Garnaut Climate Change Review

Preparing Australian fisheries and aquaculture to adapt to the potential impacts of climate change

Prepared by
Simon Vieira, Paul Newton, ABARE

June 2008

Contents

1 Introduction

Unlike in most other industries, the characteristics of fishery resources mean that government intervention is required to prevent a *tragedy of the commons* outcome (Hardin 1968) whereby fishery resources become overexploited and depleted. Fishery management is the term used to describe such government intervention. Fisheries generally operate within an environment of significant uncertainty. Short term variability in fish prices, input prices, fish abundance and weather patterns are some of the factors that contribute to this uncertainty. A key objective for fishery management is to implement management controls that allow fishers enough flexibility to adapt to this variability but within the biological limits of the fishery resource and subject to environmental management objectives.

A new source of uncertainty for fisheries is climate change. There is general agreement that climate change will have direct impacts on fisheries but the magnitude, location and timing of expected impacts are unclear. Fishery managers and governments can respond to this uncertainty by taking measures to adapt to the impacts of climate change in a cost effective manner.

This paper is structured as follows. The current characteristics of Australian fisheries and aquaculture in terms of management, economic contribution and operating environment are described. Such characteristics will have a significant bearing on the adaptive capacity of the Australian fishery sector to the impacts of climate change. Some of the likely direct and indirect impacts of climate change on fisheries are then outlined. The role of fishery managers and governments in preparing fisheries to be more adaptable to the potential impacts of climate change is then explored.

2 Characteristics of Australian fisheries and aquaculture

2.1 Fishery jurisdictions

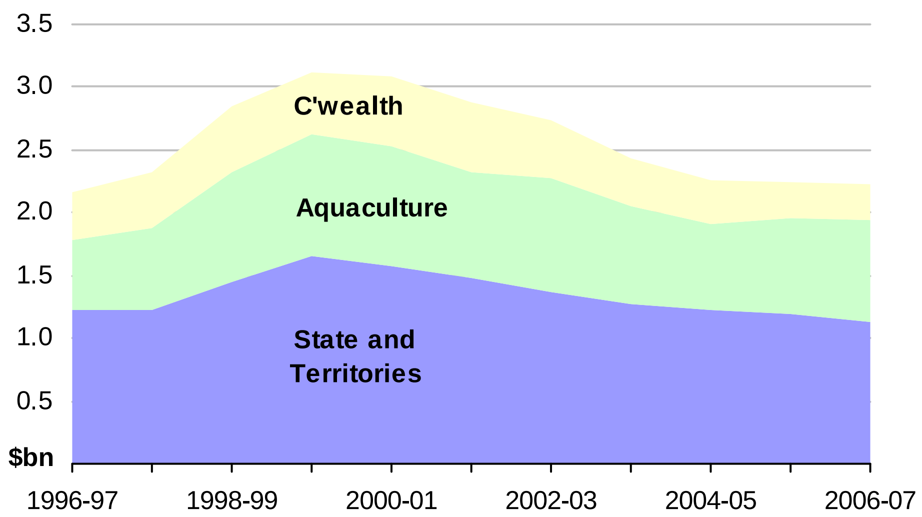
The Australian Fishing Zone (AFZ) extends 200 nautical miles off Australia's coastline, offshore islands and territories. Fishery management responsibilities in the AFZ are shared between the Commonwealth and state governments according to the Offshore Constitutional Settlement (OCS), a legal framework that allocates responsibility for managing Australia's marine resources between the States, the Northern Territory and the Commonwealth. State governments are generally responsible for the management of fisheries operating within three nautical miles of the coastline while offshore waters beyond three nautical miles are managed by the Commonwealth. Variations to these management arrangements are detailed under the OCS. For some fisheries that harvest internationally shared stocks, management is guided by international agreements.

2.2 Production, participation and employment

Commercial fisheries and aquaculture production

Gross value of production (GVP) for commercial fishing and aquaculture in Australia has been declining in real terms since 2001–02 and is estimated to be $2.19 billion in 2006–07 (figure 1), equivalent to 0.22 per cent of gross domestic product. The GVP of state wild caught fisheries was $1.14 billion in 2006–07, while Commonwealth fisheries were valued at $0.29 billion. The gross value of aquaculture production was $0.80 billion.[1] Figure 2 shows the state and Commonwealth shares of fishery GVP in 2006–07.

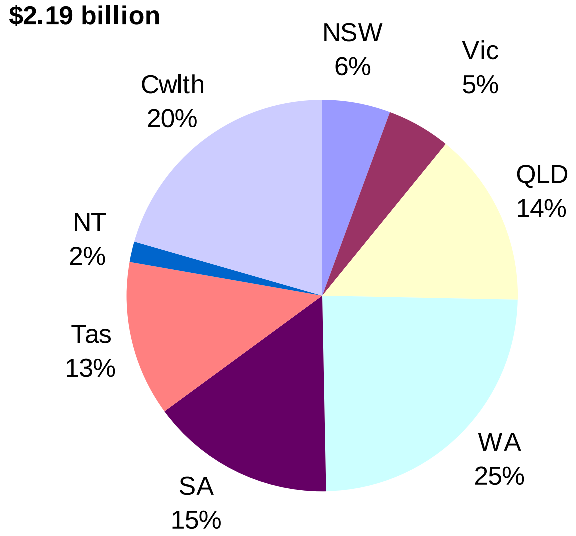
Figure 1 Real gross value of Australian fisheries and aquaculture production, 2006–07 dollars



Note: estimates for 2006–07 are preliminary.

