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Marine Park Authority

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Climate Change Vulnerability Assessment:

Queensland Marine Aquarium Supply Industry, 2010

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On behalf of Pro-vision Reef Inc

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Executive Summary

The marine aquarium supply sector comprises less than 30 businesses and operates within two hand collection fisheries adjacent to the east coast of Queensland. Much of the fishery activity occurs within the World Heritage listed Great Barrier Reef. Two of the operators hold additional permits to work in the Coral Sea Fishery, which is seaward of the Great Barrier Reef Marine Park to the extent of Australia's Exclusive Economic Zone.

The sector collects a vast array of colourful tropical and subtropical fish species, corals and invertebrates to supply Australian domestic retail aquarium outlets and international wholesalers that ultimately provide the specimens to home hobbyists. The fisheries are low volume, high value fisheries that have a high degree of reliance on coral reefs.

The threat of climate change and the associated predicted impacts on coral reefs prompted the industry to include a preliminary response to events linked to climate change in their *Stewardship Action Plan* (statement of operational standards). These response strategies complement climate change response planning developed by the government agencies that oversee sustainable fisheries production and the conservation of biodiversity on the Great Barrier Reef.

The Great Barrier Reef Marine Park Authority (GBRMPA) funded the *Climate Change Vulnerability Assessment* for the aquarium supply sector to further develop industry's climate change preparedness. The report forms the first stage of a Climate Change Adaptation Plan and is designed to assist the sector to understand:

- the range of biophysical predictions and the implications for the operation of businesses in the sector, including elevated costs associated with carbon pollution mitigation policy
- how management of the Great Barrier Reef aims to maximise reef resilience and the capacity of reefs to recover after disturbance.

The report includes an analysis of the dynamics and value of the sector; a summary of the predicted biophysical effects of climate change on the Great Barrier Reef and the added consequences of carbon pollution mitigation policy; a review of methodology for assessing ecological risk of the fisheries amid the predicted impacts of climate change; a review of the current management of the fisheries and protected areas, including the integrative response involving the management agencies and the industry and concludes with an assessment of the vulnerability of the marine aquarium supply sector to climate change.

Supply Chain Analysis

Based on a survey of operators, a 'first pass' supply chain model analysis was completed. The survey described the dynamics of the industry and determined a value and rate of return from the fisheries collectively. Key points from the survey and the supply chain analysis include:

- Whilst substantial and valuable, survey data is limited in scope and detail. Although only half the industry participated in the survey, most of the major producers of coral and live fish were included in the analysis. Since the number of firms in the industry is small, data confidentiality precludes any reporting of the relative value contribution by each firm, or by a group of larger firms in the industry.

- The production and the post production components of the supply chain are the most important cost components in this industry, accounting for 51 per cent and 32 per cent respectively, in total cost.

    → In terms of the cost of production, the costs of wages, capital costs, purchase costs of materials and energy and fuel accounts for almost 90 per cent of total costs. The most important parts are wages and capital costs, accounting for 35.5 per cent, 31.1 per cent in total cost of the production component respectively.

    → For the post production component the cost of transportation (including manufacturing freight and cartage, production freight and cartage, and packaging) accounts for more than 85 per cent of the total. The high costs in this cost component are mostly due to the export of live fish and coral to overseas markets.

- Based on average vessel cost components, large variations in revenue and costs per vessel were observed across businesses in the survey. Vessel sizes and operational capacity vary substantially, which skews the data and limits detailed analysis.

    → From survey data, total revenue of the aquarium industry is $5.7 and $8.9 million for 2007-08 and 2008-09 respectively. Total costs are $4.15 and $5.58 million. Net benefit is $1.6 and $3.35 million.

    → Based on the survey analysis, supporting estimates and most likely response, the gross value of production of the aquarium fishery is estimated to be roughly $10 to $12 million dollars per annum. The return on capital investment is roughly calculated in the range of 13 to 16 per cent. The industry is thus highly lucrative and delivers a substantial rate of return.

- There are a number of identifiable vulnerabilities facing the aquarium industry. These include the following:

    → Since a large component of coral and live fish is exported, changes in the exchange rate can have significant effects on demand and profitability. A fall in the value of the Australian dollar would normally increase the demand for Australian exports, and this is likely to happen over the near term, but exchange rate variability (ignoring trend) remains a concern, especially as at the time of writing the Australian dollar had achieved parity with the US dollar.

→ Changes in the cost of fuel and electricity can have substantial effects, but one of the major components of variable costs in the fishery is the cost of labour. Government changes in the minimum wage rate or the required employer minimum superannuation payments will greatly impact the industry.

→ Stochastic weather events including cyclones are a major source of vulnerability, limiting fishing time and the availability of the take of live fish after a weather event.

→ Changes in government policy, including increased limitation of fishing areas, will potentially affect this industry greatly, with effort concentrated in smaller areas. Area restrictions generally increase fuel costs, often dramatically, as fishers have to access more remote areas on the reef. The introduction of a carbon price will also increase costs and especially so if the price of electricity rises significantly.

Climate Change and the Great Barrier Reef

Descriptions by various authors within *Climate Change and the Great Barrier Reef: A Vulnerability Assessment* (Johnson & Marshall, 2007) paint a picture of the Great Barrier Reef in the future that sounds warning bells for fishery participants. The picture includes:

- Increased frequency and extent of coral bleaching
- Cyclones that are more damaging if not more frequent
- More extreme rainfall events if not more rainfall
- Diminished capacity of corals and the reefs they build to recover.

There is substantial confidence in these predictions on the basis of measurements and observations of key parameters, including atmospheric CO_2 and air and sea surface temperatures. The southern parts of the Great Barrier Reef are likely to be affected first. The consequences of these predictions include:

- A shift from coral dominated reefs to algal dominance
- Lower structural complexity leading to reduced habitat
- Local extinctions of sensitive, rare and highly specialised species
- Reduced population sizes
- Reduced biodiversity
- Ultimately, a shift in balance from net calcification to net erosion.

There is substantial uncertainty around the specifics of the predictions, including timing and the spatial dimensions of the predicted effects. However, the *Outlook*

Report 2009, which effectively guides the GBRMPA, states clearly that the primary focus of the GBRMPA is to maximise reef resilience to minimise the harmful effects of climate change.

Assessing Ecological Risk

The existing Ecological Risk Assessments for the two aquarium supply fisheries that operate on the Great Barrier Reef was reviewed and another ecological risk assessment methodology was adapted to add further dimensions, including climate change. The methodology now incorporates the anticipated consequences of climate change and assesses direct and indirect effects of the fishery on habitats, including the ecological processes that underpin the functional integrity of the habitat, particularly with regard to maximising reef resilience and the capacity of reefs to recover after disturbance. The purpose of the review was to see if this approach would be suitable for the next assessment of ecological risk by Fisheries Queensland.

The review considered the risk of the fishery affecting ecosystem function, given the small numbers of a wide range of species taken in the two fisheries and the lack of species-specific stock information at a scale as large as the Great Barrier Reef. The review identified fish species with limited functional redundancy (including herbivorous grazers and scrapers) and coral species that are critical to contributing to structural complexity on coral reefs, which forms habitat for a diverse range of reef species. The key outcomes of this first pass approach suggested that even when the additional layers of consideration were included, the fisheries still represented a low risk to the habitats that underpin them. Importantly, the combined methodology supports ongoing monitoring and is able to better determine the risk to ecological processes from the fisheries.

Reviewing Management Arrangements

This report explores existing GBR management arrangements and the importance of climate change in those arrangements. This section of the report is intended to focus industry attention on how they fit within the management framework so they can buffer their business impacts from climate change-related management decisions. Key arrangements to note include:

- Replacement of the *Emerald Agreement 1979* with the *Great Barrier Reef Intergovernmental Agreement 2009*. The new agreement recognises climate change and water quality as the major threats to the Great Barrier Reef. The Ministerial Council determined priorities for the Commonwealth and Queensland governments under the agreement to be: build and maintain resilience against the impacts of climate change and improve the quality of water entering the Great Barrier Reef.

- Listing under the *Environment Protection and Biodiversity Conservation Act 1999* of the Great Barrier Reef on the National Heritage List and the Great Barrier Reef Marine Park as a matter of national environmental significance.

- The number one objective of the current *GBRMPA Corporate Plan* is to address key risks affecting the outlook for the Great Barrier Reef. As detailed in the

Outlook Report 2009 climate change, water quality and loss of coastal habitats are currently the greatest threats to the Great Barrier Reef. The Outlook Report specifically pointed out that inshore coral reefs are the most vulnerable as the impacts of coral bleaching are compounded by issues of water quality and diminished capacity to recover.

- The Commonwealth and Queensland governments responded to the *Outlook Report 2009* by committing to build and maintain resilience through the *Zoning Plan* and the *Reef Water Quality Protection Plan*.

- The GBRMPA *Climate Change Action Plan* identified the *Zoning Plan* as a means for protection of refugia for thermally tolerant coral species that will provide genetic stock for recovery and to protect species and habitats that are highly vulnerable to climate change (e.g. corals).

- The *Climate Change and the Great Barrier Reef: A Vulnerability Assessment 2007* stated that the overlap of no-take areas with the location of climate change refugia should be a focus of future research effort and zoning reviews. It also recommended a management approach that is risk-based, precautionary and adaptive to changing conditions and knowledge.

Management of the aquarium supply fisheries is also described, including the various input and output controls; monitoring and assessment framework; spatial overlap with marine parks management arrangements at state and federal levels; fishery data recording and reporting; strategic direction and mechanisms for industry consultation. Key characteristics to note include:

- Handwritten logbook submission to Fisheries Queensland to monitor catch and effort for both fisheries results in a delay of a minimum of two months for accessing data of species level catch at fine spatial scales. Noting that real-time data collection in the Queensland Coral Fishery is for quota debiting purposes only.

- *Queensland Fisheries Strategy 2009-2014* to review the existing legislative framework to enable more flexible and responsive management of fisheries, investigate controls on fishing output and the use of technology, and develop models of co-management and regional management.

- Formal industry engagement and consultation through the Queensland Fisheries Advisory Committee is at a strategic level only. There is currently no formal mechanism for engagement and consultation at an operational level as the Management Advisory Committee has been disbanded. However, Coral and Aquarium Working Groups are convened by Fisheries Queensland on an as needs basis to review and provide advice on management matters related to the industry. This group has a defined list of members sourced from industry, the scientific community, conservation groups and management agencies.

Also described are the response plans for events linked to climate change by the management agencies and by Pro-vision Reef and the manner in which they are integrated.

- Implementation of the GBRMPA *Coral Bleaching Response Plan* is guided by a multi faceted system of information input to an early warning system that uses a combination of technology and community monitoring programs.

- The *Coral Bleaching Response Plan* establishes a framework for the allocation resources; assessment of the extent and severity of disturbance and action options. It also describes a range of management responses, which include separating human activity from areas most at risk and to protect refugia with resistant populations, possibly through reef protection markers or temporary closures.

- Fisheries Queensland's *Coral Stress Response Plan* is guided by the spatial bleaching information from the *Coral Bleaching Response Plan*. However, to determine spatial and depth overlap of the fisheries with bleached areas, and the linkage to groups of fish and coral critical to recovery after disturbance, requires examination of logbook data and verification with individual operators. The *Coral Stress Response Plan* establishes a task force that includes a representative from Pro-vision Reef.

- The climate change response in the Pro-vision Reef *Stewardship Action Plan* aims to complement the compulsory *in situ* assessment with the situation analysis in the *Coral Bleaching Response Plan* and to match the differentiated collection strategies with the management response in the *Coral Stress Response Plan*. It also requires operators to report the incidence of bleaching in the same format as the community monitoring programs for consistency.

Assessing Vulnerability

Finally, the assessment analysed the capacity of the industry to adapt to the anticipated changes resulting from the predicted impacts of climate change. These fisheries rely on coral reefs (the habitats that are nominated as the most vulnerable to climate change) and there is also a market disadvantage from the high cost structures in which the fisheries work relative to competitors in other countries. However, fishery participants have historically demonstrated a capacity to adapt to change, including price shocks, the zoning of the Great Barrier Reef Marine Park plus the establishment of State marine parks. For example, fishery participants rapidly developed coral husbandry and shipping skills and international markets in the short period since accreditation of the coral fishery as an export fishery in 2006.

There are undeniable vulnerabilities associated with climate change. The predicted biophysical impacts to coral reefs are the most obvious. The sheer size of the fishery area, the frequent use of inter-reefal habitat, and the extent of knowledge and experience of operators in the fisheries go some way to mitigate vulnerability. However, elevated costs associated with the anticipated policy to mitigate carbon pollution, coupled with pre-emptive and precautionary management of the Great Barrier Reef in order to maximise reef resilience and capacity to recover after disturbance convey additional uncertainty and business risk. This might influence asset valuation and the access to finance in the future. It is expected that this vulnerability assessment will lead to an adaptation planning phase during which operational strategies are revisited; ecological risk assessment is augmented and that strategies might be devised and implemented at an industry and enterprise level.

1. Introduction

1.1. Project Background

Climate change brings many challenges to which our societies will need to adapt. Those challenges will initially encompass the biophysical world around us, and then flow to the socio-cultural and economic components of our environment, which are spheres of the biophysical world and are integrally linked (Figure 1.1). Planning by governments, industries and communities to adapt to anticipated changes is critical.

Acknowledging that challenges exist and seeking to understand the specific nature of those challenges and the implications for nations, industries and communities is the logical first step in planning for adaptation. This project seeks to understand the challenges facing an industry that is reliant on the natural resources held within one of the world's natural wonders, which (as an ecosystem) has been identified as particularly vulnerable to the effects of climate change.

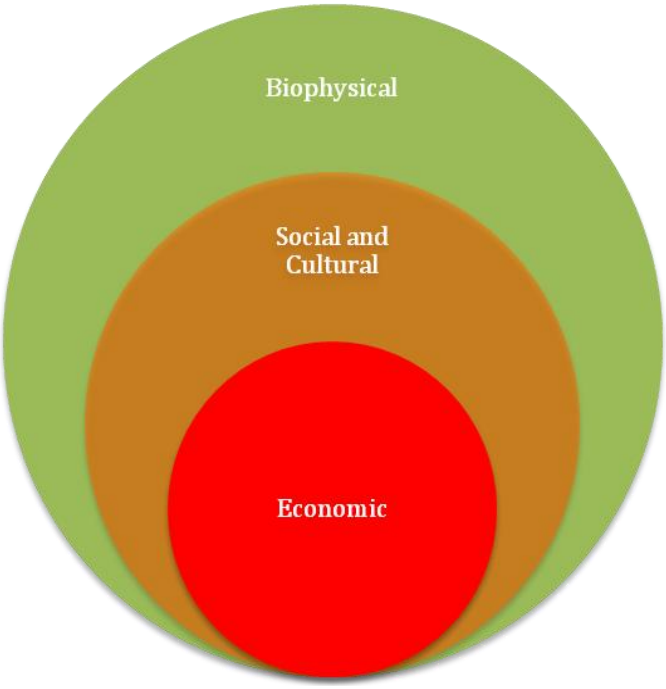


Figure 1.1. Schematic representation depicting the natural world (biophysical) encompassing humanity (social and cultural), which in turn encompasses the mechanism by which humanity typically functions and develops (economic). "Economic" may be interpreted in many ways, including subsistence, barter, or commerce.

The focus of this project is the marine aquarium supply industry in Queensland, much of which is conducted within the waters of the World Heritage listed Great Barrier Reef. The project will be conducted in two stages. The first of these stages will be presented in this document and aims to assess the vulnerability of the industry to climate change and the capacity of the industry to adapt to the anticipated challenges. The second stage will build on the outcomes of this report to develop an industry *Climate Change Adaptation Plan*.

As far as possible, the approaches taken in this project are consistent with the conceptual adaptation engagement pathway for climate adaptation (Figure 1.2), developed by the Climate Adaptation National Research Flagship, CSIRO (Gardner *et al.*, 2009)

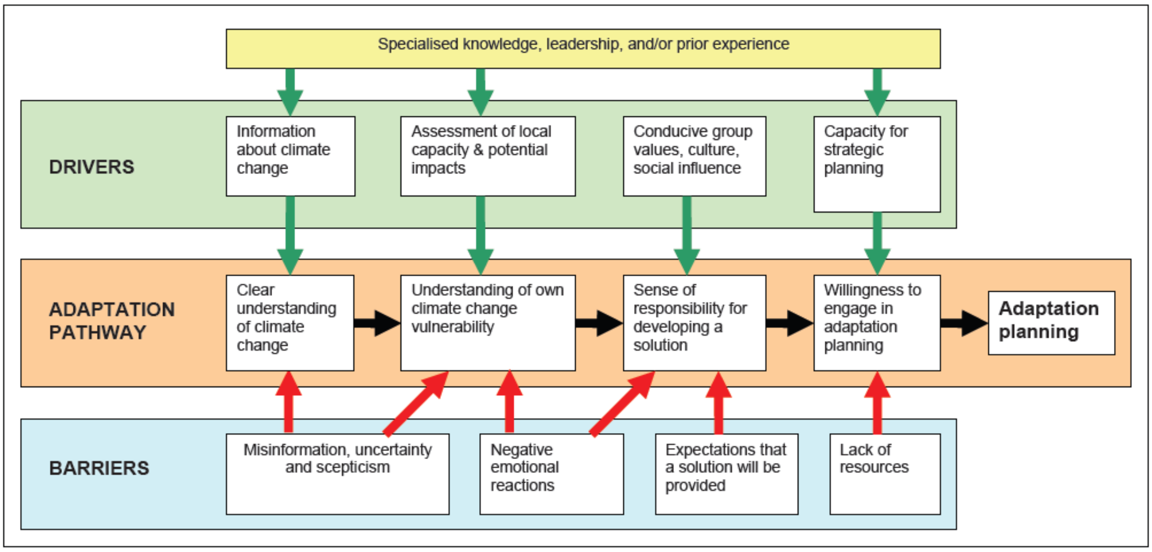


Figure 1.2. A pathway for adaptation engagement with associated drivers and barriers (from Gardner *et al.*, 2009).

This report does not prescribe binding actions for the marine aquarium supply industry but is intended to alert industry participants and resource managers of the possible implications of the predicted effects of climate change on the Great Barrier Reef so that actions, including business and management decisions, are based on some understanding that the climate change risks to the natural environment will inevitably flow to the industries that rely upon it and the communities that rely on the industries.

The marine aquarium supply industry in Queensland is small by global standards but produces premium quality specimens for display that meet the market from within a sound, and continuously improving, provenance model.

Assessments of risk to the ecosystems and the populations of species that underpin the industry have been developed to guide management of the fisheries. These assessments, and the actions that result from subsequent management arrangements, are periodically reviewed against the Guidelines for the Sustainable Management of Fisheries[1] under Australia's comprehensive environmental legislation.

The industry comprises the Marine Aquarium Fish Fishery (MAFF) and the Coral Fishery (QCF) managed by the Queensland government, and the Coral Sea Fishery managed by the Commonwealth.

There is significant overlap between these fisheries with many operators working across both Queensland fisheries and two operators working across all three. These are low volume, high-value fisheries that involve relatively few participants collecting a broad array of species and working across a very large area.

[1] http://www.environment.gov.au/coasts/fisheries/publications/guidelines.html

The peak body representing licenced aquarium specimen suppliers was established in 1992 as the Queensland Aquarium Supply Divers Association. The association became known as Pro-vision Reef Inc in 2007 to reflect a more proactive approach to achieving a prosperous future for the industry. Membership of the association includes the majority of active licences and accounts for about 90 per cent of the output from the fisheries.

A major focus of Pro-vision Reef is to ensure that the fisheries operate at the world's highest standards of environmental performance and that this is recognised in the community and the market. In 2009, Pro-vision Reef released the *Stewardship Action Plan*[2] that prescribes compulsory collection strategies for both corals and fish that aim to minimise the collector's environmental footprint.

Figure 1.3. The Pro-vision Reef *Stewardship Action Plan* is a landmark initiative that establishes an initial framework for articulating high-resolution management of fishery activity from the bottom up. In addition, the *Stewardship Action Plan* acknowledges climate change as a future challenge and accordingly establishes protocols for responding to key indicators, including reporting to the GBRMPA in a standardised format.

The *Stewardship Action Plan* was designed to make a clear statement of operational activity and standards due to the fact collection is carried out underwater and out of sight. The Plan detailed the highly selective nature of collection, the thinking behind

[2] www.pro-visionreef.org/content/stewardship-action-plan

harvesting strategies and the many environmental factors that limit fishing effort and catch.

The *Stewardship Action Plan* also served to differentiate the more costly Australian aquarium specimens in a market dominated by cheaper specimens often sourced from fisheries where the same rigorous standards do not apply.

In what was called a world's first for a fishery at the time, the *Stewardship Action Plan* includes a response plan for events linked to global climate change. Using coral bleaching as the key indicator, the *Stewardship Action Plan* requires members who encounter bleaching to carry out *in situ* site assessments according to a standardised method, and then report the incidence to the GBRMPA. Depending on the severity of bleaching, additional collection strategies apply, including not collecting at all from heavily affected sites.

Fishery participants typically collect at reefs, and some inter-reefal areas, that are not often used by other marine sectors - primarily for safety reasons because most participants use hookah apparatus that involves a significant length of air hose floating on the surface. The *Stewardship Action Plan* consequently enables the GBRMPA to collect bleaching information from reefs for which they would otherwise have little or no information, and in a format that is consistent with a long running community monitoring program.

The climate change response component of the *Stewardship Action Plan* is linked to the *Coral Bleaching Response Plan* (CBRP)[3] developed by the GBRMPA and the fishery-specific *Coral Stress Response Plan* (CSRP)[4] developed by Fisheries Queensland. The CBRP is triggered when sea surface temperature monitoring in spring indicates a high risk of bleaching in the coming summer, which in turn requires Pro-vision Reef members to engage in the climate change response component of the *Stewardship Action Plan*. At this point, Fisheries Queensland convenes a Task Force in accordance with their CSRP that includes a Pro-vision Reef representative. The role of this group is to assess the extent and severity of bleaching and to determine any management actions that might be necessary, in conjunction with actions being taken by other sectors in response to the situation.

This integrative approach to management is desired by Pro-vision Reef, Fisheries Queensland and the GBRMPA. It represents the first tentative steps toward adopting co-management for these fisheries and is consequently breaking new ground for fisheries in Queensland. Aside from establishing a mechanism by which management agencies might embark down a co-management path for commercial fisheries in Queensland, Pro-vision Reef has recognised that global climate change is an important issue that must feature in industry level planning for the future, as well as planning at an enterprise level.

Developing climate change adaptation planning for users of the Great Barrier Reef Marine Park is hampered by scepticism that counters that climate change is not the threat that scientists state. Many experienced users of the Great Barrier Reef have repeatedly observed the Reef recover from disturbance, including cyclones, coastal flooding and, in more recent times, coral bleaching. However, scientists tell us that

[3] www.pro-visionreef.org/content/culture-collaboration
[4] www.pro-visionreef.org/content/culture-collaboration

full recovery is dependent upon the existing health or resilience of the reef. This means that if the frequency and extent of disturbance is increased, the reef will not recover to the same extent that a healthy and robust system would. According to the predictions that follow, the capacity of reefs to recover is likely to be impeded in the future such that there is steady deterioration, through the cycle of disturbance and recovery, to the complexity of reef structure and the ability to support the same degree of biodiversity. Consequently, maximising reef resilience and populations of the species that perform critical functions in the recovery of reefs after disturbance is an issue to be addressed by industries reliant on the Reef, including the marine aquarium supply industry.

1.2. Project Aims

Ultimately, the aim of this project is to develop a *Climate Change Adaptation Plan* for the marine aquarium supply industry. In order to undertake such a planning exercise, substantial baseline information needs to be compiled and the impacts of climate change need to be understood, including the short term impacts of anticipated carbon pollution mitigation policy on business inputs and the subsequent strategies to alleviate cost pressure, the longer term pressure on the natural resilience of the resource itself and how fisheries and marine protected areas management might need to adapt not only to protect the resource but also to retain a profitable, sustainable industry.

The project draws on the experience of the east coast Tasmanian rock lobster fishery, which was used as a case study for the *National Coastal Vulnerability Assessment* by the Australian Government's Department of Climate Change (Pecl *et al.*, 2009). The location of this fishery means it is seen as the early warning signal for climate change impacts on Australian fisheries, as the east coast of Tasmania is currently experiencing ocean warming faster than any other region in the southern hemisphere. The East Australian Current is already extending further south, carrying warmer water into the fishery area.

The Tasmanian rock lobster study revealed that the warmer water was increasing primary productivity, which initially increased lobster biomass and fishery output. However, the warmer water also expanded the range of a species of sea urchin that grazes heavily on areas critical to the life cycle of the targeted species. Modelling suggests that short-term increases to fishery productivity will give way to longer-term decline. The project was used to identify vulnerability and to examine how the industry reliant on the fishery might adapt in the future. It is expected that the learning from the Tasmanian case study will inform adaptive planning for other fisheries nationally and internationally.

There are many differences between the east coast Tasmanian rock lobster fishery and the marine aquarium supply fisheries in Queensland – not the least of them being a significant difference in both latitudinal range (the Queensland fishery ranges across about 14 degrees of latitude) and number of species taken (~800 in Queensland versus a single species in Tasmania). However, the challenge of adapting to the biophysical changes and subsequent socio-cultural and economic impacts of climate change is shared. The challenge for this project is to identify and work with these common threads, and extend the framework to include new elements, as needed.

Embarking on this project marks a critical point in the evolving relationship between industry and the government agencies that oversee both the conservation of biodiversity and sustainable fishery production in the region where these fisheries operate. This maturing relationship is viewed as beneficial to all parties.

This first stage of the *Climate Change Adaptation Plan* has been undertaken by Pro-vision Reef with assistance from Professor Tom Kompas from the Australian National University in Canberra. Technical assistance was provided by Professor David Bellwood and Dr. Morgan Pratchett from the Australian Research Council Centre of Excellence in Coral Reef Studies at James Cook University in Townsville. An Advisory Group that includes representatives from Pro-vision Reef Inc, the GBRMPA, Fisheries Queensland, and the Queensland Seafood Industry Association provided support and guidance. The project was funded from Department of Climate Change money to support the GBRMPA *Climate Change Action Plan.*

1.3. Project Structure

This first section of the broader *Climate Change Adaptation Plan* gathers the baseline information that will assist a determination of the vulnerability of the marine aquarium supply industry in Queensland to climate change - the *Climate Change Vulnerability Assessment*.

Section 2 is an economic description of the marine aquarium supply industry in Queensland, much of which operates on the Great Barrier Reef. The section is produced by Professor Kompas. It describes the dynamics of the industry and identifies industry vulnerabilities, including those that relate to business practices from elevated cost structures, fluctuating currency valuation and proposed changes to industrial relations policy, such as compulsory superannuation responsibilities.

Section 3 of this report is a synthesis of the predictions accompanying climate change, including a range of likely development pathways for the 21st century that encompasses population dynamics, technological development and international cooperation. These pathways, or storylines, have been modelled and result in various scenarios for the degree to which the greenhouse effect is enhanced and outlines the concomitant impacts on landscapes and ecological systems. The section also outlines the predicted impacts on the Great Barrier Reef and establishes the challenges faced by resource users and managers in a warming climate.

Section 4 reviews the existing Ecological Risk Assessment methodology for the two Queensland-managed fisheries. The section does not produce new Ecological Risk Assessments but adapts a methodology that was developed for data poor fisheries (Astles *et al.*, 2009) and incorporates indirect risks to habitats from fishery activity in the context of the predicted impacts of climate change. It is here the vulnerability assessment identifies ecological processes that are critical to recovery of coral reefs after the types of disturbances anticipated to accompany climate change. Further, it identifies the fish and coral species that, to a large extent, carry out or contribute to those processes. Identification of the species and a rationale for their inclusion was provided by Professor Bellwood and Dr. Pratchett.

Section 5 reviews the current management arrangements for the Great Barrier Reef, including those that specifically apply to the two fisheries. It briefly describes the legislative and regulatory framework for fishery management at the state level and strategic assessment against the Wildlife Trade and Threatened Species provisions of Australia's environmental law. Importantly, it examines the current management provisions for the fisheries, including the fishery specific information that enables adaptive management to take place with a high level of confidence. It also describes and critiques the existing response mechanism for events linked to climate change.

Section 6 is the final section and draws together the learnings of the previous sections to assess the vulnerability of the marine aquarium supply industry to climate change, in accordance with the framework outlined in Figure 1.4, which is the framework adopted for the Tasmanian rock lobster fishery. This same framework was also used to describe the climate change vulnerability of reef building corals in Section 3, considered to be pivotal to the future of the Great Barrier Reef and the industries that rely upon it. Essentially this report will map as closely as possible onto the first five boxes of Figure 1.4, to reach an assessment of industry vulnerability to climate change.

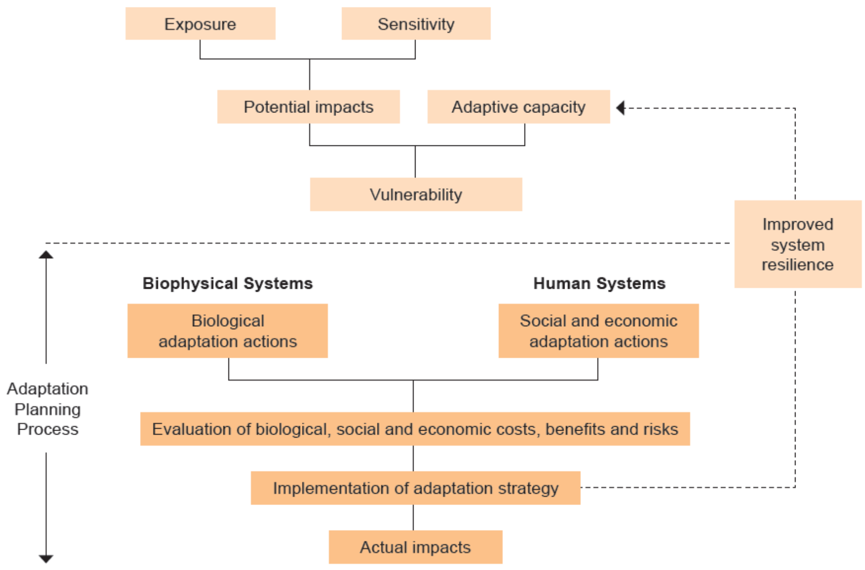


Figure 1.4. Framework for assessing vulnerability of the marine aquarium supply industry to climate change.

Beyond this vulnerability assessment, an adaptation planning process will be undertaken. The methodology for this process and the manner in which it might be implemented is yet to be determined. However, the existing *Stewardship Action Plan* could provide carriage for strategies that guide implementation of a *Climate Change Adaptation Plan* in concert with Fisheries Queensland's CSRP and the GBRMPA CBRP, which would further develop co-management of these fisheries.

2. Aquarium Sector Supply Chain Analysis

The aquarium supply industry on the Great Barrier Reef operates within the MAFF (42 commercial (A1) licences and 4 recreational (A2) licences) and the QCF (59 licences). Several businesses have multiple endorsements and many operate in both fisheries. The industry is comprised of less than 30 businesses of disparate scale, including two that also operate in the Coral Sea Fishery.

There are a number of different attributes or characteristics of these fisheries compared to other fisheries. First, the number of species is very large – in the order of 800 species. Second, the price of each species ranges widely from several dollars each for the more minor species to $5,000 to $6,000 for some species for display in public aquaria. Third, the export market for this industry is large. In some major businesses in this industry, the export value accounts for about 85 per cent of the total gross value of production. The most important export market is the United States. Finally, by its nature, this is a live-capture fishery and in that sense stands out markedly from other capture fisheries.

The Australian aquarium industry as a whole has tremendous potential and is a growing industry. The industry contains economically valuable near-shore fisheries in Australia, especially in Queensland. An economic analysis of supply chain of the fishery is essential for fisheries management. However, at present there is very little economic analysis of the fishery and almost no data available. Comparable values for other industries of the same type are also difficult to obtain or quantify. For example, estimates of Gross Value of Product for the Hawaiian aquarium fishery ranges considerably from $2-10 million in 2009 (Reef Fish Recovery Project of Hawaii, 2009).

The fish survey data of the Australian aquarium fishery in 2010, undertaken with this project, provides key statistics for the major aquarium companies. The analysis of this report is based on that survey data. In particular the objectives of this report are:

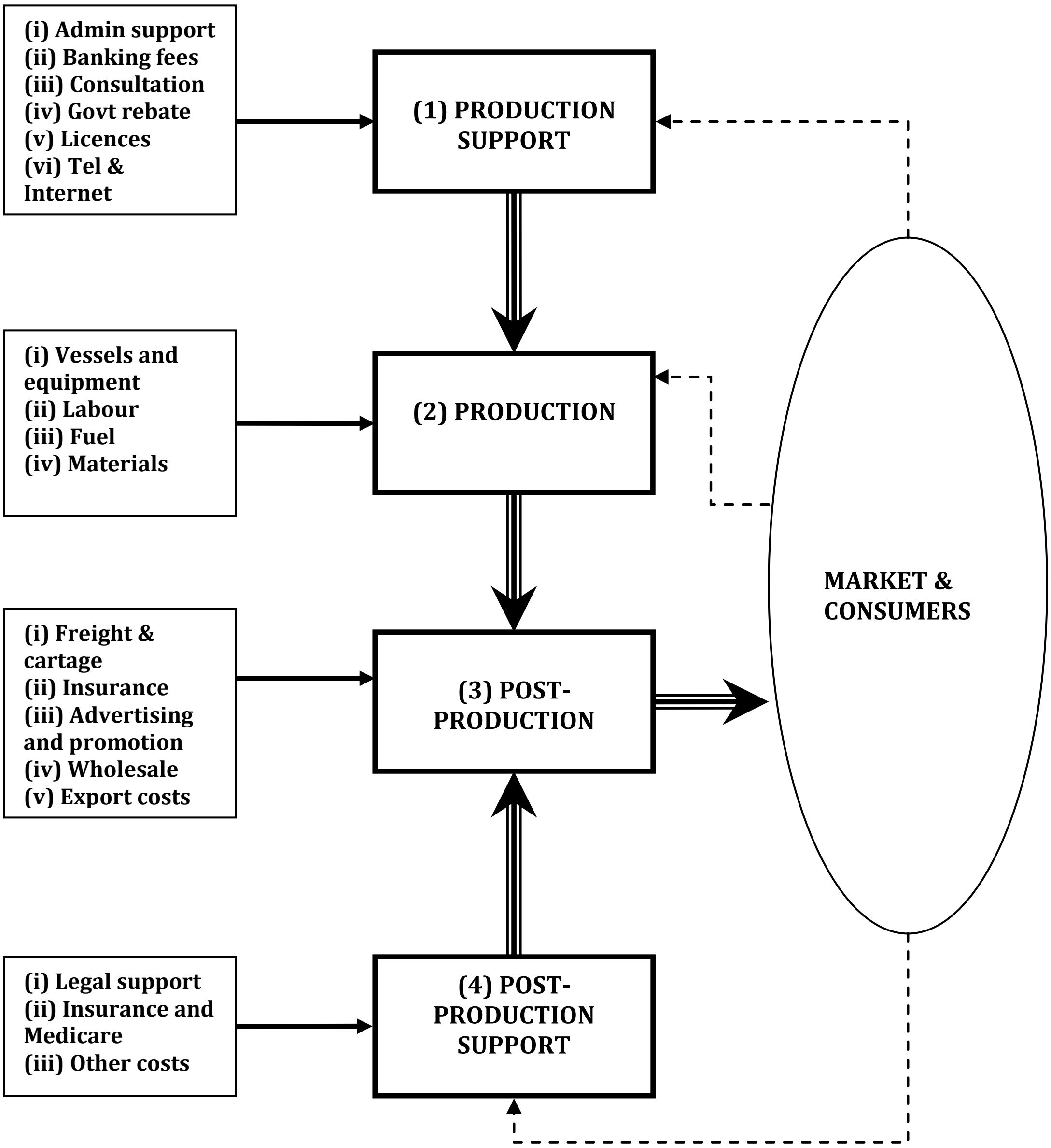
(1) To analyse revenue, costs and capital investment by operator and estimate revenue and cost components of the overall fishery

(2) To obtain fleet information (size and number of boats)

(3) To define a supply chain model of the fishery, which identifies key inputs, and activities, including revenues and costs

(4) To identify major risks or vulnerabilities facing the industry.

2.1. Supply Chain Model of the Australian Aquarium Industry



The graphic above specifies a supply chain model for the aquarium industry. The supply chain graphic includes four components: production support; production; post production and post-production support. Each component includes the key input factors to the output of that component. In the production component, for example, the key inputs required for fishing are vessels and equipment (capital), labour, fuel and materials. In the post production component the key inputs are identified by the support for the sale and marketing of aquarium products to the market. The most important share of costs of the production support area, the production area and the post production area are covered by the fishing business. However, costs and expenditures of the post-production support, as indicated, are not likely to be covered by the fishing businesses.

2.2. Survey of the Queensland Aquarium Fishery

In June 2010, a survey of Queensland aquarium business was carried out by Professor Tom Kompas from the Australian Centre for Biosecurity and Environmental Economics at the Australian National University. The survey included 10 businesses with a reported potential of 23 and 28 operating vessels in 2007-08 and 2008-09 respectively.

The survey captures a major part of the fishery (see Table 2.1.) in terms especially of gross value of production, if not in terms of number of businesses. Focusing on the analysis of aquarium business in general, this report contains 40 surveyed components that are the key activities in both costs and revenues of the aquarium industry.

The survey covers more than 43 per cent of businesses. Data confidentiality precludes specification of the distribution of the gross value of production by business, since much of the value of output is concentrated in only a few businesses. Over 100 accounting categories, which were included in the activities of one or a very few of the businesses, are not included in the analysis. Four cost items (so-called written off bad debts, borrowing expenses, entertainment expenses, and opening stock), which are not directly linked to business, are also not included in the analysis. All of the costs were analysed following the supply chain components as indicated in the supply chain graphic.

Table 2.1. Survey of Queensland aquarium fishery, 2010.

	2007-08	2008-09
Number of surveyed businesses	7	10
Potential number of surveyed vessels	23	28
Potential total vessels	44	44

2.3. Economic Performance

Total revenue and costs by each cost category are presented in Table 2.2. These are all aggregated categories drawn directly from the survey data set. Total revenue of the aquarium businesses was $5.7 and $8.9 million for 2007-08 and 2008-09 respectively (see Table 2.2). Note that the number of surveyed business in 2007-08 (7) is less than that in 2008-09 (10). The value and the share of each value chain component in total costs are as indicated in Table 2.2, as follows from the supply chain graphic. Total costs are $4.15 and $5.58 million. Production and the post production support are the most important, accounting for 51 per cent and 32 per cent in total cost respectively. Net benefit is $1.62 and $3.35 million.

2.3.1. Revenue and Costs

Table 2.2. Total revenue, costs and benefit.

