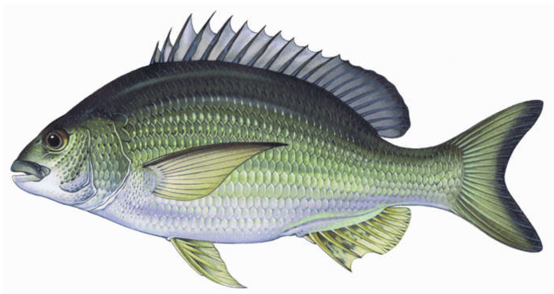

Figure 17. Illustration of a Black Bream

**Current fishery**

Victorian stocks are separate to those in NSW and WA (Norriss et al. 2002). The major commercial and recreational fisheries for Black Bream in Victorian waters occur in the Gippsland Lakes, Lake Tyers, Tamboon Inlet and Mallacoota Inlet (Pecl etal. 2011). The Gippsland Lakes fishery is particularly important and produces 74-88% of the total commercial catch in Victoria, although the recreational catch (about 200T) is greater than the commercial catch of about 150T. In South Australia, 2.4 T were caught commercially in 2008/2009. Black Bream is an important recreational species in Tasmania. Most fishing occurs along the northeast and east coasts. An estimated 48,070 (standard error: 20,148) individuals were caught in 2007/08, but about 72.7 % of the catch was released. In 2007/08 about 13,134 individuals were harvested (kept), which equates to about 11.54 tonnes (Lyle et al. 2009).

**Climate change biophysical predictions for South East Australia relevant to Black Bream**

Rainfall and resulting runoff from the catchment into estuaries play a major role in determining the salinity structure. Very large flow events can flush the salt water from the estuary, and alternatively prolonged periods of low freshwater flow can result in the estuary becoming dominated by salt water. The south eastern region of Australia is predicted to experience less rainfall by 2030, particularly during winter and spring (Figure 18). Drought conditions are also predicted to become more frequent with up to 20% more drought months over most of Australia by 2030, and up to 40% more droughts by 2070 in eastern Australia (CSIRO, 2007).

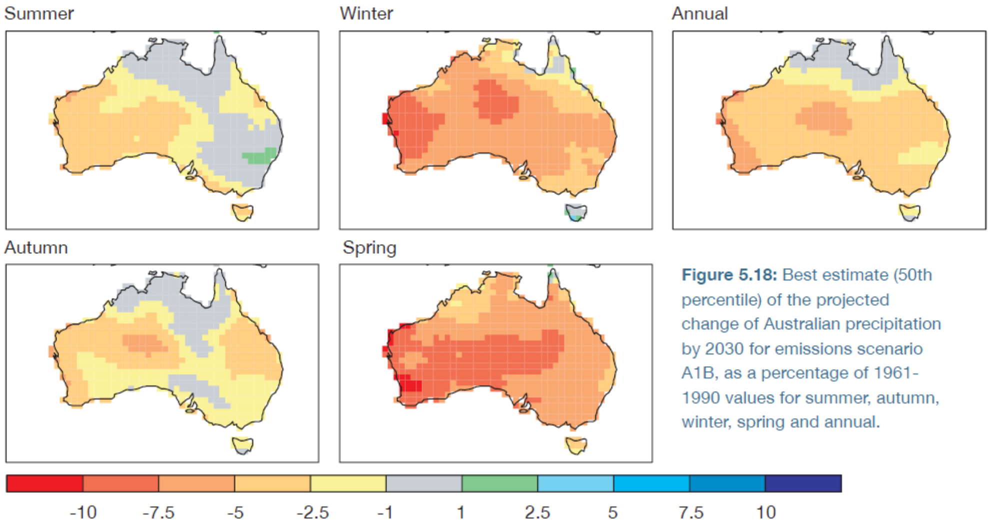


Figure 18. Best estimate (Best estimate (50th percentile) of the projected change of Australian precipitation by 2030 for emissions scenario A1B, as a percentage of 1961- 1990 values for summer, autumn, winter, spring and annual (CSIRO, 2007).

It is also predicted that future rainfall events will be more intense, with more rainfall falling per event (Figure 19). Increases in the higher intensity rainfall events combined with lower base flows are expected (Figure 20). Overall, these predictions suggest that the hydrological conditions required for producing a salt wedge suited to Black Bream spawning and larval survival are likely to reduce.

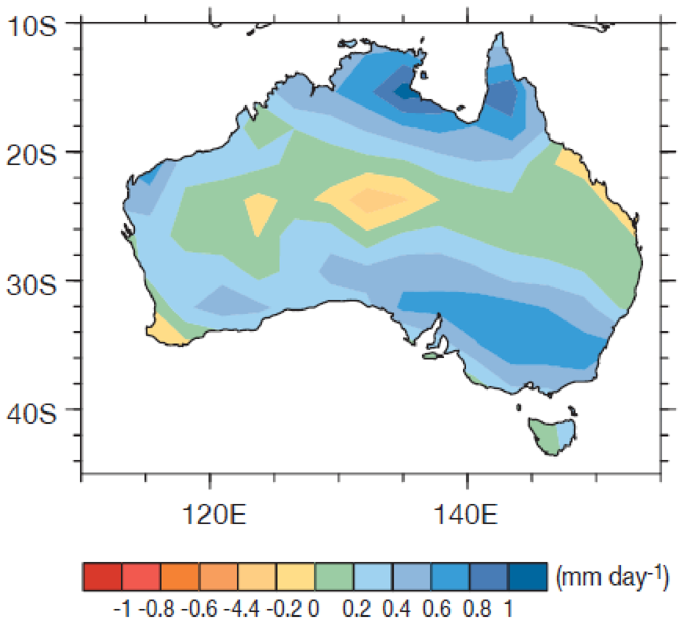


Figure 19. Mean projected changes (2080-2099 minus 1980-1999) in precipitation intensity (mm/day) for the A1B scenario. (After Tebaldi et al. 2006).

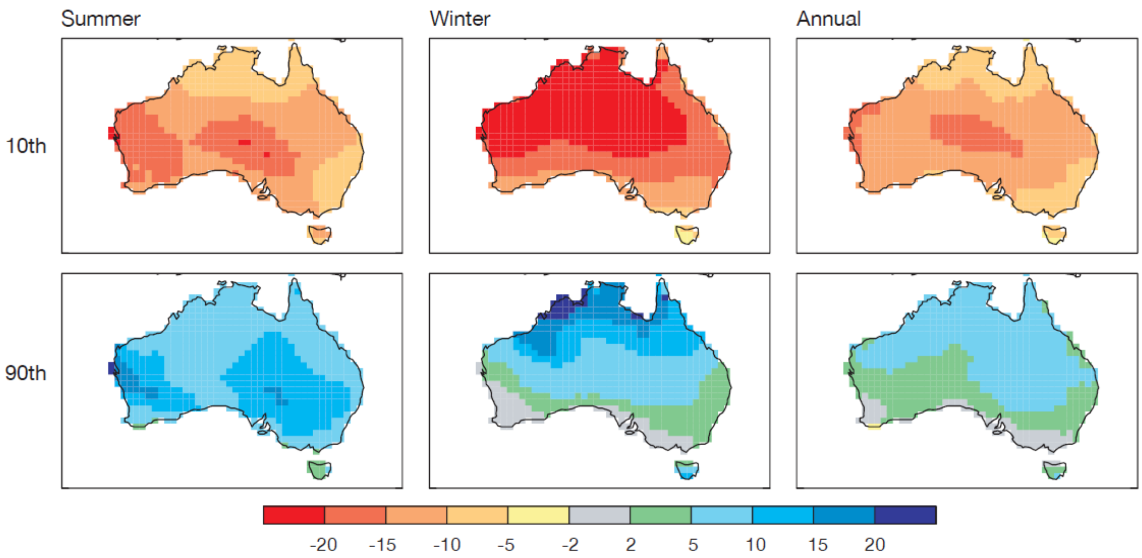


Figure 20. Projected Australian precipitation change (%) by 2030 for scenario A1B from the 10th to 90th percentile value for summer, winter and annual.

**Predicted fish stock changes to 2030**

Population/biomass

*Decreasing*

Across its range, the population is likely to have reduced spawning success. Although all life stages, other than egg and larvae, are likely to adapt to changing conditions, Black Bream populations are most likely going to shrink due to poor recruitment.

There is increasing evidence of hybridisation between Black and Yellowfin Bream along their known mixing area. The consequence of hybridisation for the population is unknown, but it may alter spawning success.

Population variation

*Increasing*

Increased high flow events and prolonged droughts will see longer gaps between strong spawning years. As Black Bream fisheries often rely on a few strong year classes to sustain the fishery, even fewer year classes could make fish stock numbers highly variable.

Egg and larval vulnerability

*Increasing*

As Black Bream eggs and larvae rely on a mixture of salt and freshwater. Years of low flow and high flow seem not to provide large areas of optimum spawning habitat (strong halocline). The reduced spawning habitat trends are expected to continue and subsequently reduce egg and larval survival.

Range

*Decreasing*

In southern NSW Black Bream populations may retreat to Victoria. South Australian, Tasmanian and Victorian Black Bream are likely to maintain their range but may reduce or disappear from some areas.

Preferred habitat

*Decreasing*

Black Bream can survive in pure seawater, but it is not known how long for and they cannot complete their life cycle in it. The increased amount of saltwater in Black Bream habitats as a result of prolonged droughts is going to potentially reduce the amount of preferred habitat available.

Intermittently closed estuaries may also be closed for great periods and create greater areas of low dissolved oxygen water. This will reduce preferred habitat and may also result in a great frequency of fish kills when estuary mouths open.

In some water bodies juvenile Black Bream are reliant on seagrass. Seagrass is expected to reduce in estuaries because of increased extreme flow events.

**Predicted fisher adaption to fish stock changes to 2030**

Fishing pressure

*Increasing*

Population growth and the drying inland waters will put more pressure on estuarine fisheries. If Black Bream numbers reduce to a point where catching them is too difficult then fishing pressure may decrease, but it is unlikely that this will happen before a continued increase in current fishing pressure.

Angler transport and boating requirements

*No Change*

Black Bream fishing access requirements will generally not need much change from current practices.

What gear and technique changes may occur

*No Change*

Black Bream fishing techniques will generally not change other than some subtle normal changes that come from fisher catch innovation.

**Recommended fisher adaption and mitigation to fish stock changes to 2030**

Anglers can have some direct and indirect impacts on Black Bream populations by doing the following:

- Recreational anglers involved in monitoring of the Black Bream stock. For example diary programs used to provide an understanding of the population status in key estuaries.
- To improve the potential of spawning success consider limiting your take home catches during the peak spawning season of Oct-Nov.
- Practice catch and release. Bream have been shown to have high post-release survival rates, especially when shallow-hooked (Grixti et al. 2008)
- Improve the survival of released under-sized fish by using best practice and reducing deep hooking (use larger hooks or lures).
- Support improved land use practice.
- Support better estuary opening and closure policies.
- Advocate for specialised flow regimes aimed at optimising recruitment with water management authorities.
- Develop a harvest strategy for Black Bream that sets limits, targets and decision rules to guide future management.
- Formalise resource sharing arrangements and develop plan based on proportional shares for commercial and recreational fishers.

**Management adaptation**

Management adaptation in this instance is about implementing measures to reduce vulnerability and increase species resilience.

Potential options include:

- Where available, introduce moderate environmental flow levels in early spring that result in salinity. stratification in the estuary.
- Review existing fisheries management controls such as bag limits and size limits to help preserve abundant year classes.
- Consider area closures for spawning aggregations.
- Monitor the stock and recruitment success.

## CASE STUDY OF KING GEORGE WHITING TO 2030

**Species:**

King George Whiting (*Sillaginodes punctatus*)

**Distribution**

King George Whiting (KGW) are native to southern Australian coastal waters and inhabit near-shore shallow waters as well as bays and inlets from Port Jackson (NSW), to northern

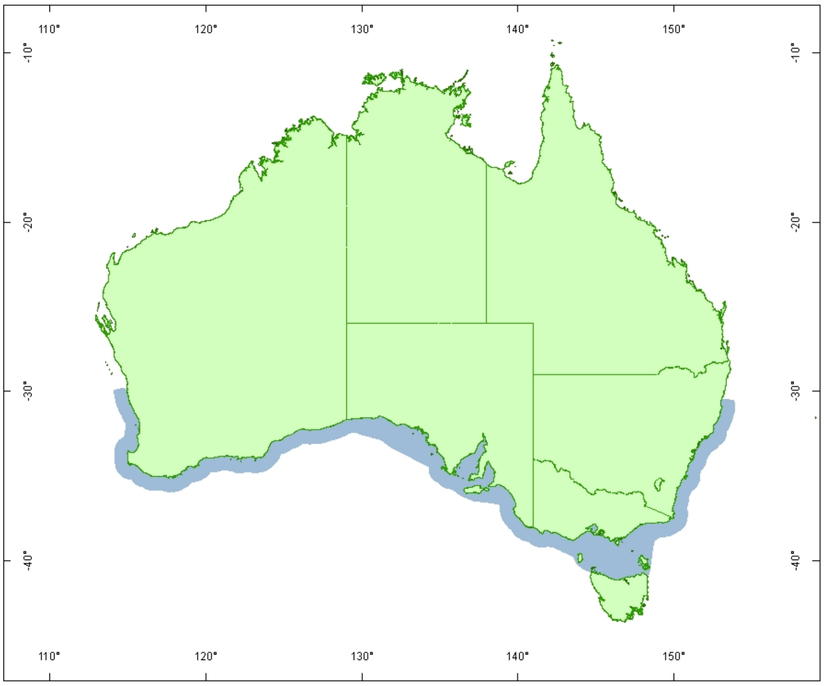


Figure 21. Map detailing the distribution of King George Whiting (Pecl et al, 2011).