[1] Total GVP is less than the sum of GVP for state, Commonwealth and aquaculture. GVP reported for Commonwealth fisheries includes southern bluefin tuna which is used as an input in South Australian aquaculture. It is excluded from total GVP to avoid double counting.

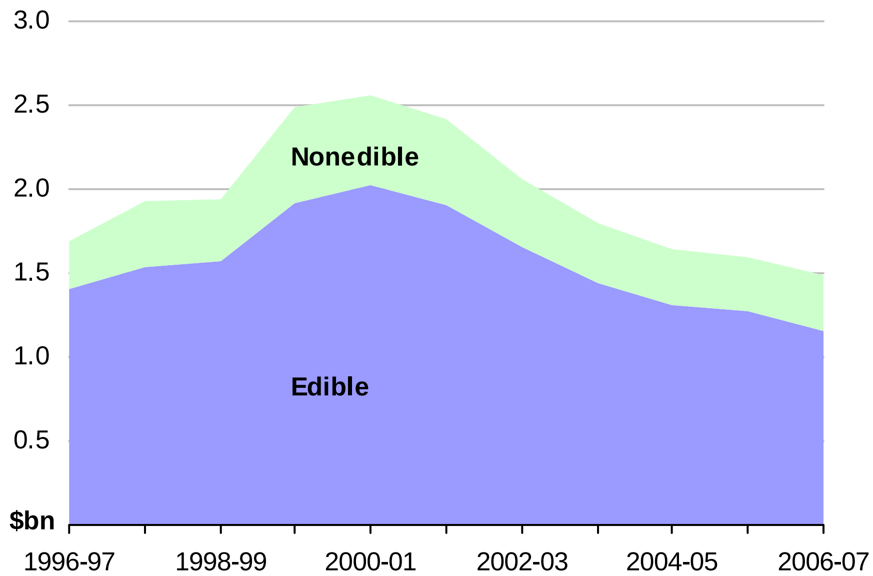
Figure 2 Gross value of Australian fisheries production by location, 2006–07



Commercial fisheries and aquaculture exports

Since 2000–01, the real value of Australian fishery exports has declined to $1.49 billion in 2006–07 (figure 3). This continued fall in export value is due to a decline in export volume, a fall in world market prices and the recent appreciation in the Australian dollar (Newton et al. 2007). The main export products in 2006–07 in value terms included rock lobster (31 per cent of the gross value of exports), pearls (21 per cent), abalone (16 per cent), whole tuna (11 per cent) and prawns (6 per cent).

Figure 3 Real gross value of edible and non-edible exports, 2006–07 dollars



Commercial fisheries and aquaculture employment

ABS census data from 2001 (ABS 2002) show that commercial fishing and aquaculture directly employed nearly 11 900 people in 2001 out of a total Australian workforce of around 8.3 million. A further 7750 people were employed in wholesaling and processing of fisheries products. It is important to note that employment data collected by ABS may allocate some fisheries related employment to other industries such as transport and generalised processing.

Recreational fisheries

Data on recreational and indigenous fishing are limited. A survey of recreational fishers in Australia (Henry and Lyle 2003) revealed a national recreational fishing participation rate[2] of 19.5 per cent for the 12 months prior to May 2000. Approximately 41 per cent of recreational effort was estimated to have occurred in inshore waters, 35 per cent in estuarine waters and 4 per cent in offshore waters. The remaining recreational effort occurred in inland waters. Expenditure on goods and services relating to recreational fishing amounted to approximately $1.8 billion over the survey period.

Indigenous fisheries

A survey of indigenous communities in northern Australia (Henry and Lyle 2003) revealed a participation rate of 91.7 per cent for the year prior to July 2000. The majority of indigenous fishing activity occurred in inshore waters (55 per cent), while 15 per cent occurred in estuaries and only 1 per cent occurred in offshore waters. The remainder of effort occurred in inland freshwater bodies.

2.3 Fisheries management

The current characteristics of fisheries management will largely influence how climate change might impact on fisheries. In industries such as agriculture, ownership of resources (such as land and livestock) can be easily defined. On the other hand, ownership of fishery resources is not easily defined. Fish stocks are generally considered a common property resource as a result. As a common property resource, governments have a role through fisheries management to limit fishery catches to appropriate levels using controls.

The majority of Australian fisheries have historically been managed with what are referred to as *input controls*. These controls place restrictions on the inputs that fishers can use to harvest fish. Such controls can include restrictions on vessel numbers, fishing gear and boat size. Input controls have two important characteristics. The first is that input controls do not provide fishery managers with direct control over catch. Secondly, input controls promote inefficient 'effort creep' whereby fishers will increase their use of unrestricted inputs in order to maximise catch. For example, an input control on net size will lead to increased use of other non-restricted inputs such as engine capacity and fish finding technology (echo sounders and global positioning systems). The end result is that catches are taken at a higher cost than required.