Category	Content	2007-08		2008-09	
Total revenue		$5,776,236		$8,936,164	
Cost contents	Cost category	Value	Share of costs	Value	Share of costs
1	Production support	$527,002	12.68%	$636,591	11.41%
2	Production	$2,239,484	53.89%	$2,738,245	49.06%
3	Post-production	$1,350,818	32.50%	$2,179,447	39.05%
4	Post-production support	$38,466	0.93%	$27,044	0.48%
Total costs		$4,155,770	100%	$5,581,327	100%
Benefit		$1,620,467		$3,354,837	

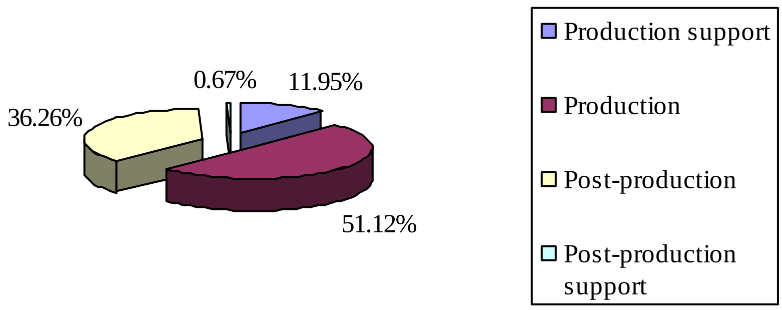


Figure 2.1. Share of in total costs of supply chain by category (average value of 07/08 and 08/09).

2.3.2. Value Chain Analysis

(1) Production support accounts for around 12 per cent of total costs, of which the cost components of rent, interest, and insurance accounts for roughly 73 per cent of total production support cost (see Table 2.3 and Figure 2.2).

Table 2.3. Average production support costs per business.

Contents	2007-08		2008-09	
	Value	Share	Value	Share
Insurance	$84,513	16.04%	$116,165	18.25%
Accounting fees	$35,946	6.82%	$22,067	3.47%
Bank charges	$11,845	2.25%	$14,632	2.30%
Computer maintenance	$6,351	1.21%	$18,369	2.89%
Interest	$145,643	27.64%	$159,297	25.02%
Postage	$9,333	1.77%	$5,822	0.91%
Telephone	$36,312	6.89%	$42,733	6.71%
Printing & stationery	$20,201	3.83%	$12,617	1.98%
Rates	$12,097	2.30%	$9,712	1.53%
Rent	$140,696	26.70%	$202,952	31.88%

Licences permits	$9,600	1.82%	$14,613	2.30%
Licensing fees	$7,503	1.42%	$8,494	1.33%
Mooring fees	$6,961	1.32%	$9,117	1.43%
Sum	**$527,002**	**100%**	**$636,591**	**100%**

The average shares of the key costs in total cost of production support are presented in Figure 2.2. Rent, interest and insurance predominate.

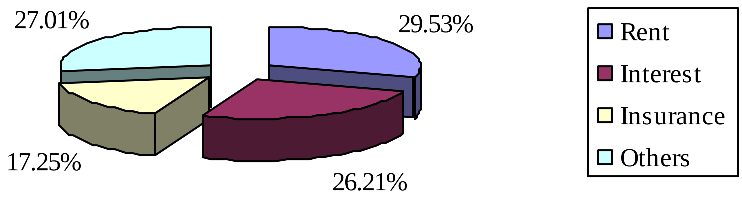


Figure 2.2. Share of detailed costs in the production support costs (average value of 07/08 and 08/09).

(2) Production cost accounts for more than half of total costs. The survey data indicates that the costs of wages, capital (as a sum of depreciation and repair and maintenance), and the purchase costs of materials and energy and fuel (as a sum of electricity and gas and fuel and oil) accounts for almost 90 per cent of production cost (see Table 2.4. and Figure 2.3.).

Table 2.4. Average production costs.

Contents	**2007-08**		**2008-09**	
	Value	Share	Value	Share
Depreciation	$418,385	18.68%	$792,970	28.96%
Electricity & gas	$93,584	4.18%	$128,657	4.70%
Repairs & maintenance	$139,185	6.22%	$197,304	7.21%
Wages	$782,997	34.96%	$983,593	35.92%
Fuel & oil	$101,049	4.51%	$147,732	5.40%
Superannuation	$292,497	13.06%	$122,201	4.46%
Work cover	$3,287	0.15%	$9,608	0.35%
Purchases cost - fish & coral	$357,066	15.94%	$298,478	10.90%
Staff training	$20,114	0.90%	$11,931	0.44%
Boat food supplies	$11,663	0.52%	$11,463	0.42%
Dive equipment	$19,657	0.88%	$34,309	1.25%
Sum	**$2,239,484**	**100%**	**$2,738,245**	**100.00%**

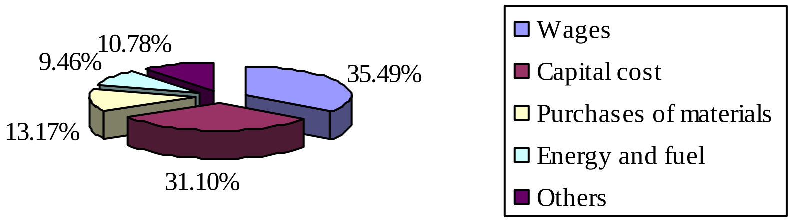


Figure 2.3. Share of detailed costs in the production costs (average value of 07/08 and 08/09).

The share of wages, capital cost, purchase costs of materials and energy and fuel accounts for about 35.5 per cent, 31.1 per cent, 13.2 per cent and 9.5 per cent in total cost of production respectively.

(3) Post production cost accounts for 36.3 per cent of total costs. An important characteristic of this fishery is the cost of transportation of live fish, corals and invertebrates overseas (including manufacturing freight and cartage, freight and cartage and packaging), accounting for more than 85 per cent of total cost of post production (see Table 2.5 and Figure 2.4).

Table 2.5. Average post-production costs.

Contents	2007-08		2008-09	
	Value	Share	Value	Share
Packaging	$276,859	20.50%	$311,917	14.31%
Advertising & promotion	$71,744	5.31%	$89,871	4.12%
Freight & cartage	$173,268	12.83%	$388,902	17.84%
Traveling expenses	$54,774	4.05%	$90,901	4.17%
Freight & cartage manufacturing	$696,058	51.53%	$1,188,710	54.54%
Motor vehicle expenses	$29,844	2.21%	$40,586	1.86%
Water - salt	$48,272	3.57%	$68,560	3.15%
Sum	**$1,350,818**	**100%**	**$2,179,447**	**100%**

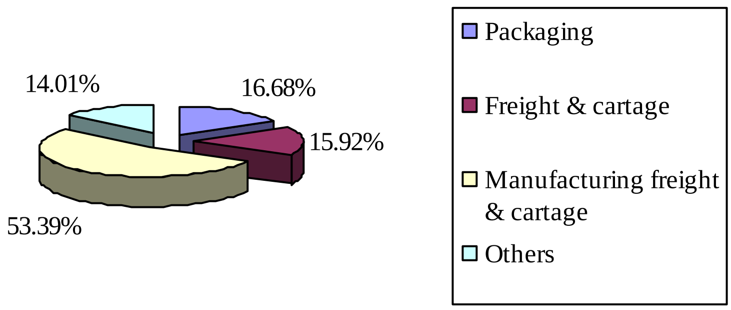


Figure 2.4. Share of detailed costs in the post production costs.

(4) Finally, the costs of post production support accounts for only approximately 1 per cent of the total costs of the supply chain.

Table 2.6. Average post-production support costs.

Contents	2007-08		2008-09	
	Value	Share	Value	Share
Subscriptions	$8,463	22.00%	$10,487	38.78%
Fees & permits	$12,526	32.56%	$12,722	47.04%
Donation	$7,649	19.89%	$2,452	9.07%
Legal costs	$9,828	25.55%	$1,383	5.11%
Sum	**$38,466**	**100%**	**$27,044**	**100%**

An overall summary of supply chain analysis of the aquarium fishery is presented in Figure 2.5.

2.3.3. Capital Investment

The data indicates an increasing trend in investment of capital and dive equipment in the industry. In an average business the value of capital and dive equipment increased by approximately 50 per cent from 2007-08 to 2008-09 (see Table 2.7). This trend corresponds to the increasing trend of revenue. On average, a dollar value of capital investment made $13.6 and $15.6 of revenue respectively (see Table 2.7).

Table 2.7. Costs of capital and equipment.

Contents	Value	Value
		Total surveyed businesses
	2007-08	2008-09
Depreciation	$418,385	$792,970
Repairs & maintenance	$139,185	$197,304
Dive equipment	$19,657	$34,309
Sum	**$577,227**	**$1,024,583**
		Average surveyed businesses
Depreciation	$59,769	$99,121
Repairs & maintenance	$23,198	$26,821
Dive equipment	$6,552	$11,436
Sum	**$89,519**	**$137,378**
		Capital investment return
Ratio of revenue over investment	$13.6	$15.6

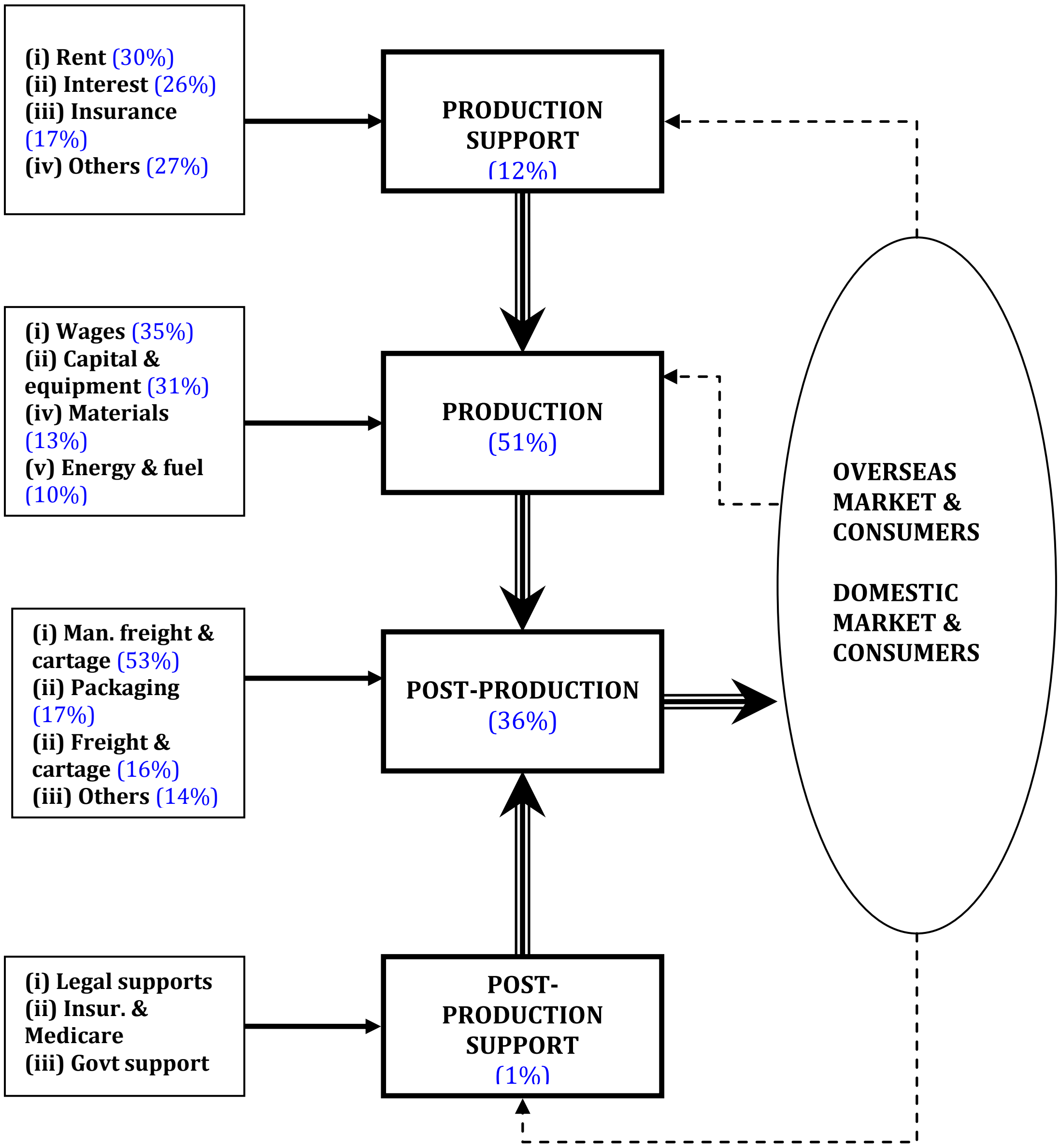


Figure 2.5. Estimated results of supply chain analysis of the Australian aquarium fishery.

2.4. Analysis of Economic Performance

The survey data is not perfectly 'balanced' in that the number of surveyed businesses is different for 2007-08 and 2008-09. Therefore this section provides an analysis of economic performance for an average business only as a suitable metric. However, recall two points:

(a) the supply chain analysis is limited by the quality and extent of the data

(b) the data is highly skewed with a large component of all revenue and cost categories defined by the largest (and relatively few in number) operators in the industry.

2.4.1. Revenue, Costs and Benefit

Total revenue and costs by each cost category per business (or on average) are presented in Table 2.8. Total revenue increased from roughly $800,000 to more than a million dollars per business, on average. The production and the post production expenditures are the most important parts of the supply chain. Table 2.8 and Figure 2.6 provide average measures of revenues and costs by supply chain categories.

Table 2.8. Average revenue and costs per business (noting that due to skewed data from widely varying size of business, the relationship between average total costs and average revenue is not linear).

Category	Content	2007-08		2008-09	
	Total revenue	$825,177		$1,039,334	
	Cost contents by category				
1	Production support	$110,836	12.54%	$105,570	9.66%
2	Production	$413,165	46.74%	$414,739	37.97%
3	Post-production	$349,399	39.52%	$566,301	51.84%
4	Post-production support	$10,650	1.20%	$5,739	0.53%

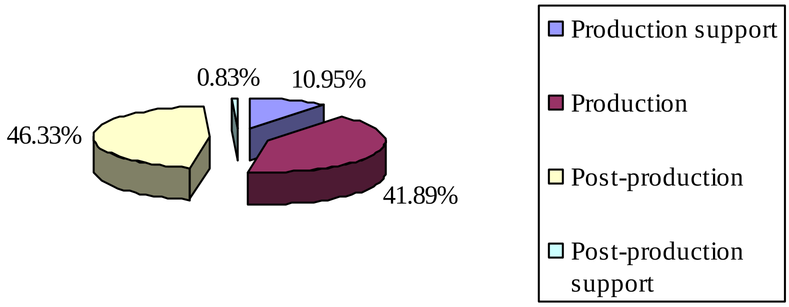


Figure 2.6. Share of total costs by category per average business (average value of 07/08 and 08/09).

2.4.2. Value Chain Analysis

The value chain analysis for an average business by major contents of production support, production, post production and post production support are indicated in Tables 2.9 to 2.12. These are highly indicative. Compared with total surveyed business revenue and cost components (Section 2.4) there is a slight difference in the percentage contribution of each major component.

Table 2.9. Average production support costs per business.

Contents	2007-08	2008-09
	Value	Value
Insurance	$12,073	$13,437
Accounting fees	$5,991	$3,152
Bank charges	$1,974	$1,732
Computer maintenance	$1,270	$3,096
Interest	$29,129	$20,229
Postage	$1,867	$1,178
Telephone	$7,262	$5,963
Printing & stationery	$5,050	$2,252
Rates	$3,024	$1,679
Rent	$35,174	$40,590
Licences permits	$3,200	$4,871
Licensing fees	$2,501	$2,831
Mooring fees	$2,320	$4,559
Sum	**$110,836**	**$105,570**

Table 2.10. Average values of production component per business.

Contents	2007-08	2008-09
	Value	Value
Depreciation	$59,769	$99,121
Electricity & gas	$15,597	$15,643
Repairs & maintenance	$23,198	$26,821
Wages	$130,500	$133,804
Fuel & oil	$20,210	$24,476
Superannuation	$58,499	$20,367
Work cover	$657	$1,647
Purchases cost - fish & coral	$89,266	$74,620
Staff training	$5,028	$2,983
Boat food supplies	$3,888	$3,821
Dive equipment	$6,552	$11,436
Sum	**$413,165**	**$414,739**

Table 2.11. Average values of post-production component per business.

Contents	2007-08	2008-09
	Value	Value
Packaging	$39,551	$38,990
Advertising & promotion	$11,957	$14,569
Freight & cartage	$28,878	$55,557
Travelling expenses	$10,955	$13,140
Freight and cartage costs	$232,019	$396,237
Motor vehicle expenses	$9,948	$13,529
Water - salt	$16,091	$34,280
Sum	**$349,399**	**$566,301**

Table 2.12. Average values of post-production support per business.

Contents	2006-07	2008-09
Subscriptions	$1,693	$2,223
Fees & permits	$3,131	$2,544
Donation	$2,550	$511
Legal costs	$3,276	$461
Sum	**$10,650**	**$5,739**

2.5. Distribution of Economic Performance by Vessel

This section provides an analysis of distribution and variations of revenue and costs per vessel across different businesses. The metric is average vessel for convenience. The graphical representations indicate the variance in the distribution across the industry of all major revenues and costs. It may have been preferable to use a diver metric (e.g. diver hours or days) for comparisons across industry, rather than vessels, especially since the normal calculation of 'effort' for this fishery is done in terms of diver hours. Unfortunately, this data was not available in time for the supply chain report.

2.5.1. Distribution of Revenue and Total Costs

The revenue per annum (an average over 2007-08 and 2008-09) by vessel varied significantly from roughly $50,000 to more than $600,000 over the two years. The revenue per annum of more than half of the vessels ranges from $50,000 to $300,000 (see Figure 2.7).

Note: This figure (and similar ones to follow) shows the distribution of the survey data, or here, revenues, across vessels - with the frequency of vessels designated by the height of the blue bars - in the survey data set. The small data set and confidentiality requirements prevent fully exact specification of boat numbers by relevant category. In Figure 2.7, for example, revenue for most of the vessels lies between $100,000 and $300,000. The average is roughly $212,000. The smooth red line in the figure is a 'best-fit' representation of the continuous distribution of the observations, or in this case, the value for revenue across vessels. There is a 'skew' to the distribution indicating some vessels as 'outliers' with large revenues (in the range of $550,000 to $650,000 per vessel).

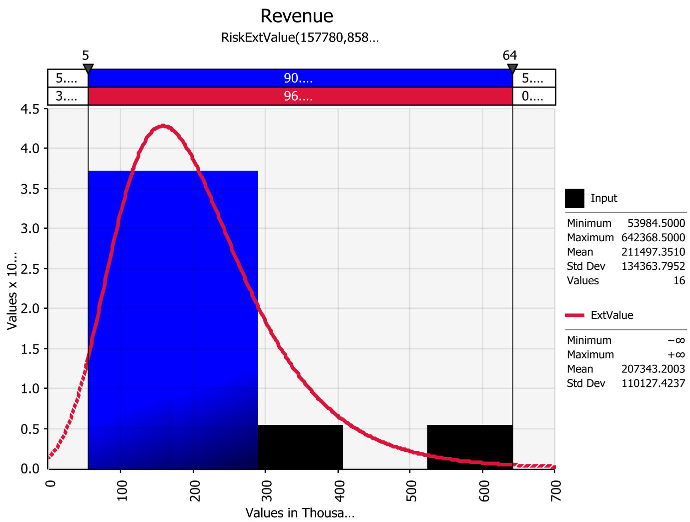


Figure 2.7. Distribution of revenue per annum by vessel.

Total cost per annum (an average over 2007-08 and 2008-09) by vessel also varied from about $20,000 to slightly less than $400,000. The cost per annum of most of the vessels is around $20,000 to $300,000 (see Figure 2.8). The average is roughly $160,000.

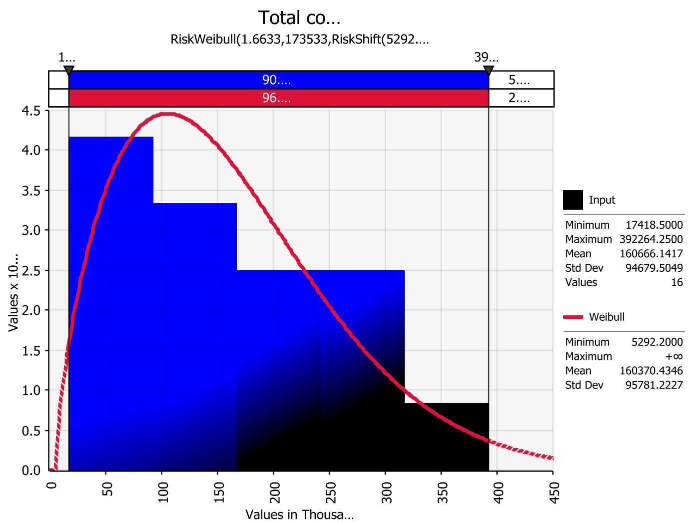


Figure 2.8. Distribution of total costs per annum by vessel.

2.5.2. Distribution of Supply Chain Components by Vessel

Supply chain analysis per vessel (see Figures 2.9 to 2.15) indicates significant variations in contents of all supply chain categories. In the production component the variations of capital, wages and electricity and gas are the most important reasons leading to large variations in production costs per vessel.

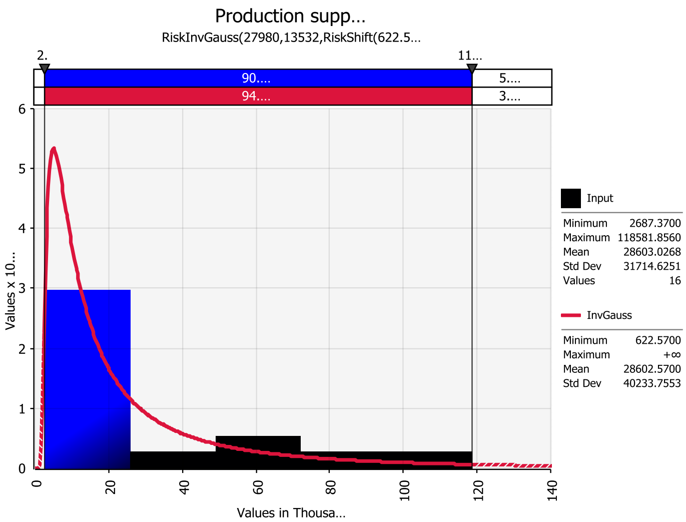


Figure 2.9. Distribution of costs of production support per annum by vessel.

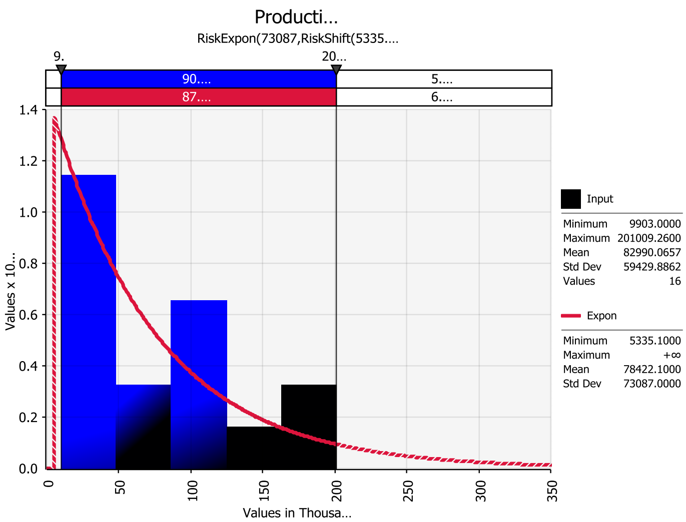


Figure 2.10. Distribution of costs of production per annum by vessel.

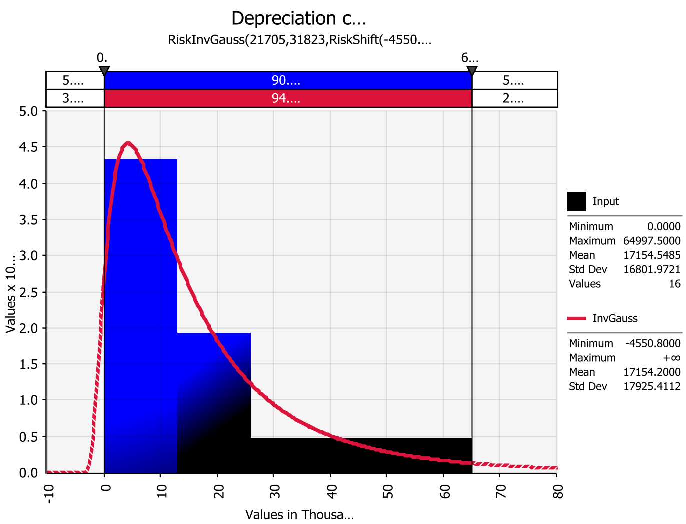


Figure 2.11. Distribution of capital costs per annum by vessel.

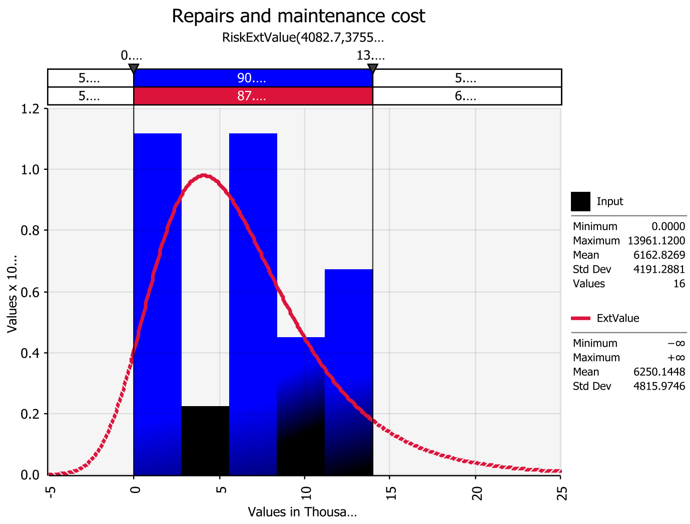


Figure 2.12. Distribution of repair and maintenance costs per annum by vessel.

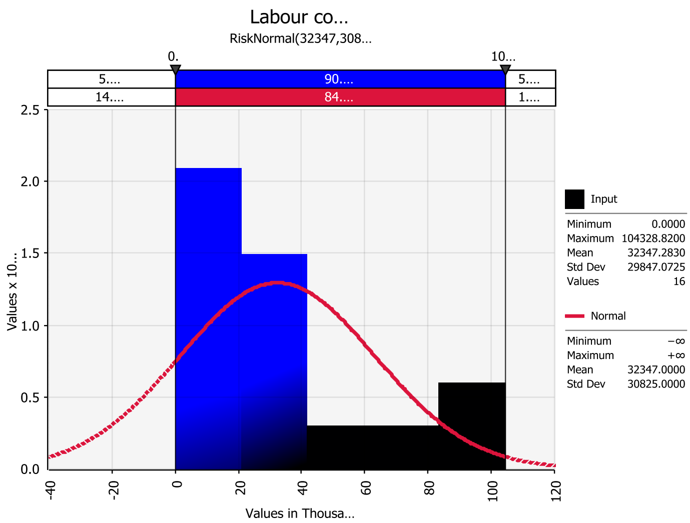


Figure 2.13. Distribution of labour cost per annum by vessel.

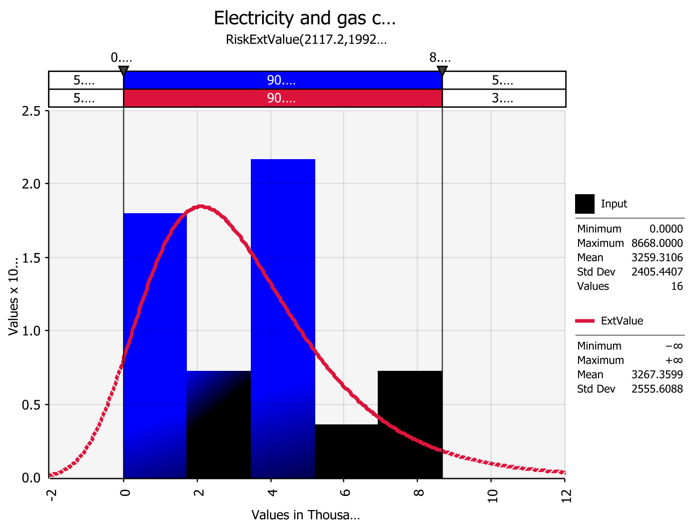


Figure 2.14. Distribution of electricity and gas cost per annum by vessel.

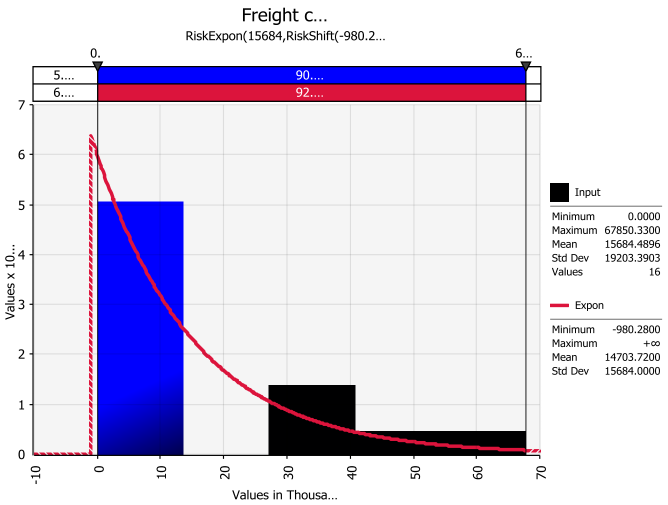


Figure 2.15. Distribution of post production cost per annum by vessel.

2.6. Estimated Gross Value, Costs and Benefits

The revenue and the costs of the fishery as a whole (both surveyed and non-survey vessels) over 2007-08 and 2008-09 are estimated based on the most likely values of revenue and costs per vessel (described in Section 2.6). The estimated results are presented in Table 2.13.

Table 2.13. Estimated revenue and costs of the fishery.

	2007-08	2008-09
Total revenue	$10,207,000	$12,312,000
Total costs	$7,516,000	$8,141,00
Benefit	**$2,691,000**	**$4,171,000**

2.7. Queensland Sector Trade

2.7.1. Fish

The Queensland aquarium fish sector is an important contributor to Australian exports of aquarium fish. In 2008-09, the Queensland aquarium sector accounted for 82 per cent of the total export value of the Australian aquarium sector. This sector exported a total of 94,000 live fish, valued at $2.8 million in 2008-09. Most of these exports are live Australian species of ornamental fish (excluding syngnathids), which accounted for 99 per cent of the total.

The main export markets for Queensland marine aquarium fish are the United States, the United Kingdom, Hong Kong and Japan, which accounted for 69 per cent of the total export value of the sector in 2008-09. The United Arab Emirates also emerged as a valuable export destination of the sector for the first time, valued at $0.5 million and accounted for 18 per cent of the total export value of the Queensland marine aquarium sector (see Table 2.14).

Table 2.14. Export destinations of Queensland marine aquarium fish sector, by selected countries.

	2006-07	2007-08	2008-09
Hong Kong	$94,471	$140,798	$186,736
Japan	$131,660	$76,600	$121,407
United Kingdom	$79,249	$72,035	$187,377
United States of America	$527,952	$864,618	$1,412,628
United Arab Emirates		$41,511	$497,007
Others	$393,426	$235,178	$366,949
Total	**$1,226,758**	**$1,430,740**	**$2,772,104**

Source: Australian Bureau of Statistics (2010).

2.7.2. Corals

The QCF became an accredited Wildlife Trade Operation on 1 July 2006. In a very short period of time, businesses adapted operations to collect, keep and transport live coral specimens and live rock for export to new markets. In 2008/09, a total of about 54,000 pieces was exported from Queensland representing 60 per cent of the total live corals exported from Australia. In 2008, the QCF collected a total of 97 tonne (59 tonne live rock, 19 tonne specialty (live) coral, 10 tonne ornamental coral, and 9 tonne other coral and coral rubble), which is less than half of the Total Allowable Catch for the fishery. This indicates that whilst the development of the QCF has been rapid since accreditation, there is still room for considerable expansion within the limits of fishery management arrangements. However, it is important to note that dive-based, weather dependent fishing in a limited-entry (capped number of licences) fishery like this one, results in significant constraints to expansion, unless technology or efficiency change significantly, or other business strategies evolve. There was no data available at the time of writing that explicitly indicated the value of these exports. Figure 2.16 shows the skewed nature of the collection frequency. Species from the *Acanthastrea* genus represent by far the most common product in the export figures for the QCF during 2008/09. However, species from 76 genera are exported. About 85 per cent of the specimens belong to just 14 genera (Table 2.15).

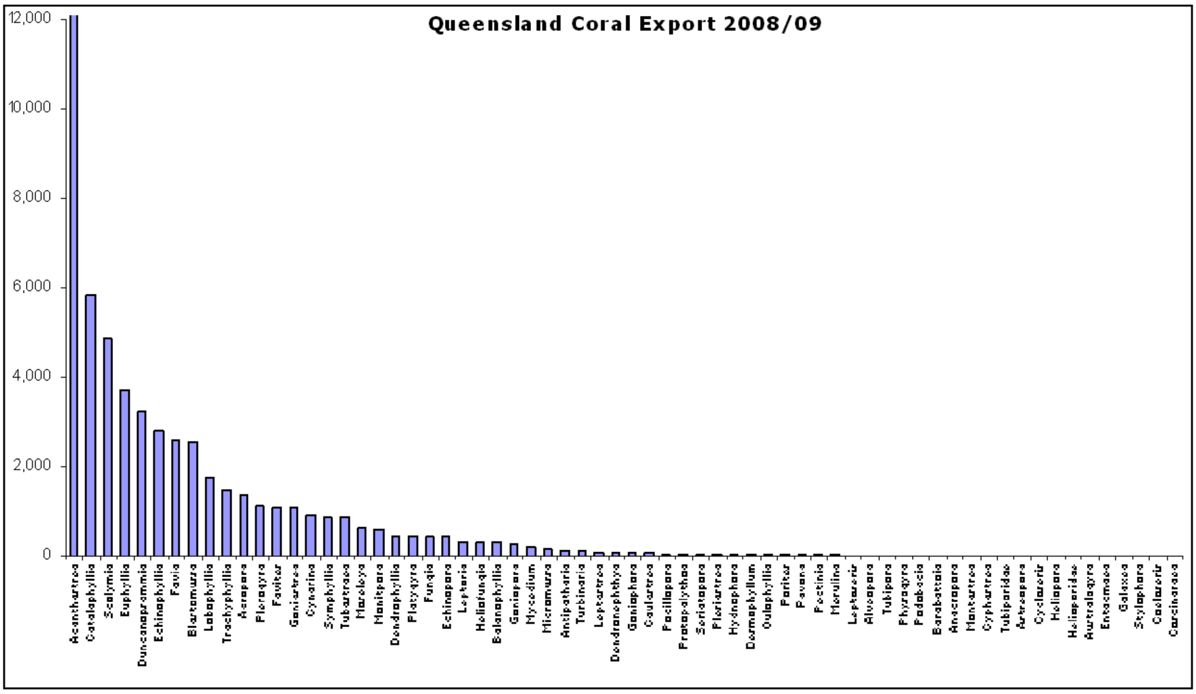


Figure 2.16. Queensland live coral exports 2008/09. Source: CITES.

CITES recognises eight Australian species of *Acanthastrea* from the family Mussidae. However, *A. lordhowensis* is the most common Acanthastrid species collected (6421 pieces in 2008/09) in Queensland. Other Australian *Acanthastrea* species exported include: *Acanthastrea* (unspecified) (5155), *A. echinata* (647) and *A. bowerbanki* (21).

The live coral catch component of the QCF represents just over 30 per cent of the 60t capacity of that part of the fishery. Table 2.15 shows that about 85 per cent of the live corals exported from Queensland are species within 14 genera and that for most of these genera, Queensland supplies a greater percentage of the total that is exported from Australia. The balance comes from Western Australia.

Table 2.15. Number of pieces of coral exported from Queensland in 2008/09. Source: CITES records (Australian Government, SEWPaC).

Genus	No. exported from QLD	% of QLD (exports)	No. pieces from Australia	% of Australian exports	QLD % of Australian exports
Acanthastrea	12,244	22.60%	15,783	17.28%	77.58%
Catalaphyllia	5,832	10.77%	9,098	9.96%	64.10%
Scolymia	4,870	8.99%	5,551	6.08%	87.73%
Euphyllia	3,740	6.90%	6,535	7.15%	57.23%
Duncanopsammia	3,259	6.02%	5,914	6.47%	55.11%
Echinophyllia	2,794	5.16%	2,975	3.26%	93.92%
Favia	2,586	4.77%	3,757	4.11%	68.83%
Blastomussa	2,563	4.73%	5,786	6.33%	44.30%
Lobophyllia	1,777	3.28%	3,542	3.88%	50.17%
Trachyphyllia	1,498	2.77%	8,015	8.77%	18.69%

Acropora	1,349	2.49%	1,989	2.18%	67.82%
Plerogyra	1,137	2.10%	1,137	1.24%	100.00%
Favites	1,064	1.96%	1,244	1.36%	85.53%
Goniastrea	1,061	1.96%	1,128	1.23%	94.06%
Total	**45,774**	**84.50%**	**74,254**	**79.31%**	

The main export markets for Queensland coral are the United States, the United Kingdom, Canada, the Netherlands and Germany, which accounted for more than 90 per cent of the total export volume of the sector in 2008-09 (Table 2.16).

Table 2.16. Primary export destinations for coral from Queensland in 2008/09. Source: CITES.

Export Destination	No. Pieces	Percentage
United States of America	34,003	60.48%
United Kingdom	5,266	9.37%
Canada	4,858	8.64%
Netherlands	3,467	6.17%
Germany	3,311	5.89%
Total	**50,905**	**90.54%**

2.8. Vulnerabilities Facing Trade

There are four main vulnerabilities facing trade in aquarium fish and coral. In summary, they are (in no particular order):

- **Fluctuations in exchange rates or exchange rate risk**

A good part of the live harvest of fish and coral in this fishery is exported. Changes in the exchange rate can affect the demand for these products. An increase in the value of the Australian relative to the US dollar, for example, will generally result in a fall in demand by American consumers for fish and coral, since the purchasing power of each US dollar is smaller. The past two or three decades have seen considerable changes in the value of the Australian dollar, from nearly US$0.50 to reaching parity. This causes considerable variance in profitability in the aquarium industry. There is no anecdotal evidence that businesses in this industry hedge or insure against exchange rate movements.

- **Stochastic weather events such as cyclones and poor weather conditions**

Stochastic weather events will result in less fishing time or added difficulty in catching fish. Cyclones, for example, generate both a loss in fishing time, sometimes up to several weeks, and considerable (albeit temporary) disruption to fish abundance and the distribution of fish stocks. Both can result in considerable loss in revenues in the industry, as do other stochastic events (see Grafton & Kompas, 2005).

- **Changes in the cost amounts of major cost components**

In the aquarium fishery the cost of labour is relatively high and a large component of total variable costs, in some cases more than 30 per cent of the total. In typical trawl fisheries this share would normally be closer to 20 or 25 per cent (see Kompas *et al.*, 2006; Kompas *et al.*, 2008 and Kompas *et al.*, 2010). This higher cost in the aquarium fishery is undoubtedly due to the expense of employing highly skilled divers. Training for such duties is reported to take years. It follows that any changes in policies or circumstances that change the wage bill will more disproportionately affect this industry. A good example of such a policy change is the recent proposed changes in the minimum employer contribution to superannuation. The resulting increase in variable costs with such a change would be substantial. Another clear vulnerability, common to all fisheries, and also a large component of variable costs in the aquarium industry, is changes in the price of fuel. This will be an added concern if the distance to harvesting areas increases due to government closures or other stochastic events. Finally, although not as a large of a component of fishing costs in the survey data as prior information would have indicated, changes in the price of electricity will also affect the aquarium industry. Storage tanks and pumps require considerable electric power. Increases in the price of electricity will increase variable costs.