Tasmania and Jurien Bay in Western Australia (Figure 21). Juvenile fish are restricted to bays and inlets while adults are found in open coastal waters (Kailola et al. 1993). Seagrass is probably crucial to newly-settled larvae through the provision of food (Jenkins and Hamer 2001) and protection from predators (Hindell 2000). From five to six months, most fish are found on sand amongst vegetated habitats (Jenkins and Wheatley 1998). Older juveniles then move into deeper water over sandy or muddy areas with patchy seagrass. When mature, the fish migrate offshore to join other adult stock in offshore waters (Jones et al. 1990; Coutin

1996; Fowler et al. 2002; Hamer et al. 2004). Spawning adults are associated with exposed, deep water, reef habitats (Fowler and McGarvey 2000).

**Biology**

King George Whiting (Figure 22) live for 15 years and reach sexual maturity at three to five years when fish are 30-35 cm in length (Scott 1954; Jones et al. 1990; Potter et al. 1996; Fowler and McGarvey 2000; Jenkins 2005). It has been suggested that possible cues that may influence the success of maturation include the presence of mature, older fish and some effect of spawning habitat, specifically exposed, deep water, reef habitats (Fowler and McGarvey 2000).

Recruitment of KGW to PPB is related to the strength of westerly winds and the offshore water temperature in the larval stage (Jenkins 2005; Jenkins and King 2006). Settlement of post larvae into shallow sub-tidal beds of *Zostera* and *Heterozostera* spp. seagrass has been shown to occur between July-November each year in SA (Fowler and Short 1996) and in spring in VIC (Jenkins and May 1994; Jenkins et al. 2000). The suitability of seagrass beds is influenced by wave exposure, with exposed beds carrying fewer post larvae than protected ones (Jenkins et al. 1997a).

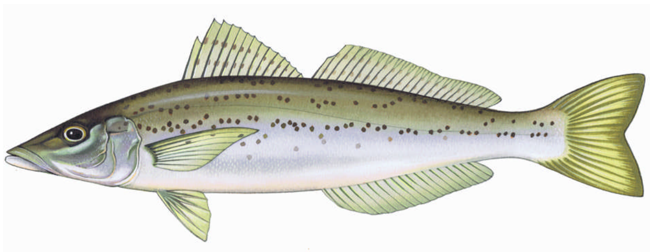

Figure 22. Illustration of a King George Whiting.

**Current fishery**

The main commercial fishery for King George Whiting (KGW) is in SA, from Gulf St Vincent to Ceduna, with smaller fisheries in central VIC and south-western WA, operating from September - November and April – June (Kailola et al. 1993). Fish are caught by seine nets, gillnets, powerhauling and handline, with the majority of fishing effort targetting 2-7 year old fish, with larger individuals caught by hand line (Kailola et al. 1993). In Victoria, it is the highest value commercial finfish species, with commercial catches, for 2010-11, of 173 t / $2.7m for VIC, and 340 t / $5.08m for SA, (ABARE 2012).

A popular species for recreational fishers, recreational angler catches account for large percentages of the fishery, e.g., the current Victorian catch of about 400 t is evenly divided between commercial and recreational sectors (DPI 2008). Corner Inlet and Port Phillip Bay (PPB) are the major commercial fishing areas, while PPB and Western Port dominate the recreational catch. Recreational anglers target immature fish, with an estimated total catch in 2000/01 of 3,621,629 individuals caught nationally, with ~26% of these released/discarded (Henry and Lyle 2003). Approximate numbers caught per year for each state were 975,349 in VIC, 2,238,071 in SA and 408,209 in WA (Henry and Lyle 2003). In 2007/08, SA residents caught a total of 1,797,148 throughout SA, with 30.5% of these released as mainly undersized fish (Jones 2009). The harvested (retained) weight was estimated at 324.4 tonnes, live wt. Relatively high total catches occurred in Spencer Gulf, Gulf St. Vincent / Kangaroo Island and west coast waters, and low catches were taken from the SE (Jones 2009).

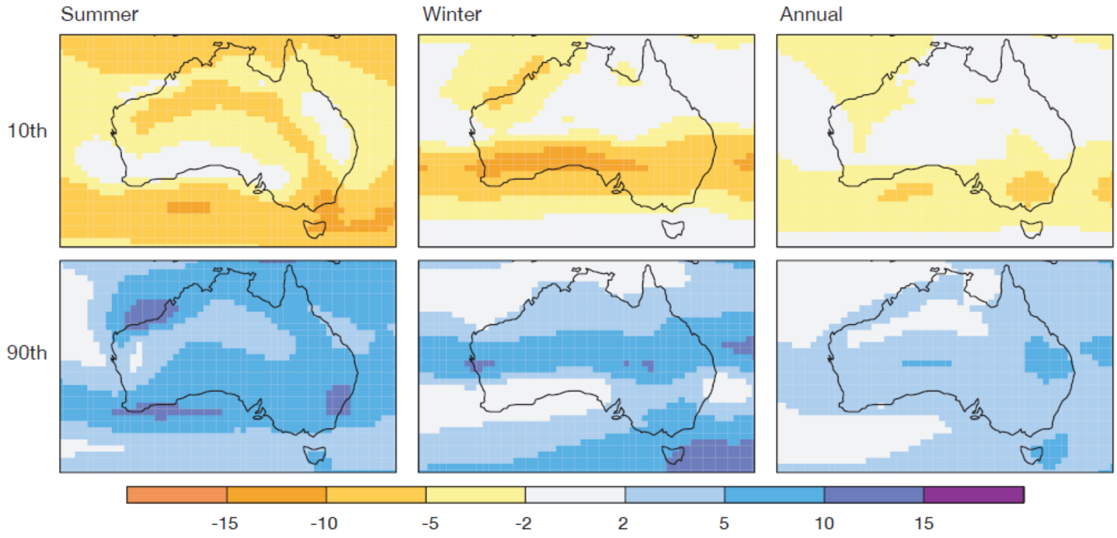


Figure 23. Projections of the estimate of net percent change to mean 10 m wind speed by 2030 for scenario A1B from the 10th and 90th percentile values for summer, winter and annual (CSIRO, 2007).

**Climate change biophysical predictions for South East Australia relevant to King George Whiting**

Storminess and water temperature are known to the influence the extent and health of seagrass beds (Short and Neckles 1999). The south eastern region of Australia is predicted to experience more intense higher velocity wind speeds during summer (CSIRO 2007) (Figure 23). High energy wind storm events increase wave action in intertidal environments and increase the likelihood of seagrass disturbance (e.g. smothered by sediment and physical dislodgement). Seagrass species are tolerant to a specific temperatures range which influences where species exist (e.g. tropical and sub-tropical). The south eastern region of Australia is also predicted to experience warmer air and water temperatures, especially during summer (Figure 24 and 25). If temperatures increase beyond the tolerance of the seagrass the beds may contract.

Seagrass beds are often associated with specific water depths, which are often dependent on the amount of light available for photosynthesis. Global sea level rise is projected by the IPCC to be 18-59 cm by 2100. Global climate models indicate that mean sea level rise on the east coast of Australia may be greater than the global mean sea level rise (CSIRO, 2007).

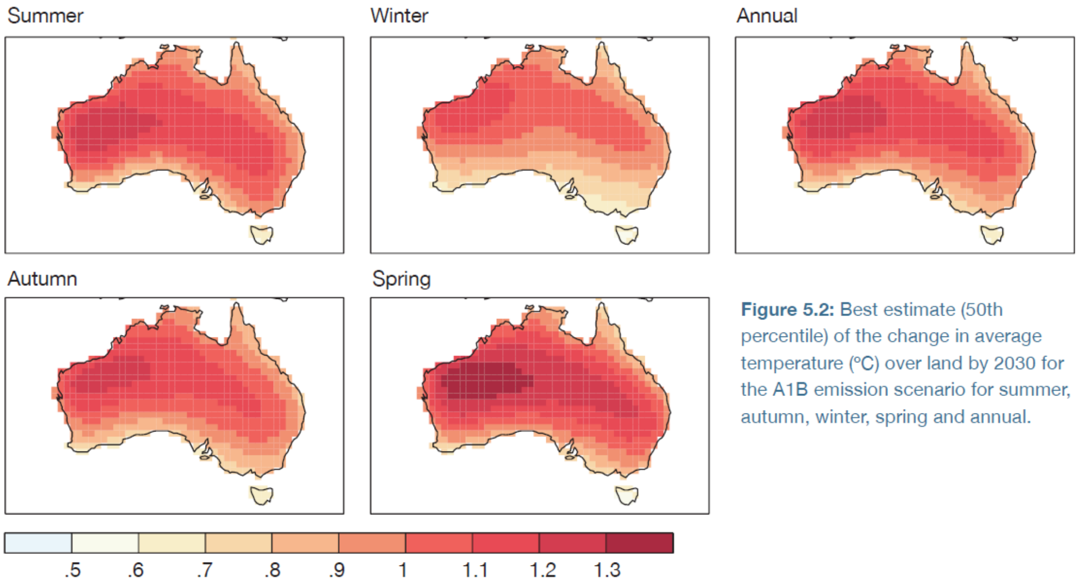


Figure 24. Best estimate (50[th] percentile) of the change in average temperature (ºC) over land by 2030 for the A1B emission scenario for summer, autumn, winter, spring and annual (CSIRO, 2007)

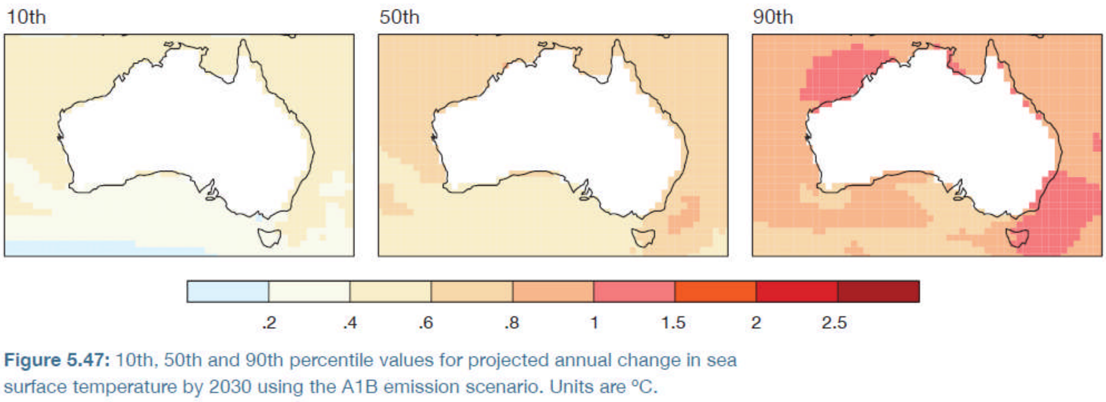


Figure 25. 10th, 50th and 90th percentile values for projected annual change in sea surface temperature by 2030 using the A1B emission scenario. Units are ºC.

**Predicted fish stock changes to 2030**

Population/biomass

*Uncertain, possible decrease*

There is limited information about what will happen to the westerly currents that are believed to distribute eggs and larvae across south eastern Australia. While warmer water may increase the survival of larvae this may be offset by reduced seagrass and currents for dispersal.

Population variation

*Uncertain, possible increase*

The South Australian and eastern Victorian stocks are likely to continue their current population trends while central and western Victoria stocks may become increasingly variable with changes expected to westerly winds and currents that could reduce larvae distribution.

Egg and larval vulnerability

*Decreased*

There is evidence that the increasing water temperature in south eastern Australia will actually increase egg and larvae survival. As long as there is sufficient current strength for dispersal, vulnerability of larvae may decrease.

Range

This species may move further south, retracting along southern NSW and appearing in greater number in Tasmania, where it is already becoming a more frequent visitor. If conditions suit, KGW may establish themselves as a key species for northern Tasmanian fishers.