An increasing number of fisheries in Australia are managed with *output controls* as the primary management control (some level of input controls may still be required to address additional management objectives such as reducing environmental impacts). Output controls allow management to directly restrict catch through the setting of a total allowable catch (TAC). The most effective form of output control involves the use of individual transferable quotas (ITQs) whereby an ITQ represents a fisher's entitlement to a share of the TAC in any given period. Unlike in input managed fisheries where operators' choice of fishing inputs is distorted and managers are forced to respond to improvements in productivity by tightening controls further, under an ITQ system operators have a clear incentive to maximise profits from their quota holding and the benefits of productivity improvements are captured by operators. The transferable characteristic of ITQs also means that quota entitlements can move to the more profitable operators in a fishery who have a higher willingness to pay for quota entitlements. Such movements of quota are likely to improve overall fishery profitability. Limitations associated with the use of ITQs include difficulties associated with setting TACs appropriately, costly monitoring of catches and problems associated with catch discarding. This means that the appropriateness of ITQ focused management will vary across fisheries and that the costs and benefits of moving towards ITQs should be carefully considered.

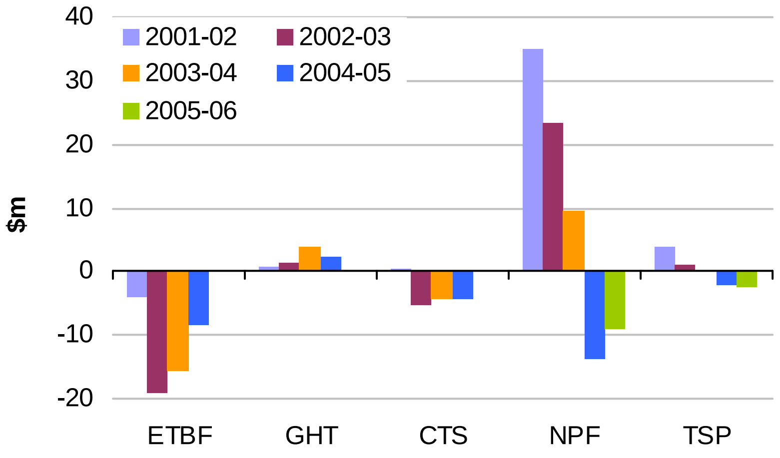
A common key objective for management in Australian fisheries is to manage fish stocks so as to maintain sustainability and profitability. The biological sustainability of Commonwealth fisheries in recent times has been a matter of concern (Larcombe and McLoughlin 2007). Out of a total of 97 stocks that are currently managed in Commonwealth fisheries, 19 are classed as *overfished* or

[2] The percentage of Australian residents aged over 5 years that fished at least once in a period.

subject to overfishing. Furthermore, 51 stocks are classed as *uncertain* due to a lack of biological information. Twenty seven stocks are classed as *not overfished* (Larcombe and McLoughlin 2007). It is likely that the biological status of many species in state managed fisheries are similarly uncertain or overfished.

The profitability of most Commonwealth fisheries has also been weak in recent times. ABARE's recent estimates of net economic returns for five key Commonwealth fisheries have been close to zero or negative (Figure 4).[3] Net economic returns can be defined as total fishery profit less estimates of unpaid labour, the opportunity cost of capital and management costs. These low profits are partly due to increased fuel costs and a recent appreciation of the Australian dollar, the latter of which reduces the prices received by domestic producers for exported products. Such factors are beyond the control of fishery managers. However, low fishery profitability in the long term is also linked to overfished stocks and overcapitalised fishing fleets—factors that are the focus of fisheries management.

Figure 4 Real net economic returns for Commonwealth fisheries, 2006–07 dollars



Note: Eastern tuna and billfish fishery (ETBF), gillnet hook and trap sector (GHT), Commonwealth trawl sector (CTS), northern prawn fishery (NPF) and Torres Strait prawn fishery (TSP). Net economic return estimates for 2005–06 not yet available for ETBF, GHT and CTS.

The Australian Government has recently taken measures to improve the sustainability and profitability of Commonwealth fisheries. In November 2005, the Australian Government announced the $220 million *Securing our Fishing Future* initiative, the main aim of which was to rebuild overfished stocks and enhance industry profitability. The initiative included $149 million for a licence buyback package to allow fishing businesses to exit the industry. The buyback resulted in 550 active and inactive licences being purchased. Linked to the initiative was a direction to AFMA from the then Minister for Fisheries, Forestry and Conservation to immediately halt overfishing in Commonwealth fisheries. A key outcome was the release of the *Commonwealth Fisheries Harvest Strategy Policy and Guidelines* in September 2007. This document specifies what management actions should be taken to achieve the objectives of biological sustainability and profitability. During this period of activity, TACs for a number of species in the Commonwealth southern and eastern scalefish and shark fishery were reduced. With time, these recent changes should result in higher stock abundances, lower harvesting costs and improved profitability.

[3] Data on the profitability of state managed fisheries are limited and so are not discussed. However, the general problems of overcapitalisation can also be expected to be a feature of many state managed fisheries.

Until recently, limited actions had been taken to deal with any potential climate change related impacts in fisheries. In October 2007, a *National Interim Climate Change Response Plan for Fisheries and Aquaculture (Interim Response)* was initiated. Its key objective was ‘to assist Australian governments in providing fisheries stakeholders and fisheries managers with a policy framework that embraces research and development, and that promotes climate change adaptation and emission mitigation in fisheries and aquaculture’. This interim response is temporary and will remain valid until the release of a *National Climate Change and Fisheries Action Plan* which is currently being finalised. The Action Plan aims to develop strategies to assist the fisheries and aquaculture sector to manage their operations to mitigate contributions to climate change and, more importantly, to adapt to the potential impacts of climate change. Such potential impacts of climate change are now discussed.