- **Changes in government policy which limit fishing areas and fishing time**

The use of restricted fishing areas and closures can greatly influence profitability in the fishery. Recent closures appear to have caused increases in distances travelled to fishing areas (increasing travel time and fuel costs) and this has the potential to concentrate fishing effort in smaller areas. It is also possible that closures can severely change the catch composition to less valuable species, as species composition of a community varies considerably from reef to reef. It should be emphasised that there is no extant scientific evidence that indicates that the aquarium industry has anything but a negligible effect on the stock of fish or coral in the Great Barrier Reef. Unlike with the ‘stock effect’ generated in other fisheries, where the use of marine protected areas restricts harvest and generates larger stocks and resilience to stochastic events (see Grafton *et al*., 2006 and Kompas *et al*., 2010), there is thus no direct or economic rationale for further permanent closures relevant to the aquarium industry in the Great Barrier Reef Region.

3. Climate Change

Fluctuating climatic conditions have been a feature of our planet's existence for four and a half billion years. Continental drift and shifting ocean circulation, glacial expansion and contraction, marine regression and transgression' species evolution and mass extinctions, and more recently, the emergence and global migration of humanity, are just some of the causes, consequences and effects of the cycles of change that our planet has endured and to which life has adapted.

The changes to our landscapes and ecological systems that have occurred as a result of cyclic climatic changes over time have been significant. However, scientists tell us that human influences on the global climate system since the Industrial Revolution in the 18th century are causing changes that have not been seen for hundreds of thousands of years, at a pace that is likely to exceed anything experienced for many millions of years.

Increased concentrations of naturally occurring greenhouse gases have changed, and are changing, the composition of our atmosphere and oceans. Greenhouse gases absorb warmth from their surroundings and re-radiate some of it back toward Earth's surface, slowing the rate at which the planet loses heat (Figure 3.1). This "greenhouse effect" is nothing new. Plants and animals have enjoyed the benefits of its warming influence for hundreds of millions of years. Without the greenhouse effect, Earth's average temperature would fall below freezing. However, human activities are now increasing the concentration of carbon dioxide in our atmosphere, amplifying the natural warming caused by the greenhouse effect.

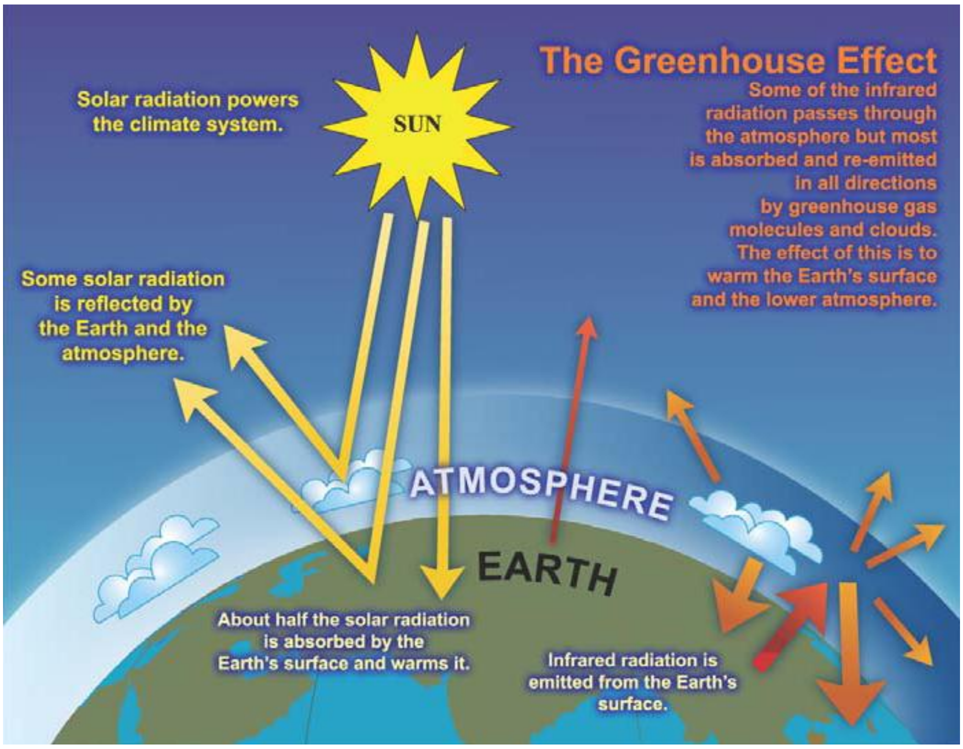


Figure 3.1. The "Greenhouse Effect" (from Poloczanska & Richardson (2009).

The "greenhouse effect" is a natural mechanism by which temperature is moderated. Increases in greenhouse gases (CO_2, CH_4 and N_2O) since the Industrial Revolution has resulted in an “enhanced greenhouse effect”, which affects the degree to which long wave infrared radiation either passes through the atmosphere or is absorbed and re-emitted, thereby increasing natural warming of the earth's surface and the troposphere. Primarily, this change has occurred through combustion of fossil fuels, including coal and oil, but also from deforestation and agriculture, including grazing livestock at an unprecedented scale. Predictions by the Intergovernmental Panel on Climate Change (IPCC) include a suite of environmental effects that will impact upon natural systems and the social and economic structures that depend upon them.

The IPCC is the leading body for the assessment of climate change, established by the United Nations Environment Program and the World Meteorological Organisation to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences. The IPCC is a scientific body comprising thousands of scientists from all over the world who contribute on a voluntary basis to review and assess the most recent scientific, technical and socio-economic information produced worldwide that is relevant to the understanding of climate change.

Atmospheric carbon dioxide (CO_2) is identified as a key indicator of progression toward a changing climate and the subsequent implications for natural systems. The *4th IPCC Assessment Report 2007* stated that, in 2004 CO_2 represented about 77 per cent of total anthropogenic greenhouse gas emissions (measured by industrial emissions). The remainder comprised methane (from agriculture, waste and energy), nitrous oxide (mostly from agriculture) and, to a lesser extent, various halocarbons (including CFCs, HFCs, HCFCs and perfluorocarbons) (CSIRO, 2009).

Since the Industrial Revolution, global CO_2 concentration has risen 37 per cent, methane 150 per cent and nitrous oxide 18 per cent. The CO_2 concentration in 2008 of 383 parts per million (ppm) is much higher than the natural range of 172 to 300 ppm that has existed for the past 800,000 years (CSIRO, 2009). As of September 2010, atmospheric CO_2 was 386.8 ppm and rising based on readings by the United States National Oceanic and Atmospheric Administration[5].

As national governments throughout the world examine strategies for the mitigation of carbon pollution, it can be expected that strategies adopted will result in a cost burden that will ultimately be borne by consumers. Industries that intensively use electricity and fuels, such as petrol and diesel, can expect to operate in a higher cost environment that potentially has implications for competitiveness or even commercial viability.

It is not the intent of this vulnerability assessment to reproduce or to debate the science of climate change. The intent of the assessment is to increase our understanding of the implications accompanying the predicted effects of climate change on the Great Barrier Reef and its adjacent coastline, and more specifically on the operation of the commercial fisheries that supply aquarium specimens to domestic and international markets, noting that most of these fishers have substantial land-based investments in their businesses in the form of holding facilities.

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[5] http://co2now.org/

The vulnerability assessment acknowledges that fisheries and marine protected area management agencies have a priority focus on the predicted effects of climate change on the Great Barrier Reef in the discharge of their responsibilities. The GBRMPA *Outlook Report 2009*[6] identifies climate change, especially ocean acidification and rising sea surface temperatures, as the most serious threat to the reef; followed by water quality from catchment run-off. Maximising the resilience of coral reef ecosystems to these threats clearly guides management of the marine park into the future. Consequently, this is the framework within which all marine park users must fit.

In acknowledging the many challenges ahead, it is instructive to examine how participants in these two fisheries might adapt to the anticipated changes, not only of a biophysical nature but also from shifts in market demand, cost structures and resource management, so that they can operate on a sustainable and profitable basis into the future.

3.1. Climate Change Predictions

3.1.1. IPCC Special Report on Emissions Scenarios

The *IPCC Special Report on Emissions Scenarios* (SRES) grouped scenarios into four storyline families (A1, A2, B1, and B2) (Table 3.1.) that explore alternative development pathways, covering a wide range of demographic, economic, and technological driving forces and resulting greenhouse gas emissions.

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

Table 3.1. IPCC scenarios are projections (initialised with observations for 1990) of possible future emissions for four scenario families, A1, A2, B1, and B2, which emphasise globalised vs. regionalised development on the A,B axis and economic growth vs. environmental stewardship on the 1,2 axis (Raupach *et al.*, 2007).

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

[6] http://www.gbrmpa.gov.au/corp_site/about_us/great_barrier_reef_outlook_report

capita economic growth and technological changes are more fragmented and slower than in other storylines.

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

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

Storyline A1 (globalised, economically oriented) contains various scenarios relating to technological development. The three variants lead to different emissions trajectories (Figure 3.2): A1FI (intensive dependence on fossil fuels), A1T (alternative technologies largely replace fossil fuels) and A1B (balanced energy supply between fossil fuels and alternatives) (Raupach *et al.*, 2007). Figure 3.2 has been included to indicate that there are wide ranging consequences for the future based on the manner in which humanity develops.

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

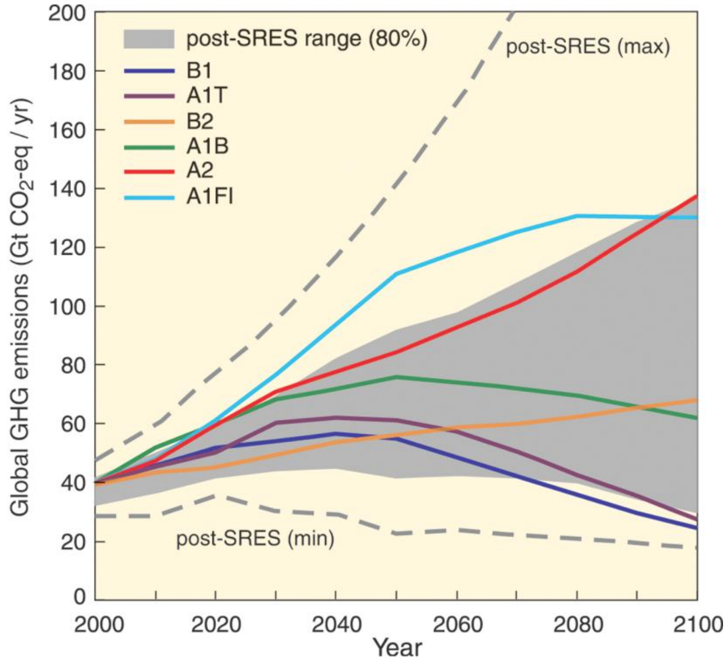

Figure 3.2. Predicted global greenhouse gas emissions by SRES scenario, demonstrating the wide disparity of outcomes determined by the pathway of human development adopted in the 21st century. None of these scenarios include global agreement on carbon mitigation policy, which is expected but as yet not developed (IPCC, 2007).

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

Despite debate at the margins, there is widespread agreement that the foreseeable future will be characterised by change brought about by an enhanced greenhouse effect. Whichever development pathway manifests through the 21st century, critical parameters of atmospheric CO_2 and air temperature are expected to rise appreciably, with consequences for sea level, ocean chemistry and extremes of weather. Consequently, it may be instructive to be guided by the predictions emanating from the best (B1) and worst (A2) case scenarios when considering to what extent our world will be affected by climate change (Table 3.2), bearing in mind the inherent uncertainty attached to the future range of possible impacts relating to predicted scenarios.

Table 3.2. Atmospheric concentration of carbon dioxide (CO_2 parts per million), global temperature rise (T°C) above 1961 to 1990 average, and sea level rise (SL cm) above 1961 to 1990 level for four SRES storylines for 2020s, 2050s and 2080s.

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

Regardless of which identified development pathway manifests through the 21st century, the predicted consequences of climate change will vary regionally. The impacts will be felt initially and to a greater extent at higher latitudes and inland from the coast, particularly at higher altitudes. The northern hemisphere has a greater proportion of landmass than the southern hemisphere and is expected to warm sooner (Figure 3.3). However, Australia is the hottest and driest continent with unique biophysical characteristics, limited water resources and a growing population that is mostly nestled on the eastern seaboard. Queensland is projected to experience the largest percentage increase in population between 30 June 2007 and 2056, more than doubling the 2007 population of 4.2 million to 8.7 million people by 2056. As a result Queensland is projected to replace Victoria as Australia's second most populous state in 2050 (ABS data, 2008[7]).

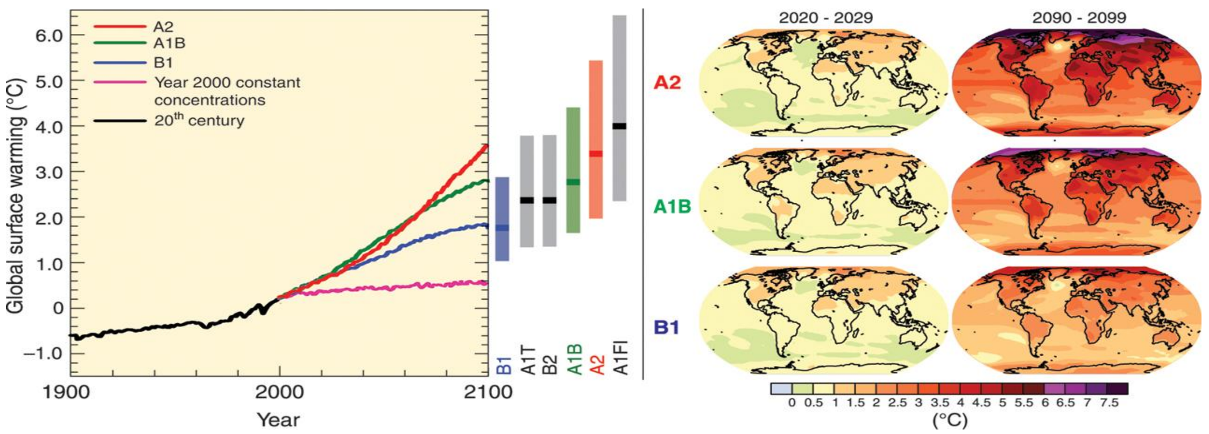

Figure 3.3. Anticipated surface warming according to the SRES storylines. It is apparent that the northern hemisphere will warm sooner than the southern hemisphere. Importantly, global climate change impact is an aggregation of many local scale impacts (IPCC, 2007).

3.1.2. Climate Change and Uncertainty

Projecting future climate conditions is inherently uncertain. Mathematical modelling is subject to incomplete understanding of the physical processes of the climate system and how they work together and interact. Predicting future greenhouse gas concentrations is complicated by a range of socio-economic factors, including

[7] http://www.abs.gov.au/Ausstats/abs@.nsf/mf/3222.0

population growth, levels of affluence, intensity of energy use and the implementation of strategies designed to mitigate future emissions (Lough, 2007).

The ability to predict regional consequences of climate change is further complicated by the course spatial resolution used by the models. Predicting the effects of climate change is typified by uncertainty. This does not imply that we do not face significant challenges brought about by climate change. It means that the range of future climate conditions and subsequent impacts, particularly on a regional or local scale, cannot be accurately forecast.

There is, however, a range of parameters from which conclusions can be drawn with a high level of confidence, even at the regional scale. The IPCC state that even if all greenhouse gas emissions ceased today, we would still be committed to increasing atmospheric CO_2, temperature and sea level rise in the decades ahead but at a reduced rate than is currently predicted. For the Great Barrier Reef and adjacent communities, that means predictions relating to coral bleaching, ocean acidification, cyclone intensity and coastal inundation remain.

A substantially more certain future scenario is that carbon pollution mitigation policy will eventually be developed and implemented. There is currently no formal carbon pollution mitigation policy in Australia, although there are many schemes and incentives for individuals and businesses to reduce their carbon footprint.

In 2013 signatories to the Kyoto protocol, including Australia will set new emissions targets and it can be expected that existing proposals on the table in Australia will require modification. The cost of achieving targets set by international agreement will eventually be borne by the consumer.

Carbon pollution mitigation policy is potentially the most immediate, widespread and recognisable impact of climate change. Industries that are intensive users of fuel and electricity will likely face elevated costs of production that could impact upon competitiveness or even commercial viability. This includes, but is by no means limited to, the marine aquarium supply industry in Queensland.

3.2. Projected Impacts on the Great Barrier Reef

This study will use the predicted values for critical parameters, including atmospheric CO_2 and air temperature, from the best and worst case scenarios described by the SRES as a guide to what we might expect to see on the Great Barrier Reef in the future. Storyline B1 creates the least extreme scenario with atmospheric CO_2 at double the pre-industrial concentration by 2100. Storyline A2 creates the most extreme scenario with atmospheric CO_2 at three times the pre-industrial concentration by 2100.

The timeframes for predictions adopted for this project are taken from Johnson & Marshall (2007) (Table 3.3). The earlier timeframe of 2020 being just 10 years away gives the marine aquarium industry participants a tangible indication of what could be expected, which in turn could prompt participants to consider what the future operating environment might look like. The later timeframe of 2050 is appropriate as it is at this point in the future that the scenarios diverge substantially depending largely on population predictions and technological development within each storyline.

The scenarios do not include strategies to mitigate excess greenhouse gas accumulation in the atmosphere. However, as there is currently no binding global agreement, it is appropriate to read the values attached to these scenarios at face value. Table 3.3 outlines the expected variations to key parameters, including atmospheric CO_2 and air temperature, plus the predicted flow on effects for sea surface temperature, sea level and ocean chemistry.

Table 3.3. Projected changes in climate for the Great Barrier Reef region for 2020 and 2050 based on the SRES B1and A2 storylines (modified from Lough, 2007).

Projected Change	2020		2050	
	B1	**A2**	**B1**	**A2**
CO_2 parts per million (pre-industrial = 270 ppm)	421	440	479	559
Air temperature (relative to 1961 to 1990 average and on basis that tropical and coastal areas of Australia will warm at ~global average)	+0.6°C	+1.4°C	+0.9°C	+2.6°C
SST for GBR (relative to 1961 to 1990 average 25.9°C)	+0.5°C	+0.5°C	+1.1°C	+1.2°C
Sea level rise (relative to 1961 to 1990 baseline)	+7cm	+38cm	+13cm	+68cm
Ocean chemistry (estimated decrease in ocean pH based on projections of 0.3 to 0.5 decrease by 2100)	-0.06	-0.10	-0.15	-0.25

Atmospheric CO_2, air temperature and sea surface temperature are critical parameters for the Great Barrier Reef and the industries that rely upon it because of the consequences for coral bleaching, sea level rise and the intensity of cyclones that cause damage to the Reef and the diminished capacity for reefs to recover due to ocean acidification.

Section 3.1.2 outlined the degree of uncertainty involved with predicting the manner with which climate change will manifest, due mostly to mathematical climate modelling and the range of socio-economic development scenarios. However, certain critical parameters have been observed and measured on the Great Barrier Reef leading to predictions that have been stated with a high level of certainty (Table 3.4).

Table 3.4. Summary of certainty and regional detail of projected changes (Lough, 2007)

Parameter	Regional Projection	Certainty
Air temperature rise	Greater inland than along the coast	**High**, already observed
Sea Surface Temperatures	Greater in southern GBR and in winter	**High**, already observed
Sea Level Rise	Limited, up to 0.68m increase by 2050	**High**, already observed and may accelerate
Ocean Acidification	Limited, generic 0.5 pH drop by 2100	**High**, already observed drop in pH
Tropical Cyclones	Similar distribution but modulated by ENSO#	Low for location and frequency **High** for increased intensity
Rainfall and River Flow	Similar spatial and inter-annual variability modulated by ENSO and PDO*	Low for changes in averages **High** for more extremes
ENSO Events	Continued source of high inter-annual	Low

	variability but modulated by PDO

El Niño Southern Oscillation: climatic pattern lasting six to 18 months.
* Pacific Decadal Oscillation: climatic pattern lasting 20 to 30 years.

The cascading effect of elevated greenhouse gas concentration in the atmosphere on air temperature and ocean chemistry and the subsequent biophysical consequences have been examined at length in Johnson and Marshall (2007). Table 3.5 summarises the predicted effects of climate change on reef building corals from that publication.

Table 3.5. Vulnerability of Reef Building Corals on the Great Barrier Reef to Climate Change (summarised from Johnson & Marshall, 2007).

Stressor	Exposure	Sensitivity	Potential Impact	Adaptive Capacity	Vulnerability
Water Temperature	Increased by 0.4°C since the end of the 19th century. Expected to rise by 0.5°C by 2020 and 1.2°C by 2050 (Lough, 2007).	Warming seas have pushed corals closer to their thermal maxima and further warming can push corals to beyond thermal tolerance, resulting in bleaching (Hoegh-Guldberg *et al.*, 2007a).	Bleaching. Thermal tolerance varies among species so the extent and intensity of bleaching will affect species regenerative capacity. This can also alter future species composition and diversity.	Corals have the ability to acclimate to seasonal variations in temperature. However, the upper range of some species adaptive capacity could already be exhausted. There is some discussion of "evolutionary switching" of symbionts but this is not likely to assist on any reasonable scale.	An increase of 2°C in the average sea temperature in tropical and sub tropical Australia will lead to annual bleaching with up to 97% of reefs affected and will almost certainly result in regular large-scale mortality events (Hoegh-Guldberg *et al.*, 2007a).
Storms and Floods	The number of severe cyclones (category 4 and 5) has nearly doubled over the past 30 years in all ocean basins.	Part of the natural cycle and brings many benefits. However, if the frequency of intensity of disastrous storms increases beyond the reefs capacity for recovery between events, reef resilience will decline.	Direct physical damage from tropical storms is exacerbated by coastal run-off and reduced water quality that inhibit the capacity of the affected reefs to recover and may lead to a shift to algal domination.	Coral reefs have evolved to adapt to storm and flood damage. However, future adaptive capacity will be compromised by the expected magnitude of events and the reduced calcification from ocean acidification.	Coral communities will become increasingly vulnerable as storm activity increases and recovery processes decline through ocean warming and acidification.
Sea Level Rise	Predicted to rise by up to 0.9m by 2100. Could be much greater depending on the fate of the Greenland Ice Sheet.	Healthy corals can keep pace with predicted rise but other climate change impacts may compromise coral health.	Due to the slowing effect of other climate change effects on growth, it is possible that coral populations could be left behind by a rapid rise.	Corals with high growth rates will likely keep pace with sea level rise. However, the health of corals is a major determining factor.	Vulnerability exists for species composition and diversity on reefs.
Ocean Acidification	Present day chemistry of the oceans is fundamental to the ability of reef building corals to calcify and form coral reefs	Reduced carbonate ion concentration significantly reduces the ability of reef building corals to form their skeletons.	Calcification must exceed bioerosion for the reef to maintain itself and grow. Reduced calcification risked the reef going into a state of net erosion.	The ability of marine calcifying organisms such as coral to adapt to the unprecedented and rapid rates of changes in ocean chemistry, combined with other stressors relating to climate change, will be limited.	There is overwhelming evidence corals and the reefs they build will not be able to maintain themselves and grow if CO_2 concentrations rise above 500ppm (Hoegh-Guldberg *et al.*, 2007a).

3.2.1. Sea Surface Temperature

Average water temperatures of the Great Barrier Reef are now significantly warmer than at the end of the 19th century (Hoegh-Guldberg *et al.*, 2007a). As with changes in global temperature, these changes are unprecedented in terms of rates of change seen over the past several hundred, if not several thousand, years. Warming seas have pushed corals ever closer to their thermal maxima, with the result that warmer than average years (part of natural climate variability) now push corals beyond their thermal tolerance.

The most dramatic manifestation of corals being pushed beyond their thermal tolerances is coral bleaching, which is a condition in which corals lose the pigmentation of their dinoflagellate symbionts. Coral bleaching is essentially a stress response in corals that arises as the intricate endosymbiosis between animal and single-celled plant begins to break down.

Corals will bleach in response to a range of conditions including high or low irradiance, elevated or reduced temperatures, reduced salinity, and the presence of some toxins. Rising temperatures push corals beyond their evolved thermal tolerance making them more susceptible to bleaching. Therefore it is anticipated that in the future, there will be more bleaching events that affect a larger extent of reefs. The frequency and extent of those bleaching events will elicit management response that will, in turn, impact upon fishery participants.

3.2.2. Cyclones

Average annual Sea Surface Temperatures (SSTs) on the Great Barrier Reef are projected to continue to warm over the coming century and could be between 1°C and 3°C warmer than present temperatures by 2100. Based on observed trends, it is likely that SSTs might warm more in winter and in the southern Great Barrier Reef.

Projected average SSTs by 2020 could be 0.5°C warmer and greater than 1°C warmer by 2050. There is no indication in current climate projections as to how SST extremes will change but it is likely they will follow a similar path as air temperatures extremes with a shift towards more warm SST extremes and reduction in cold SST extremes.

There is mounting observational evidence that the destructive potential of tropical cyclones around the world has increased in recent decades. For the Australian region, there is evidence from the period 1970 to 1997 that despite a decrease in the number of tropical cyclones, there was an increase in the number of intense cyclones. From 1969 to 1997 there were no category 5 and only two category 4 tropical cyclones. Although there has been an apparent decline in the number of tropical cyclone days affecting the Great Barrier Reef, TC Ingrid (category 4), TC Larry (category 5) and TC Hamish (category 5) occurred in 2005, 2006 and 2009 respectively.

Although warmer water temperatures might be expected to increase the intensity of tropical cyclones, their formation depends upon a number of other factors. It is, however, likely that tropical cyclones in a warming world will be more intense with higher maximum wind speeds and greater rainfall.

Although there are no clear indications that the number and location of tropical cyclones will change in the Australian region, there is some evidence their intensity will increase as measured, for example, by higher maximum wind speeds. More intense tropical cyclones will also interact with higher sea levels to produce more devastating storm surges and coastal inundation in a warmer world.

3.2.3. Rainfall Events

General global projections for a warmer world are for an enhanced hydrological cycle with more extreme droughts and floods and increased evaporation.

As already observed, it is likely that a given rainfall deficit in a warmer world will result in greater drought conditions than the same rainfall deficit in the early 20th century. This is due to higher temperatures increasing evaporative losses, decreasing soil moisture and, thus, the intensity of drought conditions and reduced river flows. Most climate models project increases in extreme daily rainfall events – even where projected changes in average rainfall are small or unclear. The intensity of extreme rainfall events such as the January 1998 Townsville flood event might become more common.

The magnitude of droughts and high intensity rainfall events are likely to be greater in a warmer world compared to current climate conditions, with consequent effects on river flow and the spatial extent of flood plumes affecting the Great Barrier Reef. Thus, the observed extremes of very low flow years and very high flow years are likely to be more common.

3.2.4. Ocean Acidification

The oceans absorb CO_2 from the atmosphere and are estimated to have absorbed about half of the excess CO_2 released into the atmosphere by human activities in the past 200 years. This absorbed CO_2 is resulting in chemical changes in the ocean, which it is estimated has already caused a decrease in oceanic pH of 0.155. In addition to lowering seawater pH, acidification is also causing an increase in bicarbonate ions rather than carbonate ions in seawater. This has significant implications for all organisms that require calcium carbonate to calcify their shells or skeletons (Howard *et al.*, 2009). Changes in calcification rates in southern ocean zooplankton have already been recorded (Moy *et al.*, 2009).

With continued emissions of CO_2, oceanic pH is projected to decrease by about 0.4 to 0.5 units by 2100. This is outside the range of natural variability and a level of ocean acidity not experienced for several hundreds of thousands of years. Of particular concern is that the rate of this change in ocean chemistry is about 100 times faster than at any other time over the past several million years. In addition, ocean acidification is essentially irreversible during our lifetimes and would take tens of thousands of years to return to pre-industrial levels.

The magnitude of projected changes in ocean chemistry can be estimated with a high level of confidence but the impacts on marine organisms and various geochemical processes are much less certain. The scale of changes may also vary regionally with the Southern Ocean most likely seeing the greatest changes in the short term. In addition, changes in ocean chemistry will result in interactions and feedbacks with the global carbon cycle, atmospheric chemistry and global climate in ways that are currently not understood.

Coral reefs are in a balance between accretion and erosion. Consequently, calcification must always exceed erosion in order for reefs to grow. A greater than 10 per cent decline in growth rate has already been recorded for massive *Porites* species of corals on the Great Barrier Reef (De'ath *et al.*, 2009). Weakening the ability of organisms to calcify makes reef structures much less robust thereby diminishing their resistance to cyclones, bleaching and other stressors and their ability to recover. Hoegh-Guldberg *et al.* (2007a) stated that there is overwhelming evidence that corals and the reefs they build will not be able to maintain themselves and grow if the atmospheric CO_2 concentrations rise above 500 ppm when the Great Barrier Reef will effectively commence net erosion, not only through normal biophysical erosion but additionally through carbonate dissolution (Fabricius *et al.*, 2007).

It is expected ocean pH will drop below levels that are considered critical for calcification first in the southern Great Barrier Reef, preventing a latitudinal displacement of species toward cooler southern waters in response to ocean warming. Consequently, the popular theory that suggests that species assemblages will merely migrate away from the equator is countered by ocean acidification.

Ocean acidification is the greatest threat to the Great Barrier Reef, which is recognised in the *Outlook Report 2009*. A mid-point somewhere between the best and worst case SRES scenarios would suggest atmospheric CO_2 of 500ppm would be reached mid century in the absence of global carbon pollution mitigation. The implications of this are that the Great Barrier Reef will be in a net erosive state, which will be compounded by synergistic effects. Coral reefs that are subject to widespread and frequent bleaching plus intense cyclones and rainfall events have a reduced capacity to recover from these disturbances. These effects in combination with declining pH reduce, over time, the overall resilience of the Great Barrier Reef.

4. Assessing Fishery Risk in a Changing Climate

Ecological Risk Assessments for the MAFF and the QCF were carried out by Roelofs (2008a & 2008b respectively). These assessments built on detailed Species Sustainability or Vulnerability Assessments, which were undertaken by Roelofs and Silcock (2008a & 2008b respectively). At the time these assessments were done, future climate risks were not explicitly addressed other than to consider:

1. Proneness to bleaching for coral species

2. Reliance of fish on coral for food and shelter.

The knowledge base and thinking on climate change risks to marine resources has evolved considerably since 2008, so it is timely to revisit this work. The work that follows was done as a first pass assessment by the author, in consultation with the project Advisory committee.

Ecological Risk Assessments are designed to provide a formal assessment of the impacts of the fishery on target species and to identify areas at risk from overfishing based upon Fletcher *et al.* (2002), which is the standard 'how to' guide for Ecologically Sustainable Development reporting in Australian fisheries. This approach considers each aspect of a fishery and assigns a level of consequence (from negligible to catastrophic) for the impact of that aspect and the likelihood of this consequence occurring (from remote to likely) for each species.

The Ecological Risk Assessments examine targeted species identified through the sustainability assessments (Roelofs & Silcock, 2008a & 2008b). Roelofs and Silcock focused attention on the vulnerability of targeted species on the basis of a number of life history traits, including growth, lifespan, reproduction and recruitment. Their sustainability assessment methodology was robust and included a mix of biological and fishery factors that exerted influence on a species' vulnerability, including: ecological niche, physical accessibility, market price and suitability for aquaria.

The MAFF and the QCF are integrally linked, regardless of whether some operators fish in one or the other fisheries. The complexity of habitat and the ability of that habitat to respond successfully after disturbance are critical to both fisheries. Climate change infers greater challenges on coral reef habitats to recover from stress. Fisheries and protected areas managers now place great emphasis on maximising resilience, partly by minimising the impacts from activities that can be managed, such as fishing.

Climate change projections for the region where the fisheries operate suggest there will be an increased frequency and extent of coral bleaching and increased intensity of cyclones and rainfall events, each of which will reduce the resilience (or health) of the ecosystem. Increasing acidification is expected to further stifle the capacity of corals and coral reef habitats to recover from these events; therefore, this review will add to the existing Ecological Risk Assessments and consider the indirect physical impacts of the fishery on habitats. Moreover, it will examine the risk to key functional species, or species groups, that play differing and complimentary roles in preconditioning reefs to permit recovery of corals after disturbance. The key functional groups associated with the aquarium fisheries include a range of grazing and scraping herbivorous fishes in the MAFF and coral species in the QCF that contribute to the structural complexity of reefs. The structural complexity and integrity of coral reefs is critical to supporting a diversity of marine life, including species collected in the MAFF.

Larger scale threats such as eutrophication, bleaching and storm damage require maximising the capacity of coral reef systems to recover. Ocean acidification is the greatest long-term threat to the Great Barrier Reef and a major impediment to recovery from stress, including severe and repeated disturbance from events linked to climate change. Minimising that threat is a challenge for global economies.

This section of the climate change vulnerability assessment will examine how the ecological risk posed by the marine aquarium supply fisheries might be assessed with a view to maximising the capacity of corals and coral reefs to recover from events linked to climate change. Consequently, attention will be on the interaction of the fisheries with habitats, and the species whose ecological function is critical to the recovery of corals and coral reefs after or during stress. These species will be included in the current assessment, in addition to those identified in the existing Ecological Risk Assessments.

The section does not seek to produce a new Ecological Risk Assessment for the fisheries. It builds on the existing work and explores an alternative methodology based on factors that are expressed in a paper by Astles *et al.* (2009), which used a qualitative assessment methodology to determine the risk of impacts on marine habitats and harvested species in a data-deficient New South Wales fishery. Hereafter, the broad methodological framework used by Astles *et al.* (2009) will be referred to as the Astles risk assessment. Whilst that methodology was tested on a trawl fishery with a range of fishery interactions with habitat and non-target species, there appears to be a level of transferability in the methodology that could apply to the aquarium supply fisheries. Essentially the methodology uses three steps:

1. Risk context (the objective at risk)

2. Risk identification (the source of the risk

3. Risk characterisation (the level of that risk), and documents any issues arising. The level of risk is a combination of the resilience of each component and the impact profile of the fishery.

The Astles risk assessment methodology is particularly pertinent to the climate change vulnerability assessment as it incorporates indirect fishery effects on habitats and critical ecosystem functions and services. Adaptation of this method and incorporation into the existing method enables the assessor to evaluate fishery risks in the context of the predicted impacts of climate change in a precautionary and proactive manner. The emphasis of fishery effects on processes of reef recovery after disturbance can be expected to feature prominently in all fisheries management in the future.

4.1. Queensland Marine Aquarium Fish Fishery

The MAFF is a diver-based, hand-harvest fishery collecting a diverse suite of marine fish species for use in either private or public aquaria. Operating since the 1970s, the MAFF supports around 40 commercial collection licences and operates along the east coast of Queensland within the bounds of the Offshore Constitutional Settlement.

Operators in the MAFF are permitted to harvest aquarium fish and invertebrates along the entire Queensland east coast in areas that are not closed through general fisheries closures or marine parks zoning under the Commonwealth *Great Barrier Reef Marine Park Act 1975* and the Queensland *Marine Parks Act 1982*. The fishery area also comprises five Special Management Areas that can only be accessed by certain holders of an A1 symbol. While five such areas are described in Fisheries Queensland legislation, one is no longer accessible under Great Barrier Reef Marine Park legislation.

Effort in the fishery is restricted by the number of active divers allowed per licence, diving safety limits (depth and duration of dive) and environmental factors such as weather and water turbidity. Notably, not all fish species are equally valuable to the industry or attractive to the market and collection of a particular species is not governed by factors such as whether a fish is abundant and easily caught.

The total annual number of fish and invertebrate specimens collected in the MAFF was around 162,000 individuals in 2009 (Table 4.1). While a diverse assemblage of fish species are targeted for the aquarium trade (about 600 species of fish), much of the trade tends to be centred on a limited number of individual species (For example, Green chromis (*Chromis viridis*) is the most common damsel fish collected. However, more than 30 damsel fish species appear in the catch, more than 25 species of butterfly fish and around 25 species of wrasse.)

Table 4.1. Total catch of fish in the MAFF in 2009.

Common Name	Number	Freq
Fish		
Damsel fish	32,545	26.65%
Butterfly fish	11,856	9.71%
Wrasse - unspecified	11,830	9.69%
Fish - unspecified	7,613	6.23%
Gobies, blennies and dartfishes	7,043	5.77%
Anemonefish	6,918	5.67%
Angelfish - personifer (QLD yellowtail)	6,089	4.99%
Angel fish - scribbled	5,519	4.52%
Assessor	4,191	3.43%
Tusk fish - harlequin	4,037	3.31%
Cleaner wrasses	3,681	3.01%
Surgeonfish - all others	3,332	2.73%
Pygmy angels	3,311	2.71%

Dottybacks		2,780	2.28%
Cardinal fish - unspecified		2,039	1.67%
Pufferfish and boxfish		1,899	1.56%
Angel fish - unspecified		1,662	1.36%
Anthias		1,309	1.07%
Trigger fish		1,024	0.84%
Scorpion fish - unspecified		828	0.68%
Moorish idol		824	0.67%
Blue tang		757	0.62%
Banner fish		670	0.55%
Cod - reef unspecified		360	0.29%
	TOTAL	**122,117**	
Invertebrates			
Star fish		12,207	30.94%
Molluscs - unspecified		6,600	16.73%
Invertebrates		5,845	14.82%
Crustaceans		5,817	14.75%
Shrimps - all others		2,749	6.97%
Shrimp - coral banded		2,452	6.22%
Bêche-de-mer - unspecified		2,237	5.67%
Sea-urchin		1,542	3.91%
	TOTAL	**39,449**	
Sharks & Rays			
Ray - sting unspecified		458	52.34%
Shark - unspecified		218	24.91%
Shark - epaulette		199	22.74%
	TOTAL	**875**	

Catch per unit of effort has been relatively stable in the MAFF after a decline in catch following rezoning of the marine park from 2004 and the subsequent period of adjustment where new fishing grounds were subject to exploration and businesses adapted to a new operating environment.

4.1.1. Broad Fishery Risks

For the purpose of this exercise, risk is defined as the “likelihood that the activity of the MAFF will lead to detrimental effects on key ecological processes that could result in biodiversity loss and long-term degradation of habitats”. This definition was chosen to explicitly target recovery of habitats after disturbances linked to climate change.

Astles *et al.* (2009) extended a similar definition to include elements such as “the reduction in biomass below a critical level as a percentage of spawning biomass”. However, the MAFF features hundreds of species and, as it functions to a large extent within the Great Barrier Reef Marine Park, a substantial component of spawning biomass is not accessible to fishery participants due to ‘no-take’ zones totaling 33 per cent of the Great Barrier Reef Marine Park in addition, MAFF species are generally not targeted by other fishing sectors.

The Astles risk assessment considers major ecological components at a broad level to eliminate those components that are not at substantial risk from the activities of the fishery. Those ecological components that may have a negative interaction with the fishery become the focus of the next level of the hierarchical structure, which undergoes more detailed assessment of risk.

Astles *et al.* (2009) identified ecological components to assess as part of the assessment for the trawl fishery. However, as the MAFF has no bycatch, byproduct or 'catch' of threatened and protected species, this assessment will examine species assemblages, diversity and ecological processes, harvested species and marine habitats.

<u>Risk Context</u>

The context of the risk (the objective at risk) is the operation of the fishery in light of the predicted effects of climate change. This will primarily relate to increased frequency and extent of coral bleaching but also relates to recovery after bleaching, cyclones and flooding. Ocean acidification is identified as a long-term threat to the marine environment globally that no fishery management or best-practice strategy alone can avert.

<u>Risk Identification</u>

Astles *et al.* (2009) identified several sources of risk to ecological components resulting from the activity of the fishery. These included:

- retaining fish for sale
- discarding unwanted catch
- physical contact of fishing gear with the ocean environment
- loss of fishing gear from the vessel.