The South Australian Gulfs may warm to such a point that KGW reduce their use of these sheltered waters, especially if seagrass is reducing at the same time.

Supporting preferred habitat

For coastal and sheltered waters, seagrass is expected to decrease with increased extreme flows and storms. Increased turbidity as well as the physical damage from these events provides a real challenge for this habitat type. Without quality seagrass habitats KGW will decrease in number and range.

**Predicted fisher adaption to fish stock changes to 2030**

Fishing pressure

*Increasing*

KGW is a prized table fish and fishing pressure will increase with increasing human population size (especially around sheltered bays and inlets) and reduced inland fishing opportunities during prolonged droughts.

Tasmania is likely to have a new KGW fishery emerge if the population there increases to such numbers that the species can be predictably exploited. Flathead fishers would possibly switch some effort to KGW.

Angler transport and boating requirements

*No Change*

KGW fishing access requirements will generally not need much change from current practices.

What gear and technique changes may occur

*No Change*

KGW fishing techniques will generally not change other than some subtle normal changes that come from fisher catch innovation.

**Recommended fisher adaption and mitigation to fish stock changes to 2030**

Recreational fishers should consider:

- Keeping abreast of the current bag and size limits.
- Supporting stock monitoring like an angler diary program to assess spawning success and spawning areas.
- Support and monitor seagrass preservation and rehabilitation.
- Understand and contribute to reducing marine pests in KGW habitats.

**Management adaptation**

Management adaptation in this instance is about identifying and where possible implementing measures to reduce habitat loss.

Potential options include:

- Understand current seagrass areas and reliance by KGW on them.
- Identification and protection of key seagrass beds for juvenile KGW. Advocate to agencies that are involved in catchment management to help protect seagrass beds in key nursery regions.
- Review existing fisheries management controls such as bag limits and size limits to help share the catch between recreational and commercial fishers.
- Gain a better understanding of the westerly currents and spawning mechanisms for south eastern Australia, allowing more accurate predictions of larval supply to bays under climate change.
- Develop a joint Victorian/South Australian harvest strategy for King George Whiting that sets limits, targets and decision rules to guide future management.
- Formalise resource sharing arrangements and develop plan based on proportional shares for commercial and recreational fishers.

## CASE STUDY OF MAHI MAHI TO 2030

**Species:**

Mahi Mahi (*Coryphaena hippurus*)

**Distribution**

Mahi Mahi are a tropical oceanic species found in the Atlantic, Indian and Pacific oceans. In Australian waters they are generally found from Western Australia around to Montague Island in New South Wales. Studies have found the species is limited in habitat by sea surface temperatures of 19-20 Celsius.

**Biology**

Mahi Mahi are fast growing fish, reaching weights of 1 kg within 6 months and 10kg after 1 year (Figure 26). The species has a short life span, generally between 2-4 years. They have maximum weight of 25kg and maximum size of 2m in length. The species is highly fecund, producing up to 1.5 million eggs per female and are known to spawn frequently once mature.

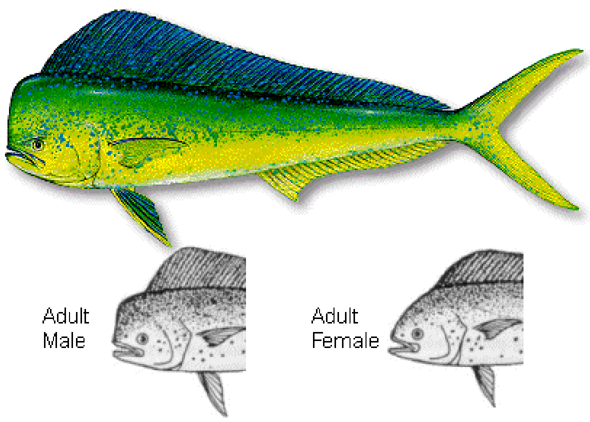


Figure 26. Distinguishing features of male and female Mahi Mahi

The fish predates upon larval or small juvenile fish and invertebrates, which are often associated with drifting clumps of algal and other flotsam. Mahi Mahi are also preyed upon by large tuna, sharks, marlin and swordfish.

**Current fishery**

Although a highly valued eating fish, the commercial fishery for Mahi Mahi in tropical Australian waters is relatively small. The catch by recreational and charter fishers is likely to exceed the commercial harvest. Catches tend to peak in the summer and autumn period due to their strong association with increased water temperatures. There is no reported commercial catches for this species in Victoria or Tasmania.

In December 2010, a recreational fisher caught a Mahi Mahi off Barwon Heads near the Port Phillip Bay heads whilst targeting Yellowtail Kingfish. The catch was of significant interest to the local fishing media and recreational fishers using social networking media. Of similar note, last summer anglers reported catches of Spanish Mackerel outside of Sydney Harbour and Wahoo as far south as Green Cape, south of Eden.

**Climate change biophysical predictions for South East Australia relevant to Mahi Mahi**

The East Australian Current (EAC) is the western boundary current of the wind-driven South Pacific subtropical gyre, and the mechanism by which warm salty water flows from low latitudes. The EAC is predicted to continue to increase in the number and penetration southward of eddies. This wil be coupled with overall sea surface temperatures . Since 1950, the southward flow has strengthened and warmer, saltier water is now found 350km further south (Figure 27).

The marine waters of South East of Australia are recognised internationally as a climate change hotspot. The South East is expected to be the area of the greatest and most rapid warming (>2.5 degrees Celsius by 2100).

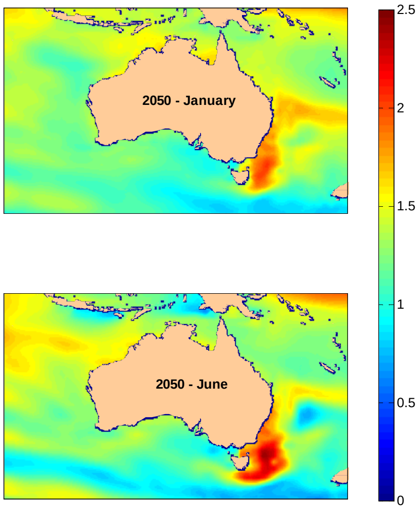


Figure 27. Predicted warming of South East Australian waters in January/June 2050 Source: Dr Alistair Hobday, CSIRO Hobart.

**Predicted fish stock changes to 2030**

Population/biomass

*Increasing*

The population of Mahi Mahi is likely to increase on eastern Victoria and Tasmania due to the increasing strength of the EAC and shortened cold water period over winter. Western Victoria and Eastern South Australian water temperature predictions are too uncertain to predict what the population of Mahi Mahi will do in those areas, but if anything it is likely to increase.

Population variation

*Decreasing*

As the EAC strengthens and provides regular warmer temperatures further south the occurrence of Mahi Mahi will also become more regular. Mahi Mahi may also become resident in South East Australia (Southern NSW, Eastern Victorian).

Egg and larval vulnerability

*No changes are predicted. This might reflect lack of information at this time.*

Currently the eggs and larvae for this species are found predominantly in the northern extent of the species range.

Range

*Increasing*

As the EAC continues to strengthen, the species is expected to undergo a range expansion further south into southern NSW, eastern and central Victorian waters, as well as northern and eastern Tasmania. The species has been observed infrequently in these locations over the years, however, under future climate change scenarios it is likely that the species inhabit these southern regions for a longer period of time and in higher numbers, thereby creating new offshore fishing opportunities.

Preferred habitat

*Increasing*

Water temperature increases in the south east will provide more preferred habitat for this species. The occurrence of typical prey items may change and influence the quality of these new warmer habitats

**Predicted fisher adaption to fish stock changes to 2030**

Fishing pressure

*Increasing*

South Eastern Australia (excluding NSW) does not have a strong game fishing background. If the population of Mahi Mahi can be exploited close to access points and major human populations then their will be considerable fishing effort directed at the species. They are a strong fighting fish with excellent table qualities.

Given their biology, Mahi Mahi are regarded as being resilient to fishing pressure.

Angler transport and boating requirements

*Changing*

Mahi Mahi are generally found offshore in deeper waters. While many south eastern Australian Fishers do already have suitable vessels the large majority would need to upgrade to safely target the species.

In the example of the recently emerged southern blue-fin tuna fishery; fishers have invested in larger boats, or they have taken smaller boats where they were never intended to go, or they have utilised the services of charter operators. This trend is likely to unfold for Mahi Mahi.

What gear and technique changes may occur
*Changing*
Most non-game fishers will need heavier fishing tackle to effectively catch Mahi Mahi. The south east has seen increased catches in the Southern Bluefin Tuna, Gummy Shark and Yellowtail Kingfish fisheries that will have already led to south east fishers having some appropriate gear, however, they will still need specialised terminal tackle and fishing techniques to target Mahi Mahi.

Importantly Mahi Mahi are attracted to fish aggregation devices (FADs) and these devices require a change in how fishers interact with fish and other fishers.

**Recommended fisher adaption and mitigation to fish stock changes to 2030**
South eastern fishers will not need to make any major changes to protect the stock in the foreseeable future. The managing agencies will need to monitor total catch and fishers should keep to the rules and exercise sustainable fishing practices to ensure the fishery flourishes as environmental conditions allow.

The south east will need to manage its increasing exposure to game fishing opportunities. The level of respect and care for fellow fishers needs to be high on the open ocean as an incident can be harmful to both human life and the sport.

Fishers also need to advocate for better access to fishing locations where fish numbers are expected to increase and fishing related infrastructure (i.e-boat ramps, marinas, car parking, roads etc) is limited.

**Management adaptation**
Management adaptation in this instance is about capitalising on improved fishing opportunities in parts of the south east, rather than implementing measures to reduce vulnerability and increase species resilience.

Potential options include:
- Review existing fisheries management controls such as bag limits and size limits to help share the catch between recreational and charter fishers.
- As the species is highly mobile and has viable breeding populations further north the first step is to manage the fishery as a temporary population.
- Manage the fishery in places such as southern NSW (Green Cape) and far eastern Victoria (Mallacoota) as a ‘gauntlet’ fishery, recognising that the fishery will be highly seasonal as fish traverse open coastal waters.
- Develop a harvest strategy for Mahi Mahi that sets limits, targets and decision rules to guide future management.
- Formalise a resource sharing arrangements plan based on proportional shares for commercial and recreational fishers.

The use of FADs should be considered as a potential management adaptation option to enhance and improve future fishing opportunities. FADs have the potential to provide habitat and ‘hold’ fish in fishable locations for longer periods of time. This needs to be considered in tandem with the adequacy of current recreational fisheries management controls such as catch and size limits.

Although not a fisheries management issue per se, consideration of the adequacy of ocean boat launching facilities and access points in eastern Victoria and Tasmania is expected to become a growing issue if recreational and charter fishing development opportunities are to be fully realised.

In addition to the above, managers may consider the following fisheries research requirements:

- If recreational anglers should report catches of new and unusual pelagic species (location, month) using community based 'citizen science' tools such as Redmap (www.redmap.org.au)
- Whether to introduce cost effective fishery dependent monitoring such as game fishing angler diary programs and voluntary charter logbooks for relevant locations.
- Whether to introduce joint recreational fisher and researcher tagging programs for Mahi Mahi and other climate change range extenders.

## CASE STUDY OF YELLOWTAIL KINGFISH TO 2030

### Species

Yellowtail Kingfish (*Seriola lalandi*)

As part of a regional risk assessment Gibbs and Jones (2011) completed a review of Yellowtail Kingfish ecology. Key finding from this review provide the basis for this summary.

### Distribution

In Australian waters Yellowtail Kingfish are distributed from southern Queensland to central WA, including the east coast of Tasmania, and around Lord Howe and Norfolk islands (Figure 28). They often live in nearshore water and are commonly found near reef structure.

A limited tagging program in SA waters has been carried out since the early 1990s (Hutson et al. 2007), which suggests only localised movements, up to 150 km distant from the tagging sites, especially in the upper Spencer Gulf region. Micro-chemical analysis of otoliths of fish from this region also initially suggested a separate stock in this part of SA; however, the effect of strong environmental factors (i.e. high water temperatures and salinities), may confound this inference. The recent 2007–08 recreational fishing survey (Jones 2009) suggested some capture of fish during the rest of the year in this area, suggesting that some of the fish may remain in upper Spencer Gulf for the whole year (Jones, unpublished results). The seasonality of movements in Spencer Gulf may also be confounded by the presence of escaped Kingfish from sea cages located in western waters of Spencer Gulf (Fowler et al. 2002; Gillanders and Joyce 2005).