3 Impacts of climate change on fisheries and aquaculture

3.1 Environmental changes resulting from climate change

CSIRO research undertaken by Hobday et al. (2008) has looked at the potential impacts of climate change on fisheries and aquaculture in Australia. This research used CSIRO climate change model projections for relevant environmental variables to 2030 and 2070. Possible climate change impacts on fisheries are then identified given the current understanding of environmental-biological relationships. Such environmental variables include temperature, ocean currents, winds, nutrient supply, rainfall, ocean chemistry and extreme weather events (Hobday et al. 2008). There is uncertainty regarding the magnitude, location and timing of changes in these variables. However, changes that are likely to occur include:

- a warming of sea surface temperatures around Australia, particularly south east Australia
- an increase in surface winds
- a general decrease in speed of surface currents. However, the south-flowing East Australian Current (EAC) on the east coast of Australia will strengthen and penetrate further south
- reduced mixing in the water column and greater stratification
- decreased rainfall in most of Australia although there is uncertainty about the likely changes in northern Australia
- increased frequency and intensity of storms
- a rise in sea levels
- acidification of the oceans due to increased levels of carbon dioxide
- a reduction in sea ice coverage (Hobday et al. 2008).

3.2 Climate change impacts on fishery biology

Adding to the uncertainty surrounding potential changes to environmental variables, significant uncertainty also surrounds the current biological characteristics of fisheries and how these characteristics are linked to the environmental variables mentioned above. Hobday et al. (2008) discuss the potential biological impacts on fisheries in terms of changes in the following four types of characteristics:

- phenology (seasonal patterns) and physiology
- range and distribution
- composition and interactions within fish communities
- structure and dynamics of these communities.

Once again, there is agreement that climate change will impact on these biological characteristics of Australian fisheries (in some cases, they have already been impacted). But the magnitude, timing and location of impacts is uncertain. Often, other human related impacts such as overfishing will increase the significance of climate change impacts on the biology of fisheries (Walther et al. 2002, Hamilton 2007). Some key potential impacts as identified by Hobday et al. (2008) are outlined in Box 1.

Box 1 Key biological impacts as identified by Hobday et al. (2008) using CSIRO climate change projections to 2030 and 2070

Northern fisheries

- Prawn, barramundi and mud crab catches may be adversely impacted by changes in rainfall.
- A rise in sea level may reduce mangrove habitats for prawns and fish species.

South-east Demersal fisheries

- Varying impacts on recruitment of different species due to wind and ocean temperature changes.
- Warmer waters may increase the growth rates of some species.
- Some impacts on ecosystems have already been observed and have been linked to abalone and rock lobster fishery productivity declines, kelp bed declines and a failed recovery in gemfish stocks.

Western fisheries

- The Leeuwin Current is linked with the recruitment of many species, including the valuable western rock lobster but expected changes are uncertain.

Pelagic fisheries

- Increased southerly flow of the EAC has been linked to observed declines in krill and predating species and will cause an increase in the southern distribution of tropical tuna.
- Warmer waters may cause increased squid growth and maturity rates.

Sub-Antarctic fisheries

- Declines in sea ice and reduced pH levels may impact on krill and other plankton abundance with flow on impacts for other fishery species.
- Higher water temperatures could affect the metabolic rates and distribution of fish species.

Aquaculture

- Temperature increases may impact on the growth of farmed species such as Atlantic salmon in Tasmania and may also increase the risk of disease outbreaks.
- Changes to rainfall could impact on coastal aquaculture indirectly through changes to salinity, nutrients and suspended sediments.
- The locations of aquaculture production may have to shift.

Note: see Hobday et al. (2008) for more detail.

3.3 Climate change impacts on fishing infrastructure and operations

Increased storm and cyclone activity and sea level rises may all have direct impacts on fishing. Such changes may increase the risk of damage to fishing vessels and port infrastructure including unloading facilities, moorings and nearby processing facilities. An increased frequency of extreme events may also limit vessel entry and exit from ports and time spent out at sea (Hobday et al. 2008).

3.4 Indirect impacts of climate change on fisheries: mitigation policies

The introduction of the proposed national emission trading scheme is likely to result in an increase in the price of emission intensive energy sources in Australia including fuel and electricity. Many commercial fishing activities (including aquaculture) are highly fuel intensive. Fishery economic survey data collected by ABARE reveal that recent increases in fuel prices are a key explanatory factor for the low profitability of Commonwealth fisheries. Average fuel costs per vessel in 2005–06 accounted for 39 per cent of total cash costs in the Torres Strait prawn fishery and 38 per cent in the northern prawn fishery (Table 1). Energy costs for fish processing and transport activities are also likely to increase and may be passed on to fishery operators. The profitability of many fisheries may therefore be particularly susceptible to increased energy costs. Accordingly, the negative impact of increased energy costs on profitability is likely to be the main driver for climate change mitigation efforts in the fishery and aquaculture sector.

Table 1 Average fuel cost as a percentage of total cash costs for selected Commonwealth fisheries

	2003–04	2004–05	2005–06
Northern prawn fishery	25%	32%	38%
Torres Strait prawn fishery	32%	36%	39%
Commonwealth trawl sector	21%	23%	na
Eastern tuna and billfish fishery	15%	17%	na
Gillnet hook and trap sector	9%	10%	na

Source: based on ABARE fisheries survey data.