However, the MAFF is a highly targeted fishery where each individual specimen must be presented to the market in premium condition. Great care is taken with gear deployment and the selectivity and treatment of the targeted specimen. Table 4.2. identifies the following risks:

- species assemblages and diversity, ecological process
- marine habitats
- harvesting of fish for sale.

<u>Risk Characterisation</u>

Having identified the ecological components of the MAFF and the activity that could potentially impact them, the next step in the Astles risk assessment method is to identify (based on a literature review) the level of risk i.e. which of the ecological components is most at risk from the fishery activity? In the literature review, the reviewer is looking for information on 'general impacts from the fishery' – a demonstrated link between an activity and a component. On this basis, a level of risk (high, intermediate, low or negligible) is assigned to the risks associated with the fishery activity on the identified ecological components, at a broad ecosystem scale (Table 4.2).

Note that levels of risk assigned in Table 4.2 and others are for the purpose of applying the Astles risk assessment methodology. The application does not feature the extent of rigour that could be expected in a full Ecological Risk Assessment, such as applies to the existing Ecological Risk Assessments.

Table 4.2. Levels of risk posed on each ecological component by the activity of the MAFF.

Main Activity of the Fishery	**Harvesting (what's kept)**	
	Direct Risk	Indirect Risk
Ecological Component		
Species assemblages and diversity, ecological processes	Negligible	Low
Marine habitats	Negligible	Low
Harvested species	Low	Low

Astles *et al.* (2009) state that for each ecological component identified, the question should be asked: "what have other studies shown about the level of impact these fishing activities have on this component?" As this assessment incorporates activity of the fishery with the predicted impacts of climate change, direct risks on all ecological components in the MAFF are assumed to be negligible on the basis of the existing Ecological Risk Assessment. The few harvested species in the existing Ecological Risk Assessment that were assessed as a low risk are included in the 'Risks to Harvested Species' section. Indirect risks here are those that flow to the capacity of the coral reefs (that support the MAFF target species) to recover after disturbance related to climate change. The advantage of the Astles risk assessment method is that it enables this indirect risk to be recorded and monitored.

Indirect risks were assessed as low on the basis that the fishery has few participants spread over a large geographical area and the fishery, to a large extent, operates within the zoning of the Great Barrier Reef Marine Park featuring substantial no-take areas. Indirect risks were not assessed as 'negligible' because of uncertainty surrounding the compounding effects of climate change. Harvesting species that perform critical functions in habitat recovery after disturbance could compromise that recovery as the predicted effects of climate change manifest. There could be a greater risk of a shift to algal domination or diminished recruitment of corals that enhance structural complexity. The result of this would likely be reduced species assemblages and diversity.

4.1.2. Risk to Marine Habitats

Market demand that drives activity in the MAFF is for mini-reef replications. These typically include a matrix of living rock adorned with live coral and complemented by an array of reef fishes and invertebrates. The MAFF species are overwhelmingly reef fishes.

The Astles risk assessment method nominated different types of physical habitat based on the types encountered in the New South Wales trawl fishery. However, for this assessment, it is the biological communities of coral reefs that will be assessed. Coral reefs will be differentiated on the basis of proximity to shore (inshore/offshore) in recognition that inshore reefs are likely to be subject to further pressure from climate change due to predicted increases in intensity of rainfall events. High rainfall events export terrestrial sediments that additionally carry nutrients and toxins (such as pesticides). These reefs are also exposed to greater competitive pressures by reef users from other sectors, including recreational fishers and others.

<u>Risk Context</u>

The next stage in the Astles risk assessment method is to state the risk context. In this case, it is the likelihood that marine habitats will be synergistically degraded by the activity of the fishery in light of the predicted effects of climate change.

<u>Risk Identification</u>

Given that physical interaction with habitat is negligible, the risk is identified as removing fish species that perform functions critical to coral recruitment and recovery of coral reef habitat after disturbance. Based on current scientific thinking about resilience (e.g. Bellwood *et al.*, 2004), it was determined that recovery from disturbance was critical to avoiding a phase-shift on reef habitats from coral domination to algal domination and to identify the species with limited functional redundancy that could best aid recovery. Functional redundancy can be defined as 'the extent to which the ecological role of a species can be replaced by other species.'

<u>Risk Characterisation</u>

The Astles risk assessment then describes the risk characterisation, which is the level of risk for each habitat. The level of risk is determined by “the pressure a fishery exerts on a habitat and its ability to withstand such pressure”. Determining the level of risk is a three step process:

1. Vulnerability (based on the biological and physical characteristics of the habitat)
2. Fishery Impact Profile (a measure of the pressure a fishery exerts)
3. Habitat Risk Matrix (the level of risk a habitat is exposed to as a result of fishery activity).

Vulnerability

Vulnerability is described as a combination of resilience and resistance. Resilience is a qualitative description of the capacity of a habitat type to recover if damaged. Resistance refers to the physical and biological properties of habitats to withstand damage. This is an adaptation of the description used by the Astles risk assessment method which relates to habitat interaction with fishing gear. For the purpose of this study, it relates to vulnerability of habitats to the predicted impacts of climate change because of the negligible direct interaction between the activity of the fishery and the habitat. Consequently, this assessment will change commensurate with the manifestation of these impacts, such as mass bleaching, severe storm damage or high volume flooding, probably more so than through changes to the dynamics of the fishery.

Resilience and resistance are combined in a matrix (Figure 4.2) to determine the level of vulnerability for each identified habitat type.

Resilience \ Resistence	L	M-L	M	H-M	H
H	I	I-L	L	L	L
H-M	I-H	I	I-L	I-L	L
M	H	I-H	I	I-L	L
M-L	H	I-H	I-H	I	I-L
L	H	H	H	I-H	I

Figure 4.2. Vulnerability matrix. (H – high; H-M – high medium; M – medium; M-L – medium low; L – low; I – intermediate; I-L – intermediate low; I-H – intermediate high).

For each habitat, two questions were asked to determine level of resilience and resistance:

1. What is the timeframe for it to recover (resilience)?

- High - Less than 1 year
- Medium - 1-5 years
- Low - Greater than 5 years

2. What is its ability to withstand physical disturbance (resistance)?

- High - No damage
- Medium - Partial damage
- Low - Total damage.

This component of the Astles risk assessment method is considered in this study on the basis that fish collection might have an indirect impact on habitats in the context of climate change as the predicted impacts manifest. Table 4.3 uses this assessment method for inshore and offshore coral reefs, noting that coral reefs are typically complex assemblages that range from robust massive coral species to delicate branching forms and there exists a range of parameters, including life history characteristics that determine resilience and resistance for each species.

Whilst both inshore and offshore coral reefs are equally subject to disturbance from cyclones and, in time, ocean acidification, risk is generalised on the basis that water quality and accessibility creates points of difference between the two habitats. Other factors, including susceptibility to coral bleaching and proximity to other reefs that might act as a source of recruitment that can replenish damaged reefs are considered. It is also noted that depth affects susceptibility to bleaching. The vulnerability determined through this process is indicative that inshore coral reefs are likely to be subject to greater cumulative risks than offshore coral reefs.

Table 4.3. Levels of resilience, resistance and vulnerability for habitats in the MAFF.

Habitats	Resilience	Resistance	Vulnerability
Inshore Coral Reefs	Medium	Medium	**Intermediate**
Offshore Coral Reefs	High-medium	High-medium	**Intermediate-Low**

Fishery Impact Profile

A fishery impact profile provides an integrated measure of the operation of the fishery by combining information on fishery impacts and identifying knowledge gaps that need to be addressed in order to mitigate risk levels. Again, the Astles risk assessment method refers to physical interaction of the fishery with habitat. However, the method can be adapted on the basis that identification of knowledge gaps brought about by low resolution data collection will assist to draw a clearer picture of the exposure of the fishery to habitat and consequently, the extent to which critical disturbance recovery processes are at risk from the fishery.

The Astles risk assessment asks five basic questions relating to the distribution of habitats and fishery activity (Table 4.4). Each question requires a qualitative rating of 'risk prone' or 'risk averse' for each of the identified habitat types, noting that if the effect is unknown then the rating is considered risk averse (on the basis that if it was a significant risk, it is more than likely someone would have identified it by now).

Table 4.4. Five basic questions and information needed to determine the fishery impact profile ratings for marine habitats. NB: Information has been modified from the table in Astles *et al.* (2009).

Question	Info Needed	Explanation	Rating
1. Where are the habitats?	Spatial distribution of habitat types	Basic knowledge of spatial habitat distributions is needed for risk analysis of fishery-wide impacts on habitats	*Risk prone* – when distribution of habitats is not known *Risk averse* – when distribution of habitats is known
2. Where does the fishing occur?	Spatial distribution of fishing effort	A direct measure of where the fishery-related impact is occurring	*Risk prone* – when distribution of fishing effort is not known *Risk averse* – when distribution of fishing effort is known
3. What overlap is there between the area in which the fishery operates and the distribution of habitat types?	Proportion of available habitat impacted by the fishery	An indicator of impact effect size on different habitat types. Fishing effort may be concentrated on preferred sub-areas within broad habitat types	*Risk prone* – when overlap between fishing effort and habitats is known to occur *Risk averse* – when overlap between fishing effort and habitats is known not to occur
4. Do habitats have adequate protection (refuge) from fishing impacts? E.g. zoning	Proportion of total habitat which is excluded from fishery impacts	An indicator of refuge availability for habitats. Some habitats may be natural refuges because fishing gear cannot operate on them effectively	*Risk prone* – when refuge availability cannot be determined or when few areas within the fishery jurisdiction with no fishing mortality for that habitat type are available *Risk averse* – when substantial areas within the fishery jurisdiction with no fishing mortality for that habitat type are available
5. Is the use of "high-impact" fishing gear currently permitted in the fishery?	Knowledge of impacts caused by different gear types used in the fishery	An assessment of the need to exclude or modify certain gear types from the fishery	*Risk prone* – when high-impact gear is used in the Fishery *Risk averse* – when high-impact gear is excluded or not used in the fishery

The Astles risk assessment method then applies a simple decision rule based on the number of risk prone factors used to assign the qualitative fishery impact profile rating for each habitat as follows:

- High – 5 prone factors
- Intermediate-High – 4 prone factors
- Intermediate – 3 prone factors
- Intermediate-Low – 2 prone factors
- Low – 1 prone factor.

Table 4.5. Fishery Impact Profile (FIP) for marine habitats impacted by the MAFF.

Habitat	Question (from Table 4.4)					No. Prone	FIP
	1	2	3	4	5		
Inshore Coral Reefs	A	A	P	A	A	1	**L**
Offshore Coral Reefs	A	A	P	A	A	1	**L**

NB: A – risk averse, P – risk prone, H – high, H-I – high to intermediate, I – intermediate, I-L – intermediate to low, L – low.

Risk Levels

Finally, the vulnerability and fishery impact profile ratings were plotted on a habitat risk matrix (Figure 4.3) to determine risk to habitats from the activity of the MAFF. Again, the risks relate to the potential indirect impacts of activities in the fishery.

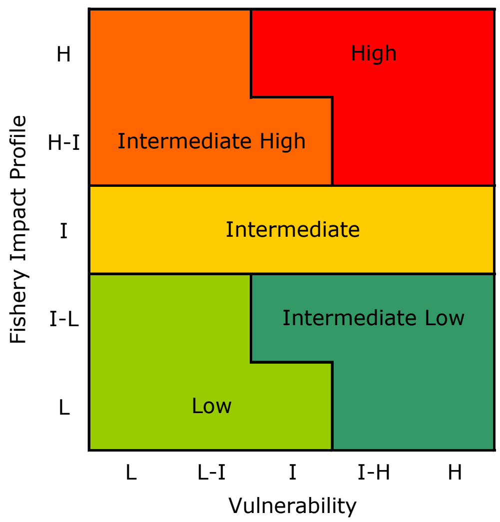

Figure 4.3. Habitat risk matrix for marine habitats in the MAFF. H –high, H-I – high to intermediate, I – intermediate, I-L – intermediate to low, L – low.

Risk was determined by the interaction of vulnerability and the fishery impact profile. The outcome of the risk to habitats from the MAFF is presented in Table 4.6. Both inshore and offshore coral reefs were assessed to be exposed to low risk from the MAFF. This assessment can be supported in the future through strategies to minimise fishery impacts on the recovery capacity of coral reef systems in the event of disturbances linked to climate change.

Table 4.6. Risk levels for marine habitats in the MAFF.

Habitat	Vulnerability	Fishery Impact Profile	Risk Level
Inshore Coral Reefs	Intermediate	Low	**Low**
Offshore Coral Reefs	Intermediate-Low	Low	**Low**

Issues Arising from Risk Assessment on Habitats

The Astles risk assessment method identified issues arising from the risk assessment that impede the reduction of risk to marine habitats from fishery activity, from the answers to the five basic questions of the fishery impact profile in Table 4.4. The information for those questions that had a risk prone answer was examined further.

In the MAFF, the issues related to the overlap of fishing activity and the identified habitats. The overlap is absolute and relates not to the physical interaction of the fishery but to the potential indirect effects of collecting species that perform functions critical to the recovery of the coral reef habitat after disturbance. In this instance, the disturbances for consideration are those linked to climate change and the recovery capacity relates directly to reversing or preventing phase-shifts from coral dominated reefs to algal dominated reefs.

To address this issue, in the first instance, Professor Bellwood was asked to identify species that perform functions relevant to the assessment of risk in the MAFF (Box 4.1). These species should then be monitored in the overall catch and have collection strategies applied to them in the event of major disturbances linked to climate change. It is noted that not all of these species currently appear in the catch record in substantial numbers.

Box 4.1. Fish species that perform functions critical to recovery of coral reef habitat after disturbance.

Key species and critical functional groups: the role of herbivores in helping reefs regenerate

Ephippidae (Batfishes)

A macroalgal-dominated reef is widely regarded as a degraded coral reef and may presage further collapse of that habitat into a barren or slime-dominated state (Bellwood *et al.*, 2004). Once a macroalgal-dominated state has been reached, a natural phase-shift reversal may occur if macroalgal browsing species are present. An experimentally induced phase-shift highlighted the key role of a single species from the ephippid family, *Platax pinnatus*, where despite the presence of 43 other nominal herbivorous species, *P. pinnatus* was primarily responsible for removing the macroalgae (Bellwood *et al.*, 2006). This suggests that for inner-shelf reefs in the Great Barrier Reef there may be extremely limited functional redundancy of species that can reverse a macroalgal phase-shift by consuming *Sargassum spp.*, the predominant algal growth. Whilst fish biomass may determine the potential for phase-shift reversal, studies have shown that low levels of coral cover may be the key limiting factor, even in the presence of healthy herbivorous fish populations (Williams *et al.*, 2001; Ledlie *et al.*, 2007).

Little is known about the early life history of *P. pinnatus*, although the juvenile stage mimicry of a toxic flatworm and reported quick growth rate suggest that juveniles rapidly reach maturity (Debelius & Kuiter, 2001). Although widespread in the Western Pacific, abundance of *P. pinnatus* on the Great Barrier Reef is thought to be relatively low and population levels are further threatened by spear fishing, lack of specific protective legislation and loss of recruitment habitats, including mangroves (Bellwood *et al.*, 2006). Owing to their browsing of macroalgae and consumption of other dietary items, including invertebrates, it is unlikely wide-scale bleaching of coral reefs would have a detrimental impact on the abundance of this species. However, this species may play an important role in maintaining a reef free of large macroalgae.

Acanthuridae (Surgeonfishes)

Naso

Naso unicornis has been shown to play a similar critical role to *Platax pinnatus* (see Ephippidae note) in removing macroalgal transplants from a mid-shelf reef (Hoey & Bellwood, 2009). The retention of organic matter in the alimentary tract of *N. unicornis* overnight is indicative of a herbivorous diet including large plant matter undergoing fermentation (Choat *et al.*, 2004) and is supported by the high concentration of acetate found there (Choat *et al.*, 2002). In accounting for ninety per cent of all standardised bites on transplanted brown thalli (macroalgae), *N. unicornis* appears to be the principle, and arguably critical, species in removing macroalgae from mid-shelf reefs on Lizard Island (Hoey & Bellwood, 2009).

It is also probable this species is at least partly responsible for maintaining the very low levels of macroalgae on outer-shelf reefs. In a recent study two species of transplanted *Sargassum* were largely ignored by *N. unicornis* at the outer-reef, presumably due to the novel status of the macroalgae at this location (Hoey &

Bellwood, 2010). However, prior observation of substantial levels of fleshy brown macroalgae in the gut content of *N. unicornis* at these same outer-reef locations (Day and Hicks Reefs: Choat *et al.*, 2002) suggest that these species continue to consume macroalgae at this shelf position and may be efficient at locating and consuming cryptic macroalgae (Hoey & Bellwood, 2010).

Although individuals of *N. unicornis* were censused at inner, mid and outer-reef locations, the biomass was greatest on the outer-shelf (Hoey & Bellwood, 2010). Abundance of macroalgal browsers (notably *N. unicornis*) did not appear to correlate to removal rates of macroalgae transplants, with similar levels found at both inner- and outer-reef locations – approximately 10 per cent per day (Hoey & Bellwood, 2010). Reduced feeding at the inner-shelf reef locations was again largely attributed to *N. unicornis*, but the markedly higher proportion of macroalgal cover already present at these locations most likely explains the lower removal rates (Wismer *et al.*, 2009). This limited browsing on inner-shelf reefs may indicate the loss of top-down control as macroalgal cover increases, even with the maintenance of intact herbivore populations (Hoey & Bellwood, 2010). As such, the resilience of inshore reefs may be more fragile than we currently understand.

Anthropogenic activity, especially fishing, poses the greatest immediate threat to *N. unicornis*, owing to its substantial size and longevity (Hoey & Bellwood, 2009). Given the preference of this species for coarse, leafy brown algae such as *Sargassum spp.* it is unlikely that a phase-shift to a macroalgal dominated reef would have a negative impact on the abundance of this species. No special protection currently exists for this species in spite of the apparent critical nature of its role as a macroalgal browser throughout the Great Barrier Reef.

Another species in the genus *Naso* worthy of comment is *Naso vlamingii*. This species is not considered a macroalgal browser in its adult life, having a diet dominated by green filamentous algae and gelatinous zooplankton; it is also known to consume fecal material of other fishes (Choat *et al.*, 2002). The relevance of this species to coral reef resilience comes instead in its juvenile stage, where *N. vlamingii* is predominantly a macroalgal browser and as a rule of thumb can be considered so up to a size of 20 cm (Green & Bellwood, 2009). Although this herbivorous role may be considered relatively minor in comparison to species that browse macroalgae during their adult lives, the limited numbers of species that perform this function mean that it may be preferential to include *N. vlamingii* as a key species.

The other member of the genus *Naso* that performs a macroalgal browsing role during its adult life is *Naso lituratus*, which consumes erect brown macroalgae (namely Phaeophyceae: *Dictyota*, *Padina*, *Sargassum* and *Turbinaria*) (Hoey & Bellwood, 2009). Like *N. unicornis* this species has been shown to have high fermentation potential, having a high amount of acetate in the hind gut (Choat & Clements, 1998). Although no bites were recorded by *N. lituratus* on macroalgal transplants in a recent study at Lizard Island, the lower biomass of this species compared to *N. unicornis* may somewhat explain this result (Hoey & Bellwood, 2009). It is useful to observe that in a further study at the outer-reef both *N. unicornis* and *N. lituratus* were seen to inspect macroalgal assays on the reef crest, suggesting that given time they were likely to sample and accept the novel food source (Hoey & Bellwood, 2010). Again, given the highly selective set of fishes with the potential to reverse a macroalgal phase-shift, the inclusion of *N. lituratus* as a potential key species ought not to be discounted.

Acanthurus

Another key role relating to reef resilience, which is offered by a second select cohort of reef fishes, is phase-shift prevention. This function is essential to the maintenance of healthy coral dominated reefs and has been in place since the first herbivores fed on reefs. Grazers literally graze the substratum of the reef, feeding upon the epilithic algal turfs, which in turn limit the growth of macroalgae, which would otherwise out-compete corals for space and light. The actual mass of algae consumed by an individual may be relatively small, but because many species of grazers school and are relatively abundant, their overall impact is considered significant (Green & Bellwood, 2009).

Many herbivorous grazers are found within the genus *Acanthurus*, of which the most abundant of species on the Great Barrier Reef is likely to be *Acanthurus nigrofuscus* (Bellwood & Fulton, 2008). Whilst actual algae mass consumed per bite is thought to be low, *A. nigrofuscus* has a high bite rate, which has been shown to increase significantly with the removing of sediment from the epilithic algal matrix (Bellwood & Fulton, 2008). Interesting, this observation draws in a second species of acanthurid, *Ctenochaetus striatus*, which has been shown to remove sediment from the substratum, allowing preferential feeding by *A. nigrofuscus* (Purcell & Bellwood, 1993). However, another study found that *A. nigrofuscus* did not increase its feeding rate when presented with a higher biomass of algal turfs after an outbreak of *Acanthaster planci* (Hart *et al.*, 1996), suggesting that populations of *A. nigrofuscus* are likely to remain stable, even in the result of a mass bleaching event. *Acanthurus olivaceus* is classified as a detritivore but consumes a combination of detritus, calcareous sediment and small amounts of algae during this process (Choat *et al.*, 2002; Green & Bellwood, 2009). As the second most abundant species found on Lizard Island within the genus *Acanthurus* (Bellwood & Fulton, 2008), it is possible that this species has some impact on cropping the epilithic algal matrix and may further improve the quality of the algae for other species, such as *A. nigrofuscus*, by removing sediment during feeding.

Acanthurus lineatus, like *A. Nigrofuscus*, is considered a grazing herbivore and also maintains a positive relationship with *C. striatus* (Choat *et al.*, 2004). Abundance of this species is not believed to be as significant as *A. nigrofuscus* although it is possible that the wary nature of this species may affect the result of visual censuses (Debelius & Kuiter, 2001). Given its territorial nature and preference for exposed reefs subject to surge it is also likely that this species may maintain turf growth in areas of the reef where *A. nigrofuscus* is less abundant.

Zebrasoma

Within the genus *Zebrasoma*, the species *Zebrasoma scopas* is reportedly the most abundant on the Great Barrier Reef, although several other species in this genus are considered grazers (Green & Bellwood, 2009). Although the body mass of a single individual is low, *Z. scopas* has a high feeding rate that, combined with its long rostrum, allows it to graze filamentous algae in areas that cannot be exploited by other species such as narrow crevices (Robertson *et al.*, 1979). These qualities may explain why a previous study observed that territories of *Z. scopas* displayed the lowest microalgal cover, compared to territories of *Acanthurus leucosternon* and *Acanthurus lineatus* (Robertson *et al.*, 1979). This species therefore merits citation as a potentially significant grazer of microalgae, being able to crop microalgae in areas otherwise off limits to other grazers.

The literature is somewhat confused regarding the preferred diet of *Zebrasoma veliferum*, with it being cited as both a grazer of microalgae (Choat *et al.*, 2002; Choat *et al.*, 2004) and a browser of macroalgae (Robertson *et al.*, 1979; Russ, 1984; Giuasu & Winterbottom, 1998). Clarification on this is needed, especially with the low numbers of macroalgal browsers documented (Bellwood *et al.*, 2004). It is possible that *Z. veliferum* is targeting different dietary items to *Z. scopas* as a previous study showed the former species to be relatively unmolested by the usually territorial latter species (Roberston *et al.*, 1979).

Overall, *Acanthurus* and *Zebrasoma* species are important in that they crop short algae and may prevent phase-shifts to macroalgae. Their large numbers, however, suggest that this role is well supported in the Great Barrier Reef, especially on mid- and outer-reefs.

Balistidae (Triggerfishes)

Literature on the feeding ecology of balistids (triggerfishes) is scarce but some species may be at least partial herbivores (Green & Bellwood, 2009). Randall *et al.* (1997) cite *Sufflamen frenatus*, *S. bursa*, *Rhinecanthus rectangulus*, *R. aculeatus*, *Balistapus undulatus* and *Melichthys vidua* as feeding in part on benthic algae, presumably as grazers. The latter, *M. Vidua*, is believed to feed heavily on benthic algae and detritus, comprising some 70 per cent of its diet (Randall *et al.*, 1997). Further study is required to better understand the impact of these species in restricting the growth of benthic algae on the reef. One study in Kimbe Bay, Papua New Guinea, found *B. undulatus* to be the most abundant of five species of triggerfish surveyed and the most widely distributed, being found across all reef zones, microhabitats and depths, which suggests that this species may be the most significant member of the family Balistidae in terms of preventing an algal phase-shift.

In addition, *B. undulatus* has been shown to be a coral reef keystone predator, being the most dominant predator of sea urchins in a study off the coast of East Africa (McClanahan, 2000). Although *Balistoides viridescens* is competitively superior to *B. undulatus*, the latter species fed more readily upon Kenya’s competitively and numerically dominant sea urchin *Echinometra mathaei* (McClanahan, 2000). This second key functional role suggests that this *B. undulatus* may warrant special protection on the Great Barrier Reef, as control of sea urchin levels is essential to prevent destructive grazing of unchecked populations that can devastate reefs.

Kyphosidae (Rudderfishes)

All species of the small Family Kyphosidae are considered macroalgal browsers and tend to bite or ‘crop’ algae, leaving the basal portions intact (Choat *et al.*, 2002). Dietary analysis of *Kyphosus vaigiensis* collected from mid-shelf and outer-shelf reefs on the northern Great Barrier Reef showed high levels of brown macroalgae (Choat *et al.*, 2002, 2004) These findings fit the morphological and physiological traits of kyphosids that allow them to process large fleshy macroalgae such as *Sargassum*. Their large, muscular stomach and unusual small hindgut chamber may make this the only “true herbivore” family, as they are able to break down and derive nutrition from macroalgae through microbial fermentation in the hindgut (Cvitanovic & Bellwood, 2009).

K. vaigiensis has been censused at all shelf locations across the Great Barrier Reef, although it is unclear whether this species is simply shy or occupies small home ranges; often this species may be readily abundant at one site but apparently absent from another, even at the same shelf location (Cvitanovic & Bellwood, 2009; Hoey & Bellwood, 2010). Nevertheless, at some mid and outer-shelf locations *K. vaigiensis* made up twenty per cent of the total macroalgal biomass (Hoey & Bellwood, 2010) and was almost exclusively responsible for the high *Sargassum* removal rates in Pioneer Bay, Orpheus Island (Cvitanovic & Bellwood, 2009). This finding suggests that under certain conditions, *K. vaigiensis* may be a critical, sole agent of macroalgae removal at some locations on the Great Barrier Reef. However, other studies at Orpheus Island identified two other species as sole macroalgal browsers (Bellwood *et al.*, 2006; Fox & Bellwood, 2008; see Ephippidae and Siganidae notes) and this suggests that there is at least some functional redundancy in terms of phase-shift reversal, albeit highly limited. This species currently does not have specific legal protection, even though it is a vulnerable species in commercial and game fishing.

Labridae (Parrotfishes)

The Tribe Scarini (Parrotfishes) within the Family Labridae contains many of key functional roles that relate to reef resilience: browsers, scrapers and excavators.

Browsers

The genera *Calotomus* and *Leptoscarus* are cited as browsers of macroalgae (Green & Bellwood, 2009) although their functional role in removing macroalgae has been little documented. Studies that have considered herbivory of macroalgae on the Great Barrier Reef have seldom made reference to the impact of these species in cropping macroalgae, probably due to their low abundance (c.f. Bellwood *et al.*, 2006; Fox & Bellwood, 2008; Hoey & Bellwood, 2009; Hoey & Bellwood, 2010).

Scrapers

Many species of scarines perform a scraping and minor excavating role on reefs. This includes the largest genus *Scarus* (with some 52 extant species, most occurring in the Indo-Pacific) and the genus *Hipposcarus* (Bellwood & Choat, 1990). Smaller individuals (<35 cm) of *Chlorurus spp.*, *Cetoscarus bicolor* and *Bolbometopon muricatum* are also included within this category (Green & Bellwood, 2009). This functional role is similar to grazing (see *Acanthurus* note) and serves to limit the establishment and growth of macroalgae as the fishes graze on the epilithic algal matrix (Green & Bellwood, 2009), irrespective of the actual dietary items being sought (c.f. Wilson *et al.*, 2003). The unique morphology of the scarine jaw, which is fused and beak-like, adds a further dimension to their grazing activity, actually scraping clean the substratum on which they feed (Bellwood, 1994), thereby providing a clean substratum upon which new sessile organisms may settle (Bonaldo & Bellwood, 2009). A further benefit of this feeding activity is the removal of sediment from the substrate and reduced capacity of the epilithic algal matrix to hold sediment, which has been shown to curb feeding rates of herbivorous fishes (Bellwood & Fulton, 2008). Furthermore, it is this removal of algae and sediment that may be key to facilitate coral settlement and growth after a disturbance (Hughes *et al.*, 2007; Bellwood & Fulton, 2008).

Scarus rivulatus may be the most significant species in this regard on the Great Barrier Reef. Fox & Bellwood (2007) found *S. rivulatus* to be one of the most abundant species at an inner-shelf reef, accounting for 88 per cent of all *Scarus spp.* censused. Taken together with its bite size, this species was found to be one of three dominant herbivores at Orpheus Island (Fox & Bellwood, 2007). Furthermore this species is estimated to graze the entire surface area of the reef crest at least once during the course of a month based on feeding observations (Fox & Bellwood, 2007), suggesting that this species' contribution to phase-shift prevention is significant. However, it should be noted that larger individuals appear to play a more profound role in coral reef resilience, actually cleaning the substratum, whereas smaller individuals simply crop the turf algae (Bonaldo & Bellwood, 2008). It is concerning therefore that in many parts of the globe, larger parrotfish individuals are particularly at risk of overfishing (Bellwood *et al.*, 2003). This is a problem that is not currently faced by the Great Barrier Reef.

Excavators

Excavators perform a similar reef resilience role to scrapers, but remove more of the substratum as they feed, being capable of removing deep crevices up to 3 mm (Bellwood, 1994). Large individuals (>35 cm) of *Chlorurus spp.*, *Cetoscarus bicolor* and *Bolbometopon muricatum* are the only species that perform this deep excavation (Green & Bellwood, 2009). Most notable of these species are *Chlorurus microrhinos* and *B. muricatum* that biooerode between one and five tonnes of carbonate per individual per year respectively (Bellwood, 2003). This additional role is vital as it removes dead coral and may also be beneficial as it exposes the hard reef matrix for up to seven days, allowing settlement by coralline algae and coral planulae (Bellwood *et al.*, 2003; Bonaldo & Bellwood, 2009).

C. microrhinos has been shown to move significant portions of the sediment produced during feeding off the Reef (Bellwood, 1995). This is likely to signify a further significant contribution to reef resilience by this species, as a phase-shift to a sediment-loaded epilithic algal matrix system can present a stable and potentially deadly state (Bellwood & Fulton, 2008). The large size of this parrotfish makes it vulnerable to overfishing and when considered alongside its moderately long generation times and critical functional roles, singles out this species as a prime candidate for specific conservation legislation.

B. muricatum also deserves special consideration for the same reasons, although this species also displays significant levels of corallivory in its feeding ecology, taking just under half of all bites on live coral (Bellwood *et al.*, 2003). This functional role is not considered detrimental to reef health as this species does not undergo population outbreaks, as with some other corallivorous taxa (e.g. *Acanthaster planci*) and does not cause significant reef degradation (Green & Bellwood, 2009). In fact, the regular corallivory of *B. muricatum* on coral reefs on the Great Barrier Reef means that this species may act as an important agent of intermediate disturbance (c.f. Connell, 1978). The loss of this unique predator would likely lead to significant changes in coral community structure, where fast-growing, grazing-resistant forms (*Pocillopora*, tabulate *Acropora* and *Montipora*) would dominate (Bellwood *et al.*, 2003).

It should be noted that the functional groups discussed here are not found uniformly across the continental shelf on the Great Barrier Reef. Hoey & Bellwood (2008) found high rates of scraping and sediment reworking on the inner-shelf reefs owing to high densities of *S. rivulatus*. In contrast, outer-shelf reefs were characterised by low densities but a high biomass of parrotfishes, notably *B. muricatum*, leading to high rates of bioerosion and coral predation (Hoey & Bellwood, 2008). The fundamental variation of process shaping coral reefs across the continental shelf may help to explain different compositions of benthic communities across the shelf (Green & Bellwood, 2009; Wismer *et al.*, 2009) and reinforces the idea that ecological processes governing the state of the Great Barrier Reef are complex and may be the purview of a handful to taxa.

The primary role of these species in the context of ecosystem disturbance is in ensuring the capacity for regeneration and preventing undesirable phase-shifts to macroalgae or sediment-laden turfs.

Siganidae (Rabbitfishes)

A number of studies in herbivory have been conducted at Orpheus Island, an inner-shelf reef on the Great Barrier Reef, several of which have identified functional roles played by the siganid family (Mantyka & Bellwood, 2007; Fox & Bellwood, 2008). Whilst it was initially thought that this family contained more than one species of macroalgal browsers (Mantyka & Bellwood, 2007), further study showed that only *Siganus canaliculatus* actually removes macroalgae to any significant degree (Fox & Bellwood, 2008). On the reef crest this species was solely responsible for the removal of *Sargassum spp.* in macroalgal transplant experiments (Fox & Bellwood, 2008). This makes for an interesting comparison with an exclusion experiment conducted a few years earlier at the same site (Bellwood *et al.*, 2006; see Ephippidae note) where a greater biomass of algae was dealt with by *Platax pinnatus*. This suggests that the binary view of coral or macroalgal-dominated reefs may not be accurate. Instead there may be several intermediate stages in the process of reef degradation, with concomitant key functional groups able to reverse each stage (Fox & Bellwood, 2008). If this is the case then we must necessarily understand the functional role of fishes in terms of reef resilience to be more intricate, and therefore more precarious, than previously thought.

S. canaliculatus is rarely observed in visual censuses and provides another example of the difficulty of assessing key herbivores through direct observation alone. By using remote video bioassays, Fox & Bellwood (2008) observed the critical impact of this species in removing macroalgae despite this species not registering in prior visual censuses. Understanding more about the habitat usage and movement patterns of this species is clearly desirable but currently frustrated by the paucity of individuals available for tagging (Fox, 2009). For example, it is not currently understood why this species restricts its feeding predominantly to the reef crest, although predation risk and tidal inundation have been suggested (Fox & Bellwood, 2008). The shy nature of this species may be advantageous and reduce removal of this species as a result of artisanal fishing, but no specific legislation protects this species from commercial or other fishing on the Great Barrier Reef. The reported high fecundity and short generation time of this species may, however, indicate reasonable levels of resilience (Froese & Pauly, 2010).

Siganus vulpinus is believed to feed on benthic algae and as such may operate as a functional grazer preventing an initial phase-shift (see *Acanthurus* note) along with all other members of the Siganidae, excluding *S. canaliculatus* (browser) and *Siganus lineatus* (detritivore) (Green & Bellwood, 2009). *S. vulpinus* deserves a mention because this species is abundant on inner-shelf reefs of the Great Barrier Reef (Mantyka & Bellwood, 2007; Fox & Bellwood, 2008). Another species that should be highlighted is *Siganus doliatus*, which along with *Chlorurus microrhinos* and *Scarus rivulatus*, dominated the biomass of roving herbivores in a recent study at Orpheus Island, Great Barrier Reef (Fox & Bellwood, 2008). Although an earlier study attributed most bites on macroalgae (esp. *Hypnea sp.*) to *S. doliatus* (Mantyka & Bellwood, 2007), Fox & Bellwood (2008) showed in a study at the same site that this high bite rate bore no relation to the removal of *Sargassum spp*. It is possible that *S. doliatus* may be targeting epiphytes on the leaves of *Sargassum* and as such may even aid growth of the macroalgae (Fox & Bellwood, 2008). *S. doliatus* is therefore better described as a grazer and this contrast with the browser, *S. canaliculatus* can be seen in their distinct feeding behaviours: *S. doliatus* was observed taking similar numbers of bites from the algae and surrounding reef substratum, whilst *S. canaliculatus* fed almost exclusively on the macroalgal assays (Fox & Bellwood, 2008).

Summary

Overall, there are two separate groups of fishes: those that prevent phase-shifts (Scarids, Acanthurids) and those that reverse them (Kyphosids, Nasos, Siganids). In the face of unprecedented changes on coral reefs, both are essential if we are to minimise the risk of a shift to undesirable states. The key role that they all share, however, is in facilitating coral settlement and enhancing regeneration. Whether by reducing sediment, keeping algae short, or removing macroalgae, it is the capacity to help reefs to regenerate or recover that is the key aspect. This makes herbivores a critical functional group on coral reefs.

4.1.3. Risk to Harvested Species

The MAFF collects around 600 species of fish plus a range of invertebrates, including star fish, molluscs and crustaceans. The existing Sustainability Assessment (Roelofs & Silcock, 2008a) used a robust methodology to identify species that were classified as medium level vulnerability or above. These species were further evaluated for their capacity to recover from, or their susceptibility to, heavy collection pressure. The recovery capacity of individual species was determined from biological data extracted from the literature.

The subsequent Ecological Risk Assessment (Roelofs, 2008a) identifies species from the MAFF logbook perceived to be at low to moderate risk from the activity of the fishery in the context of the existing spatial protection from marine park zoning and other factors, including diver accessibility and market demand. These assessments were carried out in consultation with fishery participants and others. The species identified through that process were included in the current adaptation of the Astles risk assessment methodology.

It should be noted, however, that the Astles risk assessment method for assessing impacts on habitats substantially complements the existing assessment that primarily focuses on targeted species. As the species identified by Roelofs (2008a) were included on the basis of biological characteristics that enable the species to recover after disturbance, it is unlikely that the identified species would change unless there is a shift in market demand that causes a substantial elevation in catch of other species that currently do not feature to any substantial degree.

Risk Context

In the case of targeted species in the MAFF, Roelofs (2008a) concluded few species were at risk from the activity of the fishery. Consequently, the risk context in this adaptation of the Astles risk assessment is the likelihood targeted species will be detrimentally impacted by the activity of the fishery in light of the predicted effects of climate change.

Risk Identification

Given that Roelofs (2008a) identified a number of species in the MAFF for monitoring, and that Professor Bellwood identified others with limited functional redundancy in the context of recovery of coral reef habitat after disturbance (Box 4.1), the identified risk for this adaptation of the Astles risk assessment is the collective of those species identified through those sources.

Risk Characterisation

The level of risk is determined by “the pressure a fishery exerts on a species and the biological and ecological characteristics of a species to withstand such pressure” (Astles *et al.*, 2009). Determining the level of risk is a three step process:

1. Resilience (based on the biological capacity of a species that enables it to respond to a disturbance)

2. Fishery Impact Profile (a measure of the pressure a fishery exerts)

3. Risk Matrix (the level of risk a species is exposed to as a result of fishery activity).

Resilience

The Astles risk assessment describes resilience as a set of biological characteristics that collectively describes the capacity of a species to recover from the impacts of the fishery, including reproductive strategy, growth rate and diet specificity. Those authors described resistance, as it is used in the habitats section, as related to the catchability of a species with the fishing gear used. Consequently, it features as part of the Fishery Impact Profile.

The Astles risk assessment adopted a series of biological characteristics to determine the level of resilience for each species (Table 4.7). Like the assessment of fishery impacts on habitats, levels of resilience were determined by assigning characteristics to be risk prone or risk averse. In this case, a risk prone characteristic is one that reduces a species capacity to recover from the impacts of harvest. A risk averse characteristic is one that does not reduce or may enhance a species capacity to recover from the impacts of fishing mortality. Professor Bellwood characterised the species identified in Box 1 according to the Astles risk assessment (Table 4.8).