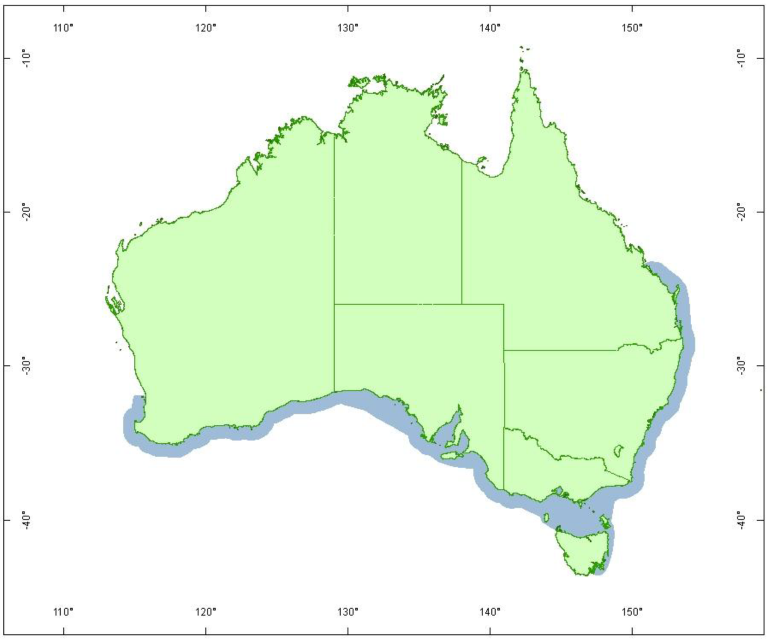


Figure 28. Map detailing the distribution of Yellowtail Kingfish (Gibbs & Jones, 2011).

The results of these tagging experiments differ markedly from those found from Kingfish tagged off the east coast of Australia, which show substantial movements; however, importantly, no fish tagged off the east coast were recaptured in SA waters, suggesting separate populations. This observation may have been a function of relatively light fishing effort for this species in this state, compared with the rest of SE Australia.

**Biology**

In NSW Yellowtail Kingfish (Figure 29) are prey for a number of shark species and occasionally marine mammals especially dolphins and seals. Kingfish are opportunistic daytime feeders with fish, squid and crustaceans forming a large part of their diet. In upper Spencer Gulf, they are known to feed on King George Whiting, Garfish, Western King Prawns and Trevally. In northern Spencer Gulf, the escaped Kingfish were not experienced feeders, and were found to consume only small remnants of vertebrate and invertebrate material, but also fed on plant material, which is not consistent with their known carnivorous diet (Fowler et al. 2003). The larger more offshore fish fed on small pelagic species, including Redbait, Australian Herring and Krill (Euphasiids) (Fowler et al. 2003).

Figure 29. Illustration of a Yellowtail Kingfish

**Current fishery**

Yellowtail Kingfish is an important commercial and recreational species. In New South Wales (NSW) the Ocean Trap and Line Fishery contributes about 99% of the total catch in the commercial sector. Historically, in South Australia (SA), Yellowtail Kingfish had been caught commercially for many years by beach seine and later, modified hauling nets in inshore waters of the SA gulfs. Schools of Kingfish were beach seined along the beaches south of Adelaide in Gulf St Vincent during the 1940s and 1950s, with landings of up to 800 kg occurring. The annual recreational harvest of Yellowtail Kingfish in NSW is likely to lie between 120 and 340 t. Since September, 2005 a licence-managed charter boat fishery, with up to 106 licences, has operated for SA, interstate or overseas clients to catch (retain or release) a number of species, including Yellowtail Kingfish. In the last two years, 11–12 licence holders reported they had harvested this species. Retained catches are reported in numbers of fish, and the annual numbers are very low relative to all other species retained in this fishery.

For many years, Yellowtail Kingfish has been a popular species taken by sport fishers in the upper reaches of the SA gulfs, as well as SA offshore waters, sometimes for human consumption, but often for catch and release fishing. Estimates of the recreational catches of Yellowtail Kingfish by SA residents are available from large statewide recreational fishing surveys for two years (2000–01 and 2007–08; Jones 2009); however, for both years, the levels of precision around the estimates for Yellowtail Kingfish are poor (+/-95% confidence limits > than the estimates). The recreational fishery for Yellowtail Kingfish can therefore be described as a 'rare event' one, in comparison with the recreational fisheries for key species, such as King George Whiting etc. An estimated approximate total catch of 9000 (+ 10,000) and 5000 (+ 4,500) Yellowtail Kingfish were caught in SA in 2000–01 and 2007–08, respectively (Jones 2009). Of these, 20–25% were released as part of catch and release fishing, and the harvested (retained) catch amounted to between 90 and 100 tonnes, live weight.

There is a small commercial fishery for Kingfish in Tasmania and Victoria. Recreational fishing for the species appears to be more common in Victoria and Tasmania, with larger fish (i.e-15kg plus) more frequently encountered in Victoria. The Tasmanian fishery is primarily along the east coast. A small number of charter boats are also running dedicated offshore trips in Victoria and having success with regular captures of large Kingfish.

**Climate change biophysical predictions for South East Australia relevant to Yellowtail Kingfish**

The East Australian Current (EAC) (Figure 30) is the western boundary current of the wind-driven South Pacific subtropical gyre, and the mechanism by which warm salty water flows from low latitudes. Since 1950, the southward flow has strengthened and warmer, saltier water is now found 350km further south (Figure 31). The EAC is predicted to continue to increase by a further 20% by 2100.

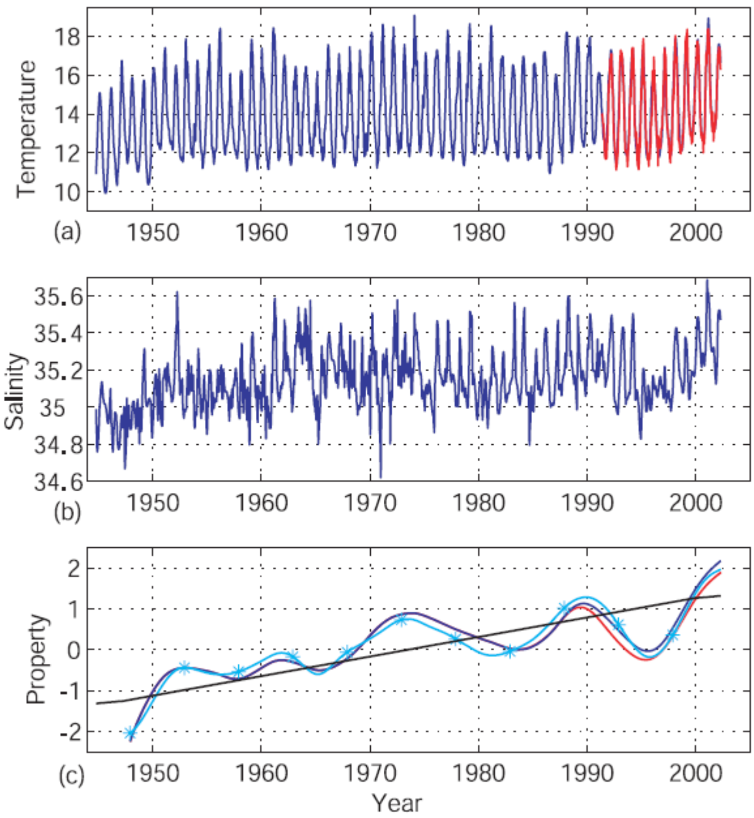


Figure 30. Historical EAC driven temperature, salinity and flow changes Source: Dr Alistair Hobday, CSIRO Hobart.

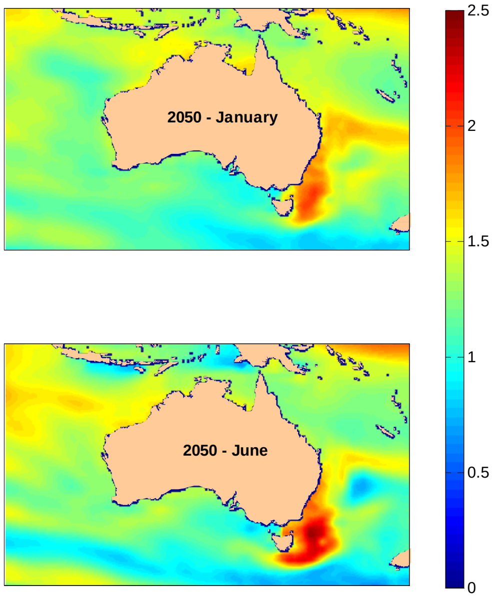


Figure 31. Predicted warming of South East Australian waters in January/June 2050 Source: Dr Alistair Hobday, CSIRO Hobart.

The marine waters of south eastern Australia are recognised as a climate change hotspot. The South East is expected to be the area of the greatest and most rapid warming in Australia (>2.5 degrees Celsius by 2100).

**Predicted fish stock changes to 2030**

Population/biomass

*Increasing*

The population of Yellowtail Kingfish has been increasing over the past few years. While Kingfish are not necessarily turning up in new locations they are turning up in greater numbers. Because Kingfish prefer the south east summer water temperatures they are likely to spend more time, more often in the south east and this increased habitat availability may lead to continued population growth.

There have been restrictions on the commercial harvest of Kingfish which may also be affecting the population numbers.

Population variation

*Decreasing*

The warmer water and increasing Kingfish population size will more than likely improve the frequency and reduce catch variation of Kingfish in the south east of Australia.

Egg and larval vulnerability

*Uncertain*

It is unsure what the changing environment will do for eggs and larvae.

Range

*Increasing*

While range expansion into southern and western Tasmania is possible, Kingfish has historically been recorded across much of the south east Australia. Over the past decades Kingfish range had anecdotally decreased, possibly due to high fishing pressure in NSW, while in the last few years they have begun returning to formally inhabited areas.

Preferred habitat

*Increasing*

Areas of south east Australia that provide suitable habitat for Kingfish during the summer will remain the same, however, the water will reach and maintain a preferred temperature for a longer period in these areas. This will mean that that Kingfish could spend a greater length of time in the south east as a result of increasing habitat (water temperature).

**Predicted fisher adaption to fish stock changes to 2030**

Fishing pressure

*Increasing*

Kingfish are already regarded among the top sport fish in Victoria, but have always been regarded as difficult to encounter and catch. As the Kingfish population increases, they will become easier to catch. This is the case in NSW where larger numbers of Kingfish are commonly found.

South East fishers will undoubtedly respond to this increase, especially if the stocks once again become plentiful close to large human populations (in particular Melbourne).

Angler transport and boating requirements
*No Change*
Inshore coastal fishing is already very common in Victoria and there is not likely to be a major change in boat or transport requirements. Charter operators will add this species to their catches if fish numbers allow them to be caught regularly.

What gear and technique changes may occur
*Changing*
Kingfish are a versatile fish that is encountered and caught in a range of situations. Fishers will need to invest in a variety of tackle and learn new behaviours to effectively target kingfish. Kingfish are commonly caught live baiting, dead baiting, trawling, jigging, casting, on fly and by spear. Quality depth sounders and GPS systems are important for this species.

**Recommended fisher adaption and mitigation to fish stock changes to 2030**
The likely management issues for recreational arising from climate change are essentially synonymous with normal recreational input to fisheries management viz::

- Follow size and catch limits and advocate for strict management controls, as this species is vulnerable to overfishing
- Provide monitoring data to researchers to help understand the south east Kingfish population.
- Use best practice catch and release methods, especially when large numbers of juvenile fish are located.
- Introduce codes of conduct and educate how to share the fishing experience between rod and line fishers and spear fishers.
- Ensure fishing ramps are suitable to allow access to the emerging fishery.

**Management adaptation**

There may be a resource sharing issue that arises in the south eastern Australia, and in particular Victoria. Kingfish may become the target of increased commercial fishing and if so, management authorities should be proactive to manage each sector under a resource sharing framework.

Management agencies may need to consider:

- Recreational fishing havens in known kingfish aggregation areas.
- Formalise resource sharing arrangements based on proportional shares for commercial and recreational fishers before kingfish become a larger proportion of each sectors catch.
- Develop a harvest strategy for Kingfish that sets limits, targets and decision rules to guide future management.
- Monitor the population in the south east.
- Enhance existing fishing opportunities using artificial reefs and FADs.

## 11. SOUTH WEST REGION SPECIES ASSESSMENT

There are many climatic variables which have, and will, cumulatively impact on marine life in Western Australian waters. The relationship, and subsequent potential impact, of the various changes on some key recreational species is not clearly understood and this section intends to assess the likely consequences of change on selected key recreational species in the south west.

**Key environmental issues and trends**

Changes to the frequency and strength of the Leeuwin Current (LC) over time (Feng *et al*. 2004) has shown an increasing number of ENSO events with a corresponding weak LC or El Nino event (Caputti *et al*. 2010). This in turn has already produced subsequent reduction in the number of La Nina events, which manifests itself along the West Australian coastline as more infrequent, but a much stronger and warmer LC.