3.5 Indirect impacts of climate change on fisheries: international agreements

The impacts of climate change may affect international agreements for the management of internationally shared stocks such as tuna (Miller 2007, Miller and Munro 2004, Sissener and Bjørndal 2005). Shifts in the spatial distribution of shared stocks as a result of climate change could alter the relative proximity of shared stocks to countries cooperating under an international agreement. This will affect each cooperating country's relative cost of harvesting. Similarly, stock movements to waters in close proximity to previously non-participating countries may make harvesting a shared stock economically viable for such countries. Where such changes occur, the previous characteristics of an agreement (in terms of catch allocations amongst countries for example) may not be appropriate.

Miller (2007) looks at how previous climate shifts have contributed to the destabilisation of international fishery agreements. The sharing of Pacific salmon, for example, between Canada and Alaska has been associated with conflicts in the past due to unexpected spatial changes in stock abundance and distribution as a result of climate variation. Each party's incentive to continue cooperating under the agreement was altered given that the catch allocation rules could not be flexibly altered in response to such unexpected climate related changes. Miller (2007) also points out that uncertainty about the future distribution of internationally shared stocks due to climate change implies that there will be uncertainty as to where the future benefits (in terms of improved catches) from current conservation measures will accrue. This can also affect current international agreements.

Miller and Munro (2004) note that for international agreements to be resilient to such impacts from climate change, agreements must have 'flexibility to respond to changing circumstances' and must 'do so in such a way that all parties perceive real gains from continued co-operation'. The flexibility of international fishery agreements can be improved by allowing bargaining amongst countries for the right to a certain allocation of a shared fish stock (Miller and Munro 2004). Predefined decision rules regarding catch sharing under different climate change related scenarios may also improve the flexibility of international agreements (Miller and Munro 2004), although may be difficult to enforce in practice.

3.6 Indirect impacts of climate change on fisheries: changes in demand for Australian fishery products

The impacts discussed so far relate to supply side impacts of climate change for fisheries. Climate change-induced changes in demand for Australian fishery products may also occur. For example, climate change may result in fish stock declines in the waters of other countries. This could reduce the supply of foreign produced fishery products on international markets and cause an increase in the demand for Australian domestic produced fishery products. Climate change is also likely to alter the supply of land-based protein substitutes such as beef, and in many cases impacts are likely to be negative (Gunasekera et al. 2007). This could potentially increase demand for fish protein sources.

3.7 Climate change impacts on aquaculture

Aquaculture industries in many cases will be subject to the same biological impacts of climate change as wild fisheries (see Box 1). The production of Atlantic salmon in waters off Tasmania, for example, already occurs in water temperatures that are at the warmer end of this species' optimal temperature range for growth. The substantial ocean warming that is predicted to occur around Tasmania due to climate change may therefore negatively impact on those salmon farming operations. Increased water temperatures may also increase the occurrence of pest and disease outbreaks in oceanic aquaculture farms. Potential non-biological impacts may include increased damage to equipment due to more frequent and intense cyclone and storm activity. Where such negative impacts arise, the current locations of aquaculture operations and the current species being produced may become economically unviable (Hobday et al. 2008).

In some cases, water temperature increases resulting from climate change may lead to positive impacts for current aquaculture operations. For instance, the growth rates of some tropical and sub-tropical aquaculture prawn species may be enhanced. Similarly, the availability of suitable locations in which such species can be grown may increase (Hobday et al. 2008).

An indirect impact for the aquaculture industry could occur through changes in the availability of wild caught fishmeal species used in aquaculture feed as a result of climate change. Climate change impacts on terrestrial based aquaculture feed products such as soybean meal may have similar consequences (Hobday et al. 2008).

3.8 Climate change impacts on recreational fisheries

For recreational fisheries, both positive and negative impacts may result from climate change. Shifts in fish distribution and abundance may provide opportunities to target new species, or alternatively, reduce the availability of previously caught species. On the east coast of Australia for example, the predicted strengthening of the southward flowing EAC is likely to result in an increased availability of tropical species in southern waters and a reduced availability of some cooler water species (Hobday et al. 2008). For coastal localities where recreationally sought species have been traditionally caught, there may be negative economic impacts associated with any reduction in such fishing activity (Roessig et al. 2004). Businesses supporting recreational fishing (such as bait and tackle shops) in such communities are most vulnerable to such negative impacts. Businesses in locations positively affected by a favourable distribution shift however may benefit.

Some individual recreational fishers may move to new areas as stocks shift. In some cases, the cost of following stocks may limit such a response from recreational fishers given that such fishing is often undertaken for enjoyment and not out of economic necessity as in the commercial sector. As recreational fishers have other substitute leisure activities from which they can derive benefits, demand for recreational fishing might, to some degree, be inversely responsive to increases in costs of participation. Additionally, the relative benefits from following a species may be small given the existence of substitute species in any given location.

The viability of recreational charter fishing operations in some locations may also be affected by more frequent extreme events. In addition, changes in the characteristics of fishing grounds traditionally targeted by charter operators (such as oceanography and species composition) might undermine their ability to provide customers with an enjoyable recreational fishing experience.