Astles *et al.* (2009) chose nine biological characteristics for assessment. However, this has been reduced to seven for this purpose because 'Fecundity' has been omitted on advice from Professor Bellwood and 'Population Size' has been omitted because it was never known for any species targeted in the MAFF so it is impossible to determine population change.

Table 4.7. List of biological characteristics used to determine resilience and the criteria for determining whether a biological characteristic is risk prone or risk averse.

Biological Characteristics	Reason for Use	Risk Averse (Score = 0)	Risk Prone (Score = 1)
1. Life History Strategy	Indication of ability of a species to maintain viable population sizes or to rebuild populations after depletion	Pelagic eggs, rapid turnover, long spawning duration	Egg cases or parental care; demersal eggs, slow turnover, short spawning period
2. Geographic Distribution	How widely a species is distributed gives an indication of the potential for refuges from fishing	Widespread on the Great Barrier Reef and adjacent jurisdictions common	Restricted range
3. Habitat Specificity	Indicates how vulnerable a species is if it only associates with particular types of habitats that are more accessible to dive collection	Broad habitat requirements; narrow habitat requirements but larger area of available habitat	Narrow habitat requirements but small area of available habitat
4. Growth Rate	Indicates how quickly it reaches adult size and therefore its ability to escape the more vulnerable stages of development (correlated with age at maturity)	Reaches adult size within 2 years	Reaches adult size greater than 2 years
5. Age at Maturity	Indicates how old a species is before it can reproduce	1–2 years	>2 years
6. Longevity	Indicates turnover of populations and productivity of a species	Short-medium (<10 years to 10– 20 years)	Long (20–50 years)
7. Diet Specificity	Indicates how restricted a species' diet is which may make accessibility to food affecting growth rate	Broad diet requirements; narrow diet requirements but larger area of available diet	Narrow diet requirements but small area of available diet

Table 4.8. Characteristics of fish species in the MAFF identified by Professor Bellwood that perform functions critical to recovery of coral reefs after disturbance.

Species	Life History	Geographic Distribution	Habitat Specificity	Abundance	Growth Rate	Age at Maturity	Longevity and Vulnerability	Diet Specificity
Platax pinnatus	Pelagic spawners. Long pelagic larval and juvenile stages. Some juveniles may drift over great distances. Juveniles often exhibit excellent mimicry (Kuiter & Debelius, 2001).	Widespread West Pacific, ranging west to the Andaman Sea (Kuiter & Debelius, 2001). Western Pacific from Ryukyu Islands to Australia (Randall *et al.*, 1997).	Often deep lagoons or deep outer reef walls (Kuiter & Debelius, 2001).	Adults occur singly or in small groups, and occasionally in large schools (Kuiter & Debelius, 2001). Relatively rare on GBR with no specific protection (Bellwood, 2006).	Quick growing and attain large maximum size (Kuiter & Debelius, 2001). Reaches 30cm (Randall *et al.*, 1997).		Minimum population doubling time 1.4-4.4 years (Froese & Pauly, eds. 2010). Vulnerable to spear fishers due to size and loss of recruitment habitat - mangroves and coastal regions (Bellwood, 2006).	Highly variable including algae and a large range of benthic or pelagic invertebrates (Kuiter & Debelius, 2001).
Naso unicornis	Pelagic spawners. Juveniles settle at 40-45mm (Kuiter & Debelius, 2001).	Widespread Indo-West Pacific (Kuiter & Debelius, 2001).	Various reef habitats, inshore, lagoons as well as deep waters along outer reef walls. Juveniles in shallow protected bays (Kuiter & Debelius, 2001).	Large schools as adults (Kuiter & Debelius, 2001). Abundance varies but constitutes significant proportion of macroalgal browsers across GBR (Hoey & Bellwood, 2009).	Reaches 70cm (Kuiter & Debelius, 2001.)		Minimum population doubling time 4.5-14 years (Froese & Pauly, eds. 2010). Vulnerable to recreational fishing - large, long-lived species (Hoey & Bellwood, 2009).	Predominantly macroalgae diet (Kuiter & Debelius, 2001). Coarse leafy brown algae like *Sargassum* (Froese & Pauly, eds. 2010).
Acanthurus nigrofuscus	Pelagic spawners - often return to same spawning site. Will feed in mixed species groups when juveniles and adults (Kuiter & Debelius, 2001).	Widespread Indo-West Pacific (Kuiter & Debelius, 2001).	Usually occurs in algae-rocky habitats. Coastal reefs and harbours to outer reef gutters and channels to about 20m depth (Kuiter & Debelius, 2001).	Adults usually in small groups, but may form large shoals (Kuiter & Debelius, 2001). Most abundant species of Genus *Acanthurus* at Lizard Island (Bellwood & Fulton, 2008).	Reaches 21cm (Randall *et al.*, 1997). Fast growth rate, max size at 2-4yrs (Hart *et al.*, 1996).	2-4yrs (Hart *et al.*, 1996).	25yrs (Hart *et al.*, 1996) Minimum population doubling time 1.4-4.4 years (Froese & Pauly, eds. 2010).	Benthic algae (Randall *et al.*, 1997).

Siganus canaliculatus	Pelagic spawners with relatively short pelagic stage. Settling at about 20-25mm (Kuiter & Debelius, 2001). Eggs negatively buoyant and adhesive (Randall *et al.*, 1997).	Widespread Indo-West Pacific and west to southern India (Kuiter & Debelius, 2001).	Adults and juveniles in-shore mangroves, algae reefs, estuaries and large lagoons with algae-rubble habitats. Mainly common on rocky substrates (Kuiter & Debelius, 2001).	Usually seen singly or in small groups at shallow depths (Kuiter & Debelius, 2001). Schools of up to 15 individuals recorded (Fox & Bellwood, 2008).	Reaches 30cm (Kuiter & Debelius, 2001) Attains 40cm (Randall *et al.*, 1997).	Length at maturity 18cm? (Froese & Pauly, eds. 2010).	Potentially vulnerable as food source in SE Asia and Indo-Pacific (Kuiter & Debelius, 2001). Population doubling time less than 15 months (Froese & Pauly, eds. 2010).	Macroalgae: *Sargassum sp.* (Fox & Bellwood, 2008). Macroalgae (Randall, 2005).
Zebrasoma Scopas	Juveniles solitary and secretive in coral gardens (Kuiter & Debelius, 2001). Pelagic spawners (Kuiter & Debelius, 2001). Group and pair spawning observed (Froese & Pauly, eds. 2010).	Widespread Indo-Pacific (Kuiter & Debelius, 2001). Common reef species (Randall, 2005).	Found at middle- and outer-reefs on Great Barrier Reef (Russ, 1984). Various reef habitats, inshore to outer reefs (Kuiter & Debelius, 2001). Common on shallow reefs in calm areas (Randall *et al.*, 1997).	Adults may swim in pairs, groups or form schools (Kuiter & Debelius, 2001).	Reaches 20cm (Randall *et al.*, 1997). Males larger than females - largest specimen 21.5cm (Randall, 2005).		High to very high vulnerability. Minimum population doubling time 1.4-4.4 years (Froese & Pauly, eds. 2010).	Filamentous or turfing algae (see Zebrasoma note).
Balistapus undulatus	Demersal eggs - aggressively defended by female (Randall *et al.*, 1997).	Indo-Pacific, including Red Sea (Randall *et al.*, 1997; Randall, 2005).	Found in a variety of habitats and depths across the reef (Bean *et al.*, 2002).	Usually solitary (Randall *et al.*, 1997; Randall, 2005). Most abundant species of balistid in Papua New Guinea (Bean *et al.*, 2002).	Attains 30cm (Randall, 2005).		Low to moderate vulnerability. Minimum population doubling time 1.4-4.4 years (Froese & Pauly, eds. 2010).	Highly varied diet: coral, urchins, crustaceans, polychaete worms, sponges, hydrozoans and benthic algae (Randall *et al.*, 1997; Randall, 2005).
Chlorurus microrhinos	Group and pair spawning (Randall *et al.*, 1997; Randall, 2005).	Islands of Oceania and western Pacific (Randall *et al.*, 1997).	Clear lagoon and seaward reefs (Froese & Pauly, eds. 2010).	Large adults usually school together (Froese & Pauly, eds. 2010).	Reaches 70cm (Randall *et al.*, 1997). Slow growth.		Moderate vulnerability with low resilience - minimum population doubling time 4.5-14 years (Froese & Pauly, eds. 2010). Vulnerable	Benthic algae (Green & Bellwood, 2009).

							to overfishing (Green & Bellwood, 2009)	
Bolbometopon muricatum	Group and pair spawning (Randall *et al.*, 1997; Randall, 2005). Preferred recruitment in lagoons (Green & Bellwood, 2009).	Indo-Pacific (Randall *et al.*, 1997; Randall, 2005).	More abundant on mid-shelf and outer-shelf reefs of Great Barrier Reef (Green & Bellwood, 2009). Clear outer lagoon and seaward reefs to 30m (Froese & Pauly, eds. 2010).	Reduced across much of their range (Green & Bellwood, 2009). Usually seen in small aggregations (Randall *et al.*, 1997; Randall, 2005).	Slow growth. Largest parrotfish, reaches 120cm (Randall *et al.*, 1997; Randall, 2005).	Late sexual maturity (Green & Bellwood, 2009).	High to very high vulnerability with low resilience - minimum population doubling time 4.5-14 years (Froese & Pauly, eds. 2010). Listed as vulnerable on IUCN Red List. Extremely vulnerable to overfishing (Green & Bellwood, 2009).	Benthic algae and live coral in equal portions (Bellwood *et al.*, 2003).
Kyphosus vaigiensis	Pelagic spawners?	Indo-Pacific, including Red Sea (Randall *et al.*, 1997; Randall, 2005). Greatest abundances in sub-tropical environments (Cvitanovic & Bellwood, 2009).	Aggregate over hard, algal coated bottoms of exposed surf-swept outer reef flats, lagoons, and seaward reefs to a depth of at least 24m. Found in exposed areas around rocky reefs (Froese & Pauly, eds. 2010).	Relatively abundant but shy species. Greatest abundance in sub-tropical environments (Cvitanovic & Bellwood, 2009). Occur in schools (Randall, 2005).	Attains 60cm (Randall *et al.*, 1997; Randall, 2005).		High vulnerability - commercial fisheries and game fish. Minimum population doubling time 4.5-14 years (Froese & Pauly, eds. 2010).	Omnivorous but feed mainly on algal plants (Randall *et al.*, 1997; Randall, 2005; Cvitanovic & Bellwood, 2009).

Overall resilience for each species is determined by summing the scores of risk prone characteristics. The level of resilience is allocated as:

- High – O risk prone characteristics
- Intermediate-High – 1 risk prone characteristics
- Intermediate – 2 risk prone characteristics
- Intermediate-Low – 3 risk prone characteristics
- Low - >3 risk prone characteristics.

Note: Roelofs (2008a) used similar (plus some additional) parameters for his Ecological Risk Assessment. Information regarding the species identified as critical to the recovery of reef habitat after disturbance related to climate change, was provided by Professor Bellwood.

Table 4.9. Determination of resilience of harvested species in the MAFF using biological characteristics.

Species	**Questions (from Table 4.7.)**							**No. Prone**	**Res.**
	1	**2**	**3**	**4**	**5**	**6**	**7**		
Roelofs (2008a)									
Amphiprion latezonatus	P	A	P	P	A	P	A	4	**L**
Amphiprion melanopus	P	A	P	P	A	P	A	4	**L**
Amphiprion ocellaris	P	A	P	P	A	P	A	4	**L**
Chaetodontoplus duboulayi	A	A	A	A	A	A	A	0	**H**
Chaetodontoplus meredithi	A	A	A	A	A	A	A	0	**H**
Choerodon fasciatus	A	A	A	A	A	A	A	0	**H**
Cleidopus gloriamaris	A	A	A	A	A	A	A	0	**H**
Paracanthurus hepatus	A	A	A	A	A	A	A	0	**H**
Professor Bellwood									
Platax pinnatus	A	A	A	A	A	A	A	0	**H**
Naso unicornis	A	A	A	A	A	A	P	1	**I-H**
Acanthurus nigrofuscus	A	A	A	A	A	A	P	1	**I-H**
Zebrasoma Scopas	A	A	A	A	A	A	P	1	**I-H**
Balistapus undulatus	P	A	A	A	A	A	A	1	**I-H**

Note that some species that were identified by Professor Bellwood do not currently feature in the catch records but could do in the future depending on market demand. Consequently, these species are not considered in the risk tables at this time. These species are:

- *Siganus canaliculatus*
- *Chlorurus microrhinos*

- *Bolbometopon muricatum*
- *Kyphosus vaigiensis.*

Fishery Impact Profile

Similar to the habitat assessment, the Astles Risk Assessment) method uses a fishery impact profile to represent the overall pressure exerted on a species by the activity of the fishery. Unlike the biological characteristics of a species, fishery factors represent those things fishery management can change to reduce risk to a species.

Ten fishery factors were chosen (Table 4.10). Each fishery factor was then assigned to be either risk prone or risk averse (Table 4.11) and a Fishery Impact Profile developed, based on the criteria below. A risk prone fishery factor was one that contributes to the disturbance from fishing that could lead a species to becoming ecologically unsustainable. The decision criteria are customised especially for the MAFF and the fishery impact profile is assessed as:

- Low – <4 risk prone factors
- Intermediate-Low – 4-5 risk prone factors
- Intermediate – 6 risk prone factors
- Intermediate-High – 7 risk prone factors
- High – >7 risk prone factors.

Table 4.10. Ten fishery risk factors to determine the fishery impact profile ratings for harvested species in the MAFF.

Category	Factor	Reason for Use	Risk Averse (Score = 0)	Risk Prone (Score = 1)
How much is caught	1. Catch level	Indicates the degree to which the species is harvested in the fishery	<10,000 individuals	>10,000 individuals
	2. Catch trend[8]	Indicates consistency in catches, changes in trends over a specified period could suggest a possible decline in stocks	Stable for 5 years or increase over 5 years	Decline for 5 years or more
	3. CPUE trend	Used as an index of abundance, changes in catch rate indicate changes in abundance	Stable for last 5 years	Decrease in last 5 years or highly variable
How is it fished	4. Fishery targets aggregations	Indicates how vulnerable a species is to being caught by MAFF fishers	No	Yes
	5. Gear selection	Indicates the ability to selectively target size/age classes	Hand guided in-situ	Mechanically driven from the surface
What is caught	6. Species identification	Indicates whether species of the same genus can be easily identified; if not then the stock status, biology and resilience of different species cannot be determined and therefore managed well	Yes	No
	7. Adequacy of data collected	Indicates whether the fishery managers have adequate information to respond to perturbations in fishery impacts or disturbances linked to climate change	Data recorded and reported to species level	Data aggregated to family level or unspecified
Where is it fished	8. Refuge availability	Indicates whether a species has available places to escape fishing mortality	Substantial areas within the fishery jurisdiction available with no fishing mortality	Few areas within the fishery jurisdiction with no fishing mortality
	9. Adequacy of data collected	Indicates whether the fishery managers have adequate information to respond to perturbations in fishery impacts or disturbances linked to climate change	Data recorded by GPS waypoint to reef or dive site	Data aggregated to 6 minute or 30 minute grid
When is it fished	10. Seasonality	Indicates whether the fishery operates at the same fishing intensity year round	Intermittent – seasonal weather patterns affect fishing patterns	Steady state – seasonal weather patterns do not affect fishing patterns

[8] Catch trends in multi-species fisheries can result from various factors and do not necessarily indicate stock decline.

Table 4.11. Fishery Impact Profile (FIP) for species in the MAFF.

Species	Questions (from Table 4.10.)										No. prone	FIP
	1	2	3	4	5	6	7	8	9	10		
Roelofs (2008a)												
Amphiprion latezonatus	A	A	A	A	A	P	A	P	A	P	3	**I**
Amphiprion melanopus	A	A	A	A	A	P	A	P	A	P	3	**I**
Amphiprion ocellaris	A	A	A	A	A	P	A	P	A	P	3	**I**
Chaetodontoplus duboulayi	A	A	A	A	A	A	A	A	A	A	0	**L**
Chaetodontoplus meredithi	A	A	A	A	A	A	A	A	A	A	0	**L**
Choerodon fasciatus	A	A	A	A	A	P	A	P	A	P	3	**I**
Cleidopus gloriamaris	A	A	A	A	A	P	A	P	A	P	3	**I**
Paracanthurus hepatus	A	A	A	A	A	P	A	P	A	P	3	**L**
Professor Bellwood												
Platax pinnatus	A	A	A	A	A	P	A	P	A	P	3	**I**
Naso unicornis	A	A	A	A	A	P	A	P	A	P	3	**I**
Acanthurus nigrofuscus	A	A	A	A	A	P	A	P	A	P	3	**I**
Zebrasoma Scopas	A	A	A	A	A	P	A	P	A	P	3	**I**
Balistapus undulatus	A	A	A	A	A	P	A	P	A	P	3	**I**

Risk Levels

Finally, the resilience and fishery impact profile ratings were plotted on a habitat risk matrix (Table 4.12) and a risk level assigned, based on the risk matrix template at Figure 4.4 to determine risk to species from the activity of the MAFF. Eleven of the species emerged with a risk level of 'intermediate'.

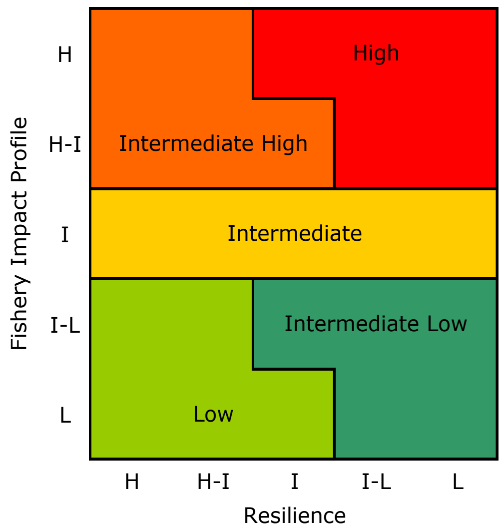

Figure 4.4. Risk matrix for species in the MAFF.H –high, H-I – high to intermediate, I – intermediate, I-L – intermediate to low, L – low.

Table 4.12. Levels of risk to harvested species in the MAFF.

Common Name	Resilience	FIP	Risk
Roelofs (2008a)			
Amphiprion latezonatus	Low	Intermediate	**Intermediate**
Amphiprion melanopus	Low	Intermediate	**Intermediate**
Amphiprion ocellaris	Low	Intermediate	**Intermediate**
Chaetodontoplus duboulayi	High	Low	**Low**
Chaetodontoplus meredithi	High	Low	**Low**
Choerodon fasciatus	High	Intermediate	**Intermediate**
Cleidopus gloriamaris	High	Intermediate	**Intermediate**
Paracanthurus hepatus	High	Intermediate	**Intermediate**
Professor Bellwood			
Platax pinnatus	High	Intermediate	**Intermediate**
Naso unicornis	Intermediate-High	Intermediate	**Intermediate**
Acanthurus nigrofuscus	Intermediate-High	Intermediate	**Intermediate**
Zebrasoma Scopas	Intermediate-High	Intermediate	**Intermediate**
Balistapus undulatus	Intermediate-High	Intermediate	**Intermediate**

Issues Arising from Risk Assessment on Harvested Species

Astles *et al.* (2009) identified issues arising from the risk assessment that impede the reduction of risk to harvested species from fishery activity from the answers to the 10 questions of the fishery impact profile in Table 4.10. The information for those questions that had a risk prone answer was examined further.

The standout issue in the risk assessment for harvest species was the resolution to which fishery data is collected and more particularly, reported. Clearly the activity of the MAFF does not create significant risk to the targeted species for a variety of reasons. However, in the context of predicted impacts of climate change, it is increasingly important that decisions using flexible, adaptive and collaborative management are based on the best possible information, including reporting catch to species level, to a finer spatial resolution and in a timely fashion. This in turn will assist industry in the composition of bottom-up operational strategies for inclusion in the *Stewardship Action Plan* and to inform decision making at the enterprise level.

The second important issue is that the species identified by Professor Bellwood as having limited functional redundancy for their role in preventing or reversing damaging phase shifts do not occur in the catch to any degree beyond negligible.

However, it is important these species are identified and that the number in the catch is monitored to ensure they don't become a significant component in the future.

Authors of subsequent Ecological Risk Assessments for the MAFF might consider the methodology adopted by Roelofs (2008a) for targeted species be retained and supplemented by the Astles risk assessment method for assessing impacts on habitats.

4.2. Queensland Coral Fishery

The adaptation of the Astles risk assessment method for the QCF will not be accompanied by the same degree of explanation as that which was produced for the MAFF.

The QCF is a small scale, quota-managed, hand-harvest fishery with 59 authorities and a commercial Total Allowable Catch of 200 tonnes compared to annual calcium carbonate accretion on the Great Barrier Reef estimated at 50 million tonnes (Harriott, 2001). The quota is split between live coral (30 per cent) and live rock/coral rubble/ornamental coral (70 per cent). Due to the strong market demand for live corals for use in private aquaria, key target species are generally the small and vibrant varieties of coral. Live rock is also a major component of the fishery, due to its suitability as a substrate for the smaller, brighter corals in aquarium tanks. Anemones (Order Actinaria) are also a key target group in the QCF.

Commercial coral harvesters can harvest from all tidal waters (under Queensland jurisdiction) extending from Cape York to the southern extent of the Great Barrier Reef Marine Park at a latitude of 24 degrees 30 minutes south (provided the area is open to coral harvesting under marine park zoning). This is referred to as 'roving harvest'. Two small areas south of the Great Barrier Reef Marine Park are open to harvesting under specific licences.

The QCF is based on hand collection by divers and therefore the amount of harvest effort is mostly limited by time and depth, although the type and location of collection habitat, weather conditions, turbid water and strong tidal currents also influence the amount of effort in some cases.

The total amount of coral collected in the QCF in the 2009 calendar year was around 90 tonne (20 tonne of live coral and 70 tonne of live rock/coral rubble/ornamental coral) (Table 4.13). Coral taxa from over 36 families are harvested for the live aquarium trade. Coral families targeted for the non living, ornamental coral trade include Pocilloporidae (cauliflower/bird's nest corals) and Acroporidae (staghorn/velvet corals).

Table 4.13. Total collection of coral in the QCF in the 2009 calendar year.

Common Name	Number	% Total	Wt (kg)	% Total	Av. Wt (kg)
Mussidae	15,979	10.43%	2,163.36	2.41%	0.14
Catalaphyllia jardinei	11,983	7.82%	1,141.01	1.27%	0.10
Montipora	11,169	7.29%	8,494.24	9.47%	0.76
Euphyllia	9,663	6.31%	1,676.81	1.87%	0.17
Faviidae	8,821	5.76%	2,004.06	2.23%	0.23
Soft coral	7,491	4.89%	349.21	0.39%	0.05
Scolymia - doughnut coral	7,277	4.75%	615.83	0.69%	0.08
Xeniidae	6,374	4.16%	338.47	0.38%	0.05
Goniopora/alvepora	6,182	4.04%	744.66	0.83%	0.12
[a stony coral]	6,115	3.99%	940.82	1.05%	0.15
Nephtheidae	5,758	3.76%	305.12	0.34%	0.05
Fungiidae	5,556	3.63%	877.52	0.98%	0.16
Pectiniidae	4,989	3.26%	571.71	0.64%	0.11
Trachyphyllia geoffroyi	4,824	3.15%	344.83	0.38%	0.07
Duncanopsammia	4,773	3.12%	571.40	0.64%	0.12
Euphyllia glabrascens	4,011	2.62%	436.91	0.49%	0.11
Dendrophylliidae	3,518	2.30%	365.51	0.41%	0.10
Button coral	3,298	2.15%	247.57	0.28%	0.08
Pocilloporidae	2,588	1.69%	2,646.82	2.95%	1.02
Corallimorph	2,227	1.45%	215.29	0.24%	0.10
Living rock	2,152	1.40%	58,731.28	65.49%	27.29
Blastomussa spp	2,007	1.31%	349.09	0.39%	0.17
Other coral	1,914	1.25%	2,973.48	3.32%	1.55
Actinaria	1,650	1.08%	138.03	0.15%	0.08
Turbinaria spp. (cup/turban/vase coral)	1,473	0.96%	811.07	0.90%	0.55
[a stony coral]	1,245	0.81%	148.79	0.17%	0.12
[a stony coral]	1,122	0.73%	152.56	0.17%	0.14
Tubipora musica (organ pipe coral)	1,093	0.71%	127.89	0.14%	0.12
Zoanthidae	1,048	0.68%	154.64	0.17%	0.15
Gorgonacea	854	0.56%	83.59	0.09%	0.10
Entacmaea quadricolor	742	0.48%	98.03	0.11%	0.13
[a stony coral]	640	0.42%	121.97	0.14%	0.19
Tubiporidae	595	0.39%	102.56	0.11%	0.17
Poritidae	588	0.38%	153.71	0.17%	0.26
Stylasteridae - lace coral	563	0.37%	44.00	0.05%	0.08
Oculinidae	543	0.35%	75.07	0.08%	0.14
Caulastrea spp	513	0.33%	52.10	0.06%	0.10
Merulinidae	504	0.33%	87.26	0.10%	0.17
gorgonian corals	475	0.31%	43.92	0.05%	0.09
Milleporidae	465	0.30%	137.45	0.15%	0.30
Agariciidae	392	0.26%	48.50	0.05%	0.12
TOTAL	**153,174**		**89,686.14**		

The CITES species database lists six genera from Family: Mussidae from Australia, including *Acanthastrea* (8 spp), *Blastomussa* (2), *Cynarina* (1), *Lobophyllia* (7), *Scolymia* (2) and *Symphyllia* (5). As identified in Section 2, *Acanthastrea* spp. feature prominently in export figures from 2008 and are likely to form the majority of the Mussidae recorded in the catch. *Catalaphyllia jardinei* is an inter-reefal species that is found in large beds on silty substrates and turbid waters. Whilst the species accounts for 7.82 per cent of the 2009 catch by pieces collected, it only accounts for 1.27 per cent of the catch by weight. And *Montipora* is a ubiquitous genus from Family: Acroporidae. The CITES species database recognises 25 species.

4.2.1. Broad Fishery Risks

As it applied to the MAFF, risk in the QCF is defined as the "likelihood that the activity of the QCF will lead to detrimental effects on key ecological processes that could result in biodiversity loss and long-term degradation of habitats". Again, this definition was chosen to explicitly target recovery of habitats after disturbances linked to climate change. Specifically, the Astles risk assessment method will be adapted to give emphasis to coral species that contribute to structural complexity of coral reefs.

Risk Context

The context of the risk is the operation of the fishery in light of the predicted effects of climate change. This will primarily relate to increased frequency and extent of coral bleaching but also relates to recovery after cyclones and flooding.

Risk Identification

The QCF is a highly targeted fishery where each individual specimen must be presented to the market in premium condition. Collection method, specimen selectivity and treatment are paramount to presenting a premium quality specimen to the market. This assessment will adapt the Astles risk assessment category of 'harvesting of fish for sale' as the key risk, to be instead 'harvesting coral for sale' (Table 4.14).

Risk Characterisation

Having identified the ecological components of the QCF and the activity that could potentially impact them, the next step in the Astles risk assessment method is to identify which of the ecological components is most at risk from the fishery activity. An assessment of 'negligible' to 'high' is assigned to the risks associated with the fishery activity on the identified ecological components at a broad ecosystem scale.

Table 4.14. Levels of risk posed on each ecological component by the activity of the QCF.

Main Activity of the Fishery	Harvesting (what's kept)	
	Direct Risk	Indirect Risk
Ecological Component		
Species assemblages, diversity, and ecological processes	Negligible	Negligible
Marine habitats	low	Negligible
Harvested species	low	Negligible

As this assessment incorporates activity of the fishery with the predicted impacts of climate change, direct risks on all ecological components in the QCF are assumed to be negligible on the basis of the existing Ecological Risk Assessment. The few harvested species in the existing Ecological Risk Assessment that were assessed as a low risk are included in the 'Risks to Harvested Species' section. Indirect risks here are those that flow to the capacity of coral reefs to recover after disturbance related to climate change and to recruit species that contribute to structural complexity. The Astles risk assessment method enables this indirect risk to be recorded and monitored.

Indirect risks to 'habitats' and 'harvested species' were assessed as negligible on the basis that the fishery has few participants spread over a large geographical area and that the fishery operates within the zoning of the Great Barrier Reef Marine Park featuring substantial no-take areas.

'Species assemblages, diversity and ecological processes' is directly linked to risks to habitats from the collection of species that contribute to structural complexity in the process of recovery after disturbance. Consequently, further assessment will focus on 'Marine Habitats' and 'Harvested Species'.

4.2.2. Risk to Marine Habitats

Participants in the QCF collect more than 100 species of coral. Each specimen is carefully chosen for its market suitability, including size, colouration and condition. While most are coral reef species (some of which are reef building), many species are associated with deeper, inter-reefal areas. These are typically found on silty substrates in depths around 25-30 m.

For this exercise, it is the biological communities of coral reefs that will be assessed. As with the MAFF, coral reefs will be differentiated on the basis of proximity to shore in recognition that inshore reefs are subject to further pressure from climate change due to predicted intensity of rainfall events associated with climate change, which exports terrestrial sediments that additionally carry nutrients and toxins such as pesticides. Also, increased flooding and freshwater can significantly change salinity. Presence of silt can decrease light levels, all of which can trigger a stress response in corals.

Risk Context

In the QCF, the risk context is the likelihood that marine habitats will be degraded by the activity of the fishery in light of the predicted effects of climate change.

Risk Identification

Given that physical interaction with habitat is in the form of selective and careful removal of corals typically weighing 50-150 g (Table 4.13), the risk is identified as removing coral species that contribute to structural complexity of coral reef habitat after disturbance.

Risk Characterisation

Risk characterisation is the level of risk for each habitat. The level of risk is determined by "the pressure a fishery exerts on a habitat and its ability to withstand such pressure". Determining the level of risk is a three step process:

1. Vulnerability (based on the biological and physical characteristics of the habitat)
2. Fishery Impact Profile (a measure of the pressure a fishery exerts)
3. Habitat Risk Matrix (the level of risk a habitat is exposed to as a result of fishery activity).

Vulnerability

Vulnerability is described as a combination of resilience and resistance. Resilience is a qualitative description of the capacity of a habitat type to recover if damaged. Resistance refers to the physical and biological properties of habitats to withstand damage. For the purpose of this study, it relates to vulnerability of habitats to the predicted impacts of climate change because of the specific, minimal and controlled interaction between the activity of the fishery and the habitat. Consequently, this assessment will change commensurate with the manifestation of these impacts, such as mass bleaching, severe storm damage or high volume flooding, probably more so than through changes to the dynamics of the fishery.

Resilience and resistance are combined in a matrix (Figure 4.1 – from the MAFF adaptation) to determine the level of vulnerability for each identified habitat type.

For each habitat, two questions were asked to determine level of resilience and resistance:

3. What is the timeframe for it to recover (resilience)?

- High - Less than 1 year
- Medium - 1-5 years
- Low - Greater than 5 years.

4. What is its ability to withstand physical disturbance (resistance)?

- High - No damage
- Medium - Partial damage
- Low - Total damage.

This component of the Astles risk assessment method is considered in this study on the basis that coral collection might have an indirect impact on habitats in the context of climate change (Table 4.15).

Whilst both inshore and offshore coral reefs are equally subject to disturbance from cyclones and, in time, ocean acidification, risk is generalised on the basis that water quality and accessibility creates points of difference between the two habitats. The vulnerability determined through this process is indicative that inshore coral reefs are likely to be subject to greater cumulative risks than offshore coral reefs.

Table 4.15. Levels of resilience, resistance and vulnerability for habitats in the QCF.

Habitats	Resilience	Resistance	Vulnerability
Inshore Coral Reefs	Medium	Medium	**Intermediate**
Offshore Coral Reefs	High-medium	High-medium	**Intermediate-Low**

Fishery Impact Profile

A fishery impact profile provides an integrated measure of the operation of the fishery by combining information on fishery impacts and identifying knowledge gaps that need to be addressed in order to mitigate risk levels. Again, the Astles risk assessment method refers to physical interaction of the fishery with habitat. However, the method can be adapted on the basis that identification of knowledge gaps brought about by low resolution data collection will assist to draw a clearer picture of the exposure of the fishery to habitat and consequently, the extent to which critical disturbance recovery processes are at risk from the fishery.

The Astles risk assessment method asks five basic questions relating to the distribution of habitats and fishery activity (Table 4.4 – from the MAFF adaptation). Each question required a qualitative rating of risk prone or risk averse for each of the identified habitat types.

The Astles risk assessment method then applies a simple decision rule based on the number of risk prone factors used to assign the qualitative fishery impact profile rating for each habitat as follows:

- High – 5 prone factors
- Intermediate-High – 4 prone factors
- Intermediate – 3 prone factors
- Intermediate-Low – 2 prone factors

- Low – 1 prone factor.

Table 4.16. Fishery Impact Profile (FIP) for marine habitats impacted by the QCF.

Habitat	Question (from Table 4.4)					No. Prone	FIP
	1	2	3	4	5		
Inshore Coral Reefs	A	P	P	A	P	3	**I**
Offshore Coral Reefs	A	P	P	A	P	3	**I**

NB: A – risk averse, P – risk prone, H – high, H-I – high to intermediate, I – intermediate, I-L – intermediate to low, L – low.

Risk Levels

Finally, the vulnerability and fishery impact profile ratings were plotted on a habitat risk matrix (Figure 4.2 – from the MAFF adaptation) to determine risk to habitats from the activity of the QCF. Again, the risks relate to the potential indirect impacts of activities in the fishery.

Risk was determined by the interaction of vulnerability and the fishery impact profile. The outcome of the risk to habitats from the QCF is presented in Table 4.17. Both inshore and offshore coral reefs were assessed to be exposed to intermediate risk from the QCF. This assessment can be supported in the future through strategies to minimise fishery impacts on the recovery capacity of coral reef systems in the event of disturbances linked to climate change.

Table 4.17. Risk levels for marine habitats in the QCF.

Habitat	Vulnerability	Fishery Impact Profile	Risk Level
Inshore Coral Reefs	Intermediate	Intermediate	**Intermediate**
Offshore Coral Reefs	Intermediate-Low	Intermediate	**Intermediate**

Issues Arising from Risk Assessment on Habitats

Astles *et al.* (2009) identified issues arising from the risk assessment that impede the reduction of risk to marine habitats from fishery activity from the answers to the five basic questions of the fishery impact profile in Table 4.4 – from the MAFF adaptation. The information for those questions that had a risk prone answer was examined further.

As with the MAFF adaptation, the issues related to the overlap of fishing activity and the identified habitats. The issue is less pronounced in the QCF than in the MAFF. The overlap is not complete because several targeted species inhabit inter-reefal and often silty habitats in depths that are not compatible with easy access for divers. Notwithstanding, there is still considerable overlap of fishery activity on coral reefs. Again the risk relates not to the physical interaction of the fishery but to the potential indirect effects of collecting species that perform functions critical to the recovery of the coral reef habitat after disturbance. In this instance, the disturbances for consideration are those linked to climate change and the recovery capacity relates to maximising recruitment of species that contribute to structural complexity of reefs, which is critical to maintaining biological diversity.

To address this issue, in the first instance, Dr. Pratchett was asked to identify species that perform functions relevant to the assessment of risk in the QCF (Box 4.2). These species should then be monitored in the overall catch and have collection strategies applied to them in the event of major disturbances linked to climate change.

Box 4.2. Coral species that perform functions critical to recovery of structural complexity to coral reef habitat after disturbance.

Corals and Coral Reefs

As the name suggests, corals are a key element of coral reefs. Scleractinian ("hard") corals have three important roles in the ecological function of coral reef ecosystems:

1. **Foundation species**, contributing significantly to basal carbon production for complex reef-based food webs. Corals act as key primary producers on reefs, fixing energy for higher trophic levels through autotrophy and heterotrophy and there are many species of fishes and non-coral invertebrates that specialise on corals for food (Cole *et al.*, 2008; Rotjan & Lewis, 2008).

2. **Habitat-forming species**, providing critical habitat for coral-dwelling and reef-associated animals (e.g. Pratchett *et al.*, 2008). The coral reef matrix provides areas of habitat, refuge and settlement for associated reef fauna and persists even after the corals themselves may have died, provided that the coral skeletons remain intact (Graham *et al.*, 2006; Wilson *et al.*, 2009).

3. **Structural engineers** (Jones *et al.*, 1994), contributing to high habitat complexity and surface topography, which promotes biodiversity on coral reefs by mediating competition and/or predation (e.g. Coker *et al.*, 2009). Scleractinian corals also play an important role in the formation of extensive carbonate frameworks that are the structural basis of coral reef habitats (Bellwood *et al.*, 2004). Importantly, corals are the main group of organisms involved in primary reef growth (scaffolding) and also contribute secondary reef framework growth (binding and cementation) (Hopley *et al.*, 2007).

Scleractinia

The order Scleractinia contains the key reef building and habitat-forming corals and typically dominates coral reef ecosystems throughout the world. There are however, marked differences in the life-histories and functional importance of different scleractinian corals, which often relates to their distinct morphologies (Jackson, 1979).

The most important coral species in providing habitat for reef-associated organisms (e.g. fishes) and increasing topographical complexity are erect branching corals from the genera (Connell *et al.*, 1997; Veron, 2000; Bruno & Bertness, 2001):

- *Pocillopora*
- *Acropora*
- *Isopora*
- *Montipora.*

These corals are typically fast-growing (Jackson, 1979) but also highly susceptible to different disturbances (e.g. cyclones, bleaching and outbreaks of corallivores) that may cause extensive coral loss (e.g. Glynn, 2006; Graham *et al.*, 2006).

Massive corals meanwhile, including *Porites*, *Favites* and *Diploastrea* are relatively resistant to most major disturbances and their robust skeletons may persist long after the coral dies, making an important contribution to primary reef growth (Hopley *et al.*, 2007).

A question worth asking is whether the high diversity of Scleractinia on the Great Barrier Reef as compared with an isolated location, such as Clipperton Atoll, actually confers any functional advantage in terms of habitat complexity? Whilst it is evident that high diversity provides the potential for functional redundancy (Bellwood *et al.*, 2004) if, as has been shown, these genera respond similarly to disturbance events, such as bleaching (Pratchett *et al.*, 2008; Pratchett *et al.*, 2009), it is questionable whether one hundred branching species is any more useful than a handful of branching species.

Coral Mortality

Contemporary scleractinian corals face many threats, both anthropogenic and natural. Rising ocean temperatures associated with global warming are causing increasing incidence of coral bleaching and may also be related to increased storm frequency and outbreaks of coral disease (Hoegh-Guldberg, 1999; Hoegh-Guldberg *et al.*, 2007b; Carpenter *et al.*, 2008). In addition, ocean acidification poses a potential, but poorly understood, threat to coral growth and reef formation (De'ath *et al.*, 2009).

Sustained and ongoing climate change will have a significant impact on coral reef ecosystems, but rather than catastrophic loss of all corals on the same time frames, it is most likely that ocean warming and ocean acidification will cause changes in the relative abundance of different corals (Hughes *et al.*, 2003). Moreover, in the Pacific and on the Great Barrier Reef, outbreaks of the corallivorous starfish (*Acanthaster planci*) remain the greatest contributor to coral loss, rather than climate change (Bruno & Selig, 2007).