It is possible that increasing number of El Nino events is the result of the combined effect of global warming and natural variability in the climate system. These events, combined with higher than normal ambient air temperatures, were followed by an unprecedented La Nina event marine heatwave event in 2011, which occurred after almost a decade of El Nino events. In the shallows around the Abrolhos Islands temperature loggers showed water temperatures 3 - 4 º C higher than normal, and fish mortalities in shallow areas occurred across a range of species including the recreationally important Baldchin Groper *Choerodon rubescens* (Pearce *et al*. 2011). Along the mainland coastline inshore embayments from Shark Bay south to Lancelin experienced extensive fish kills, primarily of inshore slow moving resident species (FMP 247 2010). Extensive Roe's Abalone mortalities occurred from Shark Bay down to Moore River which resulted in both the commercial and recreational Abalone fishery being closed.

A gradual warming of 0.02 º C along the West Australian coast has been recorded since the 1950's (Pearce *et al*. 2007). However, of most concern is the increasing rate at which sea temperatures are rising. CSIRO MK3.5 modelling projects that sea surface temperatures off the Western Australian coast are likely to rise by 0.7 – 1.1 º C by the 2030's. Further unpublished work (Feng *pers coms*) suggests a sea surface temperature increase of one degree Celsius will move approximately 100kms southwards.

The spawning activities of many marine sp. often occur in a narrow temperature band and are linked to key habitats. Water temperatures can also trigger gonadal recrudescence (Wakefield 2010) and also determine the sex of some species. The environment in which spawning has occurred can also effect larval growth rates in that there are optimum temperatures for growth and the availability of food supply at critical growth phases. The cumulative impact of temperature variations, which will occur with climate change across a range of key species, are largely unknown.

Storm and rainfall frequency is predicted to also vary with climate change. The positive effects of increased rainfall is likely to be improved flushing of south-west river systems. Recruitment benefits in some closed systems could be offset by poor management of the sand bars which close the river bars and restrict migration patterns. However, history has also shown that the increased farmland run-off can, and does, trigger damaging algal blooms that impact on recruitment of some sp. which spend part of their life cycle in estuarine environments. It is therefore difficult to assess the cumulative impact of these variables over time.

Some of the lesser known potential aquatic impacts of climate change relate to increasing salinity and acidification, which may impact on some species particularly at larval and post larval stages. However, as salinity variations in the open ocean are likely to be comparatively small, they are unlikely to directly affect the abundance or distribution of most marine fish species (Caputti *et al*. 2010). However, the potential impacts of increasing salinity and acidification in shallow waters remains unknown.

The changing aquatic environment may also present opportunities for a range of parasites and diseases to establish or increase.

Identifying the consequences across recreational fisheries of all of these variables is difficult to predict with any accuracy and will present a range of new fisheries management challenges. Inevitably some species will be able to adapt quicker than others and appreciable shifts in stock composition could occur. Prey and predator relationships will change as environmental impacts and opportunities shift.

Ultimately some of the impacts of climate change will not be identified early enough for fisheries managers to respond soon enough to fully negate their impact. It is therefore important to use the best available information to anticipate environmental trends and potential management changes that will be required. Climate change will inevitably benefit some species and pose serious threats for others.

**(a) Identification of species for assessment**

In discussions with Recfishwest six of the most popular recreational sp. were identified which are targeted by various fishing groups. In identifying key species for this study two popular recreational species that were considered initially were not included. The first was Black Bream, which was excluded because the majority of river systems in the South-West of Western Australia are already degraded to various extent as a result of poor land management to the point where Bream stocks in some systems are in a parlous state. The second is rock lobster, which was also excluded. Although the fishery has recently seen its fishery TAC halved, following low levels of recruitment, the recreational catch of early season inshore whites remains consistent and this only represents five percent of the TAC plus other research is being undertaken on this species.

In relation to selecting species for this study;

(i) Similar methodology to that set out in Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia (Pecl *et al*. 2010) has been used to identify and develop an initial list of six recreationally important Western Australian species.

(ii) Following discussion with Recfishwest staff and recreational fishers a list of important recreational species was compiled.

(iii)A broad data richness indicator for each species under consideration is included and is based upon a review of the scientific literature currently available for each species. This was undertaken to establish what knowledge was available in relation to biology, habitat and likely responses to environmental perturbations.

**(b) Identification of the spatial zones within which to compare the likely climate change projections with environmental attributes for the target species.**

Following discussion with WA Department of Fisheries researchers and Recfishwest the main recreational catch areas for the selected species have been determined and assessed against climate change induced environmental changes which are likely to occur..

**(c) Case studies into the changes likely to occur in the identified recreational species out to 2030.**

Likely perturbations for the species identified in this study have been summarised in Table 4.

**<u>WEST AUSTRALIAN DHUFISH</u>** [referenced with Dr A Hesp]

**Species:**

West Australian Dhufish *(Glaucosoma herbraicum)*

**Distribution:**

Dhufish are endemic to Western Australia and range from the Recherche Archipelago off Esperance up to Shark Bay but are most common between Cape Naturalist and the Abrolhos Islands. At 0+ *G. hebraicum* at lengths ranging from 57 to 81mm have been taken by trawling over hard substrates (Hesp et al. 2002) and more recently have also been identified over inshore Abalone artificial reefs in the south-west of the State (Adams B, Lewis P *pers comm* 2010). After one year the fish are approximately 105mm and at 130mm plus they move away from the hard substrate habitat. At 150 – 300mm they are mostly found over low lying reefs up to 30cm in height which contain rock ledges. By contrast Dhufish over 30cm are mostly found over areas of substantial reef structure and corals. Mature Dhufish spend much of their lives in depths ranging from 10m out to greater than 150m where they ultimately spawn.

**Biology:**

Dhufish can live for over forty years and reach sexual maturity at 3 – 4 years at lengths of 30 – 32cm (Hesp et al. 2002). Spawning takes place from December to March in the vicinity of reef and coral structures.

Dhufish eggs and larvae are pelagic and recent research has shown that although this results in some local recruitment of Dhufish on a broad scale gene flow between the management zones was extensive, and the entire fishery represents a single genetic stock (Berry *et al.* 2012).

Little is known about larval distribution and settlement of Dhufish, but given the pelagic nature of their eggs both the Capes and Leeuwin Currents could provide some longitudinal distribution. An additional driver of settlement could be the strong south-west sea breezes that occur around spawning time which would drive the eggs and larvae inshore to reefs and seagrass meadows, although these onshore winds tend to occur when the LC is flowing at its strongest.

**Current recreational fishery:**

The WA State of the Fisheries data for 2010 estimates the recreational catch of Dhufish at 95 tonnes in the West Coast Region of the fishery, which extends from just south of Augusta to Kalbarri (FMP 247, p 47). The commercial catch in 2010 was 60 tonnes. Dhufish are targeted throughout their area of distribution with anglers travelling long distances at sea to find the bigger fish. Dhufish are the most targeted, and by inference the most valuable, demersal species for the recreational sector in this region. Although the minimum size limit permits spawning to occur prior to the sp. becoming available in the fishery, release survival remains a problem as a result of barotrauma. The recent mandatory use of release weights has shown to reduce barotrauma mortality, but the extent of the reduction remains unclear. Since then both sectors have seen access arrangements change to reduce the mortality in the fishery by 50% following recommendations by the WA Department of Fisheries. This mortality target after the first year of assessment is being met based upon current recreational creel surveys being conducted by the WA Department of Fisheries.

The current minimum size limit for Dhufish is 50cm TL.

**Climate change biophysical predictions for Western Australia relevant to Dhufish:**

Previously unprecedented increases in water temperatures were observed throughout the northern distribution of Dhufish during March 2011 (Pearce *et al.* 2011). The primary cause of this event was a particularly strong “La Nina” event which coincided with a period of very light winds that allowed inshore shallow embayment temperatures to increase by up to 5 º C. It is possible that such events will become more frequent as part of climate changes although it is not known what the future frequency is likely to be.

Given that Dhufish spawn throughout summer and into March, eggs and larvae of this species could be vulnerable in some way to any increases in the frequency of these inshore high water temperature events.

It has been found that recruitment indices for Dhufish are highly correlated with salinity in the period November to June each year, although the actual mechanism and the impact for this link remains unclear (Lenanton *et al*. 2009).

Wind data is showing a significant positive trend, which could have a positive effect on Dhufish recruitment (Lenanton *et al*. 2009). A model of likely changes in demersal fish communities in response to temperature changes, using the alongshore temperature gradient, is currently being developed (Langlois *et al.* in prep).

**Predicted fish stock changes**

Given that growth for this species is similar throughout its range and that spawning, and the majority of its life cycle is in water deeper than 10m, no significant change in population size is predicted as a result of climate change although increasing ambient water temperatures may influence growth patterns (and thus biomass), which may have an effect on stock size available to be exploited. Increasing water temperatures may also influence trophic interactions, i.e. change the availability of preferred food sources and relationships among different trophic levels. It may also influence the timing of the spawning period, either the months in which it occurs or the length/extent of the period itself.

It cannot be assumed that the distribution range of Dhufish will move southwards over time and this species shows a distinct preference for limestone reef substrates which diminish at the southern extremity of its current range and is replaced by granite.

Although no dramatic variation in the range and population dynamics of Dhufish can therefore be predicted from the information currently available concerns remain at multiple levels. The impacts of variations in temperature, salinity, pH and prey availability that may occur with climate change and associated events is unknown.

**BALDCHIN GROPER** [Referenced with Dr D Fairclough]

**Species:**

Baldchin Groper *(Choerodon rubescens)*

**Distribution:**

Ranging from Geographe Bay in the south to Coral Bay in the north, Baldchin Groper are endemic to Western Australia. The main recreational fishing effort and catches of Baldchin are made at the Abrolhos Islands and Shark Bay. Baldchin are found in numbers in areas of shallow coral out to 100m depth. Preferred habitat ranges from coral and limestone reef formations through to hard weed covered flat bottom.

Spawning takes place from September to January with schools of up to 100 fish being sighted on several occasions in spawning aggregations around the Abrolhos Islands (Fairclough 2005; Nardi *et al* 2006).

**Biology:**

Baldchin are slow growing and can live for up to 25 years and are monandric protogynous hermaphrodites that change sex from female to male at between 8 to 12 years of age (Nardi *et a*l. 2006; D. Fairclough, Department of Fisheries Western Australia, *unpublished data*). Sexual maturity in females occurs at approximately 3 years of age at 280mm TL and fish over 50cm in length are predominately males. It has been found that 0+ age groups stay in the protected shallow water habitat where they were spawned preferring the weedy (algal) ground, which provides marginal habitat but has less predators, prior to some of the population moving offshore on to deeper reefs as they mature (Fairclough 2005).

The current minimum size limit for Baldchin Groper is 40cm TL.

**Current recreational fishery:**

The most recent published data is for the 2010 year in which the recreational catch of Baldchin was 27 tonnes in the West Coast Region of the fishery which extends from just south of Augusta to Kalbarri (FMP 247, p 47). The commercial catch was 17 tonnes. The Abrolhos Islands and Shark Bay are the two main areas where recreational anglers target this species. Baldchin are a targeted valuable demersal species for the recreational sector in this region. The commercial catch in 2005/06 was 38 tonnes. Given the level of vulnerability to barotrauma of this species a release mortality factor has been applied to the recreational retained catch. Since 2005/06 both sectors have seen access arrangements change to reduce the mortality in the fishery by 50% following recommendations from the WA Department of Fisheries research unit. This target is currently being met.

**Climate change biophysical predictions for Western Australia relevant to Baldchin Groper:**

Previously unprecedented increases in water temperatures were observed throughout the distribution area for Baldchin during March 2011 (FRR 22. 2011). The primary cause of this event was a particularly strong “La Nina” event and the secondary cause was a period of very light winds that allowed inshore shallow embayment temperatures to increase by up to 5 º C (FRR 22. 2011). It is likely that such events will become more frequent as part of climate changes although it is not known what the future frequency is likely to be.

Given that Baldchin spawn up to December, larvae and juveniles could be vulnerable to these increases in inshore water temperature changes.

Increasing ambient water temperatures may influence growth patterns (and thus biomass), which may have an effect on stock size available to be exploited. Increasing water temperatures may also influence trophic interactions, i.e. change the availability of preferred food sources and relationships among different trophic levels. It may also influence the timing of the spawning period, either the months in which it occurs or the length/extent of the period itself.

**Predicted fish stock changes**

It cannot be assumed that the distribution range of Baldchin can move southwards over time and this species shows a distinct preference for limestone reef substrates which diminish at the southern extremity of its current range and is replaced by granite.

The impacts of variations in temperature, salinity, pH and prey availability that may occur with climate change and associated events is unknown.