3.9 Climate change impacts on indigenous fisheries

Indigenous fisheries may be particularly vulnerable to climate change given the high number of individuals in indigenous communities that fish (Henry & Lyle 2003), the cultural significance attached to fishing and the species specific nature and low mobility (most activity occurs in close proximity to communities) of indigenous fishing activities. In the Torres Strait, many indigenous fishing activities are already limited by cyclone activity. Diving in the Torres Strait rock lobster fishery for example is not only limited during cyclones, but also following a cyclone due to poor water visibility. It follows that increased cyclone frequency could adversely impact this fishery.

4 Adapting to climate change in fisheries

The potential impacts of climate change will add an additional element of uncertainty to decision making for fishery managers and fishery operators. The variables that may change are many and the characteristics of changes are uncertain. Distinguishing between climate change impacts and non-climate change impacts (such as fishing-induced mortality) on the status of fish stocks will become more difficult for managers (Hobday et al. 2008, Lehodey et al. 2006, Mote et al. 2003). Also, the biological-environmental relationships that are currently understood may change in response to climate change (Hobday et al. 2008).

It should be kept in mind that operators and fishery managers already face significant uncertainty when making decisions (Brander 2007, Sethi et al. 2005). For example, in many fisheries, operators have adapted to substantial short term variability in stock abundance, fuel prices, exchange rates and fish prices (figures 5 and 6). Climate change can therefore be viewed as an additional source of long term uncertainty. The demonstrated ability of fishers to cope with uncertainty in the short term implies that fishers will potentially have a relatively high capability to adapt to the longer term challenges presented by climate change. Fishery managers and governments, however, still have a role to improve the ability of fishers to adapt to the uncertain impacts of climate change. Two key responses from fishery managers are relevant in this regard. The first is to take measures to improve the flexibility of fishers to adapt to climate change impacts as they arise. The second response is to focus research on reducing the cost of adapting to the impacts of climate change on fisheries.

Figure 5 Average real fish prices for wildcaught fisheries and year on year variability, 2006–07 prices

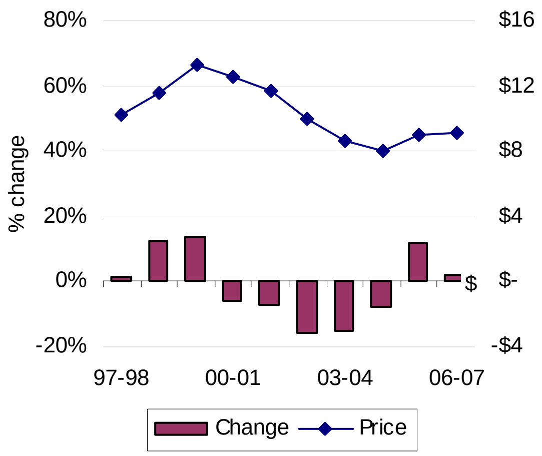
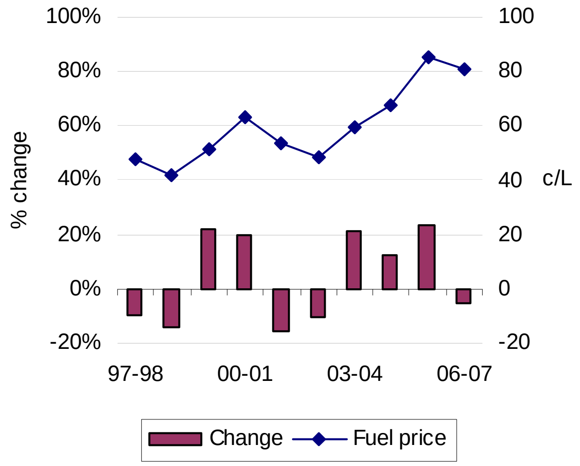


Figure 6 Real off-road diesel fuel price and year on year variability, 2006–07 prices



4.1 Reducing adaptation costs through investments in research

Adaptation to climate change can be less costly for the fisheries and aquaculture industry when research helps to reduce uncertainty about the likely timing, location and magnitude of climate change impacts. If research can help managers and industry understand ahead of time how climate change might affect a particular fishery or aquaculture operation, they can institute appropriate policies and make business decisions that will facilitate adaptation. For managers, possible policy changes might include making adjustments to spatial management restrictions or permitting new gear types, for example. For industry, research that reduces uncertainty about future outcomes in the industry can make it easier to make efficient long term investment decisions relating to the purchase of a new vessel or the construction of a new farm, for example. Industry may also be able to take steps to limit their dependence on stocks likely to be threatened by climate change, or to position themselves to take advantage of new opportunities, such as southward range shifts of commercial species. Effective communication of research findings to industry will be fundamental to allowing the benefits from research to be realised. Care should be taken however to communicate the uncertainty associated with research findings to ensure that any investment decisions that are made are fully informed.

It is important to devote at least some research effort to determining management frameworks that are robust under a wide range of possible climate change scenarios. These frameworks might complement fishers' existing ability to adapt to large annual fluctuations in economic and biological conditions. Clearly defined harvest strategies such as the Australian Government's *Harvest Strategy Policy and Guidelines* can offer a framework that specifies what pre-defined, impartial and objective based management actions should occur in response to changes in economic and biological indicators. Such frameworks give fishers greater certainty about future management arrangements while effectively protecting the sustainability of fish stocks.