Direct anthropogenic effects on reefs that also contribute to localised coral loss include overfishing, coastal development, pollution, blast fishing (not permitted in the QCF), trawling, anchor damage and over-diving (Hawkins & Roberts, 1993; Pratchett *et al.*, 2008; Veron, 2010). These disturbances may be broadly differentiated into physical versus biological disturbances (Wilson *et al.*, 2006), which kill live corals with or without affecting the structural integrity of the underlying skeleton.

Disturbances that result in an immediate loss of habitat complexity (physical disturbances) have a greater impact on fishes from all trophic levels compared with disturbances that kill corals but leave the reef framework intact (biological disturbances). Furthermore, many of these disturbances act synergistically, further eroding the ability of a coral colony to survive any given disturbance; for example, a bleached coral may be more susceptible to disease (Bruno & Selig, 2007).

Another factor contributing to declines in abundance of corals are changes to the rates of population replenishment, due to either:

1. reduced reproductive output of local coral population, or

2. reduced settlement and survivorship of corals owing to inappropriate substrate (Bellwood *et al.*, 2004; Hughes & Tanner, 2008).

Given their limited supply of energy, corals will divide their resources between growth, maintenance and reproduction (Rotjan & Lewis, 2008). Disturbances that do not kill corals outright may nonetheless cause corals to suffer sub-lethal stress, which in turn has been shown to reduce their fecundity (Baird & Marshall, 2002). Extrinsic factors may also limit recruitment potential; Hughes *et al.* (2007) showed that macroalgal growth led to significant reduction in recruitment and survival of corals when large herbivorous fishes were excluded from grazing on reef substrates.

Coral Reef Resilience

Given the significant declines in coral cover and topographic complexity on a global scale, it is imperative that we identify and implement strategies to slow, halt and ideally reverse current trends (Bellwood *et al.*, 2004). Four key approaches are identified here:

Water quality

Pollution, eutrophication and sediment loading may all be caused by anthropogenic activity, including agricultural run-off, sewage, deforestation, coastal development and a multitude of other activities associated with high population centres (Aronson & Precht, 2006; Maynard *et al.*, 2010). Regulation of these industries and activities by appropriate, well-resourced agencies would go a long way toward improving water quality along coastal margins (Hughes *et al.*, 2003; Pratchett *et al.*, 2008) where many shallow reefs are found. Improvements in water quality may serve to increase coral abundance, by either:

1. reducing competition with macroalgae

2. increasing settlement and survivorship of juvenile corals, or

3. reducing the incidence of outbreaks of *A. planci* (Fabricius *et al.*, 2010).

Regulation of direct impacts

Anthropogenic activity at sea, including destructive fishing practices and over-use of coral reef habitats (e.g. fishing, tourism) need to be reconsidered in light of their long-term viability given their negative impact on coral reefs (Kaiser *et al.*, 2000; Maynard *et al.*, 2010). Again, appropriate and responsive regulation is essential if we are to reduce our direct impact on coral reefs, although clearly their relevance and effectiveness depend on a range of cultural, social and economic factors (Pratchett *et al.*, 2008).

Herbivore abundance

Overfishing of herbivorous populations has been shown to lead to phase-shifts and reduce the capacity of an ecosystem to reverse such a state (Bellwood *et al.*, 2006; Hughes *et al.*, 2007). Given that the functional redundancy of these keystone species has been shown to be limited, especially in the case of macroalgal browsers (see

Box 4.1 for notes on Scarines, Acanthurids and Siganids), it is critical that these species receive protection in order to conserve their populations.

Marine Protected Areas

Great hope has been placed in no-take areas. The Great Barrier Reef leads the world in such protection and now stands to receive the benefits of this action. Overseas, however, without greatly expanded networks of no-take areas and stronger protection of adjacent habitats, their effectiveness will be limited (Hughes *et al.*, 2003).

4.2.3. Risk to Harvested Species

The QCF collects more than 100 species of hard and soft corals plus several species of anemone. The fishery also collects live rock, which is used as the basis for mini-reef displays. The existing Species Vulnerability Assessment (Roelofs & Silcock, 2008b) used a robust methodology to identify species that were classified as above negligible risk. These species were further evaluated for their susceptibility to, and capacity to recover from, collection pressure. The recovery capacity of individual species was determined from biological data extracted from the literature.

The subsequent Ecological Risk Assessment (Roelofs, 2008b) identifies species from the QCF logbook that were determined to be above negligible risk from the activity of the fishery in the context of the existing spatial protection from marine park zoning and other factors, including diver accessibility and market demand. These assessments were carried out in consultation with fishery participants and others. The species identified through that process will be included in the current adaptation of the Astles risk assessment methodology.

It is noted that the Astles risk assessment method for assessing impacts on habitats substantially complements the (Roelofs, 2008b) assessment. As the species identified by Roelofs (2008b) were included on the basis of biological characteristics that enable the species to recover after disturbance, it is unlikely that the identified species would change unless there is a shift in market demand that causes a substantial elevation in catch of other species that currently do not feature to any substantial degree.

Risk Context

In the case of targeted species in the QCF, Roelofs (2008b) concluded that few species were at risk from the activity of the fishery. Consequently, the risk context in this adaptation of Astles *et al.* (2009) is the likelihood that targeted species will be detrimentally impacted by the activity of the fishery in light of the predicted effects of climate change.

Risk Identification

Given that Roelofs (2008b) identified a number of species in the QCF for monitoring and that Dr. Pratchett identified others that contribute to structural complexity in the context of recovery of coral reef habitat after disturbance, the identified risk for this adaptation of the Astles risk assessment is the collective of those species or species groups identified through both sources.

Risk Characterisation

The level of risk is determined by “the pressure a fishery exerts on a species and the biological and ecological characteristics of a species to withstand such pressure” (Astles *et al.*, 2009). Determining the level of risk is a three step process:

1. Resilience (based on the biological capacity of a species that enables it to respond to a disturbance)

2. Fishery Impact Profile (a measure of the pressure a fishery exerts)

3. Risk Matrix (the level of risk a species is exposed to as a result of fishery activity).

Resilience

Astles *et al.* (2009) describes resilience as a set of biological characteristics that collectively describes the capacity of a species to recover from the impacts of the fishery, including reproductive strategy, growth rate and diet specificity. Those authors described resistance, as it is used in the habitats section, as related to the catchability of a species with the fishing gear used. Consequently, that features as part of the Fishery Impact Profile.

Like the assessment of fishery impacts on habitats, levels of resilience were determined by assigning characteristics to be risk prone or risk averse. In this case, a risk prone characteristic is one that reduces a species capacity to recover from the impacts of harvest. A risk averse characteristic is one that does not reduce or may enhance a species capacity to recover from the impacts of fishing mortality.

Table 4.17. Characteristics of species groups identified by Dr. Pratchett as being critical contributors to structural complexity of coral reefs.

Species	Life History	Geographic Distribution	Habitat Specificity	Abundance	Growth Rate	Age at Maturity	Longevity and Vulnerability	Diet Specificity
Pocillopora	Overwhelmingly sexual and brooding reproductive strategy (Ward, 1992). Despite this some species (e.g. *P. damicornis*) maintain high levels of gene flow across widely separated reefs (>1000km) (Ayre *et al.*, 1997)	Found throughout Indo-Pacific although unlike most other major genera is most diverse in the Far Eastern Pacific. Some of the most widely distributed species Many species common in high latitudes (Veron, 2000) Approximately 10 species (Veron, 1993)	Found often on exposed reef fronts where currents are strong, and often at shallow depths (Veron, 2000)	Abundant Genus. Common species are *Pocillopora damicornis, P. verrucosa, P. meandrina* and *P. eudouxi* (Veron, 1993; 2000)	Submassive to branching colonies (Veron, 2000) Relatively fast growing (Guzman & Cortes, 1989) apparently independent of colony age (Hughes & Connell, 1987) and colony size (Guzman & Cortes, 1989)	Relatively young: 1-2 years (Hughes, 1983)	Highly susceptible to bleaching (Marshall & Baird, 2000) Relatively short lived (Veron, 2000)	Autotrophic (zooxanthellae) and heterotrophic (Veron, 2000)
Acropora	Predominantly co-ordinated, broadcast spawning (self-fertilisation known but infrequent). Asexual reproduction (via fragmentation) may occur in open-branching, intermediate growth forms (arborescent and hispidose forms) (Wallace, 1999)	Found throughout the Indo-Pacific, with three species in the Atlantic. At least 150 species (Veron, 1993)	*Acropora* species are distributed across a variety of reef habitats, though individual species tend to be localised in specific habitats. For example, small corymbose and tabular species are most abundant in high energy reef front and shallow environments. Arborescent species meanwhile often predominate on upper reef slopes, reef flats and lagoons (Wallace, 1999; Veron, 2000. Some rarer species	By far the most abundant corals of most reefs on the Indo-Pacific (Veron, 2000) Especially abundant species are *Acropora formosa, A. cytherea, A. millepora, A. nasuta* and *A. hyacinthus* (Veron, 1993; 2000)	Colonies are usually branching, bushy or plate-like (Veron, 2000) Morphological, colour and behavioural differences between colonies from temperate locations and their tropical counterparts (Veron, 1993). Fast growing with high O_2, good light penetration and clear water conditions (Wallace, 1999)	3-8 years (Wallace, 1999)	Often outcompete all other corals in shallow tropical reefs especially where the water is clear (Veron, 2000). Highly susceptible to bleaching (Marshall & Baird, 2000) Relatively short-lived (Wallace, 1999; Veron, 2000). Sensitive to many perturbations (inc. *Acanthaster planci*), but early colonisers of disturbed sites (Wallace, 1999)	Autotrophic (zooxanthellae) and heterotrophic (Veron, 2000)

			are found only in deep and unusual habitats (Wallace, 1999)					
Isopora	Veron considers *Isopora* a subgenus of *Acropora* (Veron, 2000) Wallace considers it a Genus in its own right (Wallace *et al.*, 2007) Data limited: as for *Acropora* but less abundant. Hermaphrodite polyps and *in situ* fertilisation (Wallace, 1999)							
Montipora	Predominantly timed broadcast spawning (Heyward, 1986) with some evidence of asexual reproduction (Highsmith, 1982)	Indo-Pacific range. Many species of *Montipora* occur in the Philippines rather than the Great Barrier Reef. Current records are incomplete and poorly known. At least 80 species (Veron, 1993)	Predominantly upper reef slopes, reef flats and lagoons (shallow reef environments) (Veron, 2000)	Abundant Genus. Common species are *Montipora foliosa, M. tuberculosa, M. digitata* and *M. efflorescens* (Veron, 1993; 2000)	Colonies are submassive, laminar, encrusting or branching. Species often have multiple growth forms (Veron, 2000)	3-8 years, but mostly depends on size.	Show varied susceptibility to bleaching at different locations, but appear relatively resistant (Marshall & Baird, 2000)	Autotrophic (zooxanthellae) and heterotrophic (Veron, 2000)

Overall resilience for each species is determined by summing the scores of risk prone characteristics identified in Table 4.7 (from the MAFF adaptation). Dr. Pratchett characterised the species groups identified in Box 2 according to the Astles risk assessment (Table 4.17). The summary is presented in Table 4.18.

The level of resilience is allocated as:

- High – O risk prone characteristics
- Intermediate - High – 1 risk prone characteristics
- Intermediate – 2 risk prone characteristics
- Intermediate - Low – 3 risk prone characteristics
- Low - >3 risk prone characteristics.

Table 4.18. Determination of resilience of harvested species in the QCF using biological characteristics.

Species	**Questions (from Table 4.7.)**							**No. Prone**	**Res.**
	1	**2**	**3**	**4**	**5**	**6**	**7**		
Roelofs (2008b)									
Catalaphyllia jardinei	A	A	A	A	A	A	A	0	**H**
Plerogyra spp.	A	A	A	A	A	A	A	0	**H**
Euphyllia glabrascens	A	A	A	A	A	A	A	0	**H**
Duncanopsammia axifuga	A	A	A	A	A	A	A	0	**H**
Scolymia vitensis	A	A	A	A	A	A	A	0	**H**
Blastomussa wellsi	A	A	A	A	A	A	A	0	**H**
Blastomussa merleti	A	A	A	A	A	A	A	0	**H**
Acanthastrea lordhowensis	A	A	A	A	A	A	A	0	**H**
Trachyphyllia geoffroyi	A	A	A	A	A	A	A	0	**H**
Various Gorgonians	A	A	A	A	A	A	A	0	**H**
Entacmaea quadricolour	A	A	A	A	A	A	A	0	**H**
Dr. Pratchett									
Acropora spp.	A	A	A	A	A	A	A	0	**H**
Pocillopora spp.	A	A	A	A	P	A	A	1	**I-H**
Isopora spp.	-	-	-	-	-	-	-	-	**-**
Montipora spp.	A	A	A	A	P	A	A	1	**I-H**

Fishery Impact Profile

Similar to the habitat assessment, the Astles risk assessment method uses a fishery impact profile to represent the overall pressure that is exerted on a species by the activity of the fishery. Unlike the biological characteristics of a species, fishery factors represent those things that fishery management can change to reduce risk to a species.

Ten fishery factors were chosen (Table 4.19). Each fishery factor was then assigned to be either risk prone or risk averse. A risk prone fishery factor was one that contributes to the disturbance from collection that could result in the continued target of a species becoming ecologically unsustainable. The decision criteria are customised especially for the QCF and the fishery impact profile is assessed as:

- Low – <4 risk prone factors
- Intermediate - Low – 4-5 risk prone factors
- Intermediate – 6 risk prone factors
- Intermediate - High – 7 risk prone factors
- High – >7 risk prone factors.

Table 4.19. Ten fishery risk factors to determine the fishery impact profile ratings for harvested species in the QCF.

Category	Factor	Reason for Use	Risk Averse (Score = 0)	Risk Prone (Score = 1)
How much is caught	1. Catch level	Indicates the degree to which the species is harvested in the fishery	<10,000 individuals	>10,000 individuals
	2. Catch trend	Indicates consistency in catches, changes in trends over a specified period could suggest a possible decline in stocks	Stable since logbooks changed	Decline since logbooks changed
	3. CPUE trend	Used as an index of abundance, changes in catch rate indicate changes in abundance	Stable for last 5 years	Decrease in last 5 years or highly variable
How is it fished	4. Fishery risk of localised depletion from concentrated selected take	Indicates how vulnerable a species is to being caught by QCF fishers	Yes	No
	5. Gear selection (general selectivity)	Indicates the ability to selectively target size/age classes	Hand guided in-situ	Mechanically driven from the surface
What is caught	6. Species identification	Indicates whether species of the same genus can be easily identified; if not then the stock status, biology and resilience of different species cannot be determined and therefore managed well	Yes	No
	7. Adequacy of data collected	Indicates whether the fishery managers have adequate information to respond to perturbations in fishery impacts or disturbances linked to climate change	Data recorded and reported to species level	Data aggregated to family level or unspecified
Where is it fished	8. Refuge availability	Indicates whether a species has available places to escape fishing mortality	Substantial areas within the fishery jurisdiction available with no fishing mortality	Few areas within the fishery jurisdiction with no fishing mortality
	9. Adequacy of data collected	Indicates whether the fishery managers have adequate information to respond to perturbations in fishery impacts or disturbances linked to climate change	Data recorded by GPS waypoint to reef or dive site	Data aggregated to 6 minute or 30 minute grid or broader e.g. in/out of key collection areas like Cairns and Keppels
When is it fished	10. Seasonality	Indicates whether the fishery operates at the same fishing intensity year round	Intermittent – seasonal weather patterns affect fishing patterns	Steady state – seasonal weather patterns do not affect fishing patterns

Table 4.20. Fishery Impact Profile (FIP) for species in the MAFF.

Species	Questions (from Table 4.18.)										No. prone	FIP
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
Roelofs (2008b)												
Catalaphyllia jardinei	A	A	A	A	A	A	A	A	P	A	1	**L**
Plerogyra spp.	A	A	A	A	A	P	P	A	P	A	3	**I/L**
Euphyllia glabrascens	A	A	A	A	A	A	A	A	P	A	1	**L**
Duncanopsammia axifuga	A	A	A	A	A	A	P	A	P	A	2	**L**
Scolymia vitensis	A	A	A	A	A	A	P	A	P	A	2	**L**
Blastomussa wellsi	A	A	A	A	A	A	P	A	P	A	2	**L**
Blastomussa merletti	A	A	A	A	A	A	P	A	P	A	2	**L**
Acanthastrea lordhowensis	A	A	A	A	A	A	P	A	P	A	2	**L**
Trachyphyllia geoffroyi	A	A	A	A	A	A	A	A	P	A	1	**L**
Various Gorgonians	A	A	A	A	A	P	P	A	P	A	3	**I/L**
Entacmaea quadricolour	A	A	A	A	A	A	P	A	P	A	2	**L**
Dr. Pratchett												
Acropora spp.	A	A	A	A	A	P	P	A	P	A	3	**I/L**
Pocillopora spp.	A	A	A	A	A	P	P	A	P	A	3	**I/L**
Isopora spp.	A	A	A	A	A	P	P	A	P	A	3	**I/L**
Montipora spp.	A	A	A	A	A	P	P	A	P	A	3	**I/L**

Risk Levels

Finally, the resilience and fishery impact profile ratings were plotted on a habitat risk matrix (Figure 4.4 – from the MAFF adaptation) to determine risk to species from the activity of the MAFF.

Table 4.21. Levels of risk to harvested species in the MAFF.

Scientific Name	Resilience	FIP	Risk
Roelofs (2008b)			
Catalaphyllia jardinei	High	Low	**Low**
Plerogyra spp.	High	I/Low	**Low**
Euphyllia glabrascens	High	Low	**Low**
Duncanopsammia axifuga	High	Low	**Low**
Scolymia vitensis	High	Low	**Low**
Blastomussa wellsi	High	Low	**Low**
Blastomussa merletti	High	Low	**Low**
Acanthastrea lordhowensis	High	Low	**Low**

Trachyphyllia geoffroyi	High	Low	**Low**
Various Gorgonians	High	I/Low	**Low**
Entacmaea quadricolour	High	Low	**Low**
Dr. Pratchett			
Acropora spp.	High	I/Low	**Low**
Pocillopora spp.	Intermediate High	I/Low	**Low**
Isopora spp.	-	-	**-**
Montipora spp.	Intermediate High	I/Low	**Low**

Issues Arising from Risk Assessment on Harvested Species

Astles *et al.* (2009) identified issues arising from the risk assessment that impede the reduction of risk to harvested species from fishery activity from the answers to the 10 questions of the fishery impact profile in Table 4.20. The information for those questions that had a risk prone answer was examined further.

The standout issue in the risk assessment for harvest species was the manner with which fishery data is collected and reported. Clearly the activity of the QCF does not create significant risk to the targeted species for a variety of reasons. However, in the context of predicted impacts of climate change, it is increasingly important that decisions using flexible and adaptive management are based on the best possible information, including reporting catch to species level and to a consistent, fine spatial resolution. This in turn will assist industry in the composition of bottom-up operational strategies for inclusion in the *Stewardship Action Plan*.

Authors of subsequent Ecological Risk Assessments for the QCF might consider that the methodology adopted by Roelofs (2008a) for targeted species should be retained and supplemented by the Astles risk assessment method for assessing impacts on habitats.

4.3. Discussion and Conclusions

Adaptation of the Astles risk assessment method as an extension of the method used by Roelofs & Silcock (2008a & 2008b) is a useful way of incorporating indirect fishery impacts on habitat in the context of the predicted effects of climate change.

Separating biological and life history characteristics of the targeted species (unchanging in any reasonable timeframe) from fishery factors (changeable) enables the risk matrix to identify areas of greatest risk. If for any reason species that currently do not feature to any substantial extent appear in the catch record, those species can be added to the list of assessed species. And as fishery dynamics change and the fishery interacts with other habitats, the risk matrix can be adjusted accordingly.

The habitat types identified for this review were kept deliberately broad, separating inshore and offshore coral reefs on the basis that inshore reefs are exposed to greater risk from events linked to climate change on top of water quality and resource sharing issues. However, with more detailed information around collection, the habitat assessment can become more detailed.

Inclusion of fish species with limited functional redundancy in the recovery of reefs after disturbance and coral species that contribute to structural complexity to support biological diversity enables the assessment of the fishery interaction with these species and for the development of operational strategies regarding these species to be built into industry best-practice initiatives.

The adaptation of the Astles risk assessment method to the MAFF and QCF identified that the manner in which fishery data is collected is likely to create uncertainty in management decision making as the frequency and extent of predicted climate change impacts manifests. For fishery and protected areas management to be adaptive and responsive to changing circumstances in the marine environment, it is in the interests of fishers that decisions are made with the highest resolution of information possible such that those decisions are made with confidence and in a timely manner. The development of electronic fishery data recording and reporting is seen as a desirable path to explore as a means of maximising production efficiency and environmental performance in these fisheries.

5. Management Arrangements

This section will describe the framework for the management of activities within the MAFF and QCF fishery areas. This includes the management of all activities that might impact upon natural systems, biodiversity and sustainable fisheries production and the agencies that carry out the management. This framework will demonstrate how prominently climate change features in the priorities and actions of the government agencies that oversee the fisheries and the environment in the wider region where the fisheries are conducted, particularly on the Great Barrier Reef and adjacent catchments.

The section also examines the current management provisions for the fisheries, including the fishery specific information that enables flexible and adaptive management with a high level of confidence. It also describes and critiques the existing response mechanism for events linked to climate change. It is not the intent of this section to prescribe changes to management of the fisheries but to identify opportunities that make management more inclusive of the requirements of industry and the fishery and protected areas management agencies in anticipation of the predicted effects of climate change.

5.1. The Great Barrier Reef

The Great Barrier Reef is the largest coral reef ecosystem in the world, spanning a length of 2300 km along the east coast of Queensland north from about 24˚30'S, which is slightly north of Fraser Island. There are about 2900 reefs, which represent about 10 per cent of all the coral reef areas in the world.

In 1974 a Royal Commission into oil drilling on the Great Barrier Reef highlighted the scarcity of scientific knowledge about the ecosystem as well as the lack of a dedicated regulatory authority to manage it. The Royal Commission culminated the following year with the *Great Barrier Reef Marine Park Act 1975*, which established the Great Barrier Reef Marine Park and the GBRMPA.

The Great Barrier Reef Marine Park spans about 344,400 km^2 and is a multiple use marine park, supporting a wide range of uses, including commercial marine tourism, Defence activities, fishing, ports and shipping, recreation, scientific research and Indigenous traditional use.

In 1981 the Great Barrier Reef was internationally recognised with inscription on the World Heritage List. The Great Barrier Reef World Heritage Area extends from the low water mark of the mainland and includes all islands, internal waters of Queensland and Seas and Submerged Lands Act exclusions. It covers an area of about 348,000 km^2. It's an important distinction to recognise because World Heritage listing crosses domestic jurisdictional boundaries and carries a suite of obligations that accompany the 1972 World Heritage Convention.

In July 2004 the Representative Areas Program was implemented under the *Zoning Plan (2003).* Under that program 70 bioregions (important breeding and nursery areas such as seagrass beds, mangrove communities, deepwater shoals and coral reefs) were identified in the Great Barrier Reef to be represented in the world's largest network of 'no-take' zones that collectively cover 117,000 km^2 (or 33 per cent) of the Great Barrier Reef Marine Park. A further 32 per cent of the entire Marine Park has other limitations on extractive use and the entire area is protected from activities such as oil drilling or mining. In November 2004 the Great Barrier Reef Coast Marine Park was established under the *Marine Parks Act 2004 (QLD)* in adjacent Queensland waters. Zoning under the Coast Marine Park complements zoning under the Representative Areas Program.

In May 2007 the Great Barrier Reef was included on the National Heritage List established under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and in November 2009 the Great Barrier Reef Marine Park was inserted into the EPBC Act as a matter of national environmental significance. As a consequence, the environmental impact assessment and approval requirements under the EPBC Act will apply where an action in the Marine Park has, will have or is likely to have, a significant impact on the environment, and where an action outside the Marine Park has, will have or is likely to have, a significant impact on the environment in the Marine Park.

5.2. International Agreements

A number of international conventions are relevant to the Great Barrier Reef, all of which are provided for under the EPBC Act. International conventions include the following.

- Convention on Wetlands of International Importance Especially as Waterfowl Habitats, 1971 (the Ramsar Convention)
- Convention for the Protection of the World Cultural and Natural Heritage, 1972 (the World Heritage Convention)
- Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1973 (CITES)
- International Convention for the Prevention of Pollution from Ships, 1973 (the MARPOL Convention)
- Convention on the Conservation of Migratory Species of Wild Animals, 1979 (the Bonn Convention)
- United Nations Convention on the Law of the Sea, 1982 (the Law of the Sea Convention or UNCLOS)
- Convention on Biological Diversity, 1992 (the Biodiversity Convention)
- United Nations Framework Convention on Climate Change, 1992 (the FCCC).

5.3. Great Barrier Reef Intergovernmental Agreement

The *Great Barrier Reef Intergovernmental Agreement 2009* provides a framework for the Australian and Queensland governments to work together to protect the Great Barrier Reef. The Agreement recognises that key pressures on the Great Barrier

Reef such as climate change impacts, catchment water quality and coastal development cannot be effectively addressed by either government on their own. The 2009 Intergovernmental Agreement replaces the *Emerald Agreement 1979.*

The new Agreement provides a contemporary framework for cooperation between the governments, recognising challenges such as climate change and catchment water quality that were not foreseen at the time of the 1979 Agreement. The guiding principles that underpin the agreement emphasise the precautionary principle will be applied to protecting the environmental, World Heritage and National Heritage values of the Great Barrier Reef.

Implementation of the Intergovernmental Agreement is driven by the Great Barrier Reef Ministerial Council, which is comprised of two Ministers each from the Australian and Queensland governments with responsibility for matters relating to the environment and marine parks, science, tourism and/or natural resource management. Currently, it is comprised of the Commonwealth and Queensland Ministers with Environment and Tourism portfolios.

The Ministerial Council meets annually. At the only meeting to date the following priorities were identified:

1. Build and maintain the resilience of the Great Barrier Reef to the impacts of climate change

2. Improve the quality of water entering the Great Barrier Reef through complementary and coordinated action

3. Continue to manage fishing activities in the Great Barrier Reef World Heritage Area to ensure ecological sustainability and the protection of World Heritage values.

5.4. Jurisdictional Framework

The Commonwealth is responsible for the management of the Great Barrier Reef Marine Park within the Great Barrier Reef Region. The Great Barrier Reef Region has the same external dimensions as the Great Barrier Reef World Heritage Area (described in 5.1) but excludes islands that form a part of Queensland and waters “within the limits” of Queensland.

The Great Barrier Reef Marine Park generally extends over Queensland State coastal waters (3 nm offshore) to the low-water mark and, under the *1979 Offshore Constitutional Settlement*, vesting of title and powers over these coastal waters is subject to the operation of the *Great Barrier Reef Marine Park Act 1975*.

Queensland is responsible for the management of the Great Barrier Reef Coast Marine Park and it is carried out by Queensland Parks & Wildlife, which forms part of the Department of Environment and Resource Management. The Great Barrier Reef Coast Marine Park is contiguous with the Great Barrier Reef Marine Park and covers the area between low and high water marks and many waters within the limits of the State of Queensland.

There are around 900 islands and cays within the boundaries of the Great Barrier Reef Marine Park. The majority of the islands fall within the jurisdiction of Queensland and almost half of these are national parks established under the *Nature Conservation Act 1992 (QLD).* There are around 70 islands that are owned by the Commonwealth and form part of the Great Barrier Reef Marine Park. The Queensland Great Barrier Reef Coast Marine Park and the Queensland island national parks form part of the Great Barrier Reef World Heritage Area.

There is a joint program of field management, with shared funding on a 50:50 basis, for the Great Barrier Reef Marine Park and Queensland marine and national parks within the Great Barrier Reef World Heritage Area.

Development and land use activities in coastal catchments adjacent to the Great Barrier Reef World Heritage Area are an important influence on the World Heritage values of the Area. Queensland is responsible for natural resource management and land use planning of the islands, coast and hinterland adjacent to the Great Barrier Reef World Heritage Area including through the *Coastal Protection and Management Act 1995 (QLD)* and the *Sustainable Planning Act 2009 (QLD)*. The Commonwealth is responsible, under the EPBC Act, for regulating activities having or likely to have a significant impact on matters of "national environmental significance" as defined by the Act and on the environment within Commonwealth land and waters.

Queensland and the Commonwealth both have responsibilities relating to fisheries in the Great Barrier Reef World Heritage Area under the *Fisheries Management Act 1991 (C^{th}),* the *Fisheries Act 1994 (QLD)* and the EPBC Act. Under the *1979 Offshore Constitutional Settlement*, management of fisheries within the Great Barrier Reef Marine Park is the responsibility of Queensland through Fisheries Queensland, which is a business area of Primary Industries and Fisheries that in turn forms part of the Department of Employment, Economic Development & Innovation.

5.5. Great Barrier Reef Marine Park Authority

The GBRMPA is the Commonwealth government statutory authority responsible for the administration of the *Great Barrier Reef Marine Park Act 1975.* The main object of the Act is to "provide for the long-term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region".

The GBRMPA is a portfolio agency of the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC). It works in the policy framework of the Australian Government and provides its annual report through the portfolio Minister to the Australian Parliament.

The objectives of the current GBRMPA Corporate Plan include:

1. Address key risks affecting the outlook for the Great Barrier Reef

2. Ensure management delivers ecologically sustainable use of the Great Barrier Reef.

The number one priority of the GBRMPA is to "assess and mitigate where possible the key risks identified in the *Outlook Report 2009*, namely climate change, continued declining water quality from catchment run-off, loss of coastal habitats from coastal development and remaining impacts from fishing and illegal fishing and poaching."

5.5.1. Outlook Report 2009

The Outlook Report is a new legislative requirement established by recent amendments to the *Great Barrier Reef Marine Park Act 1975*. Under the Act, reports must be prepared by the GBRMPA every five years, independently peer reviewed and tabled in both Houses of the Australian Parliament.

The *Outlook Report 2009* stated that the Great Barrier Reef remained one of the world's healthiest reef ecosystems. However, it identified climate change, continued declining water quality from catchment run-off, loss of coastal habitats from coastal development and remaining impacts from fishing and illegal fishing and poaching as the priority issues reducing the resilience of the Great Barrier Reef.

The report pointed out that coral reef habitats are gradually declining, especially inshore as a result of poor water quality and the compounding effects of climate change. However, habitats more remote from human use, such as the continental slope and reefs in the far north are believed to be in very good condition.

In identifying climate change as the greatest threat to the Great Barrier Reef, the Outlook Report noted that management is challenged because the drivers of climate change have their origin beyond the Great Barrier Reef Region. At a more localised scale, the effects of activities in adjacent catchments affecting water quality, including land use practices and coastal development are playing an increasing role in determining the condition and future of the Great Barrier Reef.

The Report stated, "almost all the biodiversity of the Great Barrier Reef will be affected by climate change, with coral reef habitats the most vulnerable. Coral bleaching resulting from increasing sea temperature and lower rates of calcification in skeleton-building organisms, such as corals, and ocean acidification are the effects of most concern and are already evident".

Regarding fishing activity on the Great Barrier Reef, the report stated that, while significant improvements have been made in reducing the impacts of fishing, important risks to the ecosystem remain from the targeting of predators, the death of incidentally caught species of conservation concern, illegal fishing and poaching. The flow-on ecosystem effects of losing predators, such as sharks and coral trout, as well as further reducing populations of herbivores including dugongs, are largely unknown but have the potential to alter food web interrelationships and reduce resilience across the ecosystem.

The report concluded that further building the resilience of the Great Barrier Reef by improving water quality, reducing the loss of coastal habitats and increasing knowledge about fishing and its effects, will give it the best chance of adapting to and recovering from the serious threats ahead, especially from climate change. However, the report stated that the overall outlook for the Great Barrier Reef is poor and catastrophic damage to the ecosystem may not be averted.

In response to the *Outlook Report 2009*, the Australian and Queensland governments addressed the key pressures identified. In regards to climate change, the objectives are to:

- Build and maintain resilience to protect the Great Barrier Reef through measures such as the *Zoning Plan* and the *Reef Water Quality Protection Plan.*

- Develop a joint plan on managing the impacts of climate change on the Great Barrier Reef to build on the existing *Great Barrier Reef Climate Change Action Plan*. A key focus will be action to identify and evaluate strategies for maximising resilience.

- Support ongoing research to generate the information needed to respond and adapt to climate change risks and build resilience. This will build on *Climate Change and the Great Barrier Reef: A Vulnerability Assessment.*

5.5.2. Climate Change Action Plan

The *Great Barrier Reef Climate Change Action Plan* identifies strategies for direct actions and partnerships that will increase the resilience of the Great Barrier Reef to climate change. The action plan is underpinned by the knowledge, partnerships and adaptation measures that were established in the first three years of the Great Barrier Reef Climate Change Response Program by the Australian Greenhouse Office and the GBRMPA.

The *Climate Change Action Plan* outlines a five-year program of actions that Great Barrier Reef managers can take, in collaboration with stakeholders and other partners, to minimise the damage caused by climate change. The action plan is organised around four objectives (Table 5.1):

- targeted science

- a resilient Great Barrier Reef ecosystem

- adaptation of industries and regional communities

- reduced climate footprints.

Table 5.1. Objectives and actions of the GBRMPA Climate Change Action Plan.

Objective	Action	Example
1. Targeted science	1. Address critical knowledge gaps about climate change impacts on the Great Barrier Reef	Map areas of high and low resilience to prioritise investment of management effort (e.g. identify and protect refugia for thermally tolerant coral species that will provide genetic stock for recovery).
	2. Identify thresholds, improve monitoring and predictions, and evaluate strategies	Identify thresholds beyond which climate change causes irreversible damage to vulnerable species, habitats and processes.
		Evaluate resilience strategies, such as the Zoning Plan to optimise effectiveness in the context of climate change.
	3. Translate information into active management responses	Use cost-benefit analyses to select management responses that maximise ecological resilience while minimising social and economic costs.
2. A resilient Great Barrier Reef ecosystem	1. A resilient Great Barrier Reef ecosystem	Assess sustainability of fishing practices to ensure protection of habitat and key functional groups of plants and animals (for example herbivores) as a strategy for building resilience.
		Protect species and habitats that are highly vulnerable to climate change (e.g. corals).
	2. Adapt existing management to incorporate climate change considerations	Work with state fisheries management agencies to evaluate risks of climate change for sustainability of Great Barrier Reef fish populations and fisheries, which can be built into management plans.
	3. Minimise climate change impacts through local management actions	Undertake regional case studies of management responses to coral bleaching (e.g. working with communities to improve recovery potential of damaged reefs by protecting surviving corals and reducing fishing pressure).
3. Adaptation of industries and communities	1. Identify factors that confer resilience to communities and industries in the context of climate change	Enhance the relevance and uptake of information about the implications of climate change for industries and communities.
	2. Maximise resilience of industries and communities to climate change	Review the GBRMPA planning and permitting regulations, policies and guidelines to support adaptation by Great Barrier Reef industries.
		Assist industries to understand the risk to their business from climate change and to prepare adaptation responses.
4. Reduced climate footprints	1. Increase knowledge and involvement of stakeholders in climate change responses	Engage industry, stakeholder groups and the broader community to understand the implications of climate change for the Great Barrier Reef.
	2. Work with organisations and individuals to reduce their climate footprint	Showcase initiatives that reduce the climate footprint of Great Barrier Reef stakeholders (including the GBRMPA, regional Natural Resource Management groups and reef-based industries).

5.6. Fisheries Queensland

Fisheries in Queensland are managed according to the *Fisheries Act 1994* and its subordinate legislation, including the *Fisheries Regulation 2008* and legislated fishery management plans. This legislative framework is complemented by policies, licence and permit conditions and non-regulatory arrangements. Other State legislative instruments that impact on operations within marine fisheries include the *Marine Parks Act 2004*, *Nature Conservation Act 2004*, *State Penalties Enforcement Act 1999* and the *Transport Operations (Marine Pollution) Act 1995*.

The main purpose of the Fisheries Act is to provide for the use, conservation and enhancement of the community's fisheries resources and fish habitats in a way that seeks to apply and balance the principles of ecologically sustainable development.

Fisheries Queensland recently released the *Queensland Fisheries Strategy 2009-2014*. The strategy recognises a suite of challenges including:

- the potential for over-exploitation by all fishing sectors
- increasing consumer demand for fisheries products
- rising population, coastal development
- pressures on freshwater fish environments
- the effects of climate change
- biosecurity risks
- import competition and
- rising production costs.

From these challenges, three key elements were identified. The Strategy sets new directions for the management of:

1) fish habitats
2) fisheries harvest
3) the ways in which the value of fishing can be enhanced.

A selection of the goals and strategies that underpin the "new direction for the management of fisheries harvest" are presented in Table 5.2. This selection has been chosen as it corresponds with the anticipated future needs of the aquarium supply fisheries in the light of the predicted effects of climate change.

Table 5.2. A selection of goals and strategies for Fisheries Harvest from the Queensland Fisheries Strategy.

Objective	Goal	Strategy
Responsible Fishing (Fisheries Harvest)	• Introduce flexible and responsive harvest management through policy and legislative reform	• Review the existing legislative framework and develop tools that enable more flexible and responsive management of fisheries resources and fish habitats.
	• Foster self-reliance and resilience through active engagement and partnering with industry.	• Embed harvest management within the ecosystem-based framework, in partnership with stakeholders and ecosystem managers, encompassing resource access as well as species management issues.
		• Progressively review the effectiveness of existing management tools with a view to shifting from costly controls on fishing inputs to more efficient controls on fishing output and the use of technology.
		• Develop models of co-management and regional management to share the responsibility of resource management with both users and the wider community.
		• Build capacity within sectoral groups to enhance participation in fisheries management and planning processes.

5.7. Fishing Industry Engagement

Industry engagement from both the GBRMPA and Fisheries Queensland has undergone recent rationalisation whereupon the advisory structures are focused at a strategic level of engagement. Advisory committees established by both agencies seek advice from participants with regard to the documents that guide the respective agencies i.e. the *Outlook Report 2009* and *Climate Change Action Plan*, and the *Queensland Fisheries Strategy 2009-2014*.

5.7.1. GBRMPA Ecosystem Reef Advisory Committee

The Ecosystem Reef Advisory Committee (ERAC) is one of four Reef Advisory Committees (RAC). It combines and replaces the Fisheries RAC and Conservation RAC and meets twice a year to provide advice to the GBRMPA. The ERAC is a competency-based committee with members providing a cross-section of stakeholder expertise and interests in areas relevant to the ecologically sustainable use of the Great Barrier Reef. It includes a representative from the dive-based fisheries. While climate change is identified as the major threat to the Great Barrier Reef, there is no separate RAC addressing climate change but issues relating to climate change are considered by each RAC.

The terms of reference for the ERAC include providing advice to the GBRMPA on the following:

- The implementation of the key findings of the *Outlook Report 2009*

- Practical and policy responses to the implications of climate change for the GBRMPA responsibilities relating to ecosystem conservation and sustainable use within the scope of the Great Barrier Reef Climate Change Action Plan

5.7.2. Queensland Fisheries Advisory Committee

Following a review of all Queensland Government boards, committees and statutory authorities that culminated in March 2009, a single Fisheries Advisory Committee (QFAC) with a strategic focus replaced the seven Fisheries Management Advisory Committees (MAC) that operated between 1995 and 2009. This includes the Harvest MAC that incorporated aquarium supply fisheries.

QFAC, which has convened once, will be advisory in nature and will present the views of fisheries stakeholders on certain strategic issues as requested by Fisheries Queensland. It will meet twice a year and is designed to assist Fisheries Queensland to drive the implementation of the Queensland Fisheries Strategy.