It is possible that Baldchin populations will reduce in size as shallow habitat becomes degraded as a result of higher water temperatures and food supply in this environment diminishes. Indeed available food supply for Baldchin away from coral habitat may already be a limit to its southwards distribution as will preferred limestone reef habitat.

## <u>KING GEORGE WHITING</u> [referenced with Dr G Hyndes]

**Species:**

King George Whiting *(Sillaginodes punctatus*)

**Distribution:**

King George Whiting are found from Port Jackson, in NSW, to Jurien Bay in Western Australia as well as being found in northern Tasmania (Kailola *et al*. 1993). Larvae recruit into shallow inshore waters, often less than 1.5m in depth, predominantly over sand initially moving to over seagrass assemblages as they mature, approaching one year of age (Hyndes *et al*. 1998). As sub-adults, King George Whiting are found in estuaries and marine embayments and as adults then move offshore into reef areas and wider into the waters of the continental shelf.

**Biology:**

King George Whiting can live for up to 15 years and reach maturity at four years at 41cm TL (Hyndes *et al*. 1998). Spawning occurs offshore and is initiated when water temperatures are falling from June to September in Western Australia from June to September. Recruitment into sheltered nearshore waters starts in late September and continues until early November as the prevailing winds drive the buoyant eggs and planktonic larvae into shallow protected inshore waters (Hyndes *et al*. 1998). Larvae settle out of the plankton when 60 – 80 days old at 15 – 18mm in length. Juveniles then remain in protected waters from 2 – 6 metres in depth for 21½ years and at around 25cm King George Whiting move into deeper water. They reach maturity at 4 years and 37cm ML when they spawn offshore in waters ranging form 6 – 50 metres (Hyndes *et al*. 1998).

The current minimum size for King George Whiting is 28cm TL which is below length at maturity.

**Current recreational fishery:**

The commercial catch of King George Whiting in 2010 was approximately 15 tonnes in the west and south coast regions. The recreational catch during this year remains unknown. King George Whiting are targeted by the recreational sector at various locations throughout their area of distribution in estuaries and embayment's for smaller fish and offshore for larger specimens. It is likely that King George Whiting have come under increased pressure in recent years since the demersal recreational boat fishing closures in 2010. With the 2010 recreational demersal bag limit reductions and the introduction of a two month closed season for demersal species, King George Whiting have come under increasing recreational pressure as the next target species of choice. Increasingly anglers are concerned that the minimum legal size is below maturity.

**Climate change biophysical predictions for Western Australia relevant to King George Whiting:**

Studies have shown that protected near shore areas along the south west coast, particularly those which contain seagrass assemblages, are key nursery areas for a range of recreational important species including King George Whiting (Hyndes *et al*. 1998). It is in these areas that recent extreme heatwave events have caused high mortality events. These previously unprecedented increases in water temperatures where observed throughout the northern area of distribution for King George Whiting during March 2011 (FRR 22. 2011). The primary cause of this event was a particularly strong "La Nina" event and the secondary cause was a period of very light winds that allowed inshore shallow embayment temperatures to increase by up to 5 º C (FRR 22. 2011). It is likely that such events will become more frequent as part of climate changes although it is not known what the future frequency is likely to be.

**Predicted fish stock changes**

Given that pelagic King George Whiting eggs and larvae, driven by onshore winds, settle in shallow inshore embayment's juveniles would be vulnerable to these increases in inshore water temperature changes as one-off events. Furthermore spawning occurs when the LC is at its strongest and increasing ENSO events, with associated weak LCs, could reduce recruitment over significant time-frame.

## SPANISH MACKEREL [referenced wit Dr Paul Lewis]

**Species:**

Spanish Mackerel *(Scomberomerus commerson)*

**Distribution:**

Spanish Mackerel are distributed widely in Australia from Geographe Bay north across the top of the continent and south to St Helens in Tasmania (Kailola *et al*. 1993). They range from shallow inshore coastal waters out to the edge of the continental shelf and are commonly found around coral reefs, rocky shoals and current lines in areas of high turbidity.

**Biology:**

Spanish Mackerel has a gonochoristic life history in which gonad differentiates into an ovary or testis at around 30 – 40cm and are mature by their second year, at approximately 900 mm in TL. Females grow faster and larger than males and can reach a size of 2.4 m and 45 kg. They have been recorded at up to 22 years of age in Western Australia (Mackie et al, 2003). Spawning is confined to the Kimberley and to a lesser extent Pilbara Regions with no spawning recorded south of Exmouth (Mackie *et al*, 2003). It was noted that sea surface temperatures (SST) were an influencing factor in relation to the timing of spawning for Spanish mackerel.

In the early wet season (October-December) when rising SST range from 25.5 º C to 28.5 º C the majority of spawning occurs and then declines when the SST peaks at 30 º C in February (Mackie et al. 2003). Females are highly fecund and spawn several batches of eggs about 2 to 6 days apart (Kailola *et al.* 1993). Currents distribute the bouyant eggs and pelagic larvae. Juveniles up to 10cm in length live in creeks, estuaries and along sheltered mud flats early in the wet season and juveniles form loose schools as they grow.

Little is known about the extent of migration of Spanish Mackerel in West Australian waters although evidence exists for a southerly summer migration (Donahue *et al* 1982). During La Nina events a strong LC increases the numbers of Mackerel seen and caught in Perth metropolitan waters during summer and can increase the distribution of Spanish Mackerel as far south as Albany on the south coast (Mackie *et al.* 2003).

**Current recreational and commercial fishery:**

The 2010 total commercial catch of Spanish Mackerel in WA was 284 tonnes. Although a recreational target pelagic species throughout its distribution the majority of the recreational catch is taken in the Pilbara region (Mackie *et al*. 2003). There are no estimates for recreational catch during 2010.

**Climate change biophysical predictions for Western Australia relevant to Spanish Mackerel:**

Given that SST are an important spawning driver then the likelihood of a southerly movement of spawning activity is a likely outcome of rising SSTs as a result of climate change. This may also result in greater numbers being found in the southern half of the State during summer. It is also likely that the southern distribution range of Spanish Mackerel will be extended as a SST increase of 1 º C is predicted to move 100kms southwards (Feng *unpublished* 2011).

**Predicted fish stock changes**

Given that growth for this species is similar throughout its range and that spawning, and the majority of its life cycle is in water deeper than 10 m, no marked change in population is predicted as a result of climate change.

No dramatic variation in the range and population dynamics of Spanish Mackerel can therefore be predicted from the information currently available. The impacts of variations in temperature, salinity, pH and prey availability that may occur with climate change and associated events is unknown.

**<u>WESTERN AUSTRALIAN SALMON</u>** [referenced with Dr Kim Smith]

**Species:**

Western Australian Salmon *(Arripis truttaceus)*

**Distribution:**

Western Australian Salmon range from around Lakes Entrance, Victoria, right across South Australia north to Kalbarri in Western Australia. This species is rarely encountered by recreational anglers north of Lancelin. Juvenile Salmon are found over sandy substrates in shallow coastal waters and estuaries. Maturing Salmon move very quickly from the south-east of Australia where they join local pre-spawning adults along the south-west coast north as far as Rottnest Island. Though mostly encountered along the beaches and rocky headlands of the southern and south-western coasts, at times over very shallow reefs, Salmon do migrate in deeper water at times and have been found in depths of 80 metres.

**Biology:**

Western Australian Salmon can live 9-10 years reaching 80cm in length and up to 10.5kgs in weight. They are likely serial batch spawners, their eggs are planktonic and they mature in their fourth year at about 54cm TL and weighing 3 – 5 kg .

The current minimum size limit for Western Australian Salmon is 30cm TL which is below the length at maturity.

**Current recreational fishery:**

The commercial Salmon catch reported in the 2010 WA State of the Fisheries Report was 358 tonnes in 2010. There are no current catch estimates available for the recreational catch.

Western Australian Salmon are a very popular target for recreational anglers and are encountered during their westward spawning migration along the south coast in February-April and are targeted by recreational anglers northwards to Perth. The highly variable nature of their migration results in huge catch variations throughout their range with seasonal LC and Capes Current variations contributing most to availability. They are highly valued for their sporting characteristics with the many of fish being returned to the water.

**Climate change biophysical predictions for Western Australia Salmon:**

Given that Western Australian Salmon spawn along the east coast (outside this papers area of study) the main influence on fish stocks and their availability to anglers in Western Australia revolves around the variability of oceanic currents affected by climate change. The most likely outcome in Western Australia is that its northern range will move southwards which could well mean that Salmon become infrequent visitors to Perth metropolitan waters.

General trend of warming of shelf waters along the south-west coast does alter migration and spawning behaviour. When unusually warm water was distributed across the shelf such that the Salmon schools are unable to avoid it this can totally disrupt spawning behaviour. Preliminary results indicate very poor recruitment from 2011, during a strong LC.

The impacts of variations in temperature, salinity, pH and prey availability that may occur with climate change and associated events is unknown.

**Predicted fish stock changes**

Salmon will continue to be a popular species for shore and boat based recreational anglers. The market demand for commercially caught Salmon as rock lobster bait has reduced significantly in recent years and subsequently increased numbers should be available to the recreational fishery following good recruitment years. Total fishing mortality is currently at much lower levels than previously which should result in the improved northward availability of Salmon that may be anticipated following by increasing ENSO events with an associated weaker LC.

## ROE'S ABALONE [referenced with Dr Anthony Hart]

**Species:**

Roe's Abalone *(Haliotis roei)*

**Distribution:**

Roe's Abalone inhabit reef platforms and shallow inshore reefs down to 20m from Corner Inlet in Victoria up to Steep Point in Western Australia. Following calamitous mortality during a "heat wave event" in 2011 all but wiped out Roe's Abalone north of Moore River north to Steep Point. During this event inshore SSTs were 3 – 5 º C higher than normal over several days resulting in extensive Abalone and fish mortalities (Pearce et. al., 2011).

**Biology:**

Roe's Abalone is the smallest commercially harvested Abalone in Australia and can reach 12.5cm in length and probably lives for up to 20 years. It can spawn all year round given ideal circumstances although spawning in Western Australian predominantly occurs in winter (Kailola *et al*. 1993). Larvae are free swimming and move inshore assisted by onshore winds and settle on coralline algae. They mature in their third year and reach minimum legal size after 4 years.

The current minimum legal size for Roe's Abalone is 60mm.

**Current recreational fishery:**

In the 2010 season recreational catch was 58 tonnes across the fishery and the commercial catch was 91 tonnes. The Roe's Abalone fishery is very tightly managed with recreational catch limited at 40 tonnes per season (5 year moving average) from the metropolitan reef top portion of the fishery. The fishing season in the Northern and Southern Zones extends from 1 October to 15 May. The West Coast Zone is only open for 5 Sundays annually, and the time of fishing in 2006 was reduced from 90 to 60 minutes (between 7 a.m. and 8.00 a.m.), commencing on the first Sunday in November. These restrictive management controls on the west coast are already necessary to ensure the sustainability of an easily accessible (and therefore vulnerable) stock located adjacent to a population in excess of 1.6 million people (including Geraldton).

**Climate change biophysical predictions for Western Australia relevant to Roe's Abalone:**

Given that a strong La Nina event in 2011 wiped out Roe's Abalone in the northern part of its distribution range a similar event would place still further pressure on northern stocks and this would result in similar area recreational and commercial fishing closures.

Nothing is known about the impacts of salinity or pH variations on eggs, and spat of this species.

**Predicted fish stock changes**

Given that this species can spend part, or all, of its life cycle in shallow water on reef top habitat it is very vulnerable to extreme heat wave events with subsequent high levels of mortality. Evidence of such mortalities has previously been identified (Pearce *et al*. 2011) and recreational access has, and can be in the future, modified at short notice given the adaptive management regime for this fishery.