Fishery management decision making relies heavily on research and monitoring to make informed decisions that meet sustainability and profitability objectives. Maintaining accurate base-level research and monitoring will become increasingly important as uncertainty and variability increases with the onset of climate change. Current biological-environmental relationships may change under future climatic conditions and undermine the accuracy of current approaches to biological stock assessment (Hobday et al. 2008). Understanding how these relationships might be affected by climate change is likely to be an important focus of research for fishery management. Hobday et al. (2008, pp. 15–16) identify some specific areas of research where 'immediate progress with maximum reward could be made' as outlined in Box 2.

Box 2 Key research topics for climate change impacts on fisheries and reasons

Climate impacts on south-east demersal fisheries. A large amount of data are already available, changes are already being observed and significant warming is expected here.

Climate impacts on western rock lobster. The fishery is the most valuable in Australia and its recruitment is dependent on climatic factors and may therefore be impacted on.

Socio-economic impacts of climate on fisheries and aquaculture. Case studies on fisheries or aquaculture operations that are particularly vulnerable to climate change could be valuable.

Changes in the productivity of waters around Australia. Changes in water nutrient levels and productivity will impact species' distributions and directly impact some fisheries.

Long term patterns in distribution and abundance of key species. Knowledge of previous long term stock changes can inform future change.

Source: Hobday et al (2008).

4.2 Reducing adaptation costs through changes to management

Where the impacts of climate change on fisheries remain uncertain, an important question is presented for fishery managers—what measures can be taken to improve the ability of fisheries to adapt to the impacts of climate change and its associated uncertainty? Such ability will be largely dependent on the characteristics of a fishery's management.

The benefits of using an ITQ focused management system over an input based system have already been discussed. Under input focused management, numerous inputs are generally restricted to indirectly control catch. The adaptive capacity of fishers is essentially reduced for every input that is restricted as fishers have less flexibility to make production decisions that best suit the circumstances they face. Under ITQ management, while some input restrictions will generally be required (for example, to address environmental objectives), fishers will face relatively fewer restrictions on inputs and their quota holding will determine their allowable catch. With fewer input restrictions, fishers will have greater flexibility to vary the combination of inputs they use to achieve their allowable catch as they see best given the circumstances (or impacts of climate change) that they face. Output controls also give managers control over the total catch which may be important if abundance is fluctuating widely.

For some fisheries the aforementioned benefits associated with ITQ management may be outweighed by the costs. For instance, for low value fisheries the cost of monitoring catches may be prohibitively high. Similarly, ITQ management systems may be less appropriate where there is significant uncertainty surrounding stock abundance from period to period (Kompas and Che 2004). Such factors should be considered when assessing the appropriateness of ITQ management for a given fishery.

In most fisheries, management regulations require that operators own or lease a fishery endorsement in order to operate in a fishery. Often an endorsement will relate to a spatially defined jurisdiction or fishery, or similarly, a specific type of fishing method. The spatial definition of endorsements may amplify the adverse impact of a species' distribution shift from one jurisdiction to another. Similarly, endorsements that limit fishers to using a specific gear type may reduce the ability of fishers to respond to incentives to shift to more efficient fishing methods. This is particularly relevant to climate change mitigation in fisheries, given that expected increases in energy costs may provide fishers with an incentive to move to more fuel efficient gear types. In this case, not only is the characteristic of the endorsement reducing fisher flexibility to adapt but it is also preventing climate change mitigation behaviour.

The positive link between abundant fish stocks and profitability has already been mentioned. However, both characteristics are beneficial for a fishery's resilience. Greater fishery profitability implies that operators have greater scope to adjust to adverse changes in stock abundance, input costs and catch prices that might be caused by climate change. Profitable fishers also have a greater capability to experiment and seek new opportunities that might arise as a consequence of climate change. Fish stocks that are not overfished are more likely to withstand any unforeseen environmental shocks that might be brought about by climate change. Indeed, Brander (2007) believes that 'reducing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal feasible means of reducing the impacts of climate change'.

Changed species' distributions may also have the benefit of giving rise to new fishery opportunities. While it is important to allow fishers to take advantage of such opportunities, management must also ensure that the harvesting of newly developed fishery resources occurs within the biological limits of the fishery species. Fisheries management must also be aware of any ecosystem impact that a new fishery (or fishing method) may cause. Accordingly, fisheries management should take a precautionary approach to developing new fisheries. Exploratory fishing should first be introduced to determine relevant biological limits and ecosystem impacts before commercial fishing be allowed. If commercial harvesting is viable, managers must limit entry to the fishery, and put in place the appropriate controls to limit catches to sustainable levels.

The uncertainty of climate change impacts and the variable nature of fish stocks will mean that regular reviewing of fisheries management settings will be required (Brander 2007). Unexpected variations in stock abundance and other fishery characteristics may result in previous management settings becoming sub-optimal. The use of predefined harvest strategies, as previously discussed, can improve fishery management decision making in the face of such uncertainty. Fishery management must also have flexibility to respond to unexpected changes in a timely manner and alter management settings appropriately (Clark 2006). The responsiveness of fishery management may benefit from improved communication with fishers regarding their fishing patterns and observed changes in fish abundance and distribution. Overall, greater stock variability and uncertainty may require a more conservative approach from management in setting catch and effort levels for particular species (Brander 2007, Jurado-Molina and Livingston 2002).