The QFAC will examine measures to enhance the net economic value of fisheries by removing unnecessary regulation, instituting ecosystem-based management and looking at opportunities for co-management. It will prioritise actions under the Queensland Fisheries Strategy and the implementation of these measures across fisheries, including development or refinement of management arrangements. The QFAC is comprised of a representative from each of the following fishing stakeholder groups:

- Recreational
- Commercial
- Charter
- Freshwater
- Seafood marketers
- Conservation
- Indigenous
- Aquaculture.

Unless specifically requested, the QFAC will not provide advice on matters that are operational or fishery-specific. If QFAC requires updates on specific fisheries and work being undertaken by Fisheries Queensland to inform its advice on strategic matters it may request additional information or further consultation. This may include the establishment of Technical Advisory Groups, which will provide technical information that assists the government to achieve its fisheries management priorities. For commercial fishers this may include knowledge about the fishing fleet, economic influences, market information and demographics that will affect fisher behaviour and therefore how effective strategies will be.

There is currently no Technical Advisory Group for the hand collection sector. However, a Coral and Aquarium Working Group is convened by Fisheries Queensland on an 'as needs' basis to review and provide advice on management matters related to the industry. This group has a defined list of members sourced from industry, the scientific community, conservation groups and management agencies.

5.8. *Environment Protection & Biodiversity Conservation Act*

The EPBC Act, which is administered by SEWPaC, is a comprehensive piece of legislation that came into force on 16 July 2000 replacing the following Commonwealth legislation:

- *Environment Protection (Impact of Proposals) Act 1974*
- *National Parks and Wildlife Conservation Act 1975*
- *Whale Protection Act 1980*
- *Wildlife Protection (Regulation of Exports and Imports) Act 1982*
- *World Heritage Properties Conservation Act 1983*
- *Endangered Species Protection Act 1992.*

5.8.1. Commercial Fishing and the EPBC Act

In relation to commercial fishing, compliance with the Wildlife Trade and Threatened Species sections of the EPBC Act is critical for the export of product from each fishery. There is a process of Strategic Assessment through which the performance of fishery management is measured against specific criteria. In addition, the export of some species, including all species of hard coral, is subject to regulation under the Convention on International Trade in Threatened and Endangered Species of wild flora and fauna (CITES). Australia's CITES obligations are dealt with under the EPBC Act.

5.8.2. Strategic Assessment

The implementation of the EPBC Act allows the Commonwealth to assess the environmental performance of fisheries and promote ecologically sustainable management. SEWPaC is responsible for the assessment of fisheries managed under State and Commonwealth legislation in accordance with the Act, including:

- the strategic assessment of fisheries under Part 10 of the EPBC Act
- assessments relating to impacts on protected marine species under Part 13
- assessments for the purpose of export approval under Part 13A.

Fishery management performance is measured against the 'Guidelines for the Ecologically Sustainable Management of Fisheries', which were originally based on the principles that guide the Marine Stewardship Council. In August 2007 the Guidelines were revised to streamline the process for reporting and submission requirements for fishery assessments under the EPBC Act. The Guidelines outline specific principles and objectives designed to ensure a strategic and transparent way of evaluating the ecological sustainability of fishery management arrangements.

To satisfy the Commonwealth requirements for a demonstrably ecologically sustainable fishery, a fishery must operate under a management regime that meets Principles 1 and 2 of the Guidelines:

1. A fishery must be conducted in a manner that does not lead to overfishing, or for those stocks that are overfished, the fishery must be conducted such that there is a high degree of probability the stock(s) will recover.

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

The assessment process is designed to incorporate a flow of communication between fishery managers and SEWPaC in order to facilitate the best outcome for the fishery. Each fishery is unique and assessment is based on the merits of the combination of management measures in place and fishery specific issues.

Since 2000, this extensive assessment process has assisted in the implementation of ecosystem-based fisheries management and in driving continuous improvement in fishery management performance. As a result of the assessment process, a broad range of recommendations has been agreed between SEWPaC and fishery management agencies. These recommendations require fishery management agencies to demonstrate improved environmental performance and actively enhance the ecologically sustainable management of fisheries in the short to medium term.

Strategic Assessment of the MAFF and QCF determined the fisheries to be ‘Wildlife Trade Operations’, which enables export of products from those fisheries.

5.8.3. CITES

In 1975 an international convention known as CITES was established to prevent international trade from threatening species with extinction. Australia is one of more than 150 countries that are a party to CITES.

International movement of wildlife and wildlife products is regulated under Part 13A of the EPBC Act for all wildlife. The Act regulates the:

- export of Australian native species other than those identified as exempt
- export and import of species included in the Appendices to CITES
- import of live plants and animals that could adversely affect native species or their habitats.

Commercial export of regulated wildlife and wildlife products may occur only where the specimens have been derived from an approved source, such as a Wildlife Trade Operation.

There are three categories under which CITES classifies species of plants and animals according to the risk to their survival in the wild:

- Appendix I: These are species threatened with extinction and that are, or may be affected by trade.
- Appendix II: These are species that, although not threatened with extinction now, might become so unless trade in them is strictly controlled and monitored. CITES Appendix II also includes some non-threatened species, in order to prevent threatened species from being traded under the guise of non-threatened species that are similar in appearance.
- Appendix III: These are species that any CITES Party identifies as being subject to regulation within its jurisdiction for the purpose of preventing or restricting exploitation and that require the cooperation of other countries in the control of trade.

Some species relevant to the aquarium supply industry, including stony corals (Scleractinia) are listed under CITES Appendix II. CITES export permits are issued by SEWPaC for the export of all coral harvested in the QCF. The Strategic Assessment of the QCF fulfils the Non-detriment Finding as required under CITES and the EPBC Act. Of the 350 species of reef building corals found on the Great Barrier Reef, 52 genera/species are regularly collected in the QCF. The Strategic Assessment for the fishery consequently includes many more species than are actually subject to trade. Listed fish species collected in the MAFF also require CITES export permits.

5.9. Management of Aquarium Supply Fisheries

5.9.1. Marine Aquarium Fish Fishery

The MAFF operates along the Queensland east coast from the tip of Cape York south to the New South Wales border within the bounds of the Offshore Constitutional Settlement. Entry to the MAFF has been limited since 1997, which means a new entrant must purchase an existing licence.

The MAFF includes high-use regions adjacent population centres that are defined as Special Management Areas (SMA). These areas have additional limited access in order to prevent localised concentration of effort. Allocation of access to these areas was undertaken in 2003 based on a licence holder’s historic participation in the region. The boundaries of SMAs are described in the Fisheries Regulations 2008 and are additionally detailed on the individual permit authorities, where that additional access right is pertinent.

The SMAs include:

- Cairns (16 licences)
- Whitsundays (3)
- Keppel (8).

- Sunshine Coast (8) and
- Moreton Bay (11).

However, the Moreton Bay Marine Park came into effect on the 1st March 2009 and several licences were subsequently removed as part of the structural adjustment process. As well, there have been no active licences in the Whitsunday SMA since 2007 as there is exclusion in that area under the compulsory GBRMPA permits.

The general conditions of a MAFF licence include:

- Limits on the number of boats (one primary plus one other boat <7 m) and collectors (up to three) operating under a licence at any one time. The boats and collectors must be nominated.
- Fish may only be taken by hand using underwater breathing apparatus or a herding device, (including a rod), or using fishing lines, cast, scoop or seine nets (Table 5.3) and not be used for human consumption.
- Fish may only be sold by the licence holder or a person nominated by the licence holder and only be sold for display as aquarium fish, broodstock or a related purpose.

Table 5.3. Condition of gear deployment in the MAFF.

Gear	Conditions	
Fishing Lines	A fishing line may be used for taking fish under the licence only if it is has a single barbless hook.	
Cast Nets	A cast net may be used for taking fish under the licence only if the net:	
	(a)	is no longer than 3.7m and
	(b)	has a mesh size of no more than 28mm.
Scoop Nets	A scoop net may be used for taking fish under the licence only if the net:	
	(a)	is no more than 2m in any dimension and
	(b)	has:
		i. a mesh size of no more than 25mm and
		ii. a handle or shaft no longer than 2.5m.
Seine Nets	1.	A seine net may be used for taking fish under the licence only if the net:
	(b)	is no longer than 16m and
	(c)	has:
		i. a mesh size of no more than 28mm and
		ii. a drop of no more than 3m.
	2.	A person using the net under the licence must be within 100m of it.

Collectors intending to target larger fish to supply public aquaria need to obtain a General Fisheries Permit. This permit is for the use of equipment other than that which is generally allowed or if the operator intends to work outside prescribed size limits and/or species restrictions.

Fish other than the following fish may be taken under the licence: barramundi, bêche-de-mer, shell grit, star sand and any species of coral, oyster, pearl oyster or trochus.

Catch in the MAFF is reported through the use of logbooks. Catch is recorded according to the following categories:

Personifer Angelfish
Scribbled Angelfish
Pygmy Angels
Angelfish – all others
Bannerfish
Butterfly fish
Anemonefish
Damselfish – all others
Harlequin Tuskfish
Cleaner Wrasses
Wrasses – all others
Blue tang
Surgeonfish – all others
Moorish Idol
Assessors
Gobies, Blennies and Dartfish
Cardinalfish
Lionfish
Dottybacks
Anthias
Cods and Groupers
Triggerfish & Filefish
Pufferfish & Boxfish
Epaulette Shark
Sharks – all others
Rays
Other Fish
Molluscs
Sea Stars
Sea Urchins
Sea Cucumbers
Banded Coral Shrimp
Shrimps – all others
Crustaceans – all others
Invertebrates – all others

Fishing effort is recorded in the logbook according to month, year, location and dive details, including the number of collectors and total collector hours combined. Location is determined by options that include:

- Latitude and longitude
- Grid (30 minute) or Site (6 minute)
- Reef Name or Reef ID Number.

A Performance Measurement System has been developed to assess the effectiveness of management arrangements and to meet a Strategic Assessment recommendation that states that Fisheries Queensland is "to develop fishery specific objectives linked to performance indicators and measures for target stocks, protected species and impacts on the ecosystem". Within three months of a performance measure being triggered, Fisheries Queensland undertakes a review of likely causes and implications for sustainable management of the fishery. Table 5.4 outlines the framework for the Performance Measurement System for the MAFF. There is a management response for each performance measure.

Table 5.4. MAFF Performance Measurement System framework.

	Objective	Performance Indicator	Performance Measure
Target Species	Ensure MAFF resources are harvested in an ecologically sustainable manner	Total annual catch (numbers) of all species combined as reported in logbooks.	30% increase or decrease in total annual catch compared with the average annual catch over the previous 3 years
	Ensure species identified as at risk in the MAFF Ecological Risk Assessment are harvested in an ecological sustainable manner	Annual catch (numbers) per SMA	>50% change in annual catch (of a species in the list below) per SMA compared with previous year
	Ensure MAFF against unsustainable effects of localised concentration of effort in SMAs	Total number of effort days in SMAs	>20% increase in annual fishing days in a SMA compared with the average annual number of fishing days over the previous 3 years in that SMA since 1 Jan 2004
	Ensure against unsustainable effects of harvesting following severe impacts on critical coral habitat	Bleaching detected (GBRMPA Bleachwatch monitoring program) as defined in Coral Stress Response Plan	Bleaching severity & interaction with fishery is greater than Level 2 as defined in the Coral Stress Response Plan
Species of Conservation Interest	To ensure that the harvest of CITES and EPBC Act listed species is managed in an ecologically sustainable way	Total harvest (number of individuals) of CITES and EPBC Act listed species, specifically syngnathids, freshwater sawfish (*Pristis microdon*) and Maori wrasse	i. Total harvest of syngnathids exceeds 25 in any calendar year[9]
			ii. Total harvest of Maori wrasse taken under the General Fisheries Permit issued to an operator in the MAFF exceeds 30 during the period 11/5/2007 to 11/5/2012
			iii. Total harvest of the sawfish *Pristis microdon* taken under the General Fisheries Permit issued to an operator in the MAFF exceeds 75 during the period 11/5/2007 to 11/5/2012.
Social	Ensuring community confidence in management arrangements	Number of Ministerial Letters referring to fishery sustainability concerns	>5 Ministerial Letters are prepared per calendar year.
	Ensuring adequate compliance with management arrangements for the fishery	Compliance activity reports	>10% of the active vessels in the fleet are used to commit an offence under the Fisheries Regulation 2008.

[9] Take of syngnathids are not permitted in the Great Barrier Reef Marine Park

Economic	Reducing impediments to economic efficiency and/or development of industry	Number of active licences in fishery	20% decrease in the number of active licences compared to the previous year.
Ecosystem	Ensure MAFF resources are harvested in an ecologically sustainable manner	Proportion of industry adopting identified best practice protocols	<80% of active operators have adopted best practice protocols.

All dive based fisheries that operate in the Great Barrier Reef Marine Park, including MAFF participants require a Marine Parks Permit. The permits allow the GBRMPA to reduce impacts on high-use and sensitive areas, separate potentially conflicting activities and collect data for planning of Marine Parks.

Members of Pro-vision Reef must also abide by the day to day collection strategies outlined in the *Stewardship Action Plan*. The strategies in the first edition that apply to collecting fish in the MAFF are detailed Table 5.5.

Table 5.5. Collection strategies for fish collectors in the MAFF under the *Stewardship Action Plan*.

ID	Collection Strategy
i	Signatories will target primarily juvenile and sub-adult fish specimens of long lived species, e.g. *Pomacanthus* spp (except anemonefish – iii).
ii	When fish species live in schools and larger groups e.g. *Pseudanthias* spp. and *Chromis* spp., Signatories will collect no more than half of the fish from the group.
iii	Signatories will only collect mated pairs of anemonefish from large solitary anemones, such as *Heteractis magnifica*.
iv	Signatories will only collect juvenile and sub-adult anemonefish from anemones that arrange in beds, such as *Entacmaea quadricolor* subject to v.
v	Signatories will not collect anemonefish from an anemone that the collector assesses as stressed.

5.9.2. Queensland Coral Fishery

The QCF is a limited entry fishery (since 1997) that operates along the east coast of Queensland within the bounds of the Offshore Constitutional Settlement from Cape York south to 24°30'S, which is the southern extent of the Great Barrier Reef Marine Park.

There are two small collection areas south of Great Barrier Reef Marine Park. However access to these is restricted through licence conditions. The fishery area also comprises two spatially defined high-use Coral Collection Areas at Cairns and around the Keppel group of islands.

The QCF has operated under the Queensland Fisheries Policy for the Management of the Coral Fishery since 1st July 2006 coinciding with Wildlife Trade Operation accreditation under the EPBC Act. The development of this Policy is an example of the broad reaching benefits of fostering co-management of marine resources, see case study below.

Box 5.1. Development of the 'Coral Policy'.

Co-management in the Queensland Coral Fishery – a case study

A decade ago, misconception, misunderstanding and a lack of detailed information around the QCF resulted in a public campaign to close the fishery. On review, agreement was reached between the Queensland and Australian governments that there were no regulatory grounds for closure, but that a complete management restructure was required to address concerns around transparency, ecological sustainability at small spatial scales and to foster best practice initiatives (Atkinson *et al*., 2008). This resulted in the collaborative, bottom-up development of the *Coral Policy* – a State co-management tool to provide the enforceable, operational basis for the fishery.

An exhaustive process of collaboration over two years resulted in the participation and agreement of almost every member of the fishery, together with managers, compliance officers and conservation representatives to develop an effective, workable management framework. This process built the trust, engagement and stewardship foundations that were the precursor for the development of the broader aquarium industry *Stewardship Action Plan* and the current Vulnerability Assessment project.

In developing this new model for managing extractive use of marine resources in multi-use World Heritage Areas like the Great Barrier Reef, a win-win outcome has been created. This is important because it recognises that managers and fishers have a vested interest in maintaining a healthy ecosystem, and that top-down control and monitoring measures, on their own, are insufficiently flexible to deal with the range of issues the ecosystem will face in the future. By encouraging fishers to develop best-practice stewardship initiatives that have accountability features, it is possible to create a comprehensive toolbox to allow customised solutions to the situations that arise. Consequently, it becomes mutually beneficial to share knowledge and work towards outcomes that support ecosystem resilience.

Beyond day-to-day fishery management, this approach is also the basis for strong bilateral management confidence in the industry and willingness to publicly acknowledge and support these world-leading industry initiatives, as the fishery now provides a solid model for how to implement true ecosystem-based management of coral and other fisheries resources (Atkinson pers. com.). At a practical level, this has resulted in proactive management support for positive CITES Non-detriment Findings for all species taken in the QCF. The comprehensive body of knowledge available to make this assessment sits in stark contrast to the lack of knowledge for many coral species taken elsewhere and the concerns that have been raised by CITES member States around sustainable harvest.

The fishery is based on the collection of a broad range of species from the classes Anthozoa and Hydrozoa. The key components of the fishery are:

- Specialty Corals (living) e.g. Euphyllidae, Zoanthida, Corallimorpharia, Fungidae families

- Other Corals (non-living) - Acroporidae and Pocilloporidae families plus coral products including:

  → Live Rock (dead coral skeletons with algae and other organisms living on them)

  → Coral Rubble (coarsely broken up coral fragments)

  → Coral Sand (finely ground-up particles of coral skeleton) - only taken as incidental catch (up to 5 litres per trip) and may not be targeted within marine park waters.

A Total Allowable Catch of 200 tonne applies to the QCF whereby 30 per cent (60 tonne) may be collected as 'Specialty Coral' and 70 per cent (140 tonne) may be collected as 'Other Coral'. A system of Individual Transferable Quota applies to each licence.

Management of the QCF includes placing limits on the number of boats and collectors operating under a licence at any one time. Coral may be taken only by the licence holder or a nominee plus two assistant divers, which is consistent with arrangements in place for the MAFF. Fishers may only collect coral by hand or by the use of hand-held implements, and may use artificial breathing apparatus, such as SCUBA or Hookah.

Operators are required to lodge a prior notice before the conclusion of each fishing trip, notifying Fisheries Queensland of the quantities of coral taken and estimated time and location of arrival at port. The details provided in a prior notice determine the quota debit for each authority.

Operators are also required to report catch and effort through daily logbooks. This includes reporting catch to family level in most cases and to species or genus level for certain target species or at-risk species. Spatial reporting and fishing effort is recorded as GPS coordinates of highest catch for each reef and diver effort (hours).

Specialty corals are categorised into five subgroups for the purpose of quota monitoring (Table 5.6).

Table 5.6. Specialty coral categories and conversion factors for quota monitoring.

Category	Application for Quota Monitoring Purposes
LC2	Specialty coral pieces up to 100 g (estimated weight). A conversion factor of 20 pieces per kg (or 1 piece = 50 g)
LC3	Specialty coral pieces from 101 g to 500 g (estimated weight). A conversion factor of 7 pieces per kg (or 1 piece = 140 g)
LC4	Specialty coral pieces from 501 g to 1 kg (estimated weight). A conversion factor of 1.33 pieces per kg (or 1 piece = 750 g)

LC5	Soft coral pieces up to 500 g (estimated weight). A conversion factor of 25 pieces per kg (or 1 piece = 40 g)
LC6	Specialty coral pieces above 1 kg (estimated weight). Estimated weights are used for quota monitoring purposes.

As it applies to the MAFF, a Performance Measurement System has been developed to assess the effectiveness of management arrangements and to meet a Strategic Assessment recommendation. Table 5.7 outlines the framework for the Performance Measurement System for the QCF. There is a management response for each performance measure.

Table 5.7. QCF Performance Measurement System framework.

	Objective	**Performance Indicator**	**Performance Measure**
Collected Taxa	Ensure coral resources are harvested in an ecologically sustainable manner, including: • Ensuring the fishery against unsustainable effects of localised concentration of effort; • Ensuring the fishery against unsustainable effects of targeted harvesting of particularly types of coral and • Ensuring the fishery against unsustainable effects of harvesting following severe environmental impacts on the resource.	Total annual catch (kg) of species of greater than negligible ecological risk as determined by the coral fishery Ecological Risk Assessment	Annual catch >30% higher or lower than mean catch over the previous 2 years or Greater than 80% of the annual catch of a species occurs in a single 6nm x 6nm grid site.
		Total annual catch in high use management areas (reported through logbooks)	Cairns Region: • Live rock >80 t • Ornamental >5 t • Specialty >13 t Keppel Region: • Live rock >24 t • Ornamental >1 t • Specialty >11 t
		Total quota usage (reported in real time through Automatic Individual Voice Recognition - AIVR)	>75% of quota used in less than 6 months
		Bleaching detected (GBRMPA Bleachwatch monitoring program)	Bleaching severity & interaction with fishery >Level 2 as defined in the Coral Stress Response Plan
Social	1. Ensuring that operations of the QCF do not reduce the community benefit provided by coral resources in Queensland. 2. Ensuring community confidence in management arrangements	Number of ministerial letters referring to sustainability concerns with the Coral Fishery	<5 Ministerial Letters are prepared per financial year.
	Ensuring adequate compliance with management arrangements for the fishery	Compliance activity reports	<10% of the active vessels in the fleet are used to commit an offence under the Fisheries Regulation 2008.
Economic	Reducing impediments to economic efficiency/development of industry	Quota usage (reported through AIVR)	<25% of fishery quota used in >6 months. >10 licence holders use <25% of their quota holding.

Ecosystem	Ensure QCF resources harvested in an ecologically sustainable manner	Proportion of industry adopting identified best practice protocols	<80% of active operators have adopted best practice protocols

QCF participants require a Marine Parks Permit and members of Pro-vision Reef must also abide by the day to day collection strategies outlined in the *Stewardship Action Plan*. The strategies in the first edition that apply to collecting coral in the QCF are outlined in Table 5.8.

Table 5.8. Collection strategies for coral collectors in the QCF under the *Stewardship Action Plan*.

ID	Collection Strategy
i	Wherever possible, Signatories collecting Specialty Coral that arrange in beds will primarily target specimens that are smaller than 30cm. This includes those that occur in inter-reefal areas e.g. *Goniopora* spp., *Duncanopsamia* spp., *Catalaphyllia* spp. and *Trachyphyllia* spp.
ii	Wherever possible, Signatories collecting Specialty Coral that arrange singularly or in a roughly uniform manner will primarily target specimens that are smaller than 30cm. This includes *Euphyllia* spp. and *Goniopora* spp. and *Plerogyra* spp.
iii	Wherever possible, Signatories collecting Other Coral will primarily target specimens that are smaller than 45 cm.
iv	Where anemones arrange in beds, such as *Entacmaea quadricolor*, Signatories will not collect anemones from beds that the collector assesses as stressed or bleached.
v	Where anemones arrange individually, such as *Heteractis magnifica*, Signatories will not collect large to extra large specimens within Special Management Areas.

5.9.3. Responding to Disturbance Linked to Climate Change

GBRMPA, Fisheries Queensland and Pro-vision Reef all have protocols in place to respond to disturbance linked to climate change, including coral bleaching. The frameworks are linked and include management strategies that accord with the extent of disturbance. The GBRMPA plan has a broad application whereas the Fisheries Queensland and Pro-vision Reef plans apply only to the MAFF and QCF.

The GBRMPA developed the CBRP in 2002 and has reviewed and refined it annually. The CBRP was developed in conjunction with other complementary measures, including: Global Protocol for Assessment and Monitoring of Coral Bleaching and Reef Manager’s Guide to Coral Bleaching to maximise comparability and consistency with bleaching responses in other regions.

The CBRP has four primary components:

1. Early Warning System
2. Climate Change Incident Response
3. Management Actions
4. Communication Strategy.

The Early Warning System uses climate forecasts, remote sensing data, *BleachWatch* reports and site inspections to monitor conditions conducive to coral bleaching and any early signs of bleaching. Each component is described in Table 5.9.

Table 5.9. The early warning system for the CBRP.

Component	Description
Climate monitoring and prediction	Predictive Ocean Atmosphere Model Australia (POAMA) is used to forecast the likelihood of sea surface temperature anomalies of 0.6° C or greater affecting the Great Barrier Reef in the coming months (potential coral bleaching conditions). Forecasting of above average temperatures will trigger logistical preparations for bleaching assessment and monitoring.
Sea temperature monitoring	*ReefTemp* has been developed to monitor summer sea temperatures in near real-time using temperature data collected by environmental monitoring satellites, and provides early warning of potential bleaching on the Great Barrier Reef with a 1km resolution and with daily updates.
	In addition, *in situ* measurements of local sea temperatures are available from a network of weather stations that record water temperature at the surface and at 6m.
BleachWatch	A community monitoring network of voluntary observers on the Great Barrier Reef. Established in 2002 and is built on a network of regular reef users, including professionals, researchers, fishers and other recreational users who voluntarily monitor and report on conditions at reefs that they visit.
	Coordinated linkage between *BleachWatch* and the Reef Health Impact Survey (RHIS) deployed by Queensland Parks and Wildlife Service.
Site inspections	Conducted by experienced observers to validate the impact reports from the *BleachWatch* network and other voluntary programs.

Information gathered through the monitoring of the early warning system is used to develop a situation analysis. If moderate to severe, (Table 5.10) or widespread, bleaching is confirmed by site inspections then the *Climate Change Incident Response Framework* is activated and the response level is determined in accordance with the situation analysis.

Table 5.10. Situation analysis determined by the level of bleaching severity and extent.

Impacts	Description
Minor	Severe bleaching of 10–50% of colonies from highly sensitive indicator species (Pocilloporidae)
	Severe bleaching of <10% of colonies of moderately sensitive indicator species (*Acropora*)
	Paling of low sensitivity indicator species (*Porites*)
	Severe bleaching of moderate or low sensitivity indicator species but confined to reef flat
Moderate	Bleaching extends deeper than reef flat and:
	• Severe bleaching of >50% of colonies of highly sensitive indicator species (Pocilloporidae)
	• Severe bleaching of 10–50% of colonies of moderately sensitive indicator species (*Acropora*) below reef crest
	• Severe bleaching of <10% of colonies of low sensitivity indicator species (*Porites*)
	• Some mortality of high sensitivity species but confined to reef flat
Major	Bleaching extends deeper than upper reef slope and:
	• Mortality of >50% of colonies of highly sensitive indicator species (Pocilloporidae)
	• Severe bleaching of >50% of colonies of moderately sensitive indicator species (*Acropora*)
	• Severe bleaching of 10-50% of colonies of low sensitivity indicator species (*Porites*)
Severe	Mortality of 10–100% of colonies of moderate to low sensitivity indicators species (*Acropora* and *Porites*)

Localised: Impacts present in less than 10 sites within one region

Regional: Impacts present in more than 10 sites but confined to one region
Widespread: Impacts present in more than 10 sites in each of multiple regions

The *Climate Change Incident Response Framework* sets out the coordination and control mechanisms for mobilising resources to deal with climate change incidents such as coral bleaching, severe rainfall events, coral disease outbreaks and cyclone impacts. It provides detailed plans for coordinating the incident response. Once the appropriate response level has been determined (Table 5.11) the corresponding conditional planning and resource provisions are activated. The *Climate Change Incident Response Framework* is only intended to direct and coordinate management actions relating to the incident. Post incident management options including those designed to support or enhance resilience and recovery are separate from this process.

Table 5.11. The three levels of severity in the Climate Change Incident Response Framework.

Level	Implication	Description
1	Widespread low level bleaching	Low to moderate coral bleaching at multiple sites
2	Severe local bleaching and/or local mortality	Severe coral bleaching at multiple sites within one region
		Significant coral mortality at multiple sites within one region
3	Severe widespread bleaching	Severe coral bleaching throughout the Marine Park
		Significant coral mortality throughout the Marine Park

The CBRP outlines a suite of potential management actions that can support the resilience of the Great Barrier Reef to coral bleaching events. The extent and severity of bleaching will determine which actions are most appropriate and where they should be implemented (Table 5.12). As bleaching events become more frequent and severe, impacts on the reef ecosystem will become increasingly acute and apparent. Accordingly, there will be escalating expectations for management actions that can build the resilience of the reef.

Table 5.12. Options for management actions that can reduce the severity of bleaching impacts on coral reef ecosystems.

Goal	Management Actions
Protect Resistance	Identify and protect refugia with resistant populations (e.g. resistant coral species)
	Protect areas with environmental factors that facilitate resistance (e.g. high water mixing)
Build Tolerance	Minimise pressures associated with human activities that compromise coral health (e.g. physical damage)
	Protect areas with intrinsic and environmental factors that facilitate tolerance (e.g. tolerant species)
Promote Recovery	Minimise pressures associated with human activities that compromise coral recovery, in particular poor water quality (coastal development, catchment uses)
	Minimise pressures associated with human activities that compromise recruitment (e.g. damage or removal of “sources” of coral recruits)
Support Adaptive Capacity	Flexible planning to allow for targeted protection of reef areas
	Supportive policy to allow for immediate and temporary management actions to be implemented
	Social and economic diversity to facilitate changes in resource use

In 2009, Fisheries Queensland released the fishery specific CSRP, which applies only to the MAFF and QCF. The CSRP is designed to help improve the resilience of reef ecosystems by letting them recover from stress events, while allowing commercial fisheries to operate in some capacity, wherever possible.

The CSRP seeks to provide for an adaptive and responsive approach to coral stress consistent with the approach coordinated by the GBRMPA through the CBRP and to ensure fishing activities do not compromise the resilience of coral reefs that are subject to a range of stress events, including coral bleaching.

The CSRP identified critical linkages between coral bleaching and QCF and MAFF fishing activities that require examination. These are outlined in Table 5.13.

Table 5.13. Aquarium supply sector linkages with coral bleaching.

Linkage Factors	Description
Extent of spatial overlap	There is likely to be some spatial overlap between bleached areas and MAFF and QCF fishing activities. Spatial overlap will be assessed for each detected bleaching event on the east coast of Queensland.
Depth overlap	Coral bleaching occurs more commonly in shallow reef environments. While the extent of depth overlap with the MAFF and QCF is predicted to be minimal, it is important to assess in order to determine appropriate fishery responses.
Species effects (coral)	Assessment of the coral fishery target species and their proneness and resilience to bleaching is important in determining fishery responses to bleaching events.
Species effects (fish)	Depending on the severity of a bleaching event, it may be appropriate to limit the removal of important grazing species such as parrotfish, rabbit fish, surgeonfish and sea urchins and anemonefish in bleached anemones from bleached areas.

- The CSRP has direct links with each of the four key areas of the CBRP. If there is a high risk of bleaching, general logistical preparations for assessment and monitoring will be triggered under the CBRP. An important feature that will be actioned under the CSRP is the establishment of a review taskforce (composed of one representative from industry and representatives of the three management agencies – Fisheries Queensland, the GBRMPA and Queensland Parks & Wildlife Service).

Following the detection of bleaching through the GBRMPA *ReefTemp* and *BleachWatch* programs, the taskforce will review, analyse and interpret available bleaching data and records of fishing activity in the bleached areas. Fisheries Queensland will review catch and effort records for the MAFF and QCF in order to maintain the confidentiality of the data. The entire review taskforce will then consider relevant conclusions. This review will reveal the presence or absence, and volume, of fishing activity in bleached areas and will enable Fisheries Queensland to target consultation at the relevant operators in fisheries whose fishing activities are likely to interact with the stressed system. The outcome of the review will result in various levels of consultation and communication (Table 5.14).

Table 5.14. Consultation and communication following identification of spatial overlap between fishery activity and bleached areas.

Spatial Overlap	Fisheries Queensland Response
No recent reported fishing activity in the affected area	1. consult with fishery operators to: i. verify catch and effort data and ii. assess the significance of the affected area(s) to fishers (e.g. future intentions, seasonal/cyclical harvesting) 2. consult with the non-fishing stakeholders (e.g. relevant community group) to: i. assess the significance of the affected area(s) and ii. assess stakeholders' expectations of fishing activity in the area.
Recent reported fishing activity in the affected area	1. conduct data analysis to assess the extent of activity (spatial, number of operators, species caught, proportion of operators' total catch and effort) in the affected area(s) 2. consult with fishery operators to: i. verify catch and effort data (to a higher spatial and taxonomic resolution) and ii. assess the significance of area(s) 3. communicate outcomes of steps 1–2 to stakeholders 4. undertake targeted consultation with community groups, other reef users and fishers to determine an appropriate fishery response

The intensity of the management response by Fisheries Queensland will reflect the severity of bleaching and/or the overlap of fishing activities with the stressed system and will fit strategically with the approach taken by the GBRMPA. A Response Gradient from 1-5 or minimum intensity-maximum intensity is detailed in Table 5.15.

Table 5.15. Response gradient for fishery activity in areas affected by coral bleaching.

Intensity	Response
1	No changes to fishing practices (assumes already negligible impact of fishing on recovery and resilience)
2	No take of bleached corals or anemones (and associated anemonefish)
3	No take of bleached corals, reef building corals or climate-sensitive corals and anemones
4	No take of bleached corals; reef building corals; climate-sensitive corals and anemones and herbivorous/grazing species that control algal growth in coral habitats (e.g. parrotfish, rabbitfish, surgeonfish, urchins)
5	Spatial separation of coral and aquarium fish fishing from bleached areas of reef by: depth; site and reefs/areas

Once an appropriate response has been determined, its method of implementation will be established. Potential options, in order of decreasing desirability are:

1. Adaptation of the industry code of conduct (*Stewardship Action Plan*)
2. Another form of voluntary agreement from industry (e.g. Moratoria or Memoranda of Understanding)
3. Installation of reef protection markers (no anchoring areas)
4. Amendment of fishing licence conditions

5. Emergency declaration (temporary legislative action).

Also in 2009, Pro-vision Reef Inc released the *Stewardship Action Plan*. There had been a long-held desire by licence holders in the marine aquarium supply sector for a Code of Conduct that would create a minimum operational standard in both the MAFF and QCF in order to differentiate their product in the market from that sourced from destructive fisheries overseas. In assembling the Code of Conduct, several conclusions were drawn. Firstly, Codes of Conduct are not highly regarded, as they typically do not create sufficient deterrent for non-compliant behaviour. Secondly, climate change needed to be acknowledged and there needed to be a mechanism that triggered differential operating strategies in the presence of events linked to climate change.

Consequently, the Code of Conduct included independent oversight; complaints handling and appeals protocols and sanctions for non-compliant behaviour that included publicly naming those operators in breach of the industry standard and expulsion from Pro-vision Reef. The latter has implications for product differentiation in the market, as expulsion requires the operator to discontinue use of the Pro-vision Reef logo and connection with the brand. In addition, the initiative included a response plan for events linked to climate change that used coral bleaching as the key indicator. Having departed from the traditional Code of Conduct model, the initiative was named the *Stewardship Action Plan*.

Strategies under the “Responding to Climate Change” section are triggered by the link to the CBRP. When sea surface temperature monitoring under the CBRP indicates a high risk of bleaching in the coming summer, Pro-vision Reef members are required to undertake visual assessments of any bleached site that they encounter using the standardised tool detailed in Table 5.16. A representative will also participate in a task force convened by Fisheries Queensland.

Table 5.16. In situ assessment of the extent of bleaching carried out by signatories.

Stress	Depth	Indicator
Light	<10% of corals impacted	
	<2 m	Patchily bleached corals
	2-5 m	No apparent stress
	>5 m	No apparent stress
Moderate	10%-50% of corals impacted	
	<2 m	Light or yellowish bleached corals
	2-5 m	Patchily bleached corals
	>5 m	No apparent stress
Heavy	>50% of corals impacted	
	<2 m	Totally bleached white corals/dead coral with algae
	2-5 m	Light or yellowish bleached corals
	>5 m	Patchily bleached corals

Pro-vision Reef members are then required to adopt various collection strategies according to the assessed level of stress (Table 5.17). Importantly, encountering a bleached site requires members to report the incidence of bleaching to the GBRMPA and to complete the Reef Health and Impact Survey, which is the common format for reef monitoring by voluntary groups. The advantage for the GBRMPA is that licenced aquarium suppliers access a wide variety of sites that are not typically visited by other user groups.

Table 5.17. Collection strategies at affected sites for Pro-vision Reef members.

Stress	Collection Strategy
Light	Report site to the GBRMPA and complete Reef Health & Impact Summary survey
	Do not collect whole or part colonies of coral that exhibit signs of stress
	Do not collect any specimens in depths less than two (2) metres
	Do not collect anemonefish from stressed anemones at any depth
Moderate	Report site to the GBRMPA and complete Reef Health & Impact Summary survey
	Do not collect whole or part colonies of coral that exhibit signs of stress
	Do not collect any specimens in depths less than five (5) metres
	Do not collect anemonefish from stressed anemones at any depth
	Do not collect herbivorous/grazing species that control algal growth in coral habitats (e.g. parrot fish, rabbit fish, surgeon fish, and urchins) at any depth
Heavy	Report site to the GBRMPA
	No collection

Pro-vision Reef has implemented a voluntary moratorium on collection in areas subject to localised disturbance in a southern area of the Great Barrier Reef. Pro-vision Reef has also committed to substantial financial and in-kind contribution to a research project that aims to quantify the ecological effects of collecting that will enable the industry and management agencies to respond to the ecological challenges arising from the impacts of climate change.

5.10. Assessing Management in a Changing Climate

In assessing the management of the aquarium supply fisheries in the presence of the impacts, or the threat of impacts, of climate change, an analysis of strengths, weaknesses, opportunities and threats (SWOT) will be adopted. The assessment seeks to balance conservation of biodiversity, sustainable fisheries production and a profitable marine aquarium supply industry in anticipation of the manifestation of predicted impacts of climate change.

The major short to medium term climate change threat is rising sea surface temperature that results in increased frequency and severity of coral bleaching and increased intensity of storm events, including cyclones and rainfall that result in physical damage to reefs and issues around water quality from coastal catchments. These aspects combined are expected to reduce the capacity of coral reefs to fully recover after disturbance, which could lead to a shift from coral dominated reefs to algal dominated reefs. The consequence of this is expected to be reduced coral recruitment, leading to reduced structural complexity of coral reefs and the loss of specialised, endemic and naturally low abundant species of fish, coral and invertebrates. In the longer term, ocean acidification looms as the major threat to the Great Barrier Reef.

The effects of elevated sea surface temperatures will be experienced first in the southern areas of the Great Barrier Reef. The other areas expected to be most at risk are inshore reefs where water quality and competing uses add to the pressure on coral reef resilience and the capacity of coral reefs to fully recover from disturbance.

5.10.1. Strengths

- There are around 40 MAFF licences and 59 QCF licences, yet the sector comprises less than 30 collection businesses operating in an area of about 400,000 km^2. Many of these businesses maintain additional shore based infrastructure at various scales. Consequently, there is substantial investment in the industry.

- The fisheries are conducted within the Great Barrier Reef Marine Park with 117,000 km^2 designated to no-take refugia. A similar area is allocated to other zones that offer varying levels of protection from fishing. The area of the MAFF to the south of the Great Barrier Reef Marine Park features two zoned state marine parks. And there is currently 17,200 km^2 allocated to no-take zones in the Coral Sea Fishery with a much greater areas expected to be protected under bioregional planning.

- The MAFF catch mostly comprises lower trophic level prey species. Most herbivorous species in the catch are planktivores. Herbivorous grazers and scrapers that perform critical roles in recovery after disturbance do not currently feature to any substantial extent in the catch.

- The QCF collects a wide range of live species, including those inhabiting inter-reefal areas. Species that are identified as contributing to structural complexity after disturbance, including *Acropora* and *Pocillopora* spp do not currently feature to any substantial extent in the live catch.

- The MAFF and QCF feature highly selective, labour intensive collection practices with no bycatch. They are low volume, high value fisheries that target an extensive range of species that are not targeted in other commercial fisheries, or are recreational and Indigenous fisheries.