Table 7. Attributes, criteria and risk categories used to assess climate change risk for each species – WESTERN AUSTRALIAN DHUFISH

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

A = Abundance, D = Distribution, P = Phenology

Table 8. Attributes, criteria and risk categories used to assess climate change risk for each species – BALDCHIN GROPER

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

A = Abundance, D = Distribution, P = Phenology

Table 9. Attributes, criteria and risk categories used to assess climate change risk for each species – KING GEORGE WHITING

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

A = Abundance, D = Distribution, P = Phenology

Table 10. Attributes, criteria and risk categories used to assess climate change risk for each species – SPANISH MACKEREL

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

A = Abundance, D = Distribution, P = Phenology

Table 11. Attributes, criteria and risk categories used to assess climate change risk for each species – AUSTRALIAN SALMON

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

A = Abundance, D = Distribution, P = Phenology

Table 12. Attributes, criteria and risk categories used to assess climate change risk for each species – ROE'S ABALONE

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

A = Abundance, D = Distribution, P = Phenology

Table 13. Summary of species habitat and distribution, additional stressors and key knowledge and data gaps

| Species | Habitat | Normal distribution | Additional stressors over & above fishing activities | Available research information (H, M & L) | Risk as per Tables ** | Range shift potential (extension, shift or contraction) |
|---|---|---|---|---|---|---|
| West Australian Dhufish | demersal; coral & rocky substrates, often vegetated, & rocky reefs; Predominantly inshore (juveniles); often offshore (adults) | Esperance up to Exmouth | Variation in strength of oceanic currents that contribute to larval distribution. Potential recruitment impairment | High | A =1222<br>D = 2222<br>P = 2112<br>**TOTAL 21** | Contract |
| Baldchin Groper | demersal; coral & rocky substrates, often vegetated, & rocky reefs; inshore (juveniles); often offshore (adults) | Geographe Bay up to Coral Bay | Habitat loss resulting from significant periodic increases in water temperature. Potential recruitment impairment | High | A = 1222<br>D = 2221<br>P = 2121<br>**TOTAL 20** | Contract |
| King George Whiting | demersal; with seagrass (juveniles); offshore rocky reef (adults | SA border up to Jurien Bay | Loss of seagrass habitat in Owen Anchorage, Fremantle | | A = 1222<br>D = 2311<br>P = 2121<br>**TOTAL 20** | Contract |
| Spanish Mackerel | pelagic; inshore | Perth up to NT border | Potential variability of availability of small pelagic baitfish | High | A= 1212<br>D= 2111<br>P= 3123<br>**TOTAL 20** | Extend |
| Western Australian Salmon | pelagic; inshore | SA border up to Geraldton | Poor recruitment of inshore prey species | | A= 1322<br>D= 2131<br>P= 3123<br>**TOTAL 24** | Contract |
| Roe's Abalone | benthic; rocky reef | SA border to Shark Bay | Habitat loss resulting from significant periodic (La Nina) increases in water temperature. Subsequent algal growth on reef a possibility restricting future spat recolonising. | | A= 1123<br>D= 2312<br>P= 3121<br>**TOTAL 22** | Contract |

****** The scale of numerical variation appears too low to provide adequate variation across a rang of species in tables 7 to 12

Table 14. Summary of key climate change drivers, current and predicted, outlined in descriptive analysis. Relative level of impact: high, medium, and low and ? indicates a high level of uncertainty.

| Species | Ambient water temp | ENSO frequency | Salinity | Upwelling | Winds & currents | pH | Nutrients & plankton | Freshwater flows | Other |
|---|---|---|---|---|---|---|---|---|---|
| West Australian Dhufish | **MEDIUM** | **HIGH** | **?** | **LOW** | **MEDIUM** | **?** | **?** | **LOW** | Southwards movement |
| Baldchin Groper | **MEDIUM** | **HIGH** | **?** | **LOW** | **MEDIUM** | **?** | **?** | **LOW** | Southwards movement away from preferred coral habitat at Abrolhos |
| King George Whiting | **HIGH** | **HIGH** | **?** | **LOW** | **MEDIUM** | **?** | **?** | **LOW** | Loss of seagrass nearshore hypoxic environments |
| Spanish Mackerel | **MEDIUM** | **HIGH** | **?** | **LOW** | **MEDIUM** | **?** | **?** | **LOW** | |
| Western Australian Salmon | **MEDIUM** | **HIGH** | **?** | **LOW** | **MEDIUM** | **?** | **?** | **LOW** | |
| Roe's Abalone | **HIGH** | **HIGH** | **?** | **LOW** | **HIGH** | **?** | **?** | **LOW** | Reef top locations very vulnerable to increasing heat wave events |

Table 15. Projected selected species list based upon the consequences of these perturbations Relative level of impact: high, medium, and low and ? indicates a high level of uncertainty.

| Selected species | Biomass | Population variation | Egg & larval vulnerability | Range variation | Available preferred habitat | Available prey or food |
|---|---|---|---|---|---|---|
| West Australian Dhufish | **LOW** | **LOW** | **MEDIUM** | **MOVEMENT SOUTH** | **LOW** | **LOW** |
| Baldchin Groper | MEDIUM | MEDIUM | HIGH | **MOVEMENT SOUTH** | MEDIUM | ? |
| King George Whiting | HIGH | MEDIUM | HIGH | **MOVEMENT SOUTH** | MEDIUM | ? |
| Spanish Mackerel | LOW | LOW | LOW | **MOVEMENT SOUTH** | LOW | LOW |
| Australian Salmon | MEDIUM | MEDIUM | LOW | **MOVEMENT SOUTH** | LOW | ? |
| Roe's Abalone | HIGH | HIGH | HIGH | **MOVEMENT SOUTH** | HIGH | HIGH |

Table 16. Other synergistic affects/impacts on recreational fishing effort and behaviour based upon discussions and *pers obs*.

| Selected species | Variation in fishing pressure | Variation in travel required for fishers | Target species shifts | Technique & fishery changes |
|---|---|---|---|---|
| West Australian Dhufish | INCREASING<br>Increased targeting of this species is expected because of its prestige and high value | YES<br>Anglers will be prepared to travel further to target this species. | NO | More lure fishing being done to increase sport value to partly offset low bag limits.<br>Bag limit is currently one and unlikely to change although increased seasonal fishing closures could be applied. |
| Baldchin Groper | DECREASING<br>The Abrolhos Islands are the main source of recreational catch and future fishery management changes are likely to reduce catches in this area | NO | YES | No technique changes identified.<br>Increased seasonal fishing closures could be applied. |
| King George Whiting | INCREASING<br>Continuing increase in interest as access to other species, such as dhufish, are reduced. | NO | NO | No technique changes identified.<br>Increase in minimum size could reduce sectors available catch. |
| Spanish Mackerel | INCREASING<br>Increased focus on this species as a result of lower demersal bag limits | YES<br>Metro anglers may not have to travel as far to catch this species. | NO | No technique changes identified.<br>No predicted fishery management changes |
| Australian Salmon | DECREASING<br>Habitat range will likely result in this species requiring a higher travel component which could reduce effort. | YES<br>Salmon with less frequently be available in the metro area | NO | No technique changes identified.<br>No predicted fishery management changes |
| Roe's Abalone | INCREASING<br>Increasing effort mainly in the Metro area | NO<br>Few rec fisher access the most northern stocks under threat | NO | More likely to be increasingly taken by diving given reef top Abalone will become more scarce.<br>Fishery management changes will continue to be made on a seasonal basis based upon the recreational progressive catch. |

## 12. DISCUSSION

Climate change will be driven by changes in atmospheric conditions which in turn will produce a response at the ecological level. There is sufficient evidence that climate is changing even if the debate continues about the level that human activity is contributing to that change. Changes predicted by climate scientists are already being observed. Changes at the ecological level will, in turn, produce changes at the social level through decisions made by individual fishers to alter their behaviour. Behaviour changes by recreational fishers will be influenced by how much they value particular species.

Such behavioural changes are already observable where there have been changes in fish stocks due to ecological or other changes. Two examples that demonstrate such behavioural change is the recent upsurge in fishing for Southern Bluefin Tuna from regional centres in Victoria (identification of new fishing opportunities and maybe changes in population dynamics and distribution) and a similar upsurge in Barramundi fishing in the Gladstone area in Queensland following the release of large numbers of Barramundi from Lake Awoonga following record flooding in 2011 (maybe partly due to climate change).

These are examples of adaptive responses by recreational fishers and more such responses are expected as there are range shifts in species and fluctuations in fish populations. This will be particularly applicable in the south east and west regions.

While recreational fishers are likely to be quick to respond to change there can be a significant lag in management response or none at all. The challenge for management is to develop greater flexibility in management arrangements. As climate change is likely to produce different changes at the region level greater emphasis should be placed on regional management. Flexible bag and size limits, area and seasonal closures, protecting spawning aggregations and cross jurisdictional management of stocks are likely to mitigate some the impacts of climate change. The development of trigger points where management should take action will also assist.

To meet the challenges that climate change is likely to bring there will need to be changes in the focus of monitoring programs to a greater emphasis on collecting data that will better enable predictions of the future to be made. The impacts of climate change are likely to occur at the most vulnerable stages in the life cycle of fish. For most species that will be in the early stages that influence recruitment.  In relation to fisheries there should be greater focus on monitoring recruitment and the conservation and repair of nursery habitat. Understanding recruitment and the environmental drivers that influence recruitment will allow future stocks to be predicted with greater accuracy. Predicting stocks will provide a greater lead time for management response and action if required. Such an approach has been taken in predicting Barramundi stocks in the Fitzroy River through the "Crystal Bowl" project using tagging and other data collected by recreational fishers.

Recent experiences with "outliers" of various species and opportunistic take of these species are detailed in the south east region's report. RedMap provides a monitoring tool for fishers to record fish beyond their characteristic range. Keeping track of changes in fish range over time provides early warning information that in time can be translated into better fisheries management. This is another example of recreational fishers assisting in collecting data that improves understanding of climate change.

## 13. BENEFITS

Monitoring of climate and ecological responses is providing considerable evidence of the changes that climate scientists are predicting, both in term of long term gradual change and increases in the severity of short term climate events.

This report is the first national perspective of the implications of climate change on recreational fisheries providing a first set towards further discussion by recreational fishers of the ecological impact of climate change on species and most importantly discussion by recreational fishers of various adaptation and mitigation options.

This report uses the best science available to assess the ecological implications on a number of key species important to recreational fishers and in turn the possible social responses to those changes. This information provides a more informed basis for debate and can be used positively by opinion makers in recreational fishing.

The report suggests a number of challenges to government policy and fisheries management, especially to provide greater flexibility in management arrangement and provide greater focus on monitoring factors that will help predict the future and provide a greater lead time for management response.

## 14. PLANNED OUTCOMES

The following were identified as the specific outcomes and benefits that were likely to result from this project:

*Planned outcome*
i) Improved knowledge on climate change so that advocacy on behalf of the recreational sector is both professional and effective.

*Result*
The report provides a national perspective of the implications of climate change on recreational fishing through illustration by examining the likely impacts on key species of high priority to the recreational fishing industry.

*Planned outcome*
A set of proposed adaptation activities at the regional scale that will lead to more responsive and flexible recreational fishery management.

*Result*
The social elements of climate change has been given equal weight to the likely ecological changes as ultimately the effects of climate change will result in significant behavioural changes that will ultimately require more responsiveness and flexibility in management.

*Planned outcome*
A refined set of national imperatives and policies, that ensure climate change advocacy is within a wider context and compliments policy advocacy on key recreational sector policy issues such as access sharing and habitat protection.

*Result*

The report provides information that can be used as the basis for development of policy. Actual policy development is well beyond the remit of this project.

*Planned outcome*

A range of operational opportunities that encompass mitigation, safety for fishers, improved economic outcomes for the recreational fishing industry, better quality of fishing experience for fishers, and better informed fisheries management.

*Result*

A range of operational opportunities are presented in the report that offers the opportunity for fishers, fishing organisations and managers to respond to the challenges of climate change.

*Planned outcome*

Lastly and significantly, by implementing the project within the regional framework proposed by the National Climate Change Action Plan this project will also contribute towards the outcome of more regionalised management arrangements.

*Result*

The report will provide input to the National Climate Change Action Plan with the risk assessments on the species in this report adding to the species addressed in other projects. This will provide a comprehensive assessment of the key recreational and commercial species and their vulnerability to climate change. The adaptation issues for the recreational sector are different to those of the commercial sector due to the greater flexibility that recreational fishers have in relation to fishing decisions. This dimension needs to be reflected in the Action Plan.

## 15. FURTHER DEVELOPMENTS

This report will provide input to the National Climate Change Action Plan and further action is likely to result from actioning arising from that plan.

The report should be viewed as a discussion paper for the industry and taken up by recreational fishing bodies, opinion makers and fisheries management agencies.

The challenge will be whether the focus will be on further debate about climate change or the development of actions to deal with it. In relation to this many of the actions proposed also deal with a number of other challenges such as resource access and allocation.

## 16. CONCLUSIONS

This report has focused on the ecological and social responses to climate change in relation to recreational fisheries and the recreational fishing industry. There is sufficient evidence that climate is changing even if the debate continues about the level that human activity is contributing to that change. Climate change is predicted to have different impacts on different regions and a regional approach has been taken to highlight those differences.

The vulnerability to climate change varies depending on the species and how vulnerable they are at the various stages of their life cycle. Some species were identified as being resilient, others as uncertain and some as being vulnerable.

Recreational fishers are likely to able to readily adapt to changes in fish species dynamics and distribution however this is likely to result in greater challenges for fisheries managers. There is a need for a more regional and whole of stock approach to management as well as greater flexibility and responsiveness in management.

The northern region provided the following conclusions:

- A better understanding of how fishers and the sector are organised would contribute valuable information for the development of better leadership and representation, and more effective education and communication strategies.

- Develop better leadership and representation. An informed leadership was valued and as such, the education of future leaders was identified as a priority (especially in relation to climate change and climate change adaptation issues)

- Information, education and communication were identified as key elements for effective adaptation. This included the development of a range of information specifically for recreational fishers (e.g. climate change information – what might happen, how it will affect them, what can the sector do about it).

- To develop flexibility it was considered important to evaluate previous attempts at alternative management arrangements. The knowledge gained from this process could facilitate further experimentation with management structures, with a particular focus on regional management arrangements. It was also considered important to understand what drives changes within the sector (e.g. iconic species, gear changes, etc.), and how does this enhance flexibility?

- It was deemed important to develop an understanding of recreational fishing participation (e.g. what are the drivers and/or constraints that impact fishing participation, and why people are leaving recreational fishing?), and whether this participation rate will be compounded by the effects of climate change? Also, in the context of climate change, what are the implications for the sector of a decline in the number of recreational fishers?

- For the species that were assessed Mangrove Jack, Spotted Mackerel, Red Emperor, Barred Javelin and Dusky Flathead all were considered to be resilient in relation to climate change, although there was considerable uncertainty about the possible effects on the more vulnerable early stages of their life cycle.

The south east region provided the following conclusions:

- The South East climate is changing. Changes to ocean temperatures, currents, winds, rainfall and more frequent extreme weather events are being observed across South East Australia.

- South Eastern Australian marine waters have been identified as a climate change 'hotspot'. Whilst these changes present a challenge, research suggests climate change will also see improved offshore fishing opportunities for recreational fishers in Victoria with a wider range of species on offer.

- The East Australian Current (EAC) has strengthened by 20 per cent over the last 50 years and is likely to continue to strengthen by another 20 per cent by 2100. This is likely to result in more warm water sub-tropical species being observed in parts of Victoria in future.

- Important coastal and estuarine fish species highly valued by recreational anglers such as Black Bream and King George Whiting are vulnerable to the impacts of a changing climate. These species will require stakeholders, fisheries management and natural resource management agencies to work together to reduce vulnerability through the development of sound adaptation strategies.

The south west region provided the following conclusions:

**Management adaptation responses**

- There are research gaps with most species during the most critical egg and post larval stages of their respective life cycles. It is likely that it is at this point that the species in this study are most vulnerable to change or increased mortality. This period of life cycles needs to be better understood if fisheries mangers are to be able to make informed decisions within a reasonable time frame to overcome these, as yet, not clearly understood impacts.

- In order for fisheries managers to make appropriate adjustments to specific significant fish stock population variations resulting from climate change prompt accurate ongoing catch information will be required for both the recreational and commercial sectors.

- Following the "heat wave event" in Western Australia in 2010/11 when many fish, including juveniles, died in shallow bays from Dongara to Lancelin as a result of hypoxia and abnormally high water temperatures. One manageable contributing factor to the hypoxic conditions was the high accumulation of excessive amounts of decomposing wrack along the shoreline of these bays, which added significantly to rapid de-oxygenation. Subsequently some areas of seagrass have disappeared resulting in loss of high value habitat, reduced CO2 sequestration and detrimental increased sand movement. This excess wrack must be carefully managed in order to limit these shallow water mortalities and environmental degradation.

- Restocking of some of the species identified in this paper is viable to varying degrees with current practises. Given the success of recent restocking work with Black Bream in Western Australia (Gardner *et al* 2010) is would be timely to commence further research into the hatchery and subsequent restocking viability of key species. This would provide the opportunity for future timely restocking if required.

- Provision of more FADs would provide alternative recreational fishing opportunities for pelagic species and potentially redirect recreational fishing effort away from more vulnerable demersal species.

- Provision of artificial reefs would provide increased productivity and in turn improved recreational fishing opportunities.

- Protection of identified nursery areas under threat from both human activities and climate change impacts.

- Species which spend part of their life cycle in estuarine environments would have improved recruitment if water quality and flows in river systems, that feed into the estuaries, where improved.

- Wherever possible clearly identified breeding aggregations of key recreational species should be protected to maintain optimum breeding biomass.

- Encourage a whole of government approach to holistically manage aquatic eco-systems so that all species can be adequately managed and protected throughout their range.

- Pursue improved management of closed (to the sea) systems is required under scientific direction rather than leaving the decision to open a sand bar to third parties with unknown impacts on the estuarine spawning movements of oceanic species.

- Encourage a whole of government approach to the aquatic environmental to overcome issues associated with different departments having different objectives.

**Identify global climate change mitigation measures that the recreational fishing sector can [support and] adopt**

- The recreational sector should encourage and support co-operation across government to protect and repair identified key inshore nursery areas impacted by development.

- The recreational sector should pursue the effective management of excessive wrack in coastal embayment's to remove or minimise the fish kills associated with seasonal inshore increased water temperatures.

- The recreational sector can actively support any carbon sequestration initiatives that will contribute to a reduction in $CO_2$ levels. These could include fish stocking projects.

- The recreational sector can actively support rehabilitation of riparian vegetation along water courses that will reduce $CO_2$ levels and improve water quality otherwise negatively impacted by climate change.

- The recreational sector can support any proposals to reduce marine outboard $CO_2$ emissions.

- The recreational sector can become more actively involved in habitat restoration in conjunction with other organisations such as Community Catchment Councils, Coast Care Groups etc.

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## 18. APPENDIX 1

There are no intellectual property issues arising from this project and the report is in the public domain.

## 19. APPENDIX 2

Staff that worked on this project were:

Colin Creighton - Fisheries Research and Development Corporation
Bill Sawynok - Recfishing Research
Dr Stephen Sutton - Fish and Fisheries Research James Cook University
Christine Pam - Fish and Fisheries Research James Cook University
David Welch - $C_2O$ Fisheries
Richard Saunders - Department of Agriculture, Fisheries and Forestry Fisheries Queensland
Dallas D'Silva - Department of Primary Industries Fisheries Victoria
Dr Daniel Grixti - Environmental Services
Dr Daniel Spooner - Department of Primary Industries Fisheries Victoria
Ian Stagles - Recfishwest

## 20. APPENDIX 3

### WORKSHOP DATES, AGENDA AND ATTENDEES

### NORTHERN REGION WORKSHOP

**Implications of climate change for recreational fishers and the recreational fishing industry in northern Australia.**

**Location: Seagulls Resort, Townsville**
**Date: 16th May 2012**

**Overview**

In this workshop we will consider recreational fishing as a social-ecological system vulnerable to the impacts of climate change. Indeed, various studies have found fishing activities and industries dependent on marine ecosystems to be sensitive to climate change and to have a relatively low capacity for adaptation; both of which are key indicators of vulnerability. The workshop will begin by presenting and discussing information about the potential impacts of climate change on target species for recreational fishers in northern Australia. Building on this information, we will then focus on the implications of climate change for the recreational fishing system as a whole. This approach recognises that people within the system have the capacity to anticipate change and implement adaptation strategies to decrease vulnerability. The aims of the workshop are: 1) to identify potential impacts of climate change on recreational fisheries in northern Australia; 2) identify ways in which the recreational fishing system can reduce its vulnerability to the impacts of climate change and remain socially and ecologically sustainable into the future.

**Attendees:**

Stephen Sutton (JCU) - Convenor
Bill Sawynok (Recfishing Research)
Chris Makepeace (AFANT)
Tony Ham (Fisheries Queensland)
Richard Saunders (Fisheries Queensland/JCU)
Josh Cinner (JCU)
Cindy Huchery (JCU)
Christine Pam (JCU)
Owen Li (JCU/Recreational fisher)
David Welch (c2o Consulting)
Darren Cameron (GBRMPA)
Andrew Mead (Charter Operator)
Ted Morgan (Fishing Warehouse)
Trevor Fuller (Recreational fisher)

## Workshop Agenda

**8.45 – 9.00am: Arrive (tea and coffee available)**

**9.00 – 9.15am Introduction: Recreational fishing as a social-ecological system**
Establish recreational fishing as a social-ecological system from which to better understand the implications of climate change and the potential to develop effective adaptation strategies. This approach emphasises the interconnectedness of all levels of the system, including marine ecosystems, recreational fishers, services which support recreational fishers (e.g. tackle shops, media, and charter boats operators), resource and environmental managers, etc. We will introduce a climate change adaptation model which will guide us through the workshop sessions.

**9.15 – 10.30am Session 1: Species profiles, resilience and potential change**
This session will present the current state of knowledge of the fisheries biology of five recreational fishery species in northern Australia. These species will be used as examples to demonstrate mechanisms of resilience and potential vulnerability to a changing climate.

**10.30 – 11.00am: Morning tea**

**11.00 – 12.30pm: Session 2: Adaptation strategies and impacts on the system**
How do recreational fishers adapt to change and what are the potential impacts of these adaptation strategies on the recreational fishing system as a whole. Identify specific vulnerabilities within the system to climate change.

**12.30 – 1.30pm: Lunch**

**1.30 – 3.00pm: Session 3: The capacity of the recreational fishing system to adapt to climate change**
Given the vulnerabilities identified in session 2, what are the attributes / characteristics of the recreational fishing system that promote or constrain an ability to adapt to climate change? How can the recreational fishing system enhance its capacity to adapt to climate change and remain sustainable into the future?

**3.00pm – 3.30pm: Afternoon tea**

**3.30 – 4.30pm: Session 4: A research focus for the future – support for a sustainable recreational fishing system**
Identify and prioritise future research needs to enhance adaptive capacity and support a sustainable recreational fishing system in a world of climate change.

## SOUTH EAST WORKSHOP

**Convenor-** Dallas D'Silva

1-2 March 2012
DPI Queenscliff

**Aims:**
To present the latest climate change and fisheries science for:
- Snapper,
- black Bream,
- King George Whiting,
- new 'range extension' pelagic species (i.e-Mahi Mahi, stripey tuna, cobia, wahoo, spanish mackerel etc) likely to be more common in the south east in future.

To engage recreational fishers from across the south east in developing management and stakeholder adaptation options.

**Attendees:**
Dallas D'Silva (Vic DPI)
Daniel Grixti (Vic DPI)
Brendan Wing (Youfish TV)
Christopher Collins (VRFish)
Russell Conway (VRFish)
Mark Nikolai (TARFish)
David Kramer (Future Fish)
Greg Jenkins (Vic DPI)
Geoff Fisher (GFAV)
Gretta Pecl (IMAAS/UTAS)
Keith Rowling (PIRSA)
Ross Winstanley (RecFish Research)
Bill Sawynok (Recfish Research)
Rod Pearn (DPIWE Tas)
Bryan Vanderwalt (NSW Fisheries)
Bill Lussier (Vic DPI)
Simon Conron (Vic DPI)

**Apologies:**
Colin Creighton (FRDC)
Al McGlashan (NSW recreational fisher)
Al Hobday (CSIRO)

**Day 1**
**12.30pm start**
1. **Welcome** (Dallas D'Silva, Vic DPI)

2. **Introduction** (Dallas D'Silva, Vic DPI, Bill Sawynok, Recfish research)
(5-10 mins)

3. **The South East Australia Marine Hotspot changes to the East Australian Current and new pelagic species** (Dr Gretta Pecl, IMAS) (20 mins presentation/Questions & discussion 15 mins)

4. **Climate change impacts for King George Whiting** (Associate Prof Greg Jenkins, VIC DPI)
(20 mins presentation/Questions & discussion 15 mins)

5. **Climate change impacts for black Bream** (Associate Prof Greg Jenkins, VIC DPI)
(20 mins presentation/Questions & discussion 15 mins)

**14.30pm afternoon tea**
(20 mins)

6. **Climate change impacts for Snapper** (Dr Paul Hamer, VIC DPI)
(20 mins presentation/Questions & discussion 15 mins)

7. **Citizen science and REDMAP** (Dr Gretta Pecl, IMAS)
(20 mins presentation/Questions & discussion 15 mins)

8. **Citizen science and Angler diary programs** (Daniel Grixti)
(20 mins presentation/Questions & discussion 15 mins)

**16.30pm**
**Day 1 summary and wrap up**

**Dinner – Queenscliff Hotel, Esplanade**
**7pm-9pm**
**Day 2**
**8.45am morning tea**

**9.00am start**
1. **Quick recap of day 1**(Dallas D'Silva, Vic DPI)

2. **Carbon footprints and recreational fishing** (Bill Sawynok to lead)
(10 mins presentation/20 minutes break out session to brainstorm ideas)

3. **Management adaptation principles** (Dallas D'Silva, Vic DPI)
(10 mins presentation/Questions & discussion 15 mins)

**4. Management adaptation by Government/fishery managers**
(30 mins group discussion)

**5. Management adaptation by recreational fishers**
(30 mins group discussion)

**6. Summary/Wrap up**
**11.30pm**

12.00pm Finish