5 Conclusion

The potential impacts of climate change are unclear and both positive and negative impacts may arise. Therefore, for the Australian fishery and aquaculture industry, climate change can be viewed as another source of uncertainty for an industry that already deals with and adapts to significant variability and uncertainty. Given the level of uncertainty associated with climate change, the key focus for fishery managers should be to improve the ability of fisheries to adapt to whatever changes arise as a result of climate change. Two key responses from management will achieve this. The first response will be to improve fishery flexibility to adapt to the impacts of climate change. Fishery management that uses ITQs has been cited as an option that offers considerable potential to improve fisher flexibility. On the other hand, the use of endorsements that restrict the geographical location of fishing or restrict the type of fishing method that can be used will reduce the adaptive capacity of fishers and amplify any negative impacts that result from climate change. Fishery management focused on abundant stocks and high profits will allow fisheries to better cope with unforeseen environmental shocks and economic variability. The second response is to undertake research that allows some of the likely climate change impacts on fisheries and aquaculture to be anticipated with greater certainty thereby reducing the costs of adaptation.

6 References

ABS (Australian Bureau of Statistics) 2002, *Working Population Profile,* 2001 Census Community Profile Series.

Brander, K.M. 2007, Global fish production and climate change, *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 140, no. 50, pp. 19709–19714.

Clark, B.M. 2006, Climate change: A looming challenge for fisheries management in southern Africa, *Marine Policy*, Vol. 20, pp. 84–95.

Gunasekera, D., Kim, Y., Tulloh, C. and Ford, M. 2007, Climate change impacts on Australian agriculture, in *Australian Commodities*, December quarter, 07.4, Australian Bureau of Agricultural and Resource Economics, Canberra.

Hamilton, L. 2007, Climate, fishery and society interactions: observations from the North Atlantic, *Deep Sea Research II,* Vol. 54, pp. 2958–2969.

Hardin, G. 1968, The Tragedy of the Commons, *Science*, New Series, Vol. 162, No. 3859, pp. 1243–1248.

Henry, G.W. and Lyle, J.M. (ed.) 2003, *The National Recreational and Indigenous Fishing Survey*, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, July.

Hobday, A. J., Poloczanska, E. S. and R. J. Matear (ed.) 2008, *Climate Impacts on Australian Fisheries and Aquaculture: Implications for the Effects of Climate Change*, draft report to the Australian Government Department of Climate Change, Canberra, Australia, 2008.

Jurado-Molina, J. and Livingston, P. 2002, Climate-forcing effects on trophically linked groundfish populations: implications for fisheries management, *Canadian Journal of Fisheries and Aquatic Sciences*, Vol. 59, Iss. 12, pp. 1941–1951.

Kompas, T. and Che, N. 2004, *A Bioeconomic Model of the Australian Northern Tiger Prawn Fishery: Management Options Under Uncertainty*, ABARE Report to the Fisheries Resources Research Fund, Canberra, August.

Larcombe, J. and McLoughlin, K. (eds) 2007, *Fishery Status Reports 2006: Status of Fish Stocks Managed by the Australian Government*, Bureau of Rural Sciences, Canberra.

Lehodey, P., Alheit, J., Barange, M., Baumgartner, T., Beaugrand, G., Drinkwater, K., Fromentin, J-M., Hare, S.R., Ottersen, G., Perry, R.I., Roy, C., van der Lingen, C. D., Werner, F. 2006, Climate variability, fish and fisheries. *Journal of Climate,* Vol. 19, Iss. 20, pg 5009–5031.

Miller K.A. 2007, Climate variability and tropical tuna: Management challenges for highly migratory fish stocks, *Marine Policy* 31: 56–70.

Miller, K.A. and Munro, G.R. 2004, Climate and Cooperation: A New Perspective on the Management of Shared Fish Stocks, *Marine Resource Economics,* Vol. 19, pp. 367–393.

Mote, P.W., Parson, E.A., Hamlet, A.F., Keeton, W.S., Lettenmaier, D., Mantua, N., Miles, E.L., Peterson, D.W., Peterson, D.L., Slaughter, R. and Snover, A.K. 2003, Preparing for climate change: the water, salmon, and forests of the pacific northwest. *Climate Change*, Vol. 61, pp. 45–88.

Newton, P., Galeano, D., Wood, R., Vieira, S. and Perry, R. 2007, *Fishery Economic Status Report*, ABARE Report to the Fisheries Resources Research Fund, Canberra, June.

Roessig, J.M., Woodley, C.M., Cech, J.J. and Hanses, L.J. 2004, Effects of global climate change on marine and estuarine fishes and fisheries, *Reviews in Fish Biology and Fisheries*, Vol. 14, pp. 251–275.

Sissener, E.H. and Bjørndal, T. 2005, Climate change and the migratory pattern for Norwegian spring-spawning herring—implications for management, *Marine Policy*, Vol. 29, pp. 299–309.

Sethi, G., Costello, C., Fisher, A., Hanemann, M. and Karp, L. 2005, Fishery management under multiple uncertainty, *Journal of Environmental Economics and Management*, Vol. 50, pp. 300–319.

Walther, G., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J., Hoegh-Guldberg, O. and Bairlein, F. 2002, Ecological responses to climate change, *Ecological responses to recent climate change*, Vol. 416, pp. 389–395.