- Pro-vision Reef represents the major producers in both fisheries plus a range of small operators. The organisation is positive and maintains good working relationships with management agencies.

- Pro-vision Reef has demonstrated an ability to negotiate with members to impose voluntary moratoria to address localised issues.

- *Stewardship Action Plan* describes what is currently understood to be ‘best-practice’ and has a response plan for coral bleaching that links to the CBRP and CSRP. The assessment, reporting and collection strategies are reasonably consistent with these plans.

- Reefs affected by coastal flooding, cyclone damage and extensive coral bleaching are not viable collection sites.

- Fisheries Queensland's Species Vulnerability Assessments identify species whose characteristics increase their vulnerability to harvest. Characteristics include life history traits such as growth, lifespan, reproduction and recruitment, and ecological niche. The assessment includes fishery factors, such as physical accessibility, market price and suitability for aquaria.

- Fisheries Queensland's Ecological Risk Assessments additionally identifies species and ecological processes at risk from the activity of the fishery.

- Fisheries Queensland has comprehensive Performance Measurement Systems.

- Fisheries Queensland's management of the fisheries limits effort in both fisheries, including additional access restrictions adjacent major population centres and additionally limits catch in the QCF.

- Strategic Assessments ensure continuous improvement in fishery and management performance. Export from a fishery is determined by this performance and this is vital to many in the MAFF and QCF.

- The CSRP uses the bleaching information from the CBRP and then assesses spatial overlap with the MAFF and QCF (and depth overlap for key species). It establishes a task force to assess impacts and to determine a course of management response.

- Legislative and management structures have been updated to give priority and resources to address climate change and water quality.

- Comprehensive CBRP uses a combination of technology and community monitoring to gather information on the likelihood of coral bleaching and the extent and severity of the bleaching. The CBRS has a range of management responses that can be deployed at short notice dependant on the severity of the disturbance, including coral bleaching.

- There is a representative from dive-based fisheries on the ERAC. Currently, this representative is from the marine aquarium supply industry.

5.10.2. Weaknesses

- Handwritten logbook data precludes responsive and adaptive management with confidence and within a reasonable timeframe, which risks the MAFF and QCF being grouped together with higher risk fisheries and the invocation of the precautionary principle due to a paucity of knowledge where that knowledge actually exists. This applies on a day-to-day basis and in response to events linked to climate change.

- The MAFF catch features anemonefish species in numbers that do not reflect their availability from aquaculture and the QCF live catch features *Montipora* spp in substantial numbers. Species from this genus are identified by Dr. Pratchett in this report as key contributors to structural complexity on coral reefs, particularly after disturbance.

- Demand cycles occur whereby high value species, including live coral that might be reef building species, are intensively targeted if only for a limited period.

- Perception among elements of the community that aquarium fish and coral collection is not a sustainable practice, which could become emphasised in the presence of events linked to climate change.

- Not all licence holders are involved with Pro-vision Reef. This makes adoption of best practice measures and climate change adaptation measures non-uniform across the sector.

- *Stewardship Action Plan* day to day strategies do not implicitly address species identified in the Ecological Risk Assessments or species, or species groups, identified in this study by scientific experts.

- *Stewardship Action Plan* does not implicitly address spatially significant areas of risk upon activation of the CBRP.

- Ecological Risk Assessments do not assess indirect risks to habitat with regard to the capacity to recover after disturbance.

- Substantial assessment and reporting framework for strategic assessment consumes Queensland Fisheries' resources.

- There is no formal forum for ongoing industry engagement with Fisheries Queensland at a day to day operational and management level except for Coral and Aquarium Working Groups that include interested parties from outside of the fisheries. Should a Technical Advisory Group be formed, its purpose is to respond to a specific request by the QFAC.

- The majority of collection occurs in hubs in the north and the south of the state. However, the review task force established by the CSRP includes just one industry representative.

5.10.3. Opportunities

- MAFF and QCF licence holders agree to pursue electronic data collection and submission. Fisheries Queensland and the GBRMPA vigorously support the transition and collaborate with Pro-vision Reef in seeking funding support for implementation of the initiative.

- Pro-vision Reef works with Fisheries Queensland and the GBRMPA to determine the nature of data collected, hardware options and the manner in which data is handled, including privacy provisions.

- Pro-vision Reef updates the *Stewardship Action Plan* to collaboratively align *in situ* site assessment and climate change collection strategies with the CBRP and the CSRP.

- Pro-vision Reef reviews day to day collection strategies in the *Stewardship Action Plan* to maximise the capacity of coral reefs to recover from disturbance, especially on inshore reefs.

- Pro-vision Reef promotes industry initiates arising from the Climate Change Adaptation Plan in order to further differentiate product from the MAFF and QCF in the domestic and international markets.

- Fisheries Queensland "review the existing legislative framework and develop tools that enable more flexible and responsive management, explore the use of technology and develop co-management arrangements for fisheries." (Strategy B1: *Queensland Fisheries Strategy 2009-14*).

- Fisheries Queensland's Ecological Risk Assessments additionally consider the indirect physical impacts of the fishery on the capacity of habitats to recover after disturbance.

- The GBRMPA and Fisheries Queensland management responses to climate change linked disturbance differentiate on the basis of ecological risk posed by each fishery.

- Use the MAFF and QCF as models for adoption of strategies for industries to manage the impacts of climate change.

5.10.4. Threats

- Data delivery stifles effective, flexible and responsive day to day fishery management and can result in a one-size-fits-all approach to fisheries in response to events linked to climate change.

- Elevated costs associated with carbon pollution mitigation policy could force some operators to reduce travel distance from port, resulting in increased fishery overlap with inshore reefs, making them more susceptible to climate change response measures.

- The MAFF and QCF are not distinguished from higher risk fisheries when management responses are implemented, making commercial viability unnecessarily compromised.

- *Stewardship Action Plan* loses relevance if Pro-vision Reef membership declines.

- Lack of aquarium supply sector involvement in consultation and engagement in the management of the fisheries under the *Queensland Fisheries Strategy 2009-14*.

- Invoking of the precautionary principle because insufficient data creates uncertainty.

- The use of Reef Protection Markers and Temporary Closures that do not differentiate between low risk fisheries and high risk fisheries.

- The GBRMPA to use the Zoning Plan to protect climate change refugia, which might also be important collection areas.

- In the longer term, ocean acidification is predicted to bring changes of a magnitude that severely compounds predicted impacts of climate change. Such changes could ultimately preclude the collection of live corals and could severely limit the range of species available for collection in the MAFF.

5.10.5. Conclusions

The SWOT analysis indicates substantially more strengths than weaknesses in the management of the fisheries in the presence of the predicted impacts of climate change, except the longer term threat of ocean acidification.

The CBRP creates a framework for responding to disturbances related to climate change that enables the GBRMPA to respond quickly and with resources allocated to various response needs. How that plan affects the operation of commercial fisheries depends on the fishery information that has been collected and the timeframe in which it can be extracted, synthesised and integrated into the response planning under the CBRP and the CSRP.

The CSRP creates a framework for determining a consultative management response to disturbances related to climate change. It uses the data relating to spatial extent of disturbance and the degree of severity provided to the GBRMPA then determines the spatial overlap of the MAFF and QCF to inform a review taskforce. If electronic logbooks were matched to a system that allowed automated, regular data extraction and summary, the task force could be better informed to determine management responses in a timeframe that creates confidence in decision making, and the CBRP could consider fishery related risks when determining responses that will include separation of human activities from affected areas. Electronic logbooks should also reduce the work load for Fisheries Queensland by removing the data entry step and allow managers ready access to up-to-date information.

The Ecological Risk Assessments for the MAFF and QCF could be broadened to implicitly assess the risk to the capacity of coral reef habitats to recover after disturbance such as those predicted to be linked to climate change. Existing assessments conclude that both the MAFF and QCF do not pose substantial risks to targeted species or ecological processes. However, in the presence of management responses to events linked to climate change, differentiation between fisheries on the basis of ecological risk is desirable for MAFF and QCF operators as other fisheries may pose greater risk. Management response under the CBRP involving temporary closure is likely to cater for the worst case scenario, which implies catering for highest risk activities.

The industry engagement and consultation framework under the *Queensland Fisheries Strategy 2009-14* doesn't cater for ongoing interaction between Fisheries Queensland and licence holders in the MAFF and QCF in terms of trouble shooting unrelated to the function of the QFAC. Also, the review task force established under the CSRP includes one representative from industry yet the fisheries are primarily practiced in hubs in the north and south of the state. Should a bleaching event encompass areas in the north and south of the state, local knowledge could add important insight to the group.

Pro-vision Reef will need to update the *Stewardship Action Plan* to: include the fish species identified by Professor Bellwood and those identified in the Ecological Risk Assessment in the day to day operations; more closely align the *in situ* site assessments to that in the CBRP into the climate change response section; and more closely align the collection strategies in the climate change response section to those in the CSRP.

It is concluded that, when the climate change response mechanisms are invoked, there needs to be confidence on behalf of management agencies that the existing fishery activity represents a low risk and then has a means by which it responds in a manner that further minimises risks to the resilience of coral reefs. Collaboratively aligning response expectations can assist to build that confidence. Concomitantly, licence holders in the MAFF and QCF need to have confidence that management response will recognise the risk differential with other commercial fishery sectors and that decisions are based on the best possible information delivered and assessed within a timeframe that does not create added uncertainty.

6. Assessing Vulnerability

The exact impacts of climate change cannot be predicted with great accuracy, especially at a local level. This is, however, the scale at which people make most of the decisions that affect their lives and livelihoods and where impacts are likely to be most felt. Nevertheless, indications of changes already occurring along with projections from the best scientific modelling can be helpful guides used by the aquarium supply sector to help them think about what the future might hold and how to prepare for it.

Assessing vulnerability is likely to guide the development of a diverse array of options that make marine aquarium supply operators more able to respond to changes as they occur. This ability to respond effectively to change, to weather shocks, or to recover from substantial shifts in system function may be referred to as adaptive capacity or resilience.

There will be no adaptation strategies outlined in this vulnerability assessment. Determining strategies is a subsequent step in the overall process of climate change adaptation planning. That step will involve collaborative and participatory gatherings in order to move forward in an integrative manner between industry and the government agencies that oversee it; with critical input from science, market and community representatives.

This last section is designed to pull together the learnings of the previous sections in order to determine vulnerability of the marine aquarium supply industry to climate change. The term ‘vulnerability’ is used to describe and understand the challenges associated with climate change faced by the industry. It is not intended to imply a sense of helplessness or lacking optimism. The term is used in conjunction with ‘adaptive capacity’, which is the resilience of the industry and the tools possessed at an enterprise and industry level to be proactive to adapting to the challenges associated with climate change.

6.1. Exposure

Licence holders in the MAFF and QCF rely heavily on interaction with coral reefs. Whilst some coral species collected in the QCF inhabit inter reefal areas, the majority of activity in both fisheries is connected to coral reef habitats. This factor raises the level of exposure of the marine aquarium supply sector to the impacts of climate change. However, the climate change predictions suggest that the southern parts of the Great Barrier Reef will be the first to witness the manifestation of effects. And the *Outlook Report 2009* suggests that reefs distant from the shore will be better placed to recover from disturbances linked to climate change.

The aquarium supply sector features businesses of vastly disparate scale and proportion. Some businesses run multiple vessels of a size that can undertake the work in a range of sea conditions. These businesses are able to venture further to sea and might visit a substantial range of collection sites, including inshore reefs, mid shelf reefs and outer reefs. In this way, these businesses can rotate visitation to reefs and maintain the breadth of diversity on their stock lists as the market demands. These businesses have less exposure to the impacts of climate change in the shorter term, especially if they are based in the north of the Great Barrier Reef. More than half of the active coral quota belongs to Cairns based businesses, whilst about 40 per cent of the active MAFF licences belong to Cairns based businesses.

Smaller operations might be more restricted by sea conditions and the distances they travel. They might also be limited in the range of collection sites frequented and these sites might mostly be inshore reefs. Five companies hold more than half of the active MAFF licences and seven companies own more than 80 per cent of the active coral quota. Four of those seven companies form part of the five that own more than half the MAFF licences so there are a number of smaller operations. These companies are more exposed to the impacts of climate change in the shorter term, especially if they are based in the south of the Great Barrier Reef.

There is a range of other factors that are not biophysical in nature that expose the marine aquarium supply sector to the impacts of climate change. This sector is by no means alone in this exposure. Running boats and maintaining filtration systems in shore based facilities incurs substantial costs in fuel and electricity. These costs have risen appreciably in recent years and can be expected to rise further with carbon pollution mitigation policy. The supply chain analysis identified issues of foreign currency exchange and increasing employer contributions to superannuation as other factors that will increase costs in the near future.

Lastly, precautionary management of human activity that potentially impacts reef resilience and marine biodiversity conveys exposure to operators in the marine aquarium supply sector. This is expected to apply first in the southern areas of the Great Barrier Reef and to a larger extent on inshore reefs where water quality issues compound other pressures to reef resilience, including competing uses by other users of the marine environment, such as tourism, other commercial fishing sectors and recreational and Indigenous fishing.

6.2. Sensitivity

The *Outlook Report 2009* identified coral reefs as being particularly susceptible to the predicted effects of climate change on the Great Barrier Reef. In the shorter term, this is expected to manifest in more frequent and more extensive coral bleaching events. Much of the fishery activity of the marine aquarium supply sector interacts with coral reefs. Depending on the severity of bleaching (and the time since the last bleaching event) these reefs may still be viable collection sites. However, severe bleaching will likely make collection unviable at those sites. Pro-vision Reef members are required to move on from such sites under the *Stewardship Action Plan*. In addition, precautionary management designed to maximise reef resilience can exclude extractive activities from reefs. This might not only apply to affected reefs but also to unaffected reefs identified as sources of recruitment that can assist recovery.

Management to maximise recovery may, in the shorter term, consist of temporary closures. In turn, this period of closure could be extended in the event of physical damage from a cyclone or sediment flux from coastal flooding. Operators could potentially be limited in their access to workable reef areas for some time. This would become compounded by competing uses, such as tourism and recreational fishing. In the longer term, as the predicted impacts manifest, management measures are likely to include the use of the Zoning Plan to include climate change refugia, which are areas typified by thermally tolerant species of coral, thermal mixing and other characteristics that aid coral recruitment after disturbance.

Operators who focus the majority of their fishery activity on inshore reefs face a degree of sensitivity should spatial measures be implemented to promote resilience and aid recovery after disturbance if they do not have the capacity to access more distant reefs, or if a range of alternative collection sites have not been identified. In addition, it might not be a commercially viable option for some operators to travel further from port.

There are a number of mostly small operators that are not part of Pro-vision Reef. Consequently, these operators are not subject to the proactive strategies within the *Stewardship Action Plan* and may choose not to be part of any planning for climate change adaptation. These operators exacerbate their sensitivity to the range of factors that constitute the wider implications of climate change, which extend beyond the predicted biophysical impacts.

Aquaculture is growing but is still in its infancy. Manifestation of predicted impacts of climate change could see an increase in demand for cultured specimens from the wild catch sector to complement wild caught product and to maintain a broad species mix on stock lists. This sensitivity could create a signal for aquaculture practitioners to grow and expand production or for the wild catch sector to diversify.

Other sensitivities exist that are not directly related to the aquarium supply sector or the resilience of coral reefs. Despite substantial improvements in the environmental performance of the broader fishing industry over the preceding decade and the continuous improvement model within which fisheries management operates under the EPBC Act, sections of the community remain vociferously critical of commercial fishing and it is a target for some conservation groups. Community opinion usually translates to political opinion and this can make contraction of commercial fishing activity a politically expedient issue to pursue.

6.3. Potential Impact

Warming sea surface temperatures have been identified in the *Outlook Report 2009* and by Marshall & Johnson (2007) as the greatest short to medium term threat to the Great Barrier Reef. The warming sea surface temperatures increase the risk of coral bleaching and the intensity of cyclones and rainfall events. It was recognised in various chapters of Marshall & Johnson (2007) that numerous coral species are near the upper limit of their range of thermal tolerance, which indicates that further increases in sea surface temperature will likely result in mass bleaching events. The threats of physical damage from cyclones or sediment flux to inshore reefs from coastal flooding diminish the resilience of reefs to withstand impacts of disturbance and their capacity to recovery after disturbance.

The longer term threats associated with ocean acidification are currently not well understood. However, when considered in conjunction with the identified shorter term threats, it would appear that reef resilience and the capacity to recover from disturbance will be highly compromised in the future. The result could be substantially reduced biodiversity where the reef is characterised by a simplified physical structure dominated by algae and populated by robust generalists. Hoegh-

Guldberg *et al.* (2007a) indicated that the Great Barrier Reef will be in a net erosive state when atmospheric CO_2 reaches a concentration of around 500 ppm. The concentration is currently about 390 ppm and on an upward trajectory having had a natural range of 172 to 300 ppm for the past 800,000 years (CSIRO, 2009).

In terms of the operational challenges for the marine aquarium supply sector, the potential shorter term impacts include a decrease in the range of collection sites, which is expected to affect inshore reefs to a greater extent. Those operators reliant on inshore reefs face access issues that will likely be compounded by precautionary, worst case scenario management. Those operators seeking to contract travelling distances to offset cost increases might compound perception of localised concentration of effort and competition with other Reef users, thereby hastening management intervention.

Carbon pollution mitigation policy is inevitable and will likely manifest in elevated costs of key business inputs, such as fuel and electricity. It can be expected that other costs, such as freight and packaging, will also increase. As these increases manifest across economies, it can be expected that the cost of labour will also increase. Other impacts identified in the supply chain analysis include the foreign exchange rate affecting the value of exports, and industrial relations changes in preparation for an ageing economy that raises the costs associated with superannuation. Other factors include access to credit against uncertainty, which may stifle attempts by some operators to recapitalise in order to operate over a larger range of sites and to achieve economies of scale. Overall, it can be expected the degree of business risk will increase and continue to increase.

6.4. Adaptive Capacity

A key to enabling continuous adaptation is identification of things that constrain and enable the capacity of the marine aquarium supply sector to adapt. The marine aquarium sector has demonstrated substantial adaptive capacity over the years and this bodes well for a future whereby the only apparent certainty is change.

The sector is characterised by family businesses, some of whom have been in operation for decades. The extent of local knowledge and experience, particularly among the larger and older operators is substantial, indicating knowledge of the spatial and temporal distribution and abundances of various species important to the sector. This capacity enables operators to maintain a wide range of collection sites that can be visited on a rotational basis. This can be seen as an important attribute should temporary spatial closures be instigated in the event of mass bleaching or similar disturbance.

A key indicator of the adaptive capacity of the sector in a business sense is the rapid rise of the QCF since accreditation as a Wildlife Trade Operation in July 2006. Trade in coral up to that point had been for the domestic market only and represented a relatively low value contribution to the sector as a whole. However, in four short years, there has been a shift in market demand toward mini-reef systems, export markets have been established and the Australian product now has an international reputation for quality and consistency. The tradable value of quota within the fishery is now substantial, which is indicative of demand and anticipated return on investment.

The adaptive capacity in this regard can be measured firstly by virtue that the expertise for handling and husbandry of coral specimens to retain vibrancy and market appeal was not widely held until the market was open to export. Secondly, QCF licence holders have traded increasingly in species found in inter-reefal environments, which creates a useful buffer against management measures designed to protect coral reef resilience and capacity to recover after disturbance as these species are not directly associated with coral reefs. As they can be vibrant and attractive specimens, they attract strong market demand.

Following implementation of the Zoning Plan in 2004, the aquarium supply sector, like all other fishing sectors, were required to adapt to a new operating environment that included the need to explore new collection sites. This is no small or inexpensive undertaking as species assemblages vary according to many abiotic characteristics of the site, such as exposure and topography. Plus safe access and anchorage conditions must be met. By and large, the sector navigated the period through sound business acumen. Structural adjustment assistance buffered the business risk but to be successful following that period required flexible business management.

Given that aquarium supply businesses typically maintain boats and shore based filtration facilities, these businesses are reliant on fuel and electricity as critical business inputs. In recent years we have seen fuel price shocks and incremental but rapid increases in the price of electricity. In response, operators have demonstrated a willingness to explore alternative power generation for their businesses and even a departure from the erstwhile traditional business model of retaining shore-based facilities. Some smaller operators are roaming and supplying wholesalers indicating that adaptation is already evident.

Currently cultured specimens play a relatively minor role in supplementing orders and diversifying stock lists. However, this sector has grown appreciably in recent years, especially in supplying a diversity of anemonefish species and other popular species such as seahorses. The range of species available has grown indicating demand is strengthening from the marine aquarium supply sector.

A strong indicator of adaptive capacity at an industry level is the proactive stance adopted by the peak body for the sector, Pro-vision Reef. The name change from Queensland Aquarium Supply Divers Association heralded a new era of industry organisation, representation and communication. The culture of collaboration within the association assists the industry to develop community and market confidence in the industry and the sustainability of the products. It has also enabled the sector to work with the agencies that oversee sustainable production and the conservation of biodiversity in an advocative manner. Maintaining the current high level of representativeness in the organisation is critical to maximising adaptive capacity at an industry level that can filter to decision making at the enterprise level.

6.5. Vulnerability

Assessment of vulnerability should be read as flagging future challenges at an industry and enterprise level. Like any challenge, including those that confront business operations, forewarned is forearmed and this assessment is designed to equip fishers and their representatives with the information that can assist strategic decision making in the future under the scenarios accompanying climate change predictions.

The vulnerability of the aquarium supply sector to climate change is the specific suite of challenges that confront the sector's adaptive capacity. Possibly the greatest single element of vulnerability relates to acceptance by individuals within the fisheries, and the industry collectively, of climate change. Refusal to accept the science of climate change and to believe the status quo can and will be maintained could represent the greatest threat to ongoing survival at an enterprise and industry level, particularly as it is clear that management of the Great Barrier Reef has a major focus on climate change adaptation.

One of the greatest virtues of the Great Barrier Reef in the context of climate change is its immense size and complexity. The expanse and diversity of the ecosystem helps ensure there is a high level of response diversity, even to global stressors like climate change (McCook *et al.*, 2007). Within this great expanse, the MAFF and QCF have an extremely minor footprint. Both fisheries feature an extraordinary range of species that are collected across a wide range of coral reef habitats and some inter-reefal habitats. This is an important facet of adaptive capacity because, unlike other fisheries that focus on a narrow range of species, up to a thousand species of fish, corals and other invertebrates feature in the catch so the vulnerability is spread across a wide range of product.

The MAFF, in particular, typically collects lower trophic level prey species and does not target grazing herbivores and corallivores that carry out important functions in reef resilience and recovery after disturbance in any substantial number. These factors contribute to the minimal risk profile of the fishery but, just as importantly, the breadth of species diversity, the nature of the species in the fishery, and the manner in which they are collected suggest that should there be management action to exclude fishery interaction with some affected areas of habitat that the fishery can still function, at least to some extent.

However, according to the climate change predictions, this suggestion might only be valid in the shorter term and for offshore reef areas because the predictions are for widespread bleaching increasing in frequency with recovery affected by cyclones and rainfall events of greater intensity. In the longer term, recovery will be affected by ocean acidification. Consequently, integration into the management response strategies in advance of the actual events occurring will assist industry to minimise the vulnerability to the events and the subsequent management response. Through the *Stewardship Action Plan*, including improvements to subsequent editions of the initiative, the sector is well on its way to achieving that integration.

Low fishery risk and diversity of product minimises the sector's vulnerability relative to other fishing sectors but doesn't alter the fact that the manner in which fishing activity is managed in the Great Barrier Reef Marine Park to maximise coral reef resilience and the capacity of coral reefs to recover after disturbance could be a one-size-fits-all approach that caters for the highest risk fisheries. In addition, as it is expected the southern areas of the Great Barrier Reef will be affected first and inshore areas will be affected most, it can be concluded that some regions will be subject to a higher degree of vulnerability to climate change than others. This spatial differentiation will require further analysis at a subsequent stage of the climate change adaptation planning process.

Reliance on coral reef habitats increases the vulnerability of the marine aquarium supply sector to climate change. Over time, both fisheries face challenges relating to access to healthy reef systems that might be viewed as source areas for reef replenishment after disturbance and designated as climate change refugia, which could be included in a future review of the Zoning Plan. The GBRMPA *Climate Change Action Plan* reflects statements in Marshall & Johnson (2007) that the identification of climate change refugia should be a focus of future research effort and zoning reviews.

In regards to climate change refugia, Marshall & Johnson (2007) state that the size and complexity of the ecosystem means there is a high chance that some areas will remain undamaged, or at least will survive in a good enough condition that they are able to act as a source of recovery for areas damaged by climate change. These refugia may be protected from the full impacts of climate change due to physical conditions (such as proximity to upwelling of cooler water or exposure to strong currents) or biological qualities (such as a community dominated by bleaching resistant corals). Whatever the basis for their resilience, these sites are highly important to the ability of the ecosystem to sustain itself in the face of climate change.

Temporary and permanent spatial closures are likely to add to other important factors, such as increasing overheads and unfavourable market and industrial relations changes, to diminish profitability of individual enterprises and the overall value of the industry. The soaring value of the Australian dollar diminishes the value of exports and increases competition from cheap imports. The expectation of an ageing population has also triggered discussion of increasing compulsory contributions to superannuation.

The degree of vulnerability to these factors could be linked to the ability of businesses to achieve economies of scale throughout business operations and the ability to access sufficient collection sites to spread the risk that those sites might be affected by disturbance linked to climate change. Positioning a business to achieve economies and diversity of collection sites could entail further investment, which could be substantial. This in turn could be constrained by access to finance against existing collateral and cash flow linked to the operation of a business with an uncertain future. Those businesses that carry minimal capital investment could be vulnerable due to limited options, whilst those that are heavily capitalised could be vulnerable to overcapitalisation and debt obligations on devalued assets.

In terms of being impacted upon by the climate change response planning by the management agencies, the aquarium supply sector has minimised vulnerability to a limited extent through integration with agency plans in the *Stewardship Action Plan*. A key vulnerability is the challenge of maintaining membership and adherence to the operational standards and climate change responses in that initiative. Currently, although response mechanisms involve industry input through the formation of a climate change response taskforce, the manner in which fishery data is delivered to management agencies constrains confident, timely, flexible and adaptive decision making by management agencies, which in turn could result in responses that take a one-size-fits-all approach that is designed to capture the highest risk activities.

In conclusion, the marine aquarium supply sector faces many challenges linked to the predicted effects of climate change. Some of these effects relate to the biophysical impacts on coral reefs, which are habitats critical to the operation of the fisheries. The effects stem from warming of sea surface temperatures and include the increased frequency and extent of coral bleaching and the increased intensity of cyclones and rainfall events.

Operationally, management of fisheries and the conservation of biodiversity on the Great Barrier Reef add a further layer of vulnerability because management will likely involve excluding fishery activity from areas on a temporary basis in the shorter term to facilitate recovery after disturbance, and on a permanent basis in the longer term to protect climate change refugia through the Zoning Plan. Carbon pollution mitigation policy will likely increase the cost of business inputs, which might affect the collection patterns of operators and focus more collection activity closer to port thereby adding to the already intensifying management attention on inshore areas.

The aquarium supply sector has many strengths that minimise vulnerability to the predicted effects of climate change, including the small size of the industry and the vast geographic area over which it operates, the low ecological risk of the fisheries and the expansive range of species in the catch, adaptive business management capacity with a proven track record of capitalising on opportunity, and a strong representative body.

6.6. Where To From Here?

Developing strategies designed to assist adaptation to the predicted effects of climate change will require addressing the issues identified in this vulnerability assessment, among others, at an industry level and at an enterprise level. At an industry level, collaborative workshops can determine a range of strategies that might be included in a subsequent edition of the *Stewardship Action Plan*, for example. Such workshops should include maximum participation by industry, fishery and protected areas managers, researchers, and possibly market and community representatives. The central focus of the collaborative workshops will be to develop a clear understanding of adaptive capacity and resilience and how these are constrained and enabled across the marine aquarium supply industry.

Glossary

(From Johnson & Marshall, 2007 and Marine Biodiversity Decline Working Group, 2008)

Adaptation: an adjustment that moderates harm or exploits beneficial opportunities in natural or human systems in response to actual or expected climatic changes or their effects. A 'biological adaptation' is a phenotypic variant that results in highest fitness among a specific set of variants in a given environment. It occurs when the more vulnerable members of a population are eliminated by an environmental stress, leaving the more tolerant organisms to reproduce and recruit to available habitat

Adaptive Capacity: the potential for a species or system to adapt to climate change (including changes in variability and extremes) so as to maximise fitness, moderate potential damages, or take advantage of opportunities such as increased space availability

Adaptive management: environmental management practice that accommodates uncertainty and responds to events as they unfold. It involves taking a structured, iterative approach to finding the best options for action in the face of uncertainty and risk. It includes monitoring change over time, so that the results of management choices can be assessed and changes made if needed to improve future management

Assemblage: multiple species of plants and animals living in the same place and time

Biodiversity: the number and relative abundance of different genes (genetic diversity), species and ecosystems (biological communities) in a particular area

Climate change refugia: areas that have escaped or will escape changes occurring elsewhere and continue to provide a suitable habitat for a species which would not be able to survive under prevailing conditions. The term is used in reference to areas that may provide habitat for species displaced as the climate changes.

Climate Change: a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (United Nations Framework Convention on Climate Change) (see *climate variability*). The concept of increased emissions over time and gradual changes in climate is well accepted. Importantly though, fossil evidence clearly demonstrates that the Earth's climate can shift within a decade, establishing new patterns that can persist for decades to centuries. Climate change, therefore, can refer to either a gradual or abrupt change in climatic conditions

Climate Variability: variations in the mean state and other statistics of the climate (such as standard deviations and the occurrence of extremes) on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (see also *climate change*)

Climate: the ‘average weather’, or more rigorously, the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. The classical period is 30 years, as defined by the World Meteorological Organisation. These quantities are most often surface variables such as temperature, precipitation and wind

Connectivity: natural links among reefs and neighbouring habitats, especially seagrass beds, mangroves and back-reef lagoons that provide dispersal and genetic replenishment. Also refers to linkages among coastal lands and adjacent catchments, which are sources of freshwater, sediments and pollutants. The mechanisms include ocean currents, terrestrial run-off and watercourses, larval dispersal, spawning patterns and movements of adult fishes and other animals. Connectivity is an important process to ensure the productive function of the plant and animal species that contribute to the overall health of an ecosystem

Conservation: protection, maintenance, management, sustainable use, restoration and improvement of the natural environment; in relation to natural and cultural heritage, conservation is, generally, keeping in safety or preserving the existing state of a heritage resource from destruction or change.

Coral Bleaching: the paling of corals and other animals with *zooxanthellae* resulting from a loss of these symbiotic algae. Bleaching occurs in response to physiological shock due primarily to periods of increased water temperature coincident with high levels of light (see *mass coral bleaching*). Bleaching can also be caused by changes in salinity or turbidity

Critical ecosystems: crucial to the survival of particular threatened species, populations or ecological communities

Degradation: a loss of quality or functionality. It may refer to loss of extent, condition or capacity to self-regenerate

East Australian Current (EAC): a current that originates in the Coral Sea and flows southward along the east coast of Australia

Ecological footprint: a measure of our impact on the environment based on consumption of natural resources. There are different ways of calculating a community’s footprint, but calculations generally take into account how much energy and natural resources a human community uses, expressed as a measure of how much land and water are needed to produce these resources

Ecological sustainability: a state in which biological systems will remain diverse and productive over time, even though change will occur. The idea of ecological sustainability recognises human use or development of biological systems must be consistent with protection of biological diversity and maintenance of essential ecological processes and life-support systems

Ecologically sustainable use: use of a species or ecosystem within its capacity for renewal or regeneration

Ecosystem: a community of organisms interacting with one another and the environment in which they live. Such a system includes all abiotic components such as mineral ions, organic compounds and the climatic regime

Ecosystem functions: the mechanisms by which ecosystems generate supporting, providing, regulating and cultural services

Ecosystem resilience: the capacity of an ecosystem to adapt to changes and disturbances, yet retain its basic functions and structures. A resilient ecosystem can adapt to shocks and surprises and rebuild itself when damaged. Resilient ecosystems are more open to multiple uses and are more able to recover from management mistakes

El Niño-Southern Oscillation (ENSO): widespread two to seven year oscillations in atmospheric pressure, ocean temperatures and rainfall associated with El Niño (the warming of the oceans in the equatorial eastern and central Pacific) and its opposite, La Niña. Over much of Australia, La Niña brings above average rain and El Niño brings drought. A common measure of ENSO is the Southern Oscillation Index (SOI), which is the normalised mean sea level pressure difference between Tahiti and Darwin. The SOI is positive during La Niña events and negative during El Niño events

Emissions Scenario: scenarios describing how greenhouse gas emissions could progress between 2000 and 2100, depending on various hypotheses about human societies and behaviour. As there are an infinite number of possibilities to describe future emissions, scenarios are necessarily conventional with each reflecting a plausible state of the future world. The IPCC has published 40 scenarios grouped into four types (A1, A2, B1 and B2) with each representing a different evolution of humanity and associated rates of energy consumption and food production

Endemic: native to or confined to a certain geographical region

Enhanced Greenhouse Effect: increasing concentrations of greenhouse gases in the atmosphere trap more heat and raise the Earth's surface temperature

Environment: includes ecosystems and their constituent parts, including people and communities; natural and physical resources; the qualities and characteristics of locations, places and areas and their social, economic and cultural aspects

Eutrophic: nutrient-rich waters

Eutrophication: the increase in dissolved nutrients and decrease in dissolved oxygen in a (usually shallow) body of water, caused by either natural processes or pollution

Exposure: the nature and degree to which a system or species is exposed to significant climate variations. In a climate change context, it captures the important weather events and patterns that affect the system. Exposure represents the background climate conditions against which a system or species operates and any changes in those conditions

Functional Redundancy: the extent to which the ecological role of a species can be replaced by other species

Genetic diversity: the variety of genetic information contained in individual plants, animals and micro-organisms

Global Temperature: usually referring to the surface temperature, this is an area-weighted average of temperatures recorded at ground- and sea-surface-based observation sites around the globe, supplemented by satellite-based or model-based records in remote regions

Global Warming: an increase in global average surface temperature due to natural or anthropogenic *climate change*

Great Barrier Reef: tropical marine ecosystem on the northeast coast of Australia that comprises of reef, seagrass, inter-reef, pelagic, shoals and mangrove habitats and includes the islands, cays and coastal areas that are connected physically and biologically

Greenhouse Effect: greenhouse gases that are present naturally in the Earth's atmosphere trap heat from the sun to maintain the Earth's surface temperature at a habitable level

Greenhouse Gases: any of the atmospheric gases that contribute to the greenhouse effect. Naturally occurring greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide and ozone. Certain human activities, such as the burning of fossil fuels, add to the concentration of these naturally occurring gases in the atmosphere

Habitat: the locality or natural home in which a plant, an animal or a group of closely associated organisms live

Impacts: the adverse effect resulting from a threat acting on a vulnerability. Can be described in terms of loss or degradation of any, or a combination of any, ecological, social or economic features

Intergovernmental Panel on Climate Change (IPCC): an organisation set up in 1988 by the World Meteorological Organisation and the United Nations Environment Program to advise governments on the latest science of climate change, its impacts and possible adaptation and mitigation. It involves panels of climate and other relevant experts who assess climate change-related information and prepare reports, which are then critically reviewed by researchers and governments from member countries around the world

Longwave Radiation: heat radiation with wavelengths greater than 4 micrometres (infra-red)

Market-based instruments and trading-based schemes: government interventions that encourage desired behaviour through market signals rather than through explicit directives. They include cap and trade schemes, auctions and information disclosure. Trading-based schemes are a subset of market-based instruments that focus on instruments involving trading

Mass Coral Bleaching: coral bleaching extending over large areas (often affecting reef systems spanning tens to hundreds of kilometres) as a result of anomalously high water temperatures (see also *coral bleaching*)

Mitigation: mitigation of climate change refers to those responses that reduce the sources of greenhouse gas emissions into the atmosphere or enhance their sinks. Targets are usually set with respect to a baseline scenario, thus avoiding exceeding the adaptive capacity of natural systems and human societies

Nutrient run-off: nutrients such as nitrogen and phosphorus play an important role in plant growth and the productivity of aquatic ecosystems. In excessive quantities, nutrients entering aquatic ecosystems can cause algal blooms which prevent light and oxygen from reaching other biota and may also be directly toxic. This can lead to high mortality among aquatic fauna. The major contributors of phosphorus to aquatic ecosystems are land clearing and erosion. Nitrogen comes primarily from fertiliser use, animal wastes and sewage discharges

Oligotrophic: nutrient-poor waters

Pacific Decadal Oscillation (PDO): a long-lived El Niño like climate pattern with the same spatial implications for climate but lasting from 20 to 30 years rather than the six to 18 months seen in the *El-Niño-Southern Oscillation*

Precautionary principle: a principle of ecologically sustainable development whereby if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation

Primary Productivity: rate at which light energy is used by producers to form organic substances that become food for consumers

Resilience: the ability of a system to absorb shocks, resist phase shifts and regenerate and reorganise so as to maintain key functions and processes without collapsing into a qualitatively different state controlled by a different set of processes

Risk: probability that a situation will produce harm under specified conditions. It is a combination of two factors the probability that an adverse event will occur and the consequences of the adverse event. Risk encompasses impacts on human and natural systems and arises from exposure and hazard. Hazard is determined by whether a particular situation or event has the potential to cause harmful effects

Scenario: a coherent, internally consistent and plausible description of a possible future state of the climate. Similarly, an emissions scenario is a possible storyline regarding future emissions of greenhouse gases. Scenarios are used to investigate the potential impacts of climate change; emissions scenarios serve as input to climate models

Sea Surface Temperature: the temperature of ocean water at the surface. In practical terms, this will vary depending on the method of measurement used. Infrared radiometers attached to orbiting satellites typically measure the temperature in the top ten microns of the water column while drifting or moored buoys take temperature readings from the top one metre

Sensitivity: the degree to which a system is affected, either adversely or beneficially, by climate related stimuli, including average climate characteristics, climate variability and the frequency and magnitude of extremes

Sink Reefs: reefs that receive larvae via ocean currents. Some reefs may be sinks at one time of year and sources at another time, where monsoonal currents reverse in different seasons

Socioeconomic: the study of the relationship between economic activity and social life. This is a multidisciplinary field using theories and methods from sociology, economics, history and psychology

Source Reefs: reefs the have the potential to supply larvae to other reefs via ocean currents. Some reefs may be sinks at one time of year and sources at another time, where monsoonal currents reverse in different seasons

Sustainability: activities that meet the needs of the present without having a negative impact on future generations. A concept associated with sustainability is triple bottom line accounting, taking into account environmental, social and economic costs

Threshold: any level in a natural or *socioeconomic* system beyond which a defined or marked change occurs. Gradual climate change may force a system beyond such a threshold. Biophysical thresholds represent a distinct change in conditions, such as the drying of a wetland. Climatic thresholds include frost, snow and monsoon onset. Ecological thresholds include breeding events, local to global extinction or the removal of specific conditions for survival

Uncertainty: the degree to which a value is unknown, expressed quantitatively (e.g. a range of temperatures calculated by different models) or qualitatively (e.g. the judgement by a team of experts on the likelihood of the West Antarctic Ice Sheet collapsing). Uncertainty in climate projections is primarily introduced by the range of projections of human behaviour which determine emissions of greenhouse gases and the range of results from climate models for any given greenhouse gas

Upwelling: process whereby cold, often nutrient-rich waters from the ocean depths rise to the surface

Vulnerability: the degree to which a system or species is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system or species is exposed, its *sensitivity*, and its *adaptive capacity*